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CLIMATE NEUTRAL URBAN DISTRICTS IN EUROPE:

A COMPARATIVE ANALYSIS

A thesis submitted in partial fulfilment of the requirements of Edinburgh Napier University, for the award of Master by Research

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Dedication

God Almighty, I dedicated this piece to you for the strength and divine inspiration you gave me throughout the period of writing this project. To my entire family and my supervisor, thank you very much for your support.

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My appreciation goes to Almighty God for His unfailing and unending love; for all that He has done for me. I would like to thank my thesis supervisor Prof. Mark Deakin for his help and guidance in the preparation and compilation of this dissertation. He's commitment to helping with this thesis is an inspiration and despite having a packed work schedule he always made time for me. I would also express my sincere gratitude to all my lecturers who have thought me throughout my program. My heartfelt gratitude goes to my loving parents Mr. & Mrs. J. K Oye, my wonderful brothers and sisters, Oluwakemisola, Olasunkanmi, Tolulope, Eniola, Oluwatosin, Oluwayemisi and my wife Tejumola for their love, care, kindness, moral support and encouragement. I love you all. My appreciation also goes to my friends; Daniel, Eyamba, Onyebuchi, Kayode for their support and for always being there for me. Finally, I want to thank Edinburgh Napier University for giving me a chance to learn and improve my academic skills.

OYE, Kehinde Toyosi

Declaration

I declare that the work contained in this dissertation is my original work unless otherwise stated. All information cited are fully referenced and all work from others has its source clearly acknowledged in the text and its reference clearly outlined at the end of the document.

Abstract

The concept of climate neutral districts is a new field of discourse and a new planning approach facing many challenges. Climate neutral districts can make a valuable contribution to low carbon societies. The concept of climate neutral urban districts is a way to approach the issue of carbon emissions by creating test beds where new ideas and technologies can be introduced. This study uses Hackbridge and the Stockholm Royal Seaport project as case studies to show that districts are increasingly moving towards Climate neutral urban district goals with the integration of renewable energy sources.

In recent years, investigations show how cities are working at different scales, using different approaches concerning climate mitigation actions in urban districts and projects, based on different technologies and frameworks. However, one clear conclusion from the observation is that even if the idea of a "climate neutral city" is adopted by some cities in Europe, the concept of climate neutral urban districts is quite new. This thesis draws upon this message and shows how climate neutral development is important for the future of urban districts and cities at large.

The methodology this thesis presented clearly adopts an urban metabolism model that facilitate the description and analysis of material and energy flows within the districts. This allows the examination of energy and material flows in the complex urban district systems, shaped by various social, economic and environmental forces. Attributes of the model proposed is the possibility of integration and comparison between different urban regions, as the essential indicators are suggested along with standardized measuring units.

This study points to a remarkable opportunity to cross the boundaries between the built sector and environment, and to establish strong and quantitative links between these dimensions at an urban level. This has the potential to make a major contribution to the design of sustainable urban systems and infrastructure that have been observed in this study.

In this way, the thesis uncovers the need for a universal carbon accounting framework for urban district development that identifies the specific areas that needs to be

considered and targeted by developers making carbon claims, as well as a standardised approach and methodology for quantifying those emissions. This will help to make carbon claims and assertions much more meaningful and comparable, bring greater credibility to the concept of low carbon developments. A common metric for conducting carbon analyses, together with consistent terminology and a universally accepted definition shall make it easy to compare developments and their claims. However, conclusion can be drawn from this study that the urban retrofit path adopted by Hackbridge has the greater potential to develop climate neutral urban environments and it is an important direction for the future of urban districts and cities at large to combat climate change.

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Acronyms

CCI-	Clintion Climate Initiative
CLUE-	Climate Neutral Urban Districts In Europe
EC-	European Commission
HP-	Hackbridge Project
OPL-	One planet living
SRS-	Stockholm Royal Seaport
UN-	United Nation
LSOAs-	Lower Layer Super Output Area (s)

Chapter One

1.0 Introduction

1.1 Background

As the world's population increases along with higher living standards, more greenhouse gases (GHG) are emitted. Emissions' evolving from our way of living impact the global climate and have become one of modern time's great challenges. The anthropogenic impact on the climate have been debated for many years but still much need to be done if this threat is to be avoided. The migration of the majority of the population into cities creates a possible opportunity to fight these pressures in a more efficient way. This is because cities are large and concentrated emitters of GHG and therefore also a good platform to cut emission. They are also expanding which means that new and modern technology can be introduced in already built and new built districts.

Climate change has been recognised as one of the most pressing issues facing the world today. There is a strong scientific consensus that greenhouse gas (GHG) accumulations due to human activities are causing global warming with potentially catastrophic consequences (IPCC 2013). Climate change is not "a problem" waiting for "a solution." It is a highly complex phenomenon with various environmental, cultural and political implications which are reshaping our way of thinking and acting. It must be seen as one of the most serious set of political and societal challenges ever faced by human society. International agreements and European climate policies have formulated the goal of limiting the global temperature rise to 2°C by cutting GHG emissions by 80 per cent below 1990 levels until the year 2050. Whether or not this goal is achievable strongly depends on the climate mitigation efforts made in cities.

Urban sustainability has gained in credibility and is now seen as one of the key factors towards breaking the unsustainable patterns of modern societies. Around the world, much emphasis has therefore been placed on framing sustainability in cities (Williams, 2010). One feature of this is the increasing interest in developing sustainable urban districts. The idea is that these smaller urban units can act as innovative areas where new ideas are implemented and developed. These districts are also perceived as a way of creating sustainability in cities, as the ambitions within them are often higher than for general developments (Searfoss, 2011). For many of these developments, guiding documents are designed to lead the way and frame future goals and hopeful outcomes (City of Malmö, 2013; City of Stockholm, 2010; Fränne, 2006; Medearis and Daseking, 2012). However, few of these guiding documents state how they define and determine the sustainability goals. They attempt to describe the pathway and components needed to lead towards sustainable urban development but largely neglects the core issue about how to define sustainability. The ambiguity in the foundations of the programmes translates into the goals and may therefore result misguiding or unachievable targets (e.g. Pandis Iverot and Brandt, 2011).

1.2 Climate Change

In 2007, the Intergovernmental Panel on Climate Change released a report that delivered three critical and unequivocal messages, which describes the severity of global climate warming and a range of impacts affecting:

1. the natural and industrial worlds; Humans are very likely a significant cause of this change in climate; and
2. the rate at which the climate is changing, and the subsequent impacts, are
3. occurring much faster than anticipated or projected by the models (IPCC, 2007).

It is well understood and accepted that climate change is caused by an increase of carbon dioxide and other greenhouse gases in the earth's atmosphere. While the earth's climate has changed over millions of years due to natural variations in carbon dioxide levels (e.g., through volcanoes and melting permafrost), there is strong evidence correlating the current rise in carbon dioxide with human activities, primarily from the combustion of fossil fuel for energy production and use (IPCC, 2007).

Some of the known and predicted impacts of climate change include an increase in floods, droughts and severe storms, sea level rise, species extinction and a spread of diseases (IPCC, 2007). However, it is the unknown consequences of climate change, which occur once tipping points are passed leading to a series of cascading and potentially irreversible events, that worry the world's most accomplished scientists and climate experts.

The forecast impacts of climate change are likely to cause significant upheaval in our cities and to our urban infrastructure, disturb our agricultural processes and wreak havoc on natural ecosystems and biodiversity, all at great financial cost to the economy and particularly for future generations (Garnaut, 2008; IPCC, 2007; Stern, 2006). Traditionally, addressing climate change has focused on mitigation, as this was identified as being more cost effective than paying the largely unknown costs associated with the impacts of climate change (e.g., disaster relief, adaption measures, relocating climate refugees). However, as a certain degree of warming has now been locked into the climate system, greater attention is being given to adaption, particularly in the most vulnerable cities, settlements and areas.

1.3 The Need for this Study

Scientists have called for a reduction of carbon in the global economy by 80 per cent by 2050 in order to keep global warming below two degrees of pre-industrial levels (IPCC, 2007).

Over 90 developed and developing countries, representing around 80 per cent of global GHG emissions, have now made pledges to reduce their domestic emissions (Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education [DIICCSRTE], 2013c). Many of these countries have communicated their existing or proposed emissions reduction actions and measures that will assist them in achieving their targets. Carbon taxes and emissions trading schemes appear to be the most popular amongst developed countries with legally binding commitments (DIICCSRTE, 2013b), while developing countries without binding commitments have identified a range of other 'nationally appropriate mitigation actions' (NAMA's), such as energy efficiency, improved forest management and increasing the amount of renewable energy generation (UNFCCC, 2011).

While there are countless ways to tackle carbon emissions, action is commonly split between two broad areas of the economy - the 'Front End' and the 'End User'

(Newman & Ingvarson, 2012). The Front End generally refers to emissions that are produced from activities that use fossil fuels directly, such as power generation, refining and large industrial practices. Emissions are thus targeted as they enter the economy. Policies focused on the End User target carbon as it is used in the home and businesses, as well as emissions from the built environment.

While attempts are being made to understand the most effective responses, many measures to combat climate change trends are still in embryonic stages. It has been acknowledged, however, that the use of energy in the future will differ greatly from today.

In recent years, investigation shows how cities are working at different scales, using different approaches concerning climate mitigation actions in urban districts and projects, based on different technologies and policies. However, one clear conclusion from the observation is that even if the context of “climate neutral city” is used in some cities in Europe, the concept of Climate neutral urban districts is quite new for many cities unused. My thesis draws upon this message and show that carbon neutral development options as important directions for the future of urban districts and cities at large.

Thus far, this research has focussed on assessing and analysing carbon neutral developments by way of comparative analysis to evaluate climate neutral and positive strategies advanced by Hackbridge project in London and Stockholm Royal seaport in Sweden. In doing so, my case studies are important because these projects offer a particularly good example of the response to move beyond the state of the art and tends to identify the best potential in this respect.

This study presents some possible tools and ideas to deal with the climate change challenge at the level of urban districts.

In this thesis, an outline of methods and tools shall be presented that could help districts in decision-making, measuring, reporting, verifying and assessing climate neutral options.

The main issues dealt are:

- The concept of climate neutral and positive applied to districts
- Using the frameworks, methodologies, indicators and metabolic tools to benchmark and evaluate climate neutral and climate positive urban districts.

1.4 Research, Aims and Objectives

The aim of this research is to provide assessment of world class examples of climate neural urban districts (Hackbridge and Stockholm Royal Seaport) and suggest the best way forward to combat climate change.

The objectives of this thesis are to:

- compare the different methodological stand-points of Hackbridge and Stockholm Royal Seaport (SRS).
- evaluate One Planet Living (OPL) and Clinton Climate Initiative (CCI) accounting techniques they apply to benchmark climate neutrality.
- demonstrate the world-class status these climate neutral urban environments command.

1.5 Research Question

In meeting this aim in terms of the objectives set, the thesis shall answer the following question:

Which project, Hackbridge (retrofit) or Stockholm Royal Seaport (infill) does a better job in adapting to climate change and reducing energy consumption and lowering carbon emission?

1.6 Research Hypothesis

The urban retrofit path adopted by Hackbridge has the greater potential to develop climate neutral urban environments.

1.7 Research Structure

In testing this hypothesis, this thesis is organised into five chapters, which collectively address the key research questions previously proposed. A preview of the chapters is provided below.

Chapter One – Introduction: This chapter will include a clear introduction to the background of the chosen topic, the logic behind the proposed research, the purpose of the research, the hypothesis of the research, the aims of the research, the objectives of the research and the structure of the research

Chapter Two – Literature review: This chapter begins with a discussion of key literature pertaining to CLUE, GHG accounting at the city scale. Several of the more prominent existing and proposed city district scale GHG methodologies, tools and inventories are identified and a brief description of the most recognised and utilised of these frameworks and initiatives is provided, this is followed by a summary of existing tools that target GHG emissions at the urban scale. It also provides a review of European eco-cities and low carbon developments. The objective of this chapter is to better understand the areas targeted within the case studies, in terms of emissions, and how they compare with each other.

Chapter Three - The methodology used consist of variety of methods to conduct the integrative review and analysis, these include a literature review, a metabolic assessment, an evaluation and comparative analysis, and case study analysis. It is important to note that many of these review methods are often used simultaneously throughout this research.

Chapter Four - Analysis of result and findings: A clear presentation of results with analysis and interpretation of findings, exclusively in relation to the findings of the literature review.

Case Study Analysis is loosely adopted to review, analyse and compare the carbon claims. The aim of the case study analysis is to determine whether carbon claims are consistent across the case studies in terms of the emission sources included. Also, a review of the existing approaches for calculating the emissions associated with city-districts is carried out using the evaluation and comparative analysis method. These results are used to address some of the current problems associated with calculation and reporting methods

Chapter Five - This final chapter presents a summary of the findings of this research, in a format that addresses the research questions and objectives posed at the beginning of the thesis. A discussion is provided on how the research undertaken contributes to improving our knowledge and understanding around urban development's potential to reduce emissions.

Recommendations on how this research can help to inform policy are presented, particularly around issues of developing an internationally recognised framework Ideas for future work are identified, which include how cities can be further engaged and encouraged to design and construct low carbon developments.

Chapter Two

2.0 Literature Review

2.1 Why Climate Neutral Urban Districts?

Throughout the world, people are moving to cities. Today more than half the world's population is living in urban areas and this percentage is expected to rise (UN Department of Economic and Social Affairs Population Division, 2012). In Europe, the same trend applies: The spectacular urbanization since WW II will continue, and four out of five Europeans will live in urban areas by 2050 as seen in the figure below.

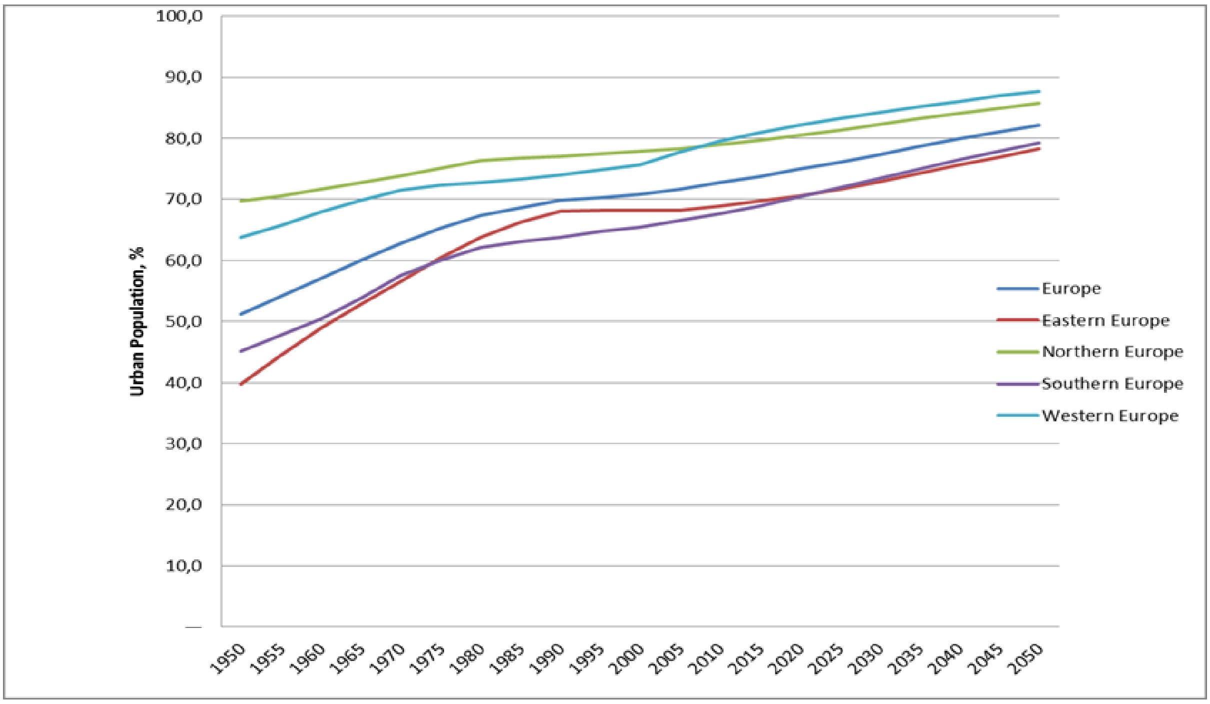

Figure 2.0: European urbanization trend for European cities (UN Department of Economic and Social Affairs Population Division, 2012).

Cities are important for reducing climate change

- They are large and rather concentrated emitters of greenhouse gases and therefore they are an ideal platform to cut emissions (Grimm et al., 2008).
- They are still expanding, and so there is an opportunity to apply modern clean technologies in new development areas, instead of being obliged to bring old systems up to standards

- In general cities comprise more young residents (Cf. e.g. UK Department for Environment Food & Rural Affairs, 2013), which could be helpful in creating a culture for experiments and change.
- Cities are often nodes in the societal systems that produce and implement innovation (research, education, start-up facilities) (Hekkert et al., 2007, Jacobsson and Johnson, 2000).

2.1.1 Goals and Content of the CLUE Project

Climate Neutral Urban Districts in Europe (CLUE) are about transforming city development and reshaping urban policies to mitigate GHG and carbon emissions and to alter the urban fabric, thereby promoting a sustainable city environment for future generations. The idea of climate mitigation in cities, to reduce or altogether remove the city's negative impacts on the global climate, is evident in several cities in Europe and beyond. However, the question posed in the CLUE project is how to best approach the specific concept of the climate neutral urban district (CLUE, 2014).

A climate neutral urban district is a city area where the use of innovative techniques and solutions have been implemented to remove the city's carbon footprint. Many European cities aim to become 100% free of fossil fuels, to avoid unsustainable GHG emissions or to become energy smart by 2050 or earlier (Erman, 2014). Similar approaches can be found across Europe. New or renewed urban districts like the Stockholm Royal Seaport and Wilhelmsburg in Hamburg (part of International Building Exhibition Hamburg) are being planned to achieve such goals. The CLUE project gathers several cities and regions with city district examples as Vienna's Aspern+ and the Vallbona district in Barcelona in an effort to try to identify good techniques and approaches to ambitious climate mitigation efforts in urban development.

The aim of CLUE:

- To achieve net zero emissions of GHG by reducing such emissions as much as possible and developing mechanisms to offset the remaining unavoidable emissions;

- To become climate-proof, or resilient to the negative impacts of the changing climate, by improving their adaptive capacities."

2.1.2 The Concept of a Climate Positive Urban District and its Process

A short, very general definition of a climate positive urban district would be one where the sum of the district's emissions is less than the sum of sequestrations, actions to mitigate emissions and offsets (Kennedy & Sgouridis 2011).

The first step of the process is to determine the emissions of the urban district by creating a baseline or inventory of emissions (D'Avignon et al., 2010; Kennedy et al., 2010). In practice, this process consists of a number of steps; choosing a method for accounting emissions, setting scopes and boundaries, data collection and finally calculating emissions. If the urban district is not climate positive after the baseline has been compiled, it needs to reduce emissions, either by mitigation efforts such as energy efficiency measures, switching from fossil fuels to renewables, sequestering carbon or investing in offsets such as projects under the flexible Kyoto mechanisms.

