An investigation into the urban energy-economy nexus

by

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Thesis presented in fulfilment of the requirements for the degree of Master in Engineering Management in the Faculty of Engineering at Stellenbosch University

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December 2018

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the authorship owner thereof (unless to the extent explicitly otherwise stated), and that I have not previously, in its entirety or in part, submitted it for obtaining any qualification.

December 2018

Abstract

Energy is arguably the most important resource for economic growth since most vital city infrastructures require energy. The majority of the world's population now live in cities, which is also where the vast majority of the world's energy is consumed. The pressures and potentials to reconcile economic growth and the sustainable use of resources are thus greatest in cities. This study investigates the city-level relationship between energy consumption and economic growth. Therefore, to answer the research questions posed in the study, the Spearman Correlation Test and the Granger Causality Test were employed to search for correlations and causalities between energy consumption and economic growth. The study performed analyses on three cities, namely: Cape Town (South Africa), Wellington (New Zealand) and Barcelona (Spain). These three cities share similar economic profiles yet have vastly different energy consumption patterns. Decoupling is a central concept of this study; it was defined as a term to describe the efforts to break the link between economic growth and the depletion of resources and the degradation of environments. It was found that when cities showed signs of decoupling, the correlation between energy consumption and economic growth was lost. Through investigating these three cities' energy-economy nexus, it was found that Wellington showed the most impressive decoupling. Therefore, Wellington's policy interventions were studied to find a cause of this decoupling. It was found that the city employed a carbon tax, a strong environmental-awareness campaign, and an increased investment in public transport while reducing investment in road infrastructure. This combination brought about a modal shift where citizens adopted energy-efficiency technologies and public transport. This study therefore recommends this combination as a model for decoupling. Finally, this study has shown the importance of inter-city learning, and argues that cities should be open about policy interventions in order to speed up the transition to a green economy. This study recommends a systems analysis of the urban energy-economy nexus in order to fully understand the dynamics between energy consumption and economic performance.

Opsomming

Energie is waarskynlik die belangrikste bron vir ekonomiese groei, aangesien die meeste belangrike stadinfrastruktuur energie benodig. Die meerderheid van die wêreld se bevolking leef nou in stede, en dit is ook waar die oorgrote meerderheid van die aarde se energie verbruik word. Die druk en potensiaal om ekonomiese groei en die volhoubare gebruik van bronne te versoen, is dus die grootste in stede. Hierdie studie ondersoek die stadsvlakverhouding tussen energieverbruik en ekonomiese groei. Om die navorsingsvrae wat in die studie gestel is, te beantwoord, was die Spearman Korrelasietoets en die Granger Oorsaaklikheidstoets gebruik om korrelasies en oorsake tussen energieverbruik en ekonomiese groei te soek. Die studie het drie stede ontleed, naamlik: Kaapstad (Suid-Afrika), Wellington (Nieu-Seeland) en Barcelona (Spanje). Hierdie drie stede het soortgelyke ekonomiese profiele, maar het baie verskillende energieverbruikspatrone. Ontkoppeling is 'n sentrale konsep van hierdie studie; dit is gedefinieer as 'n term om die pogings om die verband tussen ekonomiese groei en die uitputting van bronne en die agteruitgang van omgewings te verbreek, te beskryf. Daar is bevind dat wanneer stede tekens van ontkoppeling toon, die verband tussen energieverbruik en ekonomiese groei verlore geraak het. Deur die drie stede se energie-ekonomie-spilpunte te ondersoek, is gevind dat Wellington die indrukwekkendste ontkoppeling getoon het. Daarom is Wellington se beleidsintervensies bestudeer om 'n oorsaak van hierdie ontkoppeling te vind. Daar is gevind dat die stad 'n koolstofbelasting, 'n sterk omgewingsbewusmakingsveldtog, en 'n groter belegging in openbare vervoer gemaak is, terwyl beleggings in padinfrastruktuur verminder is. Hierdie kombinasie het gelei tot 'n modal shift waar burgers energie-effektiwiteitstegnologieë en openbare vervoer aangeneem het. Hierdie studie beveel dus hierdie kombinasie aan as 'n ontkoppelingsmodel. Ten slotte het hierdie studie die belangrikheid van inter-stadse leer getoon, en beweer dat stede oop moet wees vir beleidsintervensies om die oorgang na 'n groen ekonomie te bespoedig. Hierdie studie beveel aan 'n deeglike stelsel ontleding van die stedelike energie-ekonomie nexus ten einde die dinamika tussen energieverbruik en ekonomiese prestasie ten volle te verstaan.