In the case of CCI, this step is called formulating a roadmap with the goal of becoming climate positive in the end (CCI, 2011). Once the sum of emissions is less than the sum of the actions to mitigate emissions in the roadmap, the urban district can be considered to be climate positive. The process is summarised in Figure below.

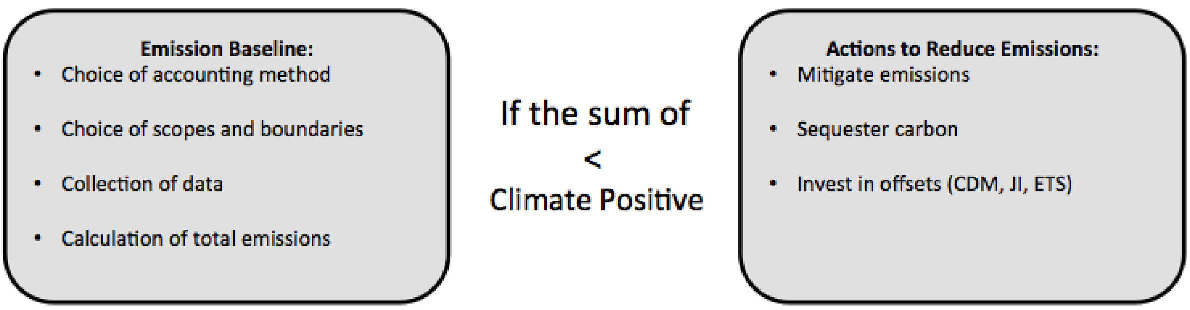

Figure 2.1: General conditions for when an urban district could be considered to be climate positive.

As an example, since SRS is using the CCI method, the steps included in the process are: Setting scopes and boundaries; data collection; and calculating the GHG emissions baseline. The next step for SRS is then mitigation of emissions (for example energy efficiency measures). Carbon sequestration and purchased offsets are not allowed in the CCI methodological approach.

In addition to the other mitigation options, a system of credits is planned where decisions and technology implemented in SRS will reduce emissions in the surrounding City of Stockholm (CCI, 2011).

2.2 The Vulnerability of Cities to Climate Change Impacts

Cities are at great risk and are particularly vulnerable to the impacts of climate change. An increase in extreme weather events and new weather patterns is predicted, and this will have varying effects on cities, depending on their geographic locations. Some of the effects include an increase in precipitation, cyclones, flooding, glacial melt and thus sea level rise, as well as drought and extreme heat events (IPCC, 2007). These events will have significant social, economic and health impacts on cities, as well as severely affecting built infrastructure and urban management systems (Garnaut, 2008; Stern, 2006; UN Habitat, 2011). As most of our cities are based around largescale infrastructure and management of resources (i.e. energy, water and waste systems), cities are particularly susceptible and vulnerable to climate change events, as disruptions to these systems affect extremely large areas of cities, and thus people (Greenpeace, 2005).

However, it is not only the resource management systems that will be affected by the increased frequency and intensity of storm events. The events are likely to cause significant damage to all sorts of infrastructure in cities, such as bridges, buildings, roads, subways and other transportation systems, in addition to sewer systems, transmission lines and mobile networks.

Heat events, which include extended periods of above average temperatures and which can lead to droughts and bushfires, are also expected to become more frequent in certain geographical areas (IPCC, 2007). Cities not designed to deal with these pressures can expect problems such as buckling of railway tracks, increased heat island effects, additional stress on power grids and more frequent power outages due to greater demand for air-conditioning, and higher levels of heat related mortality (Hennessy, 2011; UN Habitat, 2011).

The 2003 heatwave in Europe, Hurricane Katrina in New Orleans in 2005, the 2010 Pakistani floods, the 2010/11 Brisbane floods and Hurricane Sandy in North America in 2012 have all demonstrated how costly, both financially and in terms of human life, such weather events can be on cities, particularly in relation to large-scale infrastructure. Another significant risk to cities involves sea level rise. Around 13 per cent of the world's population currently resides in cities that are considered at risk of rising sea levels (UN Habitat, 2011). For some cities, adapting infrastructure to cope with this (e.g., building dykes, levees, sea walls and potentially moving buildings to comply with new planning regulations and building codes) will be costly and challenging. For many others, it may mean relocating. Climate refugees are expected to be one of the largest costs associated with climate change (Stern, 2006). Cities will need to be prepared to address this challenging, though less frequently discussed, and potentially costly issue (Garnaut, 2008).

2.2.1 Why Cities are Fundamental in Tackling Climate Change

Carbon has played an important role in the formation and reformation of cities for centuries. Cheap fossil fuels have been a driving force in the rapid expansion of cities and in shaping our urban form. It has enabled and facilitated the development of car-dependent suburbs and allowed houses to continually increase in size. The availability of cheap energy based on fossil fuels has meant little regard has been paid to things such as energy efficiency in buildings and other critical urban design features that were fundamental elements of older cities. As a result, abundant carbon abatement opportunities are now being identified at this city level, particularly within the built environment (McKinsey & Company, 2010; The World Bank, 2010; UN Habitat, 2011). Consequently, cities and their built form are now identified as a "vital part of the global response to climate change" (Broto & Bulkeley, 2013).

Furthermore, a popular graph developed by McKinsey & Company (2010), demonstrates how many of the global carbon abatement opportunities can be made on a cost neutral or positive basis; that is, the measures will have an immediate net financial benefit on the economy over their lifecycle. Most of these measures are from within the built environment. Other analyses show how longer term economic gains can be made from more fundamental shifts towards redevelopment in a more compact city (Trubka et al., 2010 a,b,c).

Fortunately, cities are well positioned to be able to take action and create change at the local level, particularly in response to climate change and other environmental issues. Being the closest level to the public, cities and local governments have greater capacity to make quick decisions because of the 'more immediate and effective communication' between citizens and local decision-makers, compared to higher levels of government (World Bank, 2010). This is critical, as the effects of environmental problems often directly impact cities, demonstrating the need for them to be more pragmatic and swift in their response. As a result, cities have in many cases been leading national governments and international agendas in terms of climate change mitigation and action (Bulkeley et al., 2011; Roseland, 2012; UN Habitat, 2011).

The dynamic and progressive nature of cities, due to their agglomeration economies, also makes them 'powerhouses' of social, environmental and technological innovation and change (Glaeser, 2011; Hollis, 2013; Trubka et al., 2010b). Cities are able to foster innovation through proximity and density, which allow the rapid transfer, exchange and development of ideas and knowledge within a small geographical area. Clusters of innovation can learn from each other, and this innovation has resulted in massive leaps in efficiency and reductions in the carbon intensity of urban systems, and has provided solutions to many environmental problems over the years (Brugmann, 2010; Glaeser, 2011; UN Habitat, 2011). Acting on climate change at the city level also helps to drive economic competitiveness through increased operational efficiency and investment in new technologies (Brugmann, 2010; Sassen, 1994).

Proximity and density are also the key to facilitating better public transport infrastructure and decentralised urban resource management options such as co- and trigeneration, as well as providing more efficient and compact housing options

(Dodman, 2009; Glaeser, 2011; Rauland & Newman, 2011). These aspects of a city (e.g., housing types, transport modes and energy, water and waste infrastructure) are all part of a city's built environment and create its urban form, which ultimately determines its resource consumption patterns and the greenhouse gas emissions associated with it (Ewing et al., 2008; Glaeser, 2011; Newton, 2012).

2.3 Frameworks and Accounting methods

Determining the carbon footprint or greenhouse gas emissions associated with a product or organisation can be a complex undertaking. However, addressing these issues at a district, community or a citywide scale is a considerably more difficult task as the magnitude of each issue increases (Dhakal, 2010). Nevertheless, despite this challenge numerous attempts have been made by academia, industry, cities and local communities to classify these emissions to better understand the GHG contribution of urban development at the various levels (Dodman, 2009).

The following is a discussion of key literature pertaining to GHG accounting at the city and district scales. Several prominent existing and proposed city-scale GHG methodologies, tools and inventories are highlighted, and a brief description of the most recognised and utilised of these frameworks and initiatives is provided.

2.3.1 Determining the GHG Contribution of Cities

Cities and urban areas are increasingly being identified as major producers of global GHG emissions (Hoornweg et al., 2011, World Bank, 2010). However, the perceived extent of their contribution varies depending on which emissions are included in the GHG analysis of any given city. For example, Satterthwaite (2008) contends that a significant proportion of the emissions that are often attributed to cities occur outside a city's official legislative boundaries (e.g., from fossil fuel power stations, waste management or agricultural practices), but occur as a result of a city's demand for resources or their urban activities. A question that therefore arises is: should emissions be assigned to the location of their production or at the place of their consumption?

The issue of boundaries thus forms a major component of the discussion around city GHG inventories. Assigning emissions to consumption acknowledges the fact that emissions generated in one city or country (particularly the case for developing nations) are often produced primarily to satisfy demand for commodities in other cities or countries (particularly industrialised nations) (Dhakal, 2010; Hoornweg et al., 2011; Satterthwaite, 2008). Nevertheless, accounting for consumption is particularly tricky and thus most GHG frameworks have tended to focus predominantly on the production side.

The concept of urban metabolism, first introduced by Wolman (1965), clearly explains how resources flow in and out of cities, and the subsequent environmental impacts associated with them. Later research led to the development of a useful tool based around this flow of materials (Materials Flow Analysis, or MFA). While this could potentially provide an appropriate methodology for determining emissions associated with cities, Kennedy and Sgouridis (2010) note that, as the analysis often uses a region's physical boundary, it is not suitable for cities and urban precincts, which are usually dependent on several emission sources outside their boundary (i.e. electricity production), but that they are directly responsible for.

Numerous GHG accounting frameworks, methodologies and inventories have been developed in recent years, and countless more have been proposed. These have attempted to address a variety of urban scales, including communities, local governments and cities, as each level acknowledges and accepts the importance of their role in addressing climate change (Carbon Disclosure Project, 2012; Hoornweg et al., 2011).

The GHG frameworks and inventories are being developed and/or proposed by a range of entities including cities and individual communities, NGOs, municipal associations and organisations (e.g., ICLEI Local Governments for Sustainability, World Bank and C40 Cities), as well as the private sector - often in the form of industry partnerships (e.g., ARUP and C40 cities, and CDP Cities and AECOM) and academia (Dhakal, 2010; Dodman, 2009; Hoornweg et al., 2011; Satterthwaite, 2008; World Bank, 2010).

Most frameworks and inventories have drawn from previous experience and earlier institutional standards and protocols. Some key existing documents include the International Local Government GHG Emissions Analysis Protocol (IEAP) developed by ICLEI, the Draft International Standard for Determining Greenhouse Gas Emissions for Cities, developed in partnership between UNEP/UN-HABITAT/WB, the GHG Protocol Standards (WRI/WBCSD), the Baseline Emissions Inventory/Monitoring Emissions Inventory methodology (EC-CoM JRC), and the Local Government Operations Protocol produced by ICLEI-USA (C40/ICLEI/WRI, 2012).

2.3.2 Academic Discourse on GHG City Methodologies

While cities are identified as being major contributors to climate change, they are also recognised as being a powerful force in global GHG mitigation (Bartholomew & Ewing, 2008; Dhakal, 2010; Dhakal & Strestha, 2010; Dodman, 2009; Hoornweg et al., 2011; Newman et al., 2009; Sattherwaite, 2008; Roseland, 2012). Much academic literature has been concerned with identifying the activities and resulting emissions attributable to cities, to better manage and reduce city-based emissions. While the discussion continues around the specific emission sources and activities (Dhakal, 2010; Dodman, 2009; Satterthwaite, 2008), as it has helped to inform public debate and contributed significantly to the development of the various city GHG accounting methodologies and inventories currently being used by several of the initiatives outlined above.

Some of the key challenges to calculating and managing carbon emissions in cities, as noted by Dhakal & Shrestha (2010), include:

…data and information gaps, developing long-term scenarios, establishing a consistent urban carbon accounting framework, understanding of the urban system dynamics, and interaction of urban activities related to carbon emissions across the multiple system boundaries, formulating appropriate policies, and operationalizing the policy instruments (p. 4753).

Fortunately, many of the issues outlined above are being addressed by recent initiatives including the collaborative development of the Global Protocol for Community-Scale GHG Emissions (GPC) mentioned above. As commonly noted in the literature, adopting a standardised GHG accounting approach, such as the GPC, will help to increase the reliability of placed-based comparisons, particularly between international cities, as well as generating a more accurate understanding of the true GHG attribution for cities globally (Dhakal, 2010).

One of the most common topics emerging out of the literature on GHG accounting for cities has been around GHG attribution and system boundaries (Dhakal, 2010; Dhakal & Shrestha, 2010; Dodman, 2009; Hoornweg et al., 2011; Matthews et al., 2008; Satterthwaite, 2008). Most research identifies the important effect consumption has on a city's emissions profile. This is largely because traditional city GHG accounting has taken a production-based approach that considers the emissions produced physically onsite or within a city's geographic/legislative boundary (Dodman, 2009). When adopting this production-based approach, larger cities often come out having smaller per capita footprints. This is demonstrated in an analysis by Dodman (2009), who compared several UK cities and showed that inhabitants of larger cities indeed often had lower per capita emissions than average UK citizens and significantly lower footprints than citizens of smaller rural cities that are likely to have more industry located in their boundaries but fewer people.

The production-based approach fails to acknowledge the fact that a significant proportion of the emissions generated from the production of commodities in one geographical area (often smaller industrial towns) are generally created primarily to satisfy the demand for those commodities in other areas – typically larger cities. Ramaswami et al., (2008) highlight this fact, that 'producer cities' (i.e., those that produce materials such as cement, steel, food and other key urban materials) often get penalised in the production-based approach, while other 'consumer' cities get rewarded for their recycling.

Nevertheless, significant urban research suggests numerous other reasons exist for the lower GHG emissions associated with larger, denser cities. Factors such as dwelling size, transport mode, infrastructure options and consumption habits can contribute significantly to larger cities having lower per capita carbon footprints compared to their suburban and rural counterparts (Beattie & Newman, 2011; Dhakal, 2010; Glaeser, 2011; Glaeser & Kahn, 2008; Newman et al., 2009; Newman & Kenworthy, 1999; Newton, 2008; Roseland, 2012).

Although the consumption-based approach for GHG accounting provides a more holistic and arguably more accurate representation of a city's emissions profile, research into this area is currently limited and there remains no accepted framework for apportioning these consumption-based emissions at a city-wide scale (Dhakal & Shrestha, 2010).

In their article 'Rigorous classification and carbon accounting principles for low and Zero Carbon Cities', Kennedy and Sgouridis (2010) attempt to include the emissions from both production and consumption within cities and thus provide a useful and comprehensive analysis of city-wide emissions.

The urban-scale climate change and sustainability assessment tools of Kennedy & Sgouridis (2011) are a relatively complex analysis of urban emissions that take into account all three Scopes of emissions. They argue that the broad and relatively simplistic carbon footprint definitions and principles that are often applied to products and organisations are not necessarily appropriate when applied to cities and precinct developments, as these larger areas need to take into account and include multiple stakeholders, a variety of urban scales and numerous emission sources (Kennedy & Sgouridis, 2011). However, they also point out that using a definition that is too narrow such as the one proposed by Wiedmann and Minx (2008), can end up "underestimating the value of urban efforts for system-wide mitigation" (Kennedy & Sgouridis, 2011).

The GHG accounting proposed by Kennedy and Sgouridis (2011) helps to bring a more thorough understanding of the total carbon associated with cities and urban areas and demonstrates how interrelated and complex cities are, and hence how complicated such GHG accounting can be. However, when applied to the district scale, this analysis arguably goes beyond what a developer could legitimately be held responsible for, even in conjunction with other key stakeholders such as utilities. It also runs the risk of being too complicated and time-intensive to get developers willing to participate in calculating and managing such a broad range of emission sources.

Nevertheless, having a comprehensive GHG analysis can be very helpful in developing appropriate carbon policies and mitigation strategies for both developers and local councils, such as sourcing commodities with lower carbon footprints and requiring lower carbon transport infrastructure (Dhakal & Shrestha, 2010). It could also help to provide a basis and framework for knowledge sharing, because, as Sovacool & Brown (2009) note, “the lack of comparative analysis between metropolitan areas makes it difficult to confirm or refute best practices and policies” (p. 4857).

2.3.3 District Carbon Claims

Countless developments around the world are demonstrating how to reduce carbon at the district level. However, as literature has demonstrated, there is currently no consistency in the way to go about the process, how to measure and report emissions, or how to assert a carbon reduction or claim.

Most developments appear to concentrate predominantly on the carbon emissions associated with onsite energy production and use. Although many also take into consideration additional factors such as water and waste, these are not always represented in terms of carbon. The embodied emissions associated with the materials used in developments are rarely accounted for in carbon analyses, despite this being a growing area of emissions (Sturgis & Roberts, 2010).

Transport appears to play a significant role in lowering the per capita carbon footprint of residents living within the case studies discussed, particularly when compared to the citywide average. However, again this is not consistently documented in all developments, nor is it clear how emissions have been calculated.

The inconsistent terminology, together with the lack of a common metric or framework for the carbon analyses, or a common process to reduce emissions, makes it difficult to compare developments and cities in terms of their carbon reduction. Therefore, in order to make any such assertions meaningful, comparable and legitimate, a standardised approach to quantifying the carbon emissions arising from district-scale development needs to be developed and promoted, as well as an ongoing evaluation process.

2.3.4 The Need for a Universal Definition and Accounting Framework

Despite the largely accepted, broad definition of the term carbon neutrality, the precise approach and methods required to undertake each specific step of the process, particularly in the case of urban development, remains unclear on several levels including:

- the specific GHG emissions that are covered (i.e. the types of gases);
- the various Scopes (i.e., direct or indirect emission sources – also known as Scope 1, 2 and 3 Emissions)61 and boundaries of emissions; and
- whether or not carbon offsets are included and, if so, the degree to which emissions have been offset before being reduced.

Further detailed information around offsets is required, for example, whether they are produced onsite or purchased from a third party, and in the latter case, how credible the offset provider is (Department of Communities and Local Government, 2009a; Wiedmann & Minx, 2008).

The case studies analysed in this study illustrate that developments currently do not address these questions systematically, resulting in significant variation in their carbon definitions, goals and achievements. A universal process for determining what factors need to be addressed and clarified when making carbon claims at the district level would therefore go a long way in helping to overcome these issues. Kennedy and Sgouridis (2011) also identify the lack of definition and need of a carbon accounting framework for urban development, stating:

Given the complexity of material and social interactions on an urban scale, we find that currently there are no concrete definitions upon which these claims can be measured and compared. Therefore, in order to make the ambitious targets of low and zero carbon emissions meaningful concepts in the context of urban planning, a carbon accounting framework needs to be rigorously defined and adapted to the urban scale (p. 5259-60).

Determining the extent of the 'urban scale' in terms of emission boundaries is a challenging and often arduous process as boundaries can extend almost indefinitely. Moreover, the intricate and continually changing nature of cities, urban areas, precincts and the systems sustaining them, as well as the activities going on within them, make carbon calculations extremely complex (Brugmann, 2010; Kennedy & Sgouridis, 2011). Nevertheless, several attempts and proposals have been made to define these boundaries and calculate the carbon footprint of entire cities and urban areas (C40/ICLEI/WRI, 2012; ICLEI, 2009; Kennedy & Sgouridis, 2011). These will be discussed shortly. First, however, an overview of the key issues associated with carbon foot printing/GHG accounting is provided, along with the methodologies currently underpinning the practice.

2.4 Accounting Methodology

2.4.1 General Principles for GHG Accounting

Aiming to meet climate change mitigation targets, a number of communities and regions aspire to set up accounting systems in order to obtain data for target setting, evaluation and benchmarking of GHG emissions. However, there is still lack of clarity regarding what type of GHG emissions cities should address and how to account for them on an urban scale (Kennedy & Sgouridis 2011).

A city is a complex system not only limited by the geographical boundaries of all its active sectors but also interconnected in a broader sense (regional, globally) through many functional relationships, materials, energy and information exchange. What to include and what to exclude from the city emission accounting system, also depends deeply on the various factors. It is hard to compare city emission targets, as the accounting methods are lacking in transparency and they differ in the type of emissions that are taken into account (Kramers et al., 2013).

The current methods to account for GHG emissions from a city or an urban district usually build on the Greenhouse Gas Protocol (Rangathan et al., 2004). This was originally developed for corporations, but versions of it have been developed with cities in mind (e.g. ICLEI, 2009). In principle, these protocols make no distinction between accounting for emissions from a city and accounting for emissions from an urban district. What differ between a city and an urban district are the scopes and boundaries that determine which emissions are included and how some emissions should be divided or allocated. This is necessary since not all the emissions of an urban district are limited to the geographical area of the district itself. Examples of emissions associated with the district but usually emitted (completely or at least partly) elsewhere are emissions from electricity use, heating, cooling, transportation and waste treatment. Generally, the protocols mentioned above classify emissions into one of three categories:

- Scope 1 or internal emissions, such as direct emissions from heating, cooling and transportation
- Scope 2 or core external emissions, such as emissions from electricity use and waste treatment

The emissions from scopes 1 and 2 are generally required to be reported (Rangathan et al., 2004; Kennedy & Sgouridis, 2011), while the inclusion of scope 3 emissions is generally voluntary. However, the scopes themselves are too vague to clearly describe what emissions should be included in the GHG accounting, especially scope 3 (WRI & WBCSD 2011). To better address this, four different types of system boundaries need to be set. For each emissions source under each scope, the four types of system boundaries are applied. These determine which scope the emissions source falls under, thereby deciding whether the emissions are included or not.

Drawing on work recently published by Kennedy & Sgouridis (2011), the system boundaries can be summarised as:

- Temporal Boundary - Determining a starting point when tracking emissions and sequestrations and if periodisation is used, for instance tracking annual emissions.
- Activity Boundary - Determining whether activities generating emissions are connected to the urban district or not.
- Geographical Boundary - Determined by the urban district’s geographical area.
- Life Cycle Boundary - Determining whether emissions in the life cycle of material and energy flows are included or excluded.

There are some issues regarding setting scope and boundary in urban districts i.e. especially transportation can be a problem: If for example the principle of the geographical boundary is applied then transportation of the residents might be included in the core activity as long as it is commuting and local (scope 1). Larger distance commuting might be scope 2, but business trips could be regarded as part of the embodied emissions under scope 3. Long distance trips and tourism might not be included in scope 1 but in scope 3. Clearly this requires adequate definitions in order to produce a feasible system.

2.4.2 Scopes and Boundaries

Determining the scope within which a specific category of emissions (such as energy, waste, etc.) falls is a process of elimination. For each of the system boundaries, each emissions category is tested to see whether it is included within the boundary or not. If an emissions category were considered to fall within all four of the system boundaries, it would be considered a scope 1 emission. Should it fall outside any of the system boundaries, it would be considered either a scope 2 or scope 3 emission (Kennedy & Sgouridis 2011). The process of determining scopes of emissions using system boundaries is summarised in Figure 2.

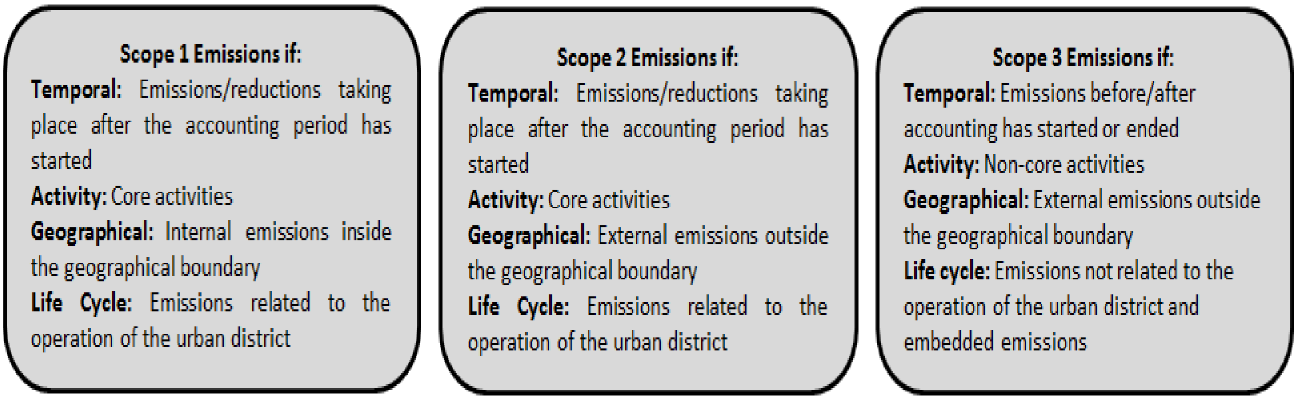

Figure 2.2: Process for determining the scopes for GHG emissions baseline

As discussed earlier, GHG accounting methodologies vary depending on the entity being assessed. Organisations, services and personal carbon footprints generally follow an inventory style GHG accounting approach, which focus primarily on the operational emissions. This approach is largely based on The GHG Protocol: A Corporate Accounting and Reporting Standard (WRI & WBCSD, 2004), which also underpins the various Australian and international GHG accounting Standards, e.g., ISO 14064-1 (ISO, 2006) and AS/NZS I46064-1 (Standards Australia, 2006). More information about the boundaries and Scopes of emissions associated with this GHG accounting methodology are provided in sections below. Cities and local governments tend to adopt this operational inventory approach when measuring their emissions, as it is far less complicated than undertaking a full life cycle GHG assessment (Hoornweg et al., 2011; ICLEI, 2010). This is particularly important for cities, which are already such large and complex systems (Dhakal, 2010; Kennedy & Sgouridis, 2011).

A life cycle inventory analysis is the other predominant GHG accounting methodology, and involves examining emissions along the entire supply chain, from production and acquisition of raw materials, to transport, manufacturing, storage and ultimate disposal. This approach is most often applied to products (DCCEE, 2011b, Matthews et al., 2008).

It is argued that district-scale development would benefit from using both approaches; a life cycle approach in quantifying emissions would be needed due to the significant emissions attributed to factors such as materials, construction processes and the resource management systems underpinning a development. At the same time, the design of buildings, density and mix of the development will largely determine the operational GHGs, including transport GHG outcomes and the building GHGs. Understanding the entire footprint of a development allows developers to identify the easiest carbon abatement opportunities (i.e. switching materials, processes or technologies as well as the density and mix issues). Developers are therefore able to make the greatest reductions to their carbon footprint through more informed purchasing and planning decisions (Matthews et al., 2008).

There are several methodologies and ways to undertake a Life Cycle Analysis, which can lead to very different GHG outcomes (Nässén et al., 2006). The main approaches include Process Analysis (PA), Economic and/or Environmental Input-Output (EIO) Analysis, or a Hybrid EIO-LCA (Matthews et al., 2008). Process Analysis is the most commonly applied method for conducting a Life Cycle Analysis and involves systematically identifying and quantifying all emissions along the supply chain, beginning with direct emissions before tracking all indirect emissions. While this process provides superior specificity in terms of data collection and overall numbers, the comprehensiveness of the process (i.e., including each section of the supply chain that has its own additional set of inputs/outputs) means that the analysis is very time consuming as it could theoretically continue indefinitely (BernersLee et al., 2011).

Economic Input-Output Analysis is another widely used approach, which uses large-scale, aggregate data based on industry sectors within an economy. The information is gathered using financial expenditure, i.e., by examining each sector's interdependence based on their financial transactions. If the EIO data for each sector is available and a sufficient accounting system is in place for the product being examined, this method can prove relatively easy compared to the PA approach (Berners-Lee et al., 2011). Nevertheless, such large data sets mean averages must be used, which limits the overall accuracy of the approach.

The EIO is often referred to as a top down approach while the PA is seen as a bottom up approach. A hybrid of these two models has also been suggested as a way of overcoming the limitations and weaknesses of both approaches and benefitting from their strengths. A Hybrid EIO-LCA involves using the basic EIO approach but, instead of utilising the broad sector data, it is "augmented with impact data for specific goods, services, and organisations" (Matthews et al., 2008, p. 5840).

A typical life cycle assessment approach may not necessarily be the most appropriate choice for precinct development, given the complexity associated with assessing multiple emission sources within a precincts boundary. It is therefore suggested that a hybrid approach would be the most suitable option for development, which effectively follows the Hybrid EIO-LCA described above. Adopting a hybrid approach for calculating the emissions associated with construction is also recommended in the Federal Government's National Carbon Offset Standard Carbon Neutral Program (DCCEE, 2011b).

2.4.3 Boundaries

Determining the boundaries of a carbon footprint or GHG inventory is one of the first steps in any carbon accounting process and the absence of agreed boundaries is one of the key causes of inconsistency among carbon precinct claims. Boundaries can be set at various levels. If the focus is on corporate carbon accounting, two levels of boundaries need to be established - the organisational boundary and the operational boundary. If a life cycle carbon analysis is the chosen methodology, boundaries are not generally associated with organisational or operational control but with the supply chain. As highlighted above, determining clear boundaries associated with the life cycle approach is critical as boundaries are essentially infinite (Matthews et al., 2008).

An organisational boundary is determined based on full ownership or financial control of the organisation. The GHG Protocol: A Corporate Accounting and Reporting Standard (WRI & WBCSD, 2004) outlines two approaches for establishing organisational boundaries, the ‘Equity share approach’ and the ‘Control approach’. The equity share approach requires corporations who have equity in other organisations, subsidiaries, partner or joint ventures to report emissions from those companies depending on the percentage they own. The control approach only requires corporations to report on emissions from organisations, subsidiaries, partner or joint ventures that they have financial or operational control over (WRI & WBCSD, 2004).

The organisational boundary is not applicable to precinct-scale land development if the aim is to achieve carbon neutrality. While a developer will be responsible for the majority of the emissions associated with the construction of a development, there are several additional emission sources that would not be captured under this boundary approach, such as the emissions generated from the utilities supplying resources to the area (e.g., energy, water and managing waste).

The operational boundaries outlined in The GHG Protocol (WRI & WBCSD, 2004) are those emissions associated with the operations of the company/corporation, once they have identified their organisational control. These emissions are generally identified using ‘Scopes’, which are discussed in more detail below. Taken together, the organisational and operational boundaries represent the overall system boundary of an organisation.

Again, in relation to district development, neither of these boundaries are likely to be relevant, as a district, particularly after construction, is likely to consist of multiple owners, stakeholders and organisations, which all ultimately contribute to the emissions profile of the precinct.

An additional boundary that is often discussed in relation to local governments and cities is the geographic and geopolitical boundary, which consists of the official jurisdictional boundaries of the physical land area associated with a local government or city (ICLEI, 2009). Kennedy and Sgouridis (2011) also discuss the issue of geographic boundaries in relation to carbon accounting in cities, stating that:

A city is a dynamic and complex system, defined in part by its geographic boundaries, but also by its interconnections with a much broader region through exchanges of materials, energy, and information. This interconnectedness complicates the task of determining which emissions should be included in a city's carbon balance (p: 5261).

The boundary issue often stimulates discussion around GHG attribution (i.e., whether emissions should be accounted for at the place of production or consumption).

With respect to transport, a precinct can only have limited responsibility from an organisational perspective, but from a local government's perspective it is very important. Thus, in order to achieve compliance with local governments carbon reduction goals, a developer may have to accept that there is a role for them in terms of urban design, density and mix, which will have an impact on the carbon outcomes. While the provision of infrastructure for public transport has historically been a state or federal responsibility, in the future it is likely to require some kind of partnership approach and will cross boundaries beyond most precinct plans.

2.4.4 Scopes

Emission sources are broadly split into two categories, direct and indirect emissions. Direct emissions are those that occur onsite or through activities that are under the full control of an organisation. Indirect emissions are those that are produced by a separate organisation/entity (e.g., electricity production or emissions from aircrafts) but still occur as a result of demand by the first organisation/product (WRI & WBCSD, 2004).

The concept of Scopes for emissions was introduced as a way of dealing with direct and indirect emission sources to avoid issues associated with double counting. Double counting occurs when the same emission sources are counted twice by different organisations, and is principally only an issue if the emissions are being reported under a mandatory reporting or emissions trading scheme (WRI & WBCSD, 2004). It is less consequential if emissions are being voluntarily reported, and indeed, it is argued that the more indirect emissions that are included under voluntary reporting, the better (DCCEE, 2011b).

Emissions are thus defined as Scope 1, Scope 2 and Scope 3 emissions. Scope 1 emissions are direct emissions from sources within an organisation's direct control. Scope 2 are indirect emissions from electricity production and Scope 3 emissions are indirect emissions from all other activities related to the organisation. Mandatory reporting in Australia (i.e. under the National Greenhouse and Energy Reporting Act) requires covered sectors and organisations to report only their Scope 1 and 2 emissions. This is because the majority of the emissions produced in large, emission intensive industrial companies come from Scopes 1 and 2 sources.

For the goods and services sectors, however, Scopes 1 and 2 can represent less than 25 per cent of their total emissions (Matthews et al., 2008). Therefore, if companies voluntarily choose to report or make carbon claims, particularly, for carbon neutrality, certain Scope 3 emissions should be reported. However, there is still a degree of flexibility in terms of which Scope 3 emissions are accounted for.

While a GHG inventory approach to calculating emissions may include some Scope 3 emissions, depending on the organisation's discretion, a life cycle approach must include all Scope three emissions contained along the supply chain and within the boundary of the product.

2.4.5 Timeframe

Another aspect requiring clarification is the timeframe in which a development will reach carbon neutrality. Buildings are often given a 'lifetime' (i.e., typically 50 years), which forms the basis for the Life Cycle Analysis. This ultimately determines how the emissions that are attributed to the building are spread over the lifetime of that building, and thus how long it will take to achieve carbon neutrality (ASBEC, 2011). Furthermore, timeframes are also needed when determining payback periods, which is particularly significant considering green buildings and developments generally require higher upfront financial expenditure due to the more innovative technologies and designs. It is important to understand the relationship between the higher upfront costs and the long-term savings that occur as a result.

It is likely to be considerably more difficult to establish a timeframe for an entire development compared to a building, due to the different lifetimes associated with different types of infrastructure, for instance, buildings, roads, technologies and resource management systems (Sturgis & Roberts, 2010). However, it is a critical element to understand and establish, as it will determine the timeframe by which the development can legitimately reach carbon neutrality and the offsets required to attain it. Operational energy is an important part of this timeframe.

In terms of GHG reporting and particularly carbon neutrality claims, the timeframe applied is generally annual, as it is often based on operational emissions. This thesis therefore recommends a combined life cycle and operational approach to calculating GHG emissions, as a development claiming carbon neutrality is likely to be required to report annually.

2.5 Emissions Reduction

Reducing emissions can be done internally or externally. Internal emissions reduction may consist of onsite energy efficiency measures, fuel switching, changing suppliers (i.e., choosing suppliers with the lowest carbon footprint), installing renewable energy onsite and purchasing certified green electricity (Department of Communities and Local Government, 2009b). External emissions reduction is generally identified as offsetting, which is discussed below.

Internal emissions reduction forms a critical part of the carbon neutral process and is generally required by most schemes to be demonstrated prior to offsetting (City of

Sydney, 2011; DCCEE, 2011b; Department of Communities and Local Government, 2009a; The Carbon Neutral Company, 2012).

2.5.1 Offsets

The term offsets typically refer to the purchase of carbon abatement credits from projects that are outside the operational control of the organisation wishing to reduce their emissions. The Federal Government has defined carbon offsetting as “reductions or removals of greenhouse gases from the atmosphere by sinks, relative to a business-as-usual baseline. Carbon offsets are tradeable and often used to negate (or offset) all or part of another entity’s emissions” (DCCEE, 2012b).

In terms of the built environment and urban precinct development, it is likely that offsets will be required, at the very minimum, to neutralise the emissions associated with the embodied energy within the materials used to create the development. Offsets could also be used to counteract emissions associated with other aspects of the development (e.g., operational emissions, if the developer chose to source the energy required for the precinct from the current fossil fuel-dominated electricity grid). However, as mentioned above, most carbon neutral schemes and standards specify that internal emissions reductions should be pursued as much as possible prior to offsetting, which often means addressing operational emissions.

It is common within the development industry to classify surplus renewable energy generated onsite and fed into the grid as a carbon offset that can then be used against other emissions sources within the development, such as embodied emissions in materials (Williams, 2012). This is often referred to as ‘netting’ (Sustainability Victoria, 2012), and involves balancing the carbon used onsite with sufficient carbon free renewable electricity produced onsite and exported to the grid over a one-year time period. The development is thus, ‘net zero’ on an annual basis (Hernandez and Kenny 2009, Williams 2012).

However, this concept is generally not accepted under official carbon neutral certification schemes, which use internationally recognised protocols for offsetting, such as the Australian Government’s National Carbon Offset Standard. This is because such offsets (i.e., energy related) are not considered to be additional forms of abatement65, as the energy sector in Australia is a covered sector under the Federal Government's current Carbon Pricing legislation, and thus any action to reduce emissions from this sector is argued to have occurred anyway due to the mechanism already in place (DCCEE, 2012b).

A developer can still use this 'netting' concept as a way of generating their own offsets to achieve carbon neutrality, but they will not be able to achieve this status through the Government's NCOS Carbon Neutral scheme or other schemes that require stringent offsetting standards.

The development of other kinds of local offsets (i.e. those created within a precinct or community) may seem like a logical option to pursue, however, all such offsets need to meet the 'additionality' criteria defined under the standards to be deemed eligible. Unfortunately, there are few options available for developing offsets from city/community-based activities under NCOS, although, there is nothing preventing communities from developing and using these offsets (as long as they provide a clear methodological approach to calculating emission reductions) to claim carbon neutrality without NCOS branding/certification. More information about offsets is provided in the following section.