Acknowledgements

This study is dedicated to my father, Johan Dippenaar, my absolute role model.

Thank you to my incredible mother, Jeanne Dippenaar, for your relentless belief in me and for being my guidance through life. To the rock in my life, my best friend, biggest supporter and sister, Lara Dippenaar, thank you is all I can say. Thank you to my big sisters Lindie and Carie for looking after me and for being the wisdom in my life. Oom Hennie, ongelooflik baie dankie vir oom se liefde, raad en leiding. Oom en Tannie Lettie se liefde is my alles.

To my supervisor, Alan Brent, thank you for your patience and direction, not only in this study but in my life. I am grateful to have been able to work with you.

Thank you to Josephine Musango for sharing your wealth of knowledge with me, and for always having an optimistic outlook on any situation.

I wish to extend my gratitude to William Stafford and Matt Heun for letting me pick your brains and for inspiring me to pursue a life in research.

Thank you to Zanie Cilliers from Sustainable Energy Africa for your technical support and generous assistance in the collection of data.

Thank you to Victoria University of Wellington for kindly hosting me for 6 weeks of productive study.

My utmost gratitude goes out to the National Research Foundation (NRF) Funding Grant number 99103, for making this study financially possible, I would not have been able to pursue this without my funding from the NRF.

To the energy in my life, my friends, your support has carried me through this journey. May love and happiness always surround you.

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Glossary

Acronyms and Abbreviations

ARMA	Autoregressive-moving-average model
BRICS	Brazil, Russia, India and South Africa
CCT	City of Cape Town
ECS	Energy Cost Share
EROI	Energy Return on Investment
EU	European Union
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GPC	Global Protocol for Community-Scale Greenhouse Gas Emissions Inventory
HDI	Human Development Index
IEA	International Energy Agency
LPG	Liquid Petroleum Gas
MD	Magisterial District
NERSA	National Energy Regulator of South Africa
NZETS	New Zealand's Emission Trading Scheme
OECD	Organisation for Economic Co-operation and Development
SDG	Sustainable Development Goals
UN	United Nations
UNDP	United Nations Development Programme

Chapter 1 Introduction

1.1. Background Information

Energy is disputably the most important resource for economic growth (Grubler *et al.*, 2012), since most vital city infrastructures all require energy: water supply and wastewater disposal; supply of food and material; transport and communication systems; the disposal of wastes; and even energy supply itself. Many of the world's largest economies rely on heavily-polluting energy supplies, however there is an increased pressure to transition to more sustainable energy supplies. Understanding the relationship between energy consumption and economic performance is thus necessary to ensure economic growth is maintained throughout the transition to alternative energy sources. In other words, the task ahead is to rethink the city for the era without cheap fossil fuels (Swilling *et al.*, 2017).

As documented in numerous studies, the majority of the world's population now live in urban areas, where quality of life and environmental concerns undermine all benefits associated with urban economies (Swilling *et al.*, 2017). The urgencies and potentials to find methods to reconcile economic growth, well-being, and the sustainable use of resources, are therefore greatest in cities (Swilling *et al.*, 2013). Furthermore, since cities each have different characteristics, understanding how an individual city functions may facilitate interventions for a smoother transition towards a sustainable city.