2.5.2 The Offset Polemic

As discussed at the beginning of this chapter, the concept of carbon offsetting has grown considerably over the last decade, leaving in its wake a thriving voluntary carbon offset market. However, there have been concerns and issues along the way, particularly relating to transparency and credibility resulting from the initial unregulated nature of the voluntary carbon market66 (Lovell et al., 2009; Moore, 2009; Murray & Dey, 2008). However, this market has rapidly matured over recent years with radically improved processes, structures, standards and regulations now underpinning it (PetersStanley et al., 2011). Nevertheless, there are still many who oppose offsetting, contesting the fundamental principle and concept of it. These issues and others are discussed below.

2.5.3 The Perceived Fundamental Flaw

The rapid development of the offset market clearly demonstrates the appeal of carbon offsetting by companies and individuals as a way of exhibiting environmental commitment and action. However, not everyone remains convinced of the virtues of it. Smith (2007) relates the concept to the story of the Pardoners in the Middle Ages who sold the benefit of their good deeds to sinners who could purge themselves of their indulgences for a fee, allowing sinners to continue transgressing. More recently, a parody of carbon offsetting was made using cheating as the commodity (see cheatneutral.com), which allows one couple to offset their infidelities using another couple's fidelity and faithfulness. Murray and Dey (2008) point out that in both situations, there is no net reduction of the sinning, transgressions or heartache, there is only a balancing of the commodities.

Friends of the Earth also stand deeply opposed to the concept of offsetting, arguing that it causes more harm than good (see Bullock et al., 2009). They contend that it will not lead to overall emissions reductions, suggesting it merely legitimises the idea that people who can afford to pay others to reduce their emissions, can do so and thus continue to pollute as normal. They also suggest that it delays investment in essential infrastructure, particularly in developed countries where investment may have gone ahead regardless, but now waits to determine if a project is eligible to generate offsets. Finally, they argue that carbon offsetting institutionalises the idea that emissions reductions can occur in either developed or developing countries, ignoring the scientific recommendation that reductions are urgently required in all locations (Bullock et al., 2009).

However, as carbon offsetting is based on the premise that emissions have the same effect on the atmosphere wherever they are produced or abated in the world, it is argued, particularly by economists, that the least cost carbon abatement opportunities should always be pursued first, regardless of their location. Thus, if it is cheaper to reduce emissions offsite through offsets than through onsite emissions reduction measures, the cheaper option should always be the preferred choice. It naturally follows that the price of offsets will increase over time as offset projects become scarcer (e.g., tree planting) or projects become ineligible (e.g., if replacing light bulbs in India becomes the norm and no longer considered ‘additional’), making domestic, onsite carbon abatement more financially viable.

Both arguments are valid, and will no doubt continue to be contested. Most carbon neutral schemes, however, do strongly recommend that in-house emissions reduction options be pursued prior to offsetting. Lovell et al (2009) also analyse the concept of offsetting in relation to sustainable and ethical consumption. They examine both the notion of nature as a commodity, which looks at the implications of marketing ‘the environment’, as well as the effect offsets have on driving behaviour and consumer’s choice of products. Their analysis proposes that the voluntary offset market is indeed a complex and uncertain one, but that ultimately it can help to shape behaviours by making people aware of the effect their everyday, often mundane actions, such as driving a car, has on the environment and atmosphere.

It is also worth mentioning that some offsets, such as biomass plantings (e.g., CDM projects in developing countries and other voluntary offsets in developed countries) can have substantial co-benefits such as increasing local biodiversity and the reducing land degradation (Karousakis, 2009).

2.6 The European Experience

The concept of an ‘eco-city’ has its roots in the early 20th century (Roseland, 1997). However, interest in the concept grew rapidly in the late 1980s when people began exploring how the newly defined notion of ‘sustainable development’ (World Commission on Environment and Development, 1987) could be interpreted within an urban context and at a city scale. Numerous articles began investigating what eco-cities may look like and the many elements that should be incorporated into their design and management. These writings were instrumental in helping to popularise the concept (Roseland, 1997).

Fast-forward two decades, and the previously aspiring eco-city concept (Engwicht, 1992) has become reality with countless demonstrations around the world. A recent eco-city survey conducted by the University of Westminster identified over 170 eco-cities globally (Joss, 2011, p. 135). The cities range in size and scale, as well as in ambition. Several have drawn considerable attention over the years due to their progressive nature, inspiring and impressive goals and successful realisation.

The largest and best-known sustainable neighbourhood developments to emerge in Europe in the 1990s: BedZED and Hackbridge in London, UK; Bo01 in Malmö, and Hammarby Sjöstad in Stockholm, Sweden. The knowledge and experience gained from these early projects is considerable, and their influence can be seen in a number of CLUEs and climate positive districts, most notably in the cases of the Stockholm Royal Seaport which draws upon the experiences of its predecessor Hammarby Sjöstad and in Hackbridge, London, where BedZED's ethos of One Planet Living is applied at district level.

These districts are thought to be in the technological forefront and a showcase for sustainable urban development with an emphasis on climate mitigation and climate neutral development i.e. they shall offer many "smart city" solutions. But as a matter of fact, there are no climate neutral urban districts yet in the world (Michael Erman, 2014).

The development demonstrates that climate neutral development can be achieved on a small neighbourhood level and even cities. The development boasts an appropriate density to support provision of local infrastructure, and although this increases the project costs, it also allows for an efficient delivery of heat and energy needs to homes with lower carbon emission rate, which would be more difficult to achieve on an individual scale

The main criticism is the difficulties most project has experienced generating more energy consumption for renewable resources. Consequently, it is the economies of scale which zero energy and carbon neutral developments demand that Bioregional have to factor into their industrial ecology over the past 10 years. This has meant devising a metabolic model of industrial ecology whose social and environmental credentials incorporate innovations able to exploit the opportunities decentralized energy system, with CHP stations, fuelled by biomass. This has meant scaling-up the innovations so the zero-carbon energy and carbon neutral principles, this sustainable community stand for and live by are no longer limited to the development of new neighbourhoods, but extend into the mainstreaming of both their social and environmental credentials into those building found in districts of existing suburbs.

2.6.1 Rationale for Choosing the Case Studies

Case study that has been chosen in this research to demonstrate the strategic value of urban infill and urban retrofits in the sustainable built sector are those known as the Stockholm Royal seaport (SRS) and the Hackbridge Project (HP).

These two city-districts offer world leading smart sustainable framework for achieving climate neutrality and climate positive outcomes respectively. They have been selected because these projects offer a particularly good example of the response to move beyond the state of the art (Deakin et al 2015). Also they are thought to be in the technological forefront and a showcase for sustainable urban development with an emphasis on climate mitigation and climate neutral development i.e. they shall offer many “smart city” solutions.

The two projects differ in their approaches in solving this same issue as highlighted. The Stockholm Royal Seaport project aims to provide its residents with advanced systems to achieve sustainable living, without requiring that residents make conscious changes to their behaviour. Hackbridge, as a retrofit programme, relies less on “sustainability by design” but features the promotion of sustainable lifestyles, including home visits and personalised schemes to lower household carbon footprints.

At first sight the case study models appear mutually exclusive in terms of their accounting, framework and scope i.e. Hackbridge is more holistic in its operation while SRS model offers more fragmented solution, but they do still complement each other in terms of the, functionalities, energy savings and carbon emission savings they both search for.

The high performance-based criteria of these city-districts as energy saving and carbon emission reduction. In classifying the morphology of these city-districts, the regional innovation systems they are the standard-bearers of, are forecast to produce saving and reductions in excess of those laid down by the EC. As standard-bearers of sustainable and inclusive growth and leading pioneers of both energy saving and carbon emission measures, these city-districts are at the forefront of regional innovation. Indeed, they are so advanced as to offer the prospect of a smart dividend for sustainable city-districts and include (neighbourhood) communities whose energy efficiencies pave the way for what are termed post-carbon economies.

2.6.2 Hackbridge Project

One Planet Living (OPL) is a clear set of ten sustainability principles put together by the organisations BioRegional and the Worldwide Fund for Nature, which set out how we can live and work within a fair share of our planet's resources. Many of the environmental principles are familiar - such as reducing waste, energy efficiency, supporting wildlife and creating more a sustainable transport system

The Hackbridge project uses the OPL framework, it aims to reduce from an Ecological Footprint of 5.32 global hectares to 1.5 and from 11.17 tonns of CO2 per capita to 1.2 tonns". The Hackbridge project concentrates on the upgrading of existing homes (retrofitting) plus the development of 1,100 new environmentally friendly home. The estimated the mass retrofit in Hackbridge will reduce the C02 emissions in the residential property sector from 1.82 - 0.92 tons per capita as illustrated in figure 2.3

Figure 2.3: Area view of Hackbridge district.

2.6.3 SRS Project

Stockholm Royal Seaport (SRS) new built development has a goal of becoming a climate positive urban district and an example of environmentally benign urban planning. To achieve this goal SRS became one of 16 projects around the world participating in the Climate Positive Program, developed by Clinton Foundation's Clinton Climate Initiative (CCI), giving a conceptual framework detailing the climate positive process. The Climate Positive Development Program was launched in a partnership between C40 Cities Climate Leadership Group, CCI and the US Green Building Council in order to help urban development project to reduce greenhouse gas emissions below zero. As illustrated in figure 2.4

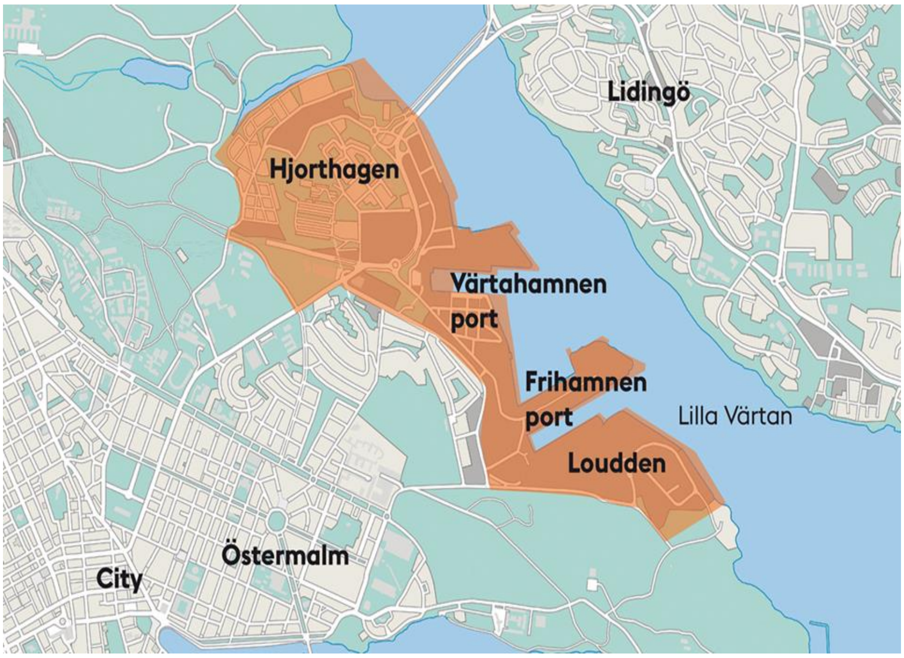

Figure 2.4: Map view of Stockhol Royal Seaport (Hjorthagen area).

The framework focuses on low energy consumption, local on-site energy production, a high share of renewables and community impact for low carbon emissions measures in order to help urban development project to reduce greenhouse gas emissions below zero (climate positive).

2.6.4 The Potential of Hackbridge and SRS Project

The review goes on address the urban mass retrofit and urban infill underway in Hackbridge and Stockholm Royal Seaport in term of the high level of energy saving and carbon reductions which the smart, sustainable and inclusive growth strategy of this city-district offers (Deakin et al., 2015). The urban morphology of these city-districts which also offers the prospect of a sustainable and inclusive growth strategy that under-grids an energy efficient – low carbon zone, but which also holds out the prospect of constructing a regional innovation system claimed to be climate neutral and climate positive respectively.

Hackbridge project offers the opportunity to extend the principle component-based grid of smart city developments and "enermatics" of the urban morphology under-gridding the sustainability of energy efficient - low carbon zones as part of an inclusive growth strategy, which offers a level of performance that is climate neutral offers (Deakin et al., 2015). Is climate neutral in terms of under-gridding the sustainability of an energy efficient – low carbon zone whose inclusive growth mitigates the adverse effects of global warming.

To further understand the similarities and differences between Hackbridge and SRS, table 2.1 of the study demonstrated how the total emissions vary as a result of the inclusion or exclusion of specific inventory components in the accounting system.

Table 2.1: Similarities and differences between C40 cities and One Planet Living framework.

	Hackbridge	SRS
Target(s)	Ecological Footprint of 5.32 global hectares to 1.5 and from 11.17 tons of CO2 per capita to 1.2 tons"	Climate positive < 0 ton GHG emissions once the entire area is operational
Goal(s)	Climate neutral	Climate positive

Functions	Residential	Residential, office and schools
Unit of measure	Ton CO2e/cap (residents only) 8 000 persons in total	Ton CO2e/cap (residents and workers) 49 000 persons in total
Boundary Principle	Direct and indirect emissions stemming from to activities directly and indirectly related to districts	Direct and indirect emissions stemming from to activities directly related to SRS's geographical area
Energy	Emissions from heating, cooling and electricity. Emission reductions from local energy production	Emissions from heating, cooling and electricity. Emission reductions from local energy production
Transportation	Tracks 100 % of emissions from transportation stemming from activities directly and indirectly related to Hackbridge district: Private trips (residents), Commuting trips (residents), aircraft emissions, fishing and	Tracks 40 % of **all** trips starting/ending within SRS: Private trips (residents), Commuting trips (both residents and workers), Business trips (both residents and workers) Goods and services

	coastal shipping emissions and long distance travel	Not included: Long distance travel
Waste	Emissions and emission reductions from the collection, transport and treatment of waste	Emissions and emission reductions from the collection, transport and treatment of waste.
Overhead Emissions	Emissions Included	Excluded due to geographical Boundary
Consumption	Emissions included	Emissions not included
Production	Emissions included	Emissions included
Tracking emissions reductions	Absolute way i.e. doesn’t allow the concept of avoided emission	Accounting perspective i.e. allows the concept of avoided emission

2.6.5 C40-CCI Accounting system

In this study, different metrics for expressing the total GHG emissions attributable to C40 cities were developed depending based on definition of boundary and life-cycle perspective. The table 2.2 below shows the accounting system used for C40 cities. The figure used the terminology of the World Resources Institute/World Business Council for Sustainable Development (WRI/WBSCD) to express emissions in relation to the boundary of a city. Scope 1 emissions include those that are produced within city boundaries. These include in-boundary components from: fossil fuel combustion; waste; industrial processes and product use; and agriculture forestry and other land use (AFOLU), which are determined as per IPCC guidelines. Scope 2 emissions include out-of-boundary emissions due to electricity used in cities. Several further out-of-boundary emissions attributable to cities are included in Scope 3.

In analysing the inclusion of cross-boundary GHG emission activities in some C40 cities occurring within urban areas has shown to increase the GHG emission of cities involved. Incorporating primarily the impacts of fuel refining was shown to increase GHG emissions associated with 8 global cities by as much as 24% (Kennedy et al., 2009).

Incorporating all five Scope 3 items increases the GHG accounting by an average of 45% for eight US cities studies by Ramaswami and Hillman (*2009*). Further, incorporating all five Scope 3 activities (*Ramaswami et al., 2008*) created consistency both in inclusions and in the numeric per capita GHG emission computed at the city-scale for Denver versus the larger national scale, both of which converged to about 25 Mt CO2e/capita.

Exclusion of airplane emissions in several C40 cities resulted in neglecting emissions from combustion of airplane fuels which should have been counted other than through fuel consumption on take-off and landing, airplane emissions occur outside of urban regions and so are not counted in Scope 1. Although it might also be argued that emissions from air travel are outside of the control of local government or council, and so it is appropriate to exclude them.

Table 2.2: Comparison of different measures for attributing greenhouse gas emission to cities.

WRI / WBCSD definition	Spatial boundary	Life-cycle perspective	Component

Scope 3	Out of boundary energy use (and further out of boundary emission not included in scope 2)	Production chain emission	Embodied emission from food and material consumed in cities Emission upstream of electric power plants Upstream emission from fossil fuel use
		Single process emission	Combustion of aviation and marine fuels Out of boundary waste (landfill) emission Out of boundary district heating emission
Scope 2	In boundary electricity use		Out of boundary electricity emission at power plant
Scope 1	In boundary emission		In boundary fossil fuel combustion In boundary waste (landfill) emission

			In boundary industrial processes and product use In boundary agriculture and other land use

2.6.6 OPL Accounting System

In this study, OPL measure emissions using DEFRA's accounting system, which arises within the district boundaries, for example by energy used in the homes and transport. The accounting approach is modelled on that of the Climate Change Act 2008, which sets an 80% CO2 reduction target by 2050 against a 1990 baseline. The act provisionally includes international aviation and shipping, CO2 emissions.

The benefit of this model is that it also captures CO2 emissions from people who use the goods and services in the district, but who don't live there. For example; pupils travel into the district from other cities to attend people travel here to work. OPL attributes those emissions to the district, whereas C40 cites accounting system does not. The two measures are interrelated - as we move towards CLUES, reductions in both metrics will be seen in this study.

To further understand how differences in GHG account system in these case studies under consideration impact the emission output, table 2.3 below of the study shall demonstrate how the total emissions vary as a result of the inclusion or exclusion of specific inventory components in the accounting system

Table 2.3: Similarities and differences between C40 cities and One Planet Living models

Similarities and differences between C40 cities and One Planet Living		
	C40	**OPL**
Boundaries and Definitions of Emissions Attribution		

Recognizes WRI definitions of Scope 1 and 2 emissions	✓	
Recognizes WRI definitions of Scope 3	optional	
Recognizes DEFRA’s accounting system for scope 1, 2 & 3		✓
Sectors Included		
Aviation and marine emission		✓
Energy emission (scope 1 and 2)	✓	✓
Industrial processes (Scope 1)	✓	✓
waste and wastewater (Scope 1)	✓	✓
waste and wastewater (Scope 3)		✓
AFOLU (Scope 1)	✓	
Encourages reporting upstream emissions from materials and fuel consumption		
Calculation Methods		
Requires an emission factor-based methodology (IPCC)	✓	✓

2.6.7 Strengths and Weaknesses of the Models

This study identifies the CCI model has an extremely straight forward, ambitious and explicit goal (climate positive). Transparency is the key, otherwise comparisons between other urban districts are impossible and valuable experiences and solutions are lost. The process of baseline, roadmap and credits offer a wide variety of different kinds of solutions and also offers the urban district to test how far different actions will get them.

The Clinton Climate Initiative focuses on low energy use, a high degree of renewables, local energy generation and a system of credits. On an urban district level, there are three main emission categories including energy, transportation and waste. The roadmap allows for technology and policy actions that reduce emissions in the surrounding areas or globally, called credits. The Climate Positive Program primarily focuses on operational emissions i.e. emissions associated with site preparation and construction phases will be tracked but will not count as operational emissions (it excludes GHG emissions from construction, no life cycle perspective and consumption of goods and services as well as long distance travel which is a clear weakness). The process of baseline, roadmap and credits offer a wide variety of different kinds of solutions and also allows a city or an urban district to test how far different actions will lead. However, the ultimate disadvantage of the CCI model is that it does not take into account the important challenge of being people centred in order to function well over time. Demanding technological solutions strongly influence the life styles of people and companies in such districts and need the users' full integration and understanding.

2.6.8 Strength of One Planet Living (OPL)

The lack of prescriptive requirements in the OPL framework is a positive benefit as it allows a team to be far more creative in designing context appropriate ways of meeting the overall targets and so has proven to be an effective vehicle for starting discussions on how sustainability bridges economic, social, and environmental issues on a project. Where they did not exist before, the OPL Framework helps create sustainability champion roles and gives a space for floating ideas for future initiatives. At a very basic level it also becomes a talking point and a social activity within the team.

The framework functions well for "co-creating" sustainability growth strategies. It engages a wider set of stakeholders internally across functional departments and externally such as with Local Authorities and the general public and so the benefits are extended, as well as increased corporate transparency

The framework is also effective as an external communication tool by drawing attention to the linkages between the consumption patterns and wider environmental impacts. It links sustainability behaviours in the workplace to personal behaviours at home. It can also help to counteract the notion that individuals cannot influence very large complex environmental problems seemingly too large for one person.

2.6.9 Weakness

At an operational level, the OPL framework is not a rating tool and this can cause difficulties for organisations accustomed to implementing these. At its most effective, it requires a shift in organisational thinking and as such, the project team must be aware of the amount of buy-in required. In order to meet targets and prevent slippage, it requires 100% buy in by all members of the project team as well as clients and stakeholders for both the headline aspirations as well as the operational targets.

Where no formal endorsement is sought, the OPL Framework can require "self-policing". This is also something that corporations could struggle with as the built environment sector is often dominated by certification requirements. A "self-policed" system does not work in countries where sustainability culture falls to securing a "label". Additionally, the evidence base is still limited from which to extract data on implementation costs – relying on the leading implementers such as the retail business B&Q ltd and the Crest Nicholson development One Brighton, both of which cite cost savings and improved sales associated with being endorsed One Planet projects. Many organisations need to draw on a previously demonstrated financial case to generate the buy-in required for the OPL framework to be successfully implemented.

2.7 Benchmarking and Indicators

In proposing a new set of indicators for benchmarking best practice in the search for climate neutrality Bourdic and Salat (2012) are particularly keen to specify them in terms of the fabric which serves the morphological models of the city-districts, neighbourhoods and blocks. They advocate for assessing the consumption of energy and emission of carbon in the built environment. This is because: "these models provide aggregations which consider all the scales that constitute the urban fabric of buildings, blocks, neighbourhoods and districts. By using intermediate scales of aggregation, the loss of information in the process is structurally lower than with other models. They provide them an undeniable opportunity to monitor the impact of energy performances on several scales."

Bourdic et al., (2012) suggest the only downside of these morphological models lies in the fact the assessments they offer are restricted to the context (city-districts, neighbourhoods and blocks) of built environments and do not extend into either the construction systems, or occupation components of energy consumption and carbon emissions. Reflecting on this dividing line in the build environment including their energy consumption and carbon emissions (Bourdic et al., 2012).

"it is probable that no single model or calculation tool will succeed in considering these four factors [city-district, neighbourhood, construction system and occupational components]at the same time. Therefore, research efforts should focus on the inter-actions and relationships between existing models. Transversal approaches based on existing models and tools may lead to a more systematic and comprehensive understanding of urban efficiency, making good –or at least better –use of all of the intervention opportunities" (CLUE, 2013).

2.7.1 An Innovative System of Indicators

In responding to this challenge, Bourdic et al., (2012) set out what they call: "an innovative system of indicators" which in their opinion should meet the call for multi-scalar and cross-sectional indicators that encompass the "intrinsic complexity" of the situation. Based on this morphologic approach, new mathematical formulas are used to generate urban sustainability indicators. They suggest the resulting indicators are "exceptional" and of particular value because as measures of sustainable urban development they are not based on the simple metrics of absolute target values, but instead founded on techniques of analysis able to relate the part (occupational components, construction systems, blocks, neighbourhoods and city-districts) to the whole.

In their view, not being over-dependant on simple indicators and instead being founded on techniques of analysis that encompass intrinsic complexity also has the advantage of using indicators to *nurture* a “*dialogue-based investigative technique”*, able to engage with stakeholders and account for the relationship between the part and the whole.

Table 2.4: List of urban indicators source.

Theme	**Concept of triptych**	**Indicator type**	**Name**	**Scale**
Energy and Bioclimatic	Environmental	Intensity	Energy Intensity per resident	D/N
			Surface Energy Intensity	D/N
			Proportion of local production	D/N
			Rate of renewable energy used	C/N
	Urban	Form	Volumetric Compactness	N/B
			Size factor	N/B
			Form Factor	N/B
			Rate of Passive volume	N/B

			Energy Consumed for heating	D/N/B/Block
			Energy Consumed for air-conditioning	D/N/B/Block

Considering the Energy and Bioclimatic indicators shown in above table 2.4 above, it is possible to illustrate how a series of them can be benchmarked against one another to demonstrate how some selected cities are performing across a range of measurements relating to the urban fabric of their respective city districts.

Table 2.5: Energy and bioclimatic indicators for selected residential city-districts (Deakin et al., 2012).

	Inner City-district Neighbourhood			Suburban City-district	Metropolitan City-Region
	London	**Toulouse**	**Berlin**	**Hackbridge**	**Paris**
Dimension of study area [km²]	~ 0.03	~ 0.03	~ 0.03	~ 1.7	~ 105
Ground floor area [m²]	89 663	64 368	55 978	91 778	67 000 000
Un-built Area [m²]	70 377	95 632	104 022	481 803	38 000 000
Built volume [m³]	1 221 499	966 768	1 042 199	616 839	580 000 000
Vertical surface [m²]	174 757	174 888	119 698	209 411	

STVR	0.216	0.248	0.169	0.488	
PVTVR [%]	77	84	61	99	82
Un-built area ratio	0.785	1.486	1.858	5.250	0.567
Energy consumption [kwh/m²/year]				539	247
C0₂ emission [kg per capita]				2.796	0.338

From Deakin et al., (2015) point of view, It is evident from the above table 2.5 that each of the 4 cities in the above figure share the same performance measures for residential land uses up to the more generic measures of energy consumption (kWh/m2/per year) and CO2 emission (kg per capita), This in turn allows each of them to be benchmarked against one another on this basis and indicating that Berlin out-performs London, Toulouse and Paris, in terms of the critical markers know as: surface-to-volume ratio (size factor) and passive volume to non-passive volume measures (rate of passive volume). These particular indicators benchmark the consumption of energy and emission of carbon in relation to the:

- surface of land they occupy relative to the volume of a building (STVR);
- Passiveness of the internal environment relative to the envelop of the building (PVTVR) (Salat, 2012).

Table 2.5 also shows Berlin has lowest energy consumption. This suggest scale does actually makes a difference. Although Salat in 2009 only considers heating demand for his energy and CO_2 calculations whereas Deakin et al in 2015 said the energy and CO_2 calculations for this predominately-suburban case study should also consider the consumption of energy serving all thermal, lighting, power and heating demand. This perhaps might go some way to explain the marked difference in energy consumption and in particular, CO_2 emission between Paris and Hackbridge. For as can be seen, energy consumption in Paris seems to cause significantly less CO_2 emission than in Hackbridge. The explanation for this according to Deakin (2015) however may rest as much with the source of the supply than with the value of analysing the urban morphology of cities at such scales.

In terms of performance the lower the STVR the better the building performance as is the case for the PVTVR (Salat 2012). The PVTRVs of between 0.66 and 0.99 mark the difference between inner city-district block developments and suburban detached, semi-detached and linked buildings. While this range of values indicates each of the city-districts would benefit from retrofit programmes, the figures also tend to suggest those with a value of 0.99 offer the greatest potential in terms of energy saving and carbon reduction.

2.8 The Urban Metabolism

The study goes on to review urban metabolism, as these represents the interests of a range of disciplines, including industrial ecology, urban ecology, ecological economics, political economy, and political ecology. What follows studies urban metabolism from the perspective of industrial ecology.

The term "urban metabolism" has been labelled as a concept and a tool and as a representative term for quantitative accounts of the overall inputs and outputs of energy, materials, and substances (such as water, nutrients, and pollutants) into and out of cities.

This involves conceptualizing a city or a district as an organism and tracking resources that go into the system, products, and wastes that leave it as it provides a platform through which to consider urban sustainability implications (Kennedy et al., 2011).

The concept of urban metabolism was developed in the industrial ecology field and originally introduced by Abel Wolman in 1965 to determine the urban metabolism of a typical American city. Following Wolman's (1965) work, other metabolism studies have been conducted to cities worldwide.

Recently, the interest for urban metabolism has increased due to the recognition that the model can provide a more comprehensive understanding of the sustainability of a city. First, the model gives a holistic and integrated viewpoint of an urban region.

Second, it is able to examine aspects of urban relationships among infrastructures and inhabitants, beyond the strictly functional analysis of urban systems. By comprising the analysis of all activities in an integrated and cyclical approach, urban metabolism can offer a way of measuring urban sustainability within the ecosystems capacity to support it. Additionally, there is a need to view the urban system as a whole if the aim is to understand and solve complex urban problems.

A definition of urban metabolism is given by Kennedy et al., (2007) as 'the total sum of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy, and elimination of waste'. Thus, the economy is basically interconnected with the surrounding environment through the material and energy flows. The impact on the environment, or the size of the metabolic throughput, can be then estimated by the amount of materials that society appropriate from the environment and return back to it in other forms (EC, 2001).

2.8.1 Applications in Urban Planning and Design

From its conception by Wolman in 1965, urban metabolism was studied for practical reasons; Wolman was particularly concerned with air pollution and other wastes produced in US cities. So, beyond the study of urban metabolism to understand it in a scientific sense, there are practical applications. This thesis reviews its applications in sustainability reporting, urban greenhouse gas accounting, mathematical modelling for policy analysis, and urban design. This list of four is perhaps not exhaustive: urban metabolism studies are data rich and may have other potential applications.

Most urban metabolism studies have been accounting exercises, used to provide indicators for assessing aspects of urban sustainability and to quantify GHG emissions of cities, such as measures of energy consumption, and material and waste flows (Kennedy et al., 2011). More recently, the urban metabolism concept has been applied in the context of sustainable urban planning and design, and policy analysis. Kennedy et al., (2011) have categorized these applications into four main areas:

Sustainability Indicators: Urban metabolism studies are an important aspect in state-of-the-environment reporting, providing information pertaining to energy efficiency, material cycling, waste management, and infrastructure to assess a city's sustainability (Kennedy et al., 2011)

Quantification of GHG Emissions: Urban metabolism studies provide a valuable input to the quantification of a city's GHG emissions, which is useful when cities or districts aim to reduce their GHG emissions (Kennedy et al., 2011)

Mathematical Models for Policy Analysis: Kennedy et al., (2011) highlights that mathematical models, developed by the MFA community, have been developed for processes within the urban metabolism of a city, such as the stocks and flows of specific metals or nutrients at the urban or regional scale

Urban Design*:* Urban metabolism studies have been used in an urban design context to redesign the flows of water, energy, materials, and nutrients through cities (Pincetl et al., 2012), using methods such as green building design, and sustainable transportation and energy systems (Kennedy et al., 2011).

2.8.2 Material Flow Analysis

The Material Flow Analysis (MFA) approach is widely used in urban metabolism (UM) analysis since metrics for the assessment of urban materials, flows and stocks are available (Barles, 2007). Early MFA analyses focused on identifying material flows at the national level (Wernick & Ausubel, 1995; WRI, 2000; EUROSTAT, 2001). Countries such as Austria, Japan, Germany and Sweden have also established material flow accounts (EUROSTAT, 2001). Material flows analysis provides a framework for analysing the ways urban areas transform natural resources and is frequently used in the engineering field, however emphasis is placed on the flow of a specific substance rather than through entire systems (Baccini & Brunner, 1991).

The goal of the MFA is to provide a system level understanding of how a city, region or nation functions. Data is represented in mass (e.g. tons) to measure the weights of material inflows and outflows. Based on the principle of mass conversion where mass in = mass out + stock changes, MFA measures the materials flowing into a system, the stocks and flows within it and the resulting outputs from the system to other systems (Sahely et al., 2003). This tool aids decision-makers in analysing material flows and stocks within a given system, evaluating the importance and relevance of these flows and stocks and controlling material flows and stocks to achieve management goals (Hendriks et al., 2000).

2.9 Morphologic Models

Urban morphology interacts with buildings, with people's behaviour and with the local climate as morphological approaches aim to quantify energy performance, consumptions and GHG emissions for the building sector. In relating urban morphology to energy consumption and CO2 emission, it is important to determine how energy consumption and CO2 emission are defined (Deakin et al., 2015).

Recent studies on urban morphology suggest the planning, development and design of districts have much impact on the levels of energy consumption and rates of carbon emission as either the layout of neighbourhood, construction of blocks, use or occupation of buildings (Deakin et al., 2012).

The morphological model first advanced by Ratti et al., (2005) and serves to reaffirm the relationship between climate and what are referred to as the 4 structural (context, buildings, systems and occupational) components of energy performance. It does this by overlaying the model with the components Salat (2007, 2009) and Bourdic and Salat (2012) offers. For here the application of the Digital Elevation Model (DEM) to analyse the context is represented, along with the tools for analysing the buildings found within the respective forms, shapes and envelopes. This in turn draws attention to the themes that make up the systems and triptych (sustainable development), which govern their use and occupation. These methods explicitly consider only the district or the city as a whole, as opposed to a simple sum of individual buildings. In theory, there is no reason for the sum of optimal elements (the building scale) to be an optimal sum (the district scale) (Bourdic and Salat, 2012).

Building energy performance is currently understood as dependent upon

(1) Urban geometry,

(2) Building design,

(3) Systems efficiency,

(4) Occupant behaviour (Ratti et al., 2005).

It should be noted that these four points are under the control of different actors in the building sector: urban planners and designers in (1), architects in (2), system engineers in (3) and occupants in (4).

Here the drive towards urban efficiency corresponds to the district or city scale. Urban morphology is responsible for creating or at least modifying the energy demand, in the first place for transport energy. But urban morphology also has a significant influence on heating and cooling energy consumption notably via the urban heat island effect or wind effects.

The second scale of urban efficiency takes into account how passive buildings are. Building form has a tremendous influence on energy requirements: a significant part of energy needs can be covered by passive heating, cooling and lighting with a proper building form (Salat, 2011). Building technologies such as insulation, glazing and ventilation are another way to reduce buildings' energy demand. The third scale deals with systems' energy efficiency. Most of the current effort is only concentrated on this point: how to improve heating or cooling systems' efficiencies. This aspect though remains only one among four available multiplier effects (leverage) for urban efficiency, which highlights the much bigger potential of a comprehensive approach.

The morphological model in figure 2.5 set out by Ratti et al., (2005) confirms the connection between climate and the four models of energy performance.

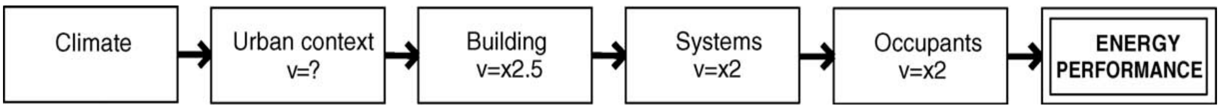

Figure 2.5: Factors that affect energy consumption in buildings.

According to (Ratti et al., 2005, Salat 2012, Baker and Steemers, 2000) building design accounts for a 2.5 ×variation in energy consumption, systems efficiency for a 2× variation and occupant behaviour for a 2× variation. The result of these multiplications can be termed the ‘product of factors’, which provides an indication between the least efficient and the most efficient statistical class of an existing building stock. The factors are not totally independent (e.g., inhabitants’ behaviour depends on the type of energy used) (Salat 2009). The cumulative effect of these factors can lead to a total variance of 10-fold. In practice, variance in energy consumption of buildings with similar functions can be as high as 20-fold.

The assertions made by Ratti et al., 2005 that amendments to the urban design and layout of buildings can lower energy consumption by as much as 30% and carbon emissions by 50% remain unproven, as too are the likelihood of additional reductions contributing to climate change adaptation strategies.

In response, Deakin et al., (2012, 2015) suggest this can best be achieved by grounding the retrofit in a case-based analysis of retrofits and building the DEM to meet the requirements. The advanced morphological model adapted by Deakin et al., (2015) does set out the grounds for this interest in climate change and application of the morphologic models set out here to mitigate the impact of any such developments as seen in the figure below. Attention is drawn to the mass retrofitting of an energy efficient - low carbon zone, both by way of an urban regeneration strategy and through the visions, master plans and scenarios such an inclusive growth is based on. Moving from top-to-bottom, this in turn indicates the Lighting and Thermal Method (LTM), supplemented here with a 3D rendering of the context grounded in ArchGIS technologies and Google maps.

This model systematically integrates renewable energies into the power, lighting and heating of the retrofit proposal and so on.

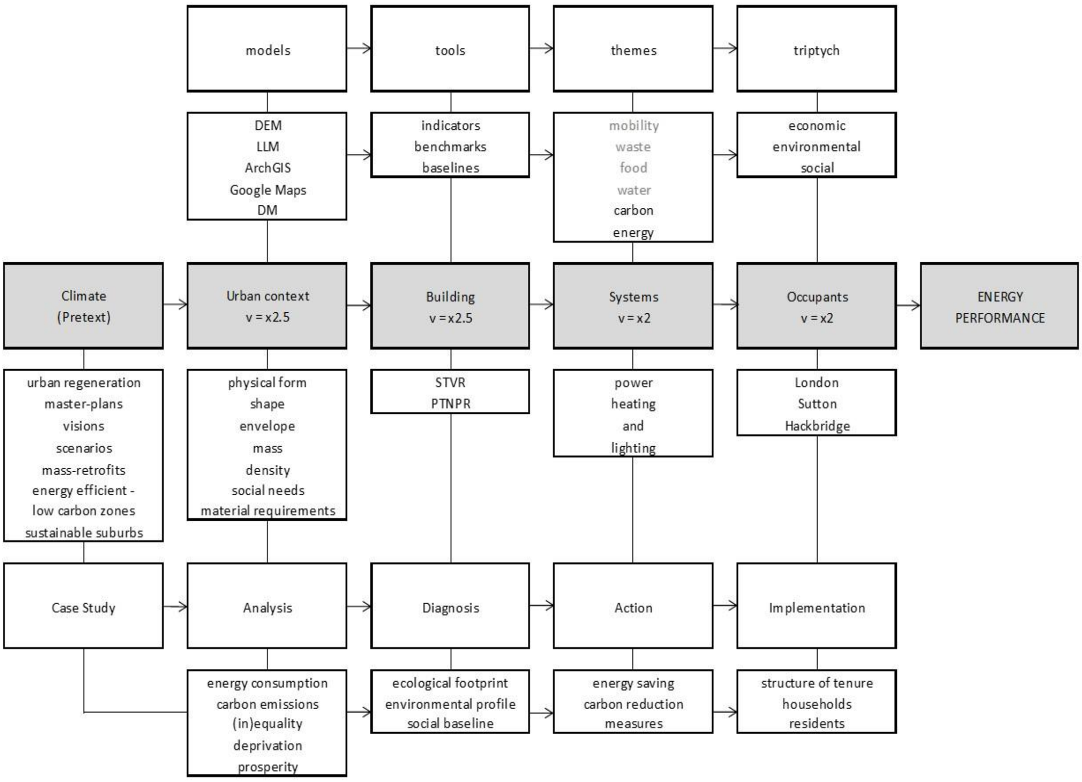

Figure 2.6: Adapted morphologic model from Deakin et al., 2015.