1.2. Why an Urban Focus

The 2014 revision of the World Urbanization Prospects report (UN-DESA, 2014) estimates that population growth and urbanisation will result in a further 2.4 billion people being added to the current global urban population by 2050. The proportion of the population living in cities and towns is expected to rise from 54 per cent (in 2015) to 60 per cent by 2030 and to 66 per cent by 2050 (UN-DESA 2014). Nearly 37 per cent of the projected urban population growth to 2050 is expected to come from only three countries: China, India and Nigeria. It is estimated that they will contribute 404 million, 292 million and 212 million urban dwellers respectively (UN-DESA 2014). Africa's urban population is expected to grow from 400 million in 2010 to 1.2 billion in 2050 (Parnell & Pieterse, 2014). This is what is generally known as the second urbanization wave, which describes the phase of urbanisation that began in the 1950s and has largely taken place in the global South. By contrast, the first urbanization wave took place between 1750 and 1950, and resulted in the urbanization of only 400 million people, mainly in the global North (Swilling & Annecke, 2012).

Sustainable cities have been included amongst the 17 global ambitions captured in the Sustainable Development Goals (SDGs)[1], which set the global agenda for sustainable development from 2015 to 2030. Goal 11 aims to create "inclusive, safe, resilient and sustainable cities". To this point, a report of the International Resource Panel (Swilling *et al.*, 2017) states that:

> *"One of the great challenges of our age is how to prepare for the doubling in size of the urban population during the period 2010-2050 by promoting a transition to socially inclusive, resource efficient and sustainable modes of urban development".*

Cities can actively contribute to meeting national government targets relating to climate change by implementing mitigation measures (Thollander and Palm, 2013; Mahomed, 2016). Local governments are especially appropriate agents to drive and implement decentralised activities, such as energy efficiency (Rezessy et al., 2006). This shift goes beyond the familiar call to 'do more with less'; cities also need to aspire to do more with renewable and sustainable resources that will need to replace unsustainably used resources (Swilling *et al.*, 2013).

1.3. Problem Statement

Given that many of the resource flows on which cities depend are finite, it follows that continuing global economic growth will depend on the decoupling of this growth from escalating resource use. Municipal and local governments will need to turn to renewable forms of energy production, or implement energy efficiency measures, in order to cater for the increasing energy demands of their cities. The economic effects of such policy changes are not known on a city level. A fundamental understanding of how the implementation of different energy policies might affect urban economies is thus required (and lacking) in order to ensure economic growth throughout the transition to a sustainable economy.

1.4. Research Objectives

This study's research objective is to improve the understanding of the urban energy-economy nexus in order to reveal the drivers of city-level decoupling. This was achieved through investigating the

[1] https://www.un.org/sustainabledevelopment/sustainable-development-goals/

relationship between energy consumption and economic performance for the selected cities. In order to ensure the main objective was achieved, the following sub-objectives were created and fulfilled:

1. Examine the approaches for correlation and causality analysis in an urban context;
2. Determine the appropriate approach for the correlation and causality analysis for cities; and
3. Undertake correlation and causality analyses between energy consumption and economy activity for selected cities.

1.5. Research Strategy

In order to achieve the objectives of this study, a research strategy was needed. A diagram showing the research strategy can be seen in Figure 1-1. As typical in a study of this kind, the first step was to conduct a literature review in order to find perspective for the study and to find similar studies which could be used as a starting point for this study. Thereafter, as it was expected to take some time to acquire data, the cities of analysis would need be decided and the data gathering process was to begin early. While the data gathering was taking place, the data analysis methodology would be determined. Once the data was gathered, and the methodology determined, the data analysis could be performed. The final step of the research strategy was to interpret the results of the analysis. Finally, to complete the cycle, the results would need to be fed back into literature, through conferences and journal papers in order to share the outcomes of this study.