Chapter Three

3.0 Methodology

3.1 Introduction

Developed over the years, urban metabolism methodology is nowadays sufficiently robust, consistent and well anchored in existing academic literature. For half a century, scientists have relied on urban metabolism (UM) as a pragmatic framework to support the needed transition toward sustainable urban development. It has been suggested that smart cities can be leveraged in this transition.

Integrated frameworks allow the examination of energy and material flows in complex systems, shaped by various social, economic and environmental forces (Holmes and Pincetl, 2012). The specific framework adopted to assess the urban metabolism for this study was modelled from the framework proposed by Kennedy and Hoornweg (2012). One of the attributes of the model proposed is the possibility of integration and comparison between different urban regions, as the essential indicators are suggested along with standardized measuring units.

Considering that the main purposes are to provide a quantitative measure of material and energy flow and to understand how the districts metabolize and function and outperform each other in the context of climate change. Newman (1999) is known for extending the metabolism model, in one of the first efforts to add social issues to urban studies, showing how resources are being used to create opportunities. He introduced variables about settlement dynamics and liveability, which has been fully integrated in the urban metabolic model proposed.

3.1.1 Expanding the State-of-the-art

This methodology builds on the current state-of-the-art advanced by Deakin et al., (2015) in figure 2.6. The model is strategically integrated into the methodological framework proposed in figure 3.1 for SRS and Hackbridge project. Consequently, it compares, evaluates, and analyse their respective frameworks, baselines and methodologies to understand some distinct differences and similarities. This also highlights their metabolics flows, boundaries, scopes, GHG accounting methods, metrics and governance in order to demonstrate the best potential way forward in response to climate change offered by a world leading smart sustainable frameworks to be climate neutral and climate positive by reduction of GHGs.

The morphological model represented in figure 3.1 also serves to reaffirm and present the key models highlighted with broken lines integrated into the state-of-the-art analysis as part of an adaptation approach. For this model systematically contributes urban metabolism assessment framework. This in turn leads to the infrastructural themes (energy, carbon, water and mobility issues) linked to the power, heating and lighting systems central to mass-retrofit proposals. The final column highlights the triptych in terms of the social, environmental and economic sustainability of those occupying this energy efficient - low carbon zone as part of an inclusive growth strategy.

Under this lies a further level of case study analysis focussing on the diagnosis, action and intervention of urban planners, architects, designers and building contractors in securing the sustainability of the HP and SRS as part of an inclusive growth strategy.

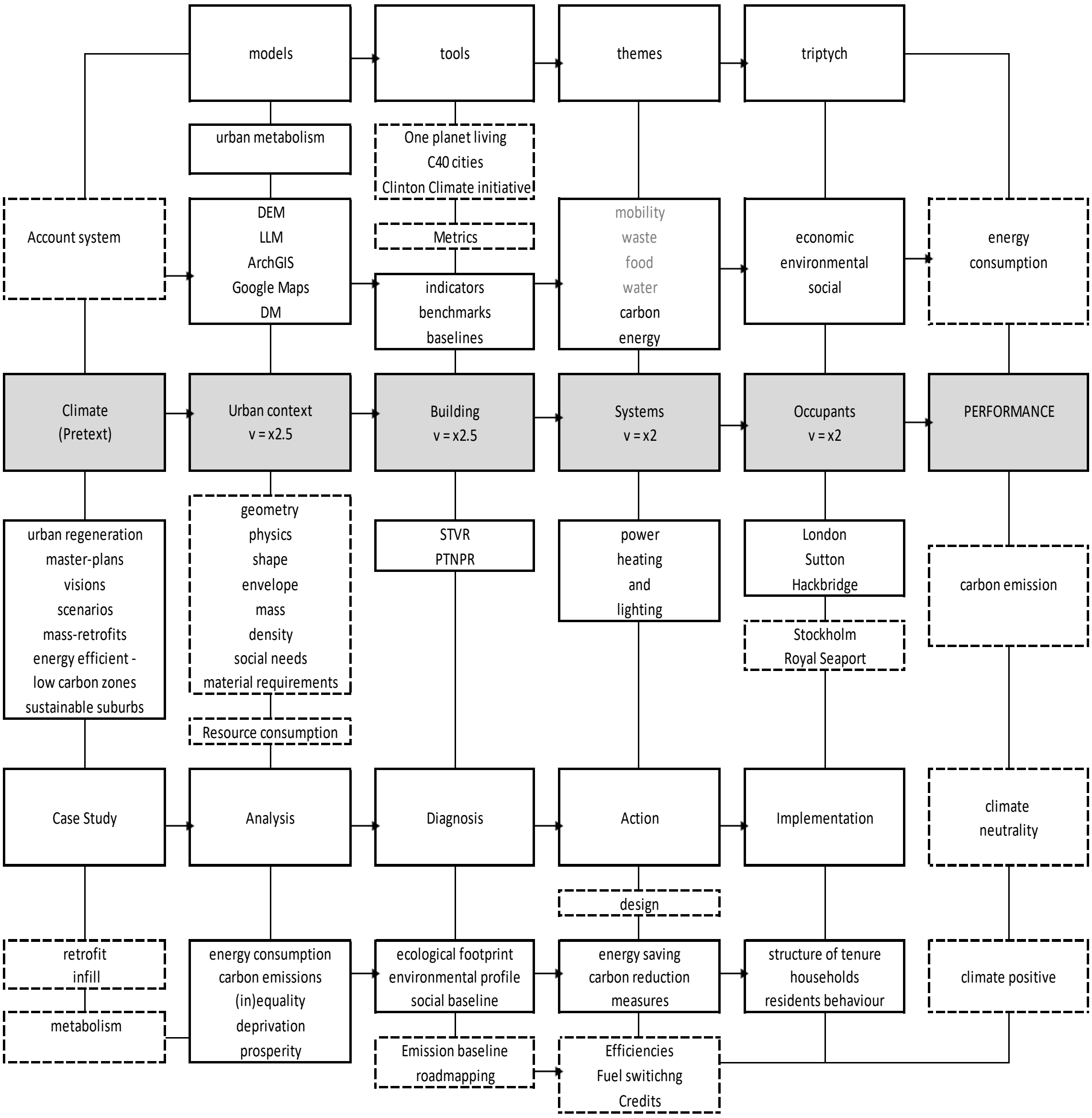

Figure 3.1. Methodological approach to evaluate Hackbridge and Stockholm Royal Seaport using a top-bottom approach.

3.2 A Case-Based Approach

A variety of methods shall be used to conduct the comparative study within this research. These include an evaluation and comparative analysis, and case study analysis. It is important to note that many of these review methods shall be often used simultaneously throughout this research.

As part of this studies, Hackbridge and Stockholm Royal seaport case studies approach to climate neutrality and climate positive shall be assessed, compared and evaluated using their respective baselines and methodologies to understand some distinct differences regarding their boundaries, scopes, GHG accounting methods, metrics and governance. This study shall describe the findings of the case studies on the possibility to create a climate neutral and climate positive urban district.

The analysis of the case studies shall go on further to study the GHG emissions of Hackbridge and SRS in a transparent way and to determine its possibilities to become a climate neutral and positive urban district respectively and to suggest a potential way forward in this respect.

3.3 Methodological Structure

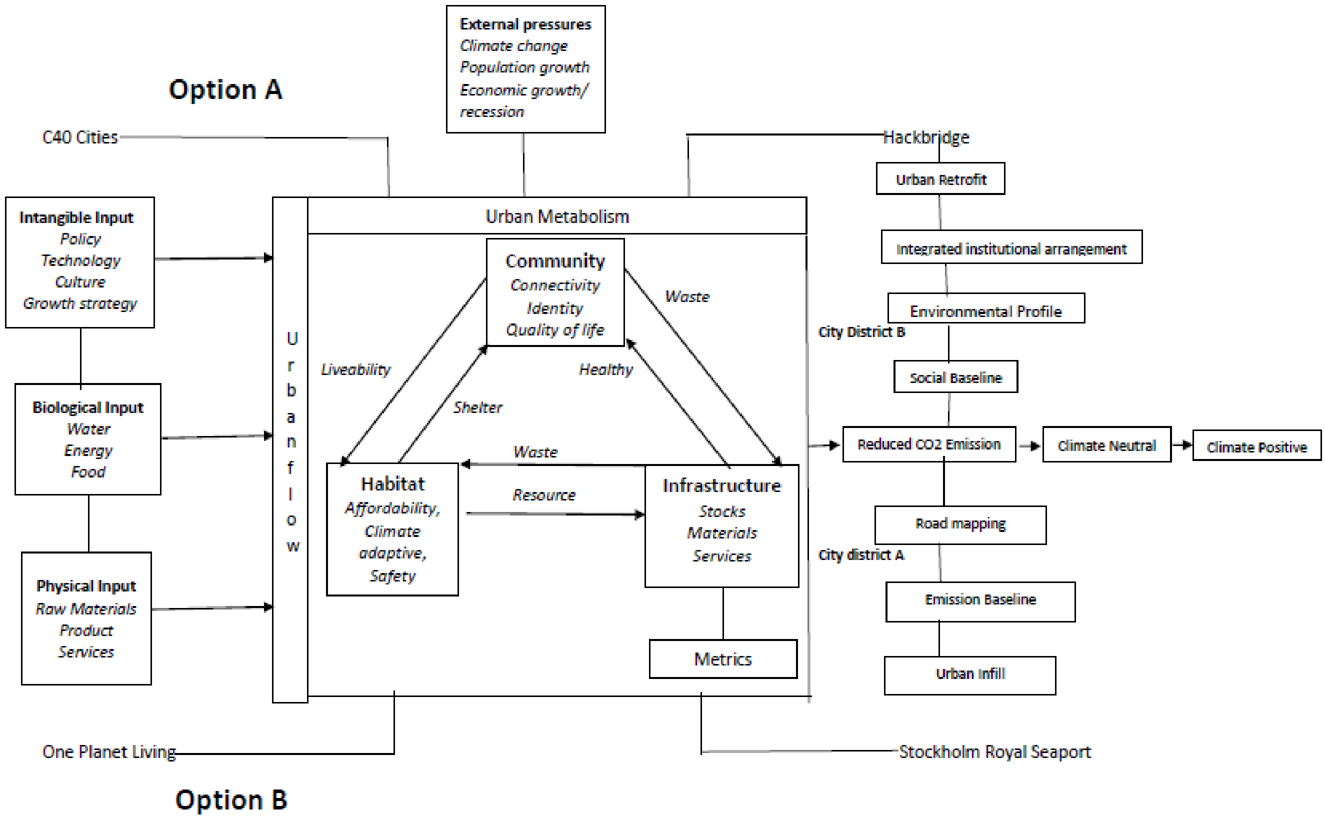

Figure 3.2: The research methodological framework developed for this study.

This uses a top-bottom approach that classified the two case studies (SRS and Hackbridge) into district A and B. This begins by comparing two world leading frameworks (One Planet Living and C40 cities) that offers smart and sustainable initiatives which supports the ground interests of IPCC which tackles climate change by reduction of GHG emission. Particular attention is drawn to urban metabolism as the major tool to analyse the urban input and asses the output in the case studies been examined.

This begins by setting out the differences in the input (intangible, biological and physical) using scopes and boundaries as major determinant for urban consumption and production for the case study districts as a way to measure the urban flow using metrics as demographics, economic structure and physical structure to assess the urban metabolism with the possible constraint of external pressure on the metabolic performance on the district.

3.4 Composition of Inputs and Outputs

Three basic accounts constituted material inputs: energy, construction materials and waste.

Each account was composed of many detailed components capturing industrial, construction and household activities plus material/energy consumption by all sectors in the district. For instance, energy consumption included diesel, petrol, heavy oil and electricity. All elements were measured and expressed in units of tonnes, and energy consumption is expressed in terms of tonnes of coal equivalent. The material flows of outputs focussed on the waste and pollution generated from urban systems.

The outputs consisted of solid waste, GHG emissions and water pollutants, and industrial products. The emission outputs resulting from energy were given particular attention, as GHG emission is a prominent urban problem been studied.

3.4.1 Environmental Metrics

This study quantifiably accounts for energy use and GHG emissions associated with residential development. These two metrics were chosen to indicate the overall energy intensiveness and climate change potential associated with different urban districts, which are highly relevant to urban planners given the current importance of energy supply issues and global climate change. Energy use described in this study corresponds to the total fuel and electrical energy required for material production, transportation, and building operation, measured in gigajoules (GJ) or mega joules (MJ). Primary GHGs, carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and chlorofluorocarbons (CFCs) emitted during the above activities are also considered. These emissions are normalized in terms of global warming potential (GWP), measured as total metric tons or tonnes of CO2 equivalents.

All calculations made are using the same basic formula:

*Activity * Emission Factor = Emissions…………….* (Kennedy et al., 2007).

Examples of activities are annual energy use [kWh of a fuel or energy carrier/year], annual person kilometres (PKM) travelled [PKM of a mode of transportation/year] and annual waste generated [ton per waste fraction and year]. The emission factors are coupled with the respective activities. In the example above, emissions from energy use are expressed as [g CO2e/kWh of fuel or energy carrier], those from transportation as [g CO2e/PKM of the mode of transportation used] and those from waste as [g CO2e/ton of waste fraction and treatment method].

3.4.2 Accounting and Assessment

The urban metabolism approach has been widely adopted as a framework since it provides an effective way to gain information on energy efficiency, recycling of materials, waste management, and the infrastructure characteristics of an urban system (Kennedy et al., 2007). It is also an effective means to quantify the inputs of energy, water, food, and other materials, as well as waste outputs in term of emission. It can be used to account for and assess the scale and potential extent of recycling of food, water, energy, and materials through the urban system. The two-main accounting and assessment methods considered for this study are based on an analysis of material and energy flows, thereby tracing the input, storage, transformation, and output processes. Material flow analysis begins with classification of the various material flows, and concludes with a balance sheet that accounts for all of these flows. If a sufficient quantity of reliable statistical data is available.

Urban metabolism (UM) provides a framework for analysing the technical and socioeconomic processes that occur in districts. This includes assessing the inputs, outputs, and stores of energy, water, and materials of an urban area (Kennedy et al. 2011). The concept is grounded on the analogy with the metabolism of living organisms, as cities can transform raw materials into infrastructure, human biomass, and waste (Wolman 1965, Bai 2007, Kennedy et al., 2007). They can also be analysed as an ecosystem to incorporate relationships between and among cities (Kennedy et al. 2011). Indeed, approximating the dynamics of natural ecosystems is often presented as an objective when developing sustainable districts, as natural ecosystems are considered to be the most sustainable systems on earth.

The UM framework captures the complex cross-scale relationships among the natural environment, the trans-boundary implications of engineered infrastructure, and the social agents and institutions that shape interactions in the district systems (Ramaswami et al. 2012). The material aspect of the interaction in districts presents an opportunity for analysis, nonetheless. While the material dimension is only one component of understanding the metabolism of cities, it allows the development of reliable metrics for the assessment of urban material flows and stocks. The consumption and production of materials is crucial for assessing the sustainability of a districts in terms of efficient functioning, resource availability, and GHG emissions (Brunner 2007).

Material flow accounting allows the consumption of a system to be visualized for a particular base year, corresponding to a static analysis of flows; but it also permits an evaluation of the consumption trends of an economic system through a time series. In addition, data computation methodologies allow flows to be broken down into urban activities (Rosado et al., 2013) - intermediate consumption (economic activities) and final consumption (households, services, and state).

3.5 Extending Urban Metabolism

The comparison between Hackbridge and SRS is further performed using metrics as demographics, economic structure and physical structure to assess the urban metabolism. The physical structure of an urban economy is described by the material throughput of that economy. To measure these urban flows, it is necessary to consider and analyse the context of urban drivers, urban patterns and urban quality as they describe the conditions under which metabolic flows arise and provide the required contextual reference frame. These will provide a deeper understanding of urban metabolism for Hackbridge and SRS.

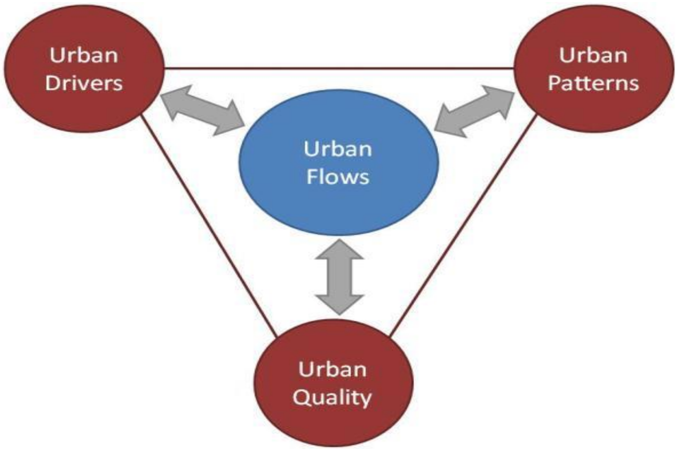

Figure 3.3: Structuring a simple indicator system for monitoring urban metabolism (from DCCE 2011).

3.5.1 Urban Drivers

This study shall identify some Indicators using urban driver that are aimed to provide relevant information on why we might observe changes in the physical metabolism over time or why we might see differences in the physical metabolism across different sustainable districts or cities.

Population and Households: This assessment shall capture and analyse the developments in population and household size, population dynamics and household structure, which are important determinant of a city's metabolism. Recent studies use information on city size in terms of population in understanding urban metabolism.

Cross-city studies have found interesting scaling relationships between different attributes of cities, notably resource consumption (Bettencourt et al., 2007). For example, infrastructures such as road networks usually scale sub-linearly with city size, i.e. each additional citizen requires less than average additional infrastructure investment. However, total electricity consumption scales supra-linearly with city size, i.e. additional dwellers consume more than the average. In this sense, the size of the city shall be measured in terms of its number of residents which is an indispensable component for describing the urban system. Evidence further suggests that the demographic structure of a population can also determine the size and make-up of a city's physical metabolism (e.g. Haq et al., 2007).

Lifestyles/ Behaviour*:* The analysis of the study shall go further to assess the unique lifestyle or behaviour for SRS and Hackbridge districts. Lifestyle is broadly understood as they way in which residents of a city live and consume (energy, goods and services). Both aspect have shown to be important for understanding a district's metabolism (e.g. Baiocchi et al., 2010) and they must be expected to be of equal importance at the city level. The following indicators shall capture some key aspects of urban life's style. GDP shall indicate the level of a city's economic output/activities, which can be expected to be closely related to the wealth of its citizens, employment opportunities etc. Income provides some insights into the monetary resources people have available for consumption and the average occupancy per occupied dwelling also provides how life is organized within the available physical infrastructure. Although in contrast, studies have shown in the UK and Germany, the building physics and reduction in household size and dwelling occupancy are more important driver of CO2 emissions than population growth (Minx, 2008; Baiocchi and Minx, 2010).

Local Climatic Conditions*:* As local climate varies from city to city or country to country, this study shall assess the impact of local climate on city's metabolism in Hackbridge and SRS. Cold winters, for example, are one factor influencing heating requirements. The annual amount of rainfall influences available freshwater resources, irrigation requirements etc.

Transportation*:* This study shall assess how the movement of people in the city or district impact the city's metabolism. A higher share of walking, biking or use of public transport reduces a city's dependency on external energy resources, avoids local air pollution and greenhouse gas emissions in a city as these factors impact the metabolism

3.5.2 The Urban Pattern

City Size: Analysis of the size of the urban territory in terms of square kilometres is a basic variable for understanding the spatial extent of the area under consideration.

Land Cover and Land Use: This assessment shall give insights into how the city territory is used for different purposes. This is not only important for aspects of urban ecosystem service provisioning, but can also be of direct relevance for getting a better grasp on the physical make-up of the administrative area, which can influence its physical metabolism.

Transportation Network: The importance of transportation in the context of size and shape

Of a city’s metabolism has been highlighted previously. The urban transport network provides important monetary and non-monetary incentives for modal choice of city residents. It measures the share of the different transport infrastructures by mode on urban land-take as well as the length of the public transport network.

Buildings: Finally, the number of dwellings (and changes in) gives another indication of how the urban built-up environment develops.

3.6 Data Availability

The case studies analysis in this study have been majorly based on urban metabolism methodology as described above. The number of field components and the extent to which they have been investigated vary depending on the availability of indicators and data. Due to some confidential reasons, data for Hackbridge to assess and analyse some components for purpose of urban metabolism were simply not available. The analysis for Hackbridge will be limited in contrast to SRS.

Chapter Four

4.0 Result and Data Analysis

4.1 Introduction

This section is based on the results of the case studies where metabolic assessment was applied in the evaluation of two urban development projects, namely, the first phase of the Stockholm Royal Seaport project and the Hackbridge. The aim is specifically to:

- Present and evaluate the results obtained by SRS and Hackbridge during the application of the metabolic assessment methodology in the context of the two case studies.
- Compare the performance of both urban development projects and the methodological approach, goals achievement and the right path in combating climate change by energy and GHG reduction.

The Stockholm Royal Sea Port (SRS) is an urban development in the northern parts of central Stockholm focusing on low environmental impact, primarily through low energy use as well as a high usage of renewable energy.

The SRS aims to become a fossil fuel free and climate positive urban development under the requirements of the Clinton Climate Initiative's (CCI) Climate Positive framework (CCI, 2011) by the time the entire area is built, around 2030. As a point of reference of how ambitious the goals are, the City of Stockholm is to become a fossil fuel free by 2050 and has an emission target of 3.0 ton CO2e/capita for 2015.

4.2 The SRS Model

This section outlines the SRS account for greenhouse gases (GHG). The account is the first of a two- step process to becoming a climate positive (climate+) urban development. The second is to create a roadmap for the urban development, which outlines the specific steps/actions to a climate+ outcome.

Note that the results presented in this report come from a calculation tool developed for the CCI framework that has been modified after special requirements for the case of Stockholm Royal Seaport.

The model includes the following parts:

- The SRS system boundaries: The model defines which emissions are included and which emissions are not included in the baseline.
- The metrics: Here the metrics for calculating the baseline emissions are described focusing on how to calculate energy demand and how to calculate the GHG emissions from the energy used. Here are also some basic data about the SRS development presented (number of residents, workers, areas etc.)
- Calculation of emissions: The energy demand is quantified and emissions calculated for the three emission categories in the baseline. Data quality is assessed briefly and emissions summarized for the baseline.

4.2.1 Characteristics of the SRS Area – Present and Future Infrastructure

The area where SRS is being built is a brownfield site currently being used for housing, gas utilities, a combined heat and power plant and a harbour. It serves as a thoroughfare for traffic to the harbour and to the island of Lidingö (population 42 000 in 2009; Lidingö stad, 2011). SRS also occupies a wedge of the National City Park in central Stockholm (City of Stockholm, 2011). The current thoroughfare will be expanded in an effort to build a partial beltway around Stockholm. By the time the development is completed, a total of 10,000 apartments housing 19 000 residents will have been built, along with a large non-residential area containing workspaces for 30 000 workers, commercial spaces and a shopping mall. The SRS project is expected to achieve full build-out in 2030, but the first residents will be moving in later this year. The planned land uses are summarised by area in Table 1.

Table 4.1*:* Built areas of Stockholm Royal seaport by type at full build-out (CCI, 2011).

Land use by type	Planned area (m^2) at full build-out
Multifamily housing	1,143,400
Office space	712,330
Commercial space	84,015
Schools	9,500

4.3 Characteristic of Hackbridge Area

As a suburb within the London Borough of Sutton, Hackbridge is home to approximately 8,000 people. The area is largely residential and the housing comprises 18th century listed cottages, late 19th century terraced houses, inter-war semi-detached homes and BedZED. In 2005, Sutton Council stated its commitment to move towards One Planet Living as a concept based around 10 sustainability principles developed by BioRegional. This is set out in the Core Planning Strategy BP61 as a:

"... key long-term target to reduce the ecological footprint of residents to a more sustainable level of 3 global hectares per person by 2020 from the current '3-planet' baseline of 5.4 global hectares. To deliver this Vision, the Council is working in partnership with BioRegional to prepare a 'Sustainability Action Plan' based on the 10 One Planet Living principles of zero carbon; zero waste; sustainable transport; local and sustainable materials; local and sustainable food; sustainable water; natural habitats and wildlife cultural and heritage; equity and fair trade; and health and happiness."

The Core Planning Strategy also states Hackbridge:

"…will be the focus for a flagship sustainable [urban] regeneration project that brings about the renewal of the fabric of the area through environmentally innovative mixed-use redevelopment schemes."

4.3.1 One Report – Two Presented Baselines

The Sutton Council has worked actively with both mitigation and adaptation of climate change since the mid-1990s and has well established metrics for calculation of the city's GHG emissions in place. There are some differences between how emissions are calculated between CCI's framework and how Sutton-Hackbridge calculate its emission. This report therefore contains two calculations, one according to the principles of the CCI framework and one according to BiorRgional way of calculating GHG emissions (henceforth referenced to as Hackbrisge 3.0). This is done so that the data can be comparable for those who work with the Hackbrisge 3.0 goal.

4.3.2 Data Calculation and Results

The general analytical framework and data analysis methods are summarized in the methodology section. Three distinct analytical approaches are employed for estimating energy use and GHG emissions associated with the case studies:

- For the metabolism, an input–output analysis model is applied;
- For building and its operation, nationally averaged specific datasets are utilized; and
- For public and private transportation, detailed location-specific data are utilized.

As a final step, the results from each study component are summed and compared to provide an overall assessment of the energy use and GHG emissions associated with the urban districts under study. The data analysis methods for each study component shown in Fig. below and are detailed in the following sections.

Emissions and Calculations: Calculations of the GHG emissions were divided into three main emission categories: energy, transportation and waste. For instance, the energy emissions category includes energy in buildings, infrastructure, water and locally generated energy. For each emissions category, the data used are described below together with any assumptions made. To determine what data to use, the following data hierarchy was adopted:

1. Where local specific data are available, these are primarily used. For instance, projected heating and hot water demand [kWh/m2 and year] for buildings.
2. Where specific data are unavailable, data for the City are used, for instance composition of the vehicle fleet [% gasoline cars, % biogas cars, etc.], and emissions from the London or Stockholm district heating mix [g CO2e/kWh].
3. Where data specific for the cities are unavailable, data for countries under study are used, for instance GHG emissions from waste management by fractions of waste in England or Sweden [g CO2e/ton waste].

Energy: The emissions emanated from energy include emissions from heating, cooling and electricity used in buildings, emissions from energy used in the infrastructure and emissions from supplying the district with water. Also included in the energy part are emissions reductions from locally generated energy, such as biogas from wastewater sludge.

Buildings: The buildings in Hackbridge is mainly residential whiles SRS are divided into four categories, residential, offices, commercial space and schools for the purpose of this study. The emissions included come from heating, cooling and electricity, with electricity end-uses tracked separately.

4.4 Data Used and Calculations

The SRS data are based on the assumption that the projected (simulated) energy use for the buildings in the first construction phase (2012- 2014) will be representative for the entire district.

For each type of building, the projected energy used is calculated. In the first build phase, strict energy requirements on energy use in buildings had yet to be implemented but simulations have demonstrated that the projected energy use is roughly 25% lower than specified in the current Swedish building codes (Boverket, 2011).

Table 4.2: Projected energy use and emission types of building (CCI, 2011).

Energy by type/buildings by type	Residential	Offices	Commercial	Schools
Heating and cooling				
Heating [kWh/m2, year]	42.5	35	25	55
Hot water [kWh/m2, year]	25	2	2	10
Cooling [kWh/m2, year]	0	20	35	0
Surface area [m2]	1,143,400	712,330	84,015	9,500
Total Energy use [GWh/ year]	77.2	40.6	5.2	0.6
Emission factor [g CO2e/ year]	98.45			
Total Emission [ton CO2e/year]	7598.3	3997.4	512.8	60.8
Electricity				
Building electricity [kWh/ m2, year]	15	25	20	15
Residential/commercial electricity [kWh/ m2, year]	30	50	80	35
Surface area [m2]	1,143,400	712,330	84,015	9,500
Total Energy use [GWh/ year]	51.5	53.4	8.4	0.48
Emission factor [g CO2e/ year]	69.73			
Total Emission [ton CO2e/year]	3,587.8	3,725.3	585.8	33.1

Total emission (heating, cooling & electricity) by building type [ton CO2e/year]	11,186.1	7,722.7	1,098.6	93.9
Total building Emission	20, 301.3			

4.4.1 Infrastructure, Water and Locally Generated Energy

The emissions from infrastructure include emissions from electricity used in streetlights, traffic lights, non-building related electricity (pumps, fountains, etc.) as well as mainly diesel fuel used in the operation of road infrastructure (road maintenance, snow cleaning, gritting, etc.) (Table 4). The emissions from water include emissions from the electricity used to collect, treat and distribute water to and from SRS.

4.4.2 Data Used and Calculations

The data regarding electricity use in infrastructure were developed using the master plans for SRS. The data for road maintenance are based on figures from the City of Stockholm (Fahlberg et al., 2007), assuming that SRS infrastructure will require the same amount of maintenance as the rest of the City.

Water use is based on technology currently in use in Hammarby Sjöstad (Pandis & Brandt, 2009) and that will be implemented in SRS, while the energy use for collection, treatment and distribution is based on figures for the City of Stockholm (Stockholm Vatten, 2010). The amount of biogas generated by wastewater sludge was estimated and the full amount assumed to replace gasoline in cars.

Table 4.3: Projected energy use and emission from infrastructure, water and locally generated energy in Stockholm royal seaport (CCI, 2011).

Activity	Annual energy use [kWh/year]	Emission factor g CO2e/kWh	Emissions [ton CO2e/year]
Infrastructure			
Electricity in street light, traffic light etc.	756,000	69.73	52.7
Road maintenance	7,670,300	297.31	2,142.4
Water			
Collection, treatment, distribution	1,862,595	69.73	129.9
Locally generated energy			
Generated biogas replacing E5 petrol	2,300,000	-586.6	-557.7
Total emission [ton CO2e/year]	1,767.3		

Transportation: The transportation emissions are divided into four categories, private trips, commuting trips, business trips and the transportation of goods and services to the area. The transportation emissions highlight the problem of measuring emissions on the urban district level in comparison with the Hackbridge district. If a strict geographical perspective is employed only emissions within that area are addressed. This might lead to sub-optimisation by clouding significant actions that could improve the whole transportation system, collaborating with the right stakeholders (public transportation companies, car sharing companies, mobility management, etc.), as well as only accounting for a fraction of the transportation emissions that the district actually generates. The accounting method used accounts for commuting emissions to where the commuter lives. That accounting method skews planned efforts by SRS to be a working centre with more than twice as many workspaces as residential spaces.

Therefore, significant emissions from worker commutes are excluded in SRS but not in Hackbridge, despite the fact that that most "Smart Growth" transportation measures can readily be undertaken on the district level to minimise them.

Based on this, the transportation emissions include emissions from residents' private and commuting trips, workers' business trips and emissions from the transportation of goods and services delivered to and from the urban district.

4.4.3 Data Used and Calculations

All activity data regarding resident and worker trips were developed using transportation studies, focusing on SRS district. The total projected travel demand was calculated. Transportation emissions from goods and services were estimated using Stockholm-specific data.

Table 4.4: Projected emission and travel behaviour and workers in Stockholm Royal Seaport (CCI, 2011).

Mode of transportation	Residents [PKM/year]	Workers {PKM/year]	Emission factors {g Co2e/PKM]	Total emission [ton CO2e/year]
Car-biogas	920,046	780,696	0.02	0.03
Car-E85	6,584,892	5,587,546	76.78	934.60
Car-Gasoline E5	36,045,366	30,585,942	170.81	11,381.30
Car-Diesel RME5	12,109,452	10,275,357	166.04	3,716.80
Car-Electric	2,418	2,025	11.56	0.05
Car-Hybrid	885,626	751,489	136.65	223.70
Local bus	11,003,413	1,184,771	4.13	50.30

Local train	27,907,469	1,777,157	0.05	1.5
Long distance bus	7,187,855	0,00	32.00	230.00
Long distance train	24,284,576	7,108,628	0.13	4.10
Physically active	18,703,695	1,184,771	0.00	0
Total residential emission	9,074.23			
Total workers emission	7,468.15			
Goods and services	3,289.26			
Transportation totals	19,831.7			

Waste*:* Each waste fraction includes emissions from collecting, transporting and treating each fraction, as well as emissions reductions from recycling compared with using virgin materials. The waste emissions exclude the upstream lifecycle emissions of production and transporting the respective goods before they are disposed of as waste. This merits a discussion about consumption that is outside the scope of this studies, but it should at least be noted that this exclusion leads to the paradox that the more food and goods consumed within the case studies, the lower their emissions. This is because the waste generated is combusted in the district heating system, which leads to lower district heating emissions compared with using fossil fuels. Each emissions factor is based on waste treatment in London/Sweden, since specific data are not available now.

4.4.4 Data Used and Calculations

The waste streams in the urban development were projected using data for the City of Stockholm combined with the possibility to collect household waste, combustibles, newspapers and paper beside or within the buildings themselves.

Table 4.5: Emission from waste for Stockholm royal seaport (CCI, 2011).

Waste fraction	Ton waste/year	Emissions factor [ton co2e/ton waste]	Annual Emission [ton CO2e/year]
Mixed municipal solid waste	7,574	All municipal solid waste is used in the city of stockholm's districts heating network and emission are therefore attributed there	
Garden waste	122	-0.4	-48.8
Bulk waste	3,168	-0.1	-316.8
Sorted waste			
Glass	718	-0.04	-28.7
Paper	2,537	-0.18	-456.7
Metal	109	-0.61	-66.5
Newspaper	986	-0.18	-161.3
Plastic	800	1.52	-1216
Electronics	329	-0.05	-16.6
Hazardous waste	49	-0.3	-14.7
Waste totals			106

4.4.5 Data Summary

Table 4.6: The summary of emission in the different categories discussed above are summarised below (CCI, 2011).

Emission Categories	**Ton CO_2 / year**	**Ton CO_2e/ capital**
Energy		
-Heating and cooling	12,169.3	0.64
-Electricity	7,932	0.42
-Water & infrastructure	2,325	0.12
-Locally produced energy	-557.7	-0.03
Transportation		
-Residents	9,074.2	0.48
-Workers	7,468.1	0.39
-Goods & services	3,298.2	0.17
Waste	106	0.01
Totals	**41,806.1**	**2.20**

4.4.6 Analysis

Energy: Energy use in buildings clearly should be an area of interest for road mapping actions. In the baseline heating (& cooling) represent 37 % of the total emissions and electricity use 28%. The energy demand is larger for heating and cooling purposes, but another influence is also that the Nordic grid electricity mix is currently less GHG intensive per kWh than the district heating mix.

There are only relatively small amounts of local energy production included in the baseline. The numbers included in the baseline is based on an average production in Stockholm and it is possible that there might be more biogas generated in SRS due to technological developments in the waste management system as well as possible road mapping actions (waste churns notably). Technological improvements in the wastewater collection and plants could also increase the amount of biogas generated.

The emissions from water in the SRS area are almost zero due to the systems low energy requirements as well as their investments in clean energy. Water demand minimization efforts are however important from a more general sustainability point of view.

The infrastructure emissions included in the baseline are mainly from the city operations (snow clearing, sanding, road maintenance etc.), which are based on a Stockholm average. Technological improvements (biogas powered vehicles, heated sidewalks etc.) are possible emission cuts to be made in the area. The emissions from street and traffic lights are currently uncertain but will have a very limited impact on emissions since the city invests in clean electricity to power its utilities.

Transportation: Transportation is a key emitter and even with the 40 % CCI accounting principle stands for 38 % of the total SRS emissions. The key emitter for both residents and workers are the emissions from cars, representing roughly 40 % of PKM travelled per day and 98 % of emissions in both cases. Transportation emissions are likely to change over the time until SRS becomes fully operational. The fuel economy of vehicles is likely to become more efficient as well as a continuing shift from fossil fuel powered vehicles to renewable ones. As soon as more detailed data about traffic projections and final decisions are made on key infrastructure parts (tram lines, busses etc.) even more detailed data can be developed.

Waste: Since the Swedish waste treatment system is already mature when it comes to material sorting, recycling and energy recovery waste emissions are relatively low. However, since we have only accounted for downstream emissions and not the emissions resulting from the production of waste, which is the main source of emissions when it comes to waste this is still a very important area for road mapping actions, both behaviour related aiming to reduce waste generation and with technical support (e.g. vacuum collection system) increase the sorting and recycling efficiency.

4.5 Data Results for Hackbridge

4.5.1 Energy Savings and Carbon reductions from residential

The corresponding carbon emission reductions are calculated as a result of knowing the potential energy savings for each footprint.

However, in the Hackbridge housing sector, the demonstrations of Deakin *et al*., (2015) ascertained the energy savings and carbon reductions that is associated on the savings calculated for the retrofit options visualized. This is achieved by way of an area-based analysis, linking levels of energy consumption and carbon emissions to the structure of tenure and the connection this in turn has to the housing market. Consequently, the table 4.7 below illustrates the calculated results for the five LSOAs. Seeing the tables per LSOA, it can be gleaned that energy saving and carbon reductions are interdependent. Higher energy savings result in higher carbon emission reductions.