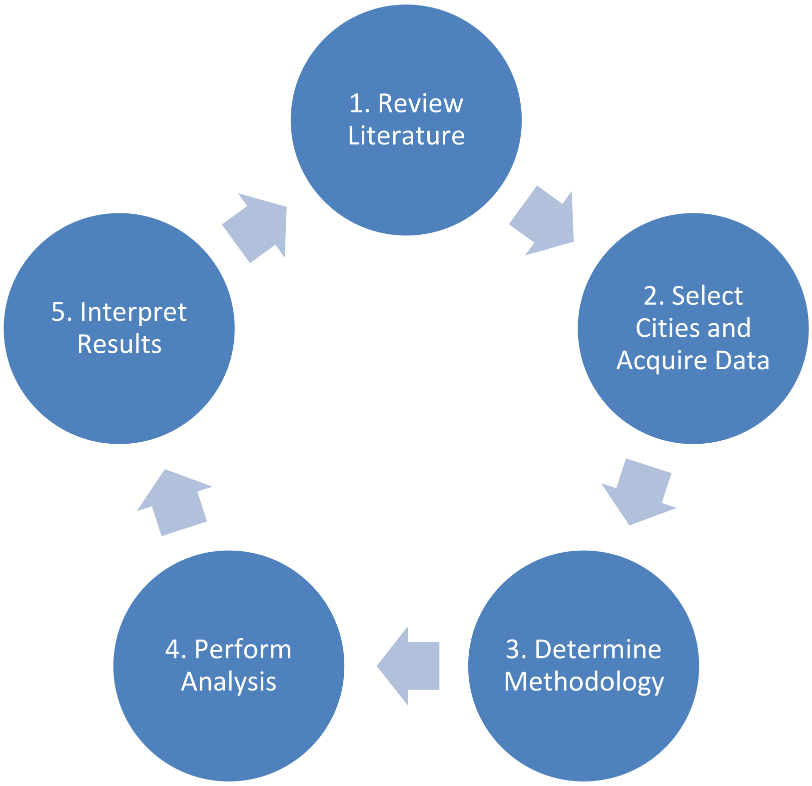

Figure 1-1: Research Strategy

1.6. Chapter Outline

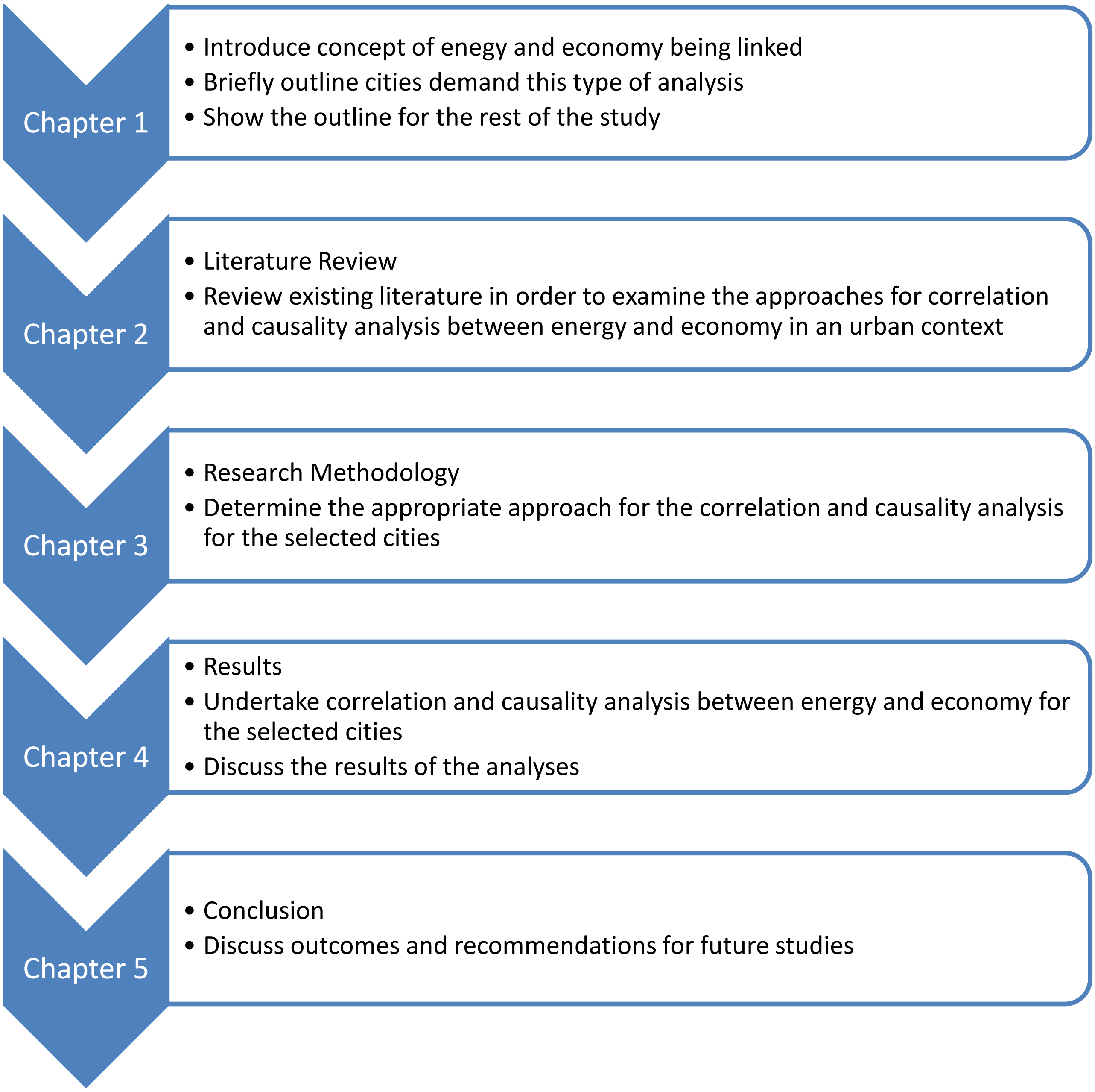

Figure 1-2: Chapter Outline

Chapter 2 Literature Review

2.1. Introduction

A literature review was conducted to investigate the linkages and causalities between energy consumption and economic growth, in order to explore how energy transitions can drive economic growth. The aim of the literature review was to understand the current body of knowledge pertaining to the energy-economy nexus in cities, and the analysis thereof, in order to address the first two research objectives.

2.2. Review Methodology

The review consisted of a systematic online search of literature databases (Science Direct, ISI Web of Science and Scopus). The literature review considered peer-reviewed journals, conference proceedings, and, to a limited extent, any other form of publication such as Masters and Doctoral thesis.

2.2.1. Literature Selection

A structured and transparent procedure was followed; as recommended by Popay (2006). The procedure started by defining research questions, conducting a literature search and screening, synthesising and reporting the results, and finally discussing the research findings. The procedure minimised the impact of author's bias, reduced the potential for duplication and promoted transparency of the methods and processes, as recommended by the Collaboration for Environmental Evidence (2013).

In order to obtain existing information on the relationship between energy and economics, the "building blocks" search technique was used. This involved breaking down the topic into three subjects and searching for these terms in databases containing science publications. Similar phrases for each subject were also used in a wide variety of combinations, ensuring coverage of the large literature base. Table 2-1 shows the keyword terms used for the search. The databases chosen for the search were Scopus and Google Scholar. The search was an iterative process and the keywords were often updated when new and relevant subjects arose.

Table 2-1: Keywords used in literature search

Keyword 1	Keyword 2	Keyword 3
Energy consumption Energy price Energy expenditure Energy cost share Energy metrics Energy	Economic growth GDP* GDP per capita Growth National growth Economy	City-level Local governments Sustainable City

*GDP – Gross Domestic Product

2.2.2. Review procedure and results

The initial keyword search resulted in 873 articles. These 873 articles were then refined by the criteria shown in Table 2. As a result, 200 articles from Scopus and 53 articles from the Google Scholar were found. These 253 articles were further screened, using a title search, based on the applicability to the study, which specifically focused on the energy-economy relationship. An abstract analysis was then conducted on the remaining 88 articles to include national and international studies that conducted studies on various countries and time frames, using a range of methodologies. The remaining 46 articles that were found to be useful to this study were reviewed.