4.5.2 Area-Based Analysis

As an area-based analysis, this assessment of consumption and emission by structure of tenure draws upon data profiled from LSOA's 1 and 5. The reasons part of this study also focuses attention on these areas are:

i. LSOAs 1 and 5 provide measures of the most and least deprived areas within the urban regeneration footprint. Here, Area 1 is the most deprived with a ranking within the 21% most deprived areas in England, whereas Area 5 has a much lower ranking within the 29% least deprived;
ii. while roughly similar in terms of building type, age, and levels of consumption and emission, the social-rented sector is prevalent in Area 1, whereas in Area

5 the owner-occupied and private-rented sector are the main sectors of the housing market;

iii. such an area-based analysis provides evidence to suggest which type of tenure consumes the least or most amount of energy and relationship this, in turn, has to the levels of emissions from the residential property in question.

Subsequently, previous analytical approach from Deakin et al., 2015 associated both LSOAs to ascertain which kind of tenure performs best or worst in terms of energy consumption and carbon emissions. This evaluation is reiterated to associate areas with different social-demographic structures in terms of energy output and carbon reductions.

Table 4.7: Energy and carbon reduction in the LSOAs.

	LSOA 1	**LSOA 2**	**LSOA 3**	**LSOA 4**	**LSOA 5**	**Total**
energy consumption total [kwh/p.a.]	6733319	14644009	5576413	13140448	8079019	**48173208**
CO_2 emission total [kg/p.a.]	1904109	4684583	1657453	4002471	2176338	**14424954**
Households	295	741	321	601	318	**2276**
energy consumption /mean household	22825	19762	17372	21864	25406	
CO_2 emission/	6455	6322	5163	6660	6844	

mean household						
mean STVR	0.59	0.53	0.53	0.55	0.56	
mean PVTVR	99.96	99.90	99.99	99.73	99.81	
owner occupied	150	571	250	427	235	**1633**
social rented	107	89	31	84	53	**364**
private rented	38	81	40	90	30	**279**

As table 4.8 below indicates, the level of energy savings and reduction in the rates of carbon emission are noticeable across all LSOAs. For the thermal option this type of retrofit results in a 25% energy saving, whereas with the thermal-plus option, the savings are as high as 65%. In terms of carbon reductions, figures 5.0 and 5.1 indicates the thermal retrofit option reduces the rate of carbon emission by 25% and as much as 50% for the thermal-plus option. In terms of tons per household, the thermal and thermal-plus retrofit options have the potential to reduce the emissions from 6 to 4.5 and 3 respectively.

Table 4.8: The energy savings across all LSOAs

	LSOA 1	**LSOA 2**	**LSOA 3**	**LSOA 4**	**LSOA 5**
current energy consumption (kWh/p.a.)	6733319	14644009	5576413	1314048	8079019
Retrofit(s):					

1. thermal	1357437	2952232	1124205	2649114	1628730
2. thermal-plus	2413222	5248413	1998586	4709537	2895521
maximum energy savings	3770659	8200645	3122791	7358651	4524251

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Table 4.9: The energy savings for the thermal option in all LSOAs. Source: Deakin et al., (2015).

	LSOA 1	**LSOA 2**	**LSOA 3**	**LSOA 4**	**LSOA 5**
current CO_2 emissions (kg/p.a.)	1904109	4684583	1657453	4002471	2176338
Retrofit(s):					
1. thermal	378727	931764	329667	796091	432874
2. thermal-plus	592368	1457374	515634	1245169	677059
Maximum CO_2 savings	971096	2389137	845301	2041260	1109932

The OPL climate neutral plan adapted by Hackbridge as highlighted from the literature review as a ten-sustainability action plan (zero carbon, zero waste, sustainable transport, local and sustainable material, local and sustainable food, sustainable water, Natural habitat and wildlife cultural heritage, equity and fair trade, health and happiness). Presently, the major focus of Hackbridge district has been to achieve climate neutral (Zero carbon) by mass retrofit in the housing sector, which actually accounts for only 25% of the total energy consumption and carbon emission in comparison to the total OPL action plan. This means the other 75% is not accounted for in the mass retrofit proposals.

SRS is also considered to under estimate the levels of energy consumption and carbon emissions since not all emissions are included in the accounting system adopted and tendency to focus on activities directly related to the geographical area. When moving from the city level to the urban district level, an additional 'layer' of emissions is added, namely those within the city, but not in the specific urban district, which can have a significant impact on total emissions. For example, in the case of SRS, many societal functions that resident use regularly, such as hospitals, libraries, sports centres, etc., are not included in the geographical area. On the other hand, two of the main sources of emissions in Stockholm are located in the SRS area, since it includes the combined heat and power plant and the harbour. There is also the question of the thoroughfare since most of the traffic it carries is not related to the SRS district itself. The emissions from these sources are instead scaled to proportion of the residents, so that every person in Stockholm gets an equal share. If emissions from activities not included in the geographical baseline but connected to the City of Stockholm were to be included in the calculations, such as emissions from hospitals, sports centres, public offices and so forth, the annual emissions of a resident in SRS would increase by at least 0.5-ton CO2e per capita (Fahlberg et al., 2007).

4.6 Interpretation

Arbitrating from the framework, accounting system adopted by Hackbridge and its net emission, it clearly shows the route to climate neutral might come sooner with one planet living. Consequently, with CCI-SRS system, adding road mapping and credit action together might still be a challenge for SRS to be climate positive, since the road mapping action is not explicit enough for SRS to be climate positive urban district, the actions and their calculated magnitude in relation to the baseline emission does not serve as a very powerful motivational tool and driving force to reach the target. In this study, the comparison between the baseline emissions and the reductions through roadmap actions demonstrated that it is difficult to become climate positive on a local scale.

As regards possible road mapping actions, even the more ambitious actions, such as influencing the residents' travel behaviour, only reduce total baseline emissions by about 10% each (CCI, 2011). Furthermore, while the current proposed actions only represent a fraction of possible emissions cuts, they are in themselves rather ambitious. The baseline energy use for buildings in the baseline is already 25% lower than the current Swedish building code requirements (Boverket, 2011) and implementing 55 kwh/m2 and year is close to the Swedish passive house standard. Therefore, it seems unlikely that the SRS district will manage to achieve climate positive status just by road mapping action strategies within the urban district itself.

In the CCI framework, not all scopes of emissions are included, both when comparing the urban district with Hackbridge district. Significant emissions caused by the urban district takes place outside the set boundaries and were not taken in consideration. This study further considers the geographical area from an urban district point of view, there are some additional considerations that were neglected but are similar but not equal to the discussions of a city's boundary and its emissions outside that boundary.

A study on cities by Davis & Caldeira (2010) concluded that 20-50% of emissions are generated outside the city's geographical boundary, or occur as the result of cross boundary emissions. Findings based on the baseline emissions in SRS, shows that emissions from activities taking place outside SRS but inside Stockholm were not included and adding these emissions from consumption, construction and long-distance travel would further increase total emissions from the baseline's 2.2 ton CO2e/capita to 2.7 ton CO2e/capita. The accounting system perspective that is used by CCI and hackbridge model does not verify that energy saved by SRS is not used by anyone else (e.g. rebound effects) or that fossil fuels replaced by new renewable energy generation are not used anywhere else.

Emissions Changes Over Time: After sufficient amounts of credit have been generated by actions outside the geographical system boundary, some problems remain, namely; the emissions are primarily based on current district heating and electricity mixes, a margin of safety needs to be added since emission factors can fluctuate by 20% or more on a yearly basis (Johansson et al., 2012b). As the energy system in the Nordic countries becomes more integrated with central Europe, the energy mixes will also change, which could impact on emissions (Eurostat, 2012).

The baseline needs to be continuously updated as measured data become available. It is also important to bear in mind that changes over time in the two key areas, buildings and transportation, were not taken into account.

The CCI model for SRS does not take into account the lock-in effects of built infrastructure when it comes to emissions (Unruh, 2000). These include technical and behavioural aspects and thus it is important to plan ahead, especially when aiming for an ambitious goal such as climate positive.

Would Hackbridge and SRS Urban District Climate neutral/Positive be enough over Time?

The emission only represents a “snapshot” of emissions at a certain point in time. Considering the characteristics of the case studies, its emissions are likely to change over time, and thereby it’s potential for the urban district to become or stay climate neutral/positive over the years hangs on a very thin line. This raises the issue of the difference between a carbon neutral urban district and a climate positive one. Surely the entire difference cannot be just 1 g CO2e (0 g = carbon neutral to -1 g = climate positive)? So how climate positive should a district be to ensure that it is climate positive enough?

Although the model still has not formally addressed this question, it could be argued that climate positive is a very ambitious goal and if an urban district is serious about achieving it, it also needs to ensure a sufficient safety margin.

Risk of Green Washing: A risk when trying to create a climate positive urban district is setting very narrow scopes of emissions, thus making it relatively easy to achieve the goal. Another key challenge using CCL model is how the urban district aims to reduce its emissions. Local actions such as energy efficiencies and fuel switching is not sufficient enough, especially if the absolute perspective of accounting emissions reductions is used. Using the less strict accounting approach makes emissions reductions far easier to be climate positive, especially if the concept of avoided emissions is allowed, as it would increase the likelihood of the actions being seen as green washing.

4.7 Reflection

The CCI model for creating a climate positive urban district, the approach of baseline, roadmap and credits seems to work well in the general sense that it promotes actions towards low energy use, a high degree of renewables and local energy generation and that the urban district can function as a catalyst for surrounding districts to reduce emissions. Credits and road mapping actions can serve as driving forces for innovation.

The Clinton Climate Initiative focuses on low energy use, a high degree of renewables, local energy generation and a system of credits. On an urban district level, there are three main emission categories including energy, transportation and waste. It allows for technology and policy actions that reduce emissions in the surrounding areas or globally, called credits. But it excludes GHG emissions from construction etc. (i.e. no life cycle perspective) and consumption of goods and services as well as long distance travel which is a clear weakness.

Compared to OPL, Clinton Climate Initiative has an extremely ambitious and explicit goal (climate positive). Strengths are its transparency, which is a key for comparisons between other urban districts. The process of baseline, roadmap and credits offer a wide variety of different kinds of solutions and allows a city or an urban district to test how far different actions will lead.

However, the disadvantage of the CCI model is that it does not take into account the important challenge of being people centred in order to function well over time. Demanding technological solutions strongly influence the life styles of people and companies in such districts and need the users' full integration and understanding. High investments and rental costs of CLUEs or even climate positive districts, due to high entailed standards, require careful consideration of social justice and equality. The key challenge for CCI is to have a high degree of transparency regarding which emissions are included and excluded in order to avoid the risk of greenwashing.

The OPL plan begins by taking a holistic approach to the problem of achieving sustainable city district, identifies specific challenges that the targeted district must overcome, and finally focuses on the possible opportunities to overcome these individuals identified challenges. With the challenges of each potential One Planet Community in mind, the overall action plan suggests practical and economically feasible tactics for applying each principle and then identifies “performance indicators.”

OPL has its strength in the framework that functions well for “co-creating” sustainability growth strategies to reduce the energy consumption and GHG emission while the lack of prescriptive requirements in the OPL framework is a possible barrier to achieve its goal.

The challenges for Hackbridge and SRS ranges from planning-related issues, such as formulating a clear strategy of what a climate neutral and climate neutral/positive urban district entails to practical issues such as implementing technology and verification systems to ensure that emissions and reductions can be tracked properly. There are also the financial dimension issues of who will pay the costs and reap the benefits of the urban district.

Consequently, reflecting on the literature review and case study analysis this thesis offers, while the OPL and CCI models appear mutually exclusive in terms of their accounting, framework and models i.e. OPL is more holistic in its operation while CCI model offers more fragmented solution, they do still complement each other in terms of the energy savings and carbo emission savings they both search for.

Chapter Five

5.0 Conclusion

This thesis reviews the knowledge currently available to drive European cities towards either a climate neutral or positive status. The study has been conducted using both literature sources, as well as analyses of case studies from European districts (Hackbridge and SRS).

This thesis has examined the potential of urban district to reduce global greenhouse gas emissions, and the question of whether the climate neutral or positive can be achieved using their set action plans. Whilst the research has showed that significant emission reduction is possible from the case studies, several issues needs to be worked through for the districts to achieve their aims.

Historically, the process of tackling carbon has focused on the front-end of the economy and has adopted a top-down approach using measures such as emission trading schemes and carbon taxes. This has resulted in rigorous carbon accounting methodologies being developed for large industry. This has generally been seen as sufficient in addressing emissions, few specific carbon measures and schemes have been developed at the other end of the economy, which includes urban district development and the built environment i.e. for Hackbridge and SRS. As a result, limited carbon accounting processes, methodologies and frameworks currently exist to measure emissions from this sector, and this prevents accurate reporting and subsequent recognition of reductions.

However, as awareness of the carbon reduction potential from the built environment has grown - a result of numerous low carbon and carbon neutral urban development demonstration projects around the world (i.e. CLUE) - the need for a consistent way to measure emissions and acknowledge the reduction has become evident in this report.

Hackbridge and SRS aim to provide world class examples of climate neural environments, as such, this thesis aims to study them with the objective of:

Objective 1: comparing the different methodological stand-points of Hackbridge and Stockholm Royal Seaport (SRS).

From this study, it is evident that significant variation currently exists in what developers target in terms of emissions reduction and, thus, which sources of emissions have been included in achieving their low carbon status. The lack of a common metric or framework for conducting carbon analyses, together with inconsistent terminology and lack of universally accepted definitions, makes it difficult to compare developments and their claims. This leads to suspicion and distrust in carbon claims, as evidenced in the case study. Furthermore, without continuous follow up and evaluation, claims can quickly become out-dated and inaccurate. This study highlights the need for a universal carbon accounting methods or framework for district-scale development that identifies the specific areas that need to be considered and targeted by developers making carbon claims, as well as a standardised approach and methodology for quantifying those emissions. This will help to make carbon claims and assertions much more meaningful and comparable, bring greater credibility to the concept of low carbon developments and thereby increase the opportunity for them to become mainstreamed. Without this, CLUE might never be possible.

Objective 2: evaluating One Planet Living (OPL) and Clinton Climate Initiative (CCI) accounting techniques they apply to benchmark climate neutrality.

The Hackbridge and SRS accounting models adopted for creating a climate neutral and positive urban district respectively seems to work well in the general sense that it promotes actions towards low energy use, with high levels of renewables and local energy generation which allows the urban district can function as a catalyst for surrounding districts to reduce emissions. Road mapping actions can serve as driving forces for innovation as well. Arbitrating from the accounting techniques used in the case studies, the accounting system adopted by Hackbridge clearly shows the route to climate neutrality might come sooner with One Planet Living. As regards the CCI-SRS system, the situation is more challenging, because simply adding road mapping actions and credits together, might still not make the SRS climate positive. This is because the road mapping action is not explicit enough for SRS to be climate positive urban district, as when comparing the calculated magnitude of these actions against the baseline, they do not serve as either a very powerful motivational tool or driving force to reach the target. In this study, the comparison between the baseline emissions and the reductions through roadmap actions demonstrated that it is difficult for the SRS to become climate positive on a local scale.

Objective 3: Demonstrating the world-class status these climate neutral urban environments command.

The Hackbridge and SRS city-districts are great examples in-terms of showcasing sustainable development with an emphasis on climate mitigation, climate neutral or positive development and whose high performance is based on their behaviour energy efficient, low carbon city-districts. In classifying the morphology of these city-districts, the regional innovation systems are the standard-bearers of, are forecast to produce saving and reductions in excess of those laid down by the EC. As standard-bearers of sustainable and inclusive growth and leading pioneers of both energy saving and carbon emission measures, these city-districts are at the forefront of regional innovation. Indeed, they are so advanced as to offer the prospect of a smart dividend for sustainable city-districts and include (neighbourhood) communities whose energy efficiencies pave the way for what are termed post-carbon economies.

5.1 Limitations and Further Research

This study has shown that carbon neutral development options as important directions for the future of urban districts and cities at large. This is why the case studies analysis conducted for this thesis is based on urban metabolism model outlined in chapter three. The number of field components and the extent to which they have been investigated varies, depending on the availability of data. Due to some confidential reasons, data to assess and analyse some components of the urban metabolic were simply not available for Hackbridge. This is why the urban metabolic analysis is limited in Hackridge when compared to the SRS.

This in turn suggests more research is necessary to understand the impact of human factors on the metabolic flows of an urban system. This study and current research has focused on quantifying these flows, but without understanding why people favor one flow path over another or why they fail to create links between different compartments of the urban system that could benefit from these flows.

At present, GHG emission frameworks cannot give a complete account of all GHG emissions related to a district. However, imperfect systems tend to reward by shifting GHG emissions to sources that are unaccounted for. This study would have benefited from an internationally standardized framework, with clear indications of its limitations (to create awareness of ‘shifting behaviour’) and high transparency (to provide indications for improvement). This would have helped this study to conduct a more meaningful comparison. This means further research is required to develop carbon accounting tools that are accessible and easy for developers to use. Turning the carbon accounting framework proposed into an ISO standard covering the metabolic of urban development at the district scale is another option that would also require further work.

5.2 Contribution to knowledge

This thesis has demonstrated that Hackbridge project (retrofit) does a better job by adapting to climate change by reducing energy consumption and lowering carbon emission than Stockholm Royal Seaport project (infill). This in turn suggests the urban retrofit path adopted by Hackbridge has the greater potential to develop climate neutral urban environments and it is an important direction for the future of urban districts and cities at large to combat climate change.

This study also:

i. Unfolds that Climate neutral/positive is a concept under development – definitions, scopes and boundaries are to be found for each local project. There is no climate neutral (or positive) urban district or city in the world yet. This makes it difficult to become more specific and give advice “how to do it”. However, this study has been able to identify some barriers to their goal fulfilment.

ii. Reveals the variation currently exists in what each respective model target in terms of emissions reduction and, thus, which sources of emissions have been included in achieving their low carbon status.

iii. Highlights the absence of a common metric for conducting carbon analyses, together with inconsistent terminology and lack of universally accepted definitions makes it difficult to compare developments and their claims. This can lead to suspicion and distrust in carbon claims, as evidenced in this study.

iv. Clarifies the need for a universal carbon accounting framework for urban development that identifies the specific areas that needs to be considered and targeted by developers making carbon claims, as well as a standardised approach and methodology for quantifying those emissions. This will help to make carbon claims and assertions much more meaningful and comparable, bring greater credibility to the concept of low carbon developments.

v. Supports the need for the baseline to be continuously updated as measured data become available. It is also important to note that changes over time in the two key areas, buildings and transportation, were not taken into account.

vi. Shows that accounting system adopted by hackbridge and its net emission clearly confirms the route to climate neutral might come sooner with one planet living rather than Clinton Climate Initiative.

vii. Demonstrates that OPL and CCI models are mutually exclusive concerning reduction of energy and carbon emissions i.e. they offer different views and action plans from their accounting system, framework and models towards tackling its emission. The OPL is more holistic in its operation while CCI model offers more fragmented solution. They offer too little similarities to complement each other.

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