Table 2-2: Filter criteria

Criteria	Included	Number of Articles
Matched searched string	Yes	873
Selected Period	2005-2016	253
Type	Articles	
Language	English	
Title Search	Relevant to study	88
Abstract Analysis	Useful to study	46

The papers that were useful to study were those that assisted in either understanding the general relationship between energy consumption and economic growth, or that assisted in leading towards a city-level understanding of the relationship. The research methodology revealed 46 articles that were reviewed in depth, and the outcomes of the review are discussed in the following sections.

2.3. Energy-Economy Nexus

In general, mainstream economists neglect the idea that high energy prices can cause economic decline or stagnation. It is frequently argued that energy costs are small compared to other expenditures that make up GDP (e.g. consumer spending, which makes up about 70%), which makes them insignificant (Aucott and Hall, 2014; Heun *et al.*, 2017). This view ignores the importance of energy as a multiplier of economic growth and development. Energy is a domestic necessity and also a factor of production (enabling a variety of services such as transportation, heating, and food production), whose price directly affects the price of other goods and services. If the price of energy increases, almost everything costs more, and this ripples through the economy.

Mainstream economic thinking has not identified energy as a primary factor of production (Stern, 2011; Aucott and Hall, 2014; Heun *et al.*, 2017). Resource economists have developed models that incorporate the role of energy in the growth process, but these ideas remain isolated in the resource economics field (Stern, 2011). However, there is a lack of consensus on the causality between energy consumption-economic growth, and electricity consumption-economic growth Ozturk (2009). These conflicting results may arise due to different data sets, countries' characteristics, variables used and different econometric methodologies have been used. However, an important conclusion on the relationship between electricity consumption and economic growth for the country-specific studies were drawn, which is that the causality is from electricity consumption to economic growth. Consequently, it is found that electricity is a limiting factor to economic growth and, hence, reductions in electricity supply will have a negative impact on economic growth (Ozturk, 2009).

2.3.1. Energy Cost Share

Recently, the impact of energy cost share on economic growth has received attention in the literature (de Wit, Heun and Douglas, 2013). The components of energy cost share in a given time period (*ECS*) are: energy type (*i*), energy price for each type (p_i), energy consumption rate for each type (Q_i), and GDP. The energy cost share for an economy at a given time *t* is calculated by (de Wit, Heun and Douglas, 2013):

$$ECS_i = \frac{\sum p_{i,t} Q_{i,t}}{GDP_t} \quad (2.1)$$

Energy cost share proves to be a useful indicator of an economy's energy expenditure, since it considers both the energy price for each type (p_i), and the energy consumption rate for each type (Q_i) in relation to the country's GDP. It therefore gives a good indication of the energy investment in relationship to economic growth at a particular point in time.

However, there is an upper threshold to countries' energy cost share (Bashmakov, 2007). When the energy cost share rises above this threshold, recessionary pressures reduce the energy demand, thereby reducing energy prices, which in turn reduces the total energy cost share to its earlier (equilibrium) value (Heun and de Wit, 2012). Interestingly, there is only a correlation between energy costs, income levels and economic activity, when the energy affordability threshold is exceeded. Beyond the energy affordability threshold, economic growth becomes highly dependent on fuel expenditure.

A study of the economic growth (GDP) and energy cost share of US between 1950 and 2013 revealed an energy affordability of around 4% of GDP; since the energy cost share in the US is approximately 5% of GDP further economic growth is unlikely (Aucott & Hall 2014). Furthermore, the energy cost share of the US is likely to increase as the energy return on investment (EROI) for petroleum will continue to decline and prices will increase over the long term. However, this study used expenditures on primary fuel (coal, oil, natural gas and nuclear ore) to calculate energy cost share does not give an indication of the cost of energy to the consumer. Furthermore, primary fuel cost are changing as new methods of extracting energy are developed and governments heavily influence the price of energy through a range of financial instruments, such as subsidies, taxes and levies.

There are at least two ways that countries can lower their fuel cost share in the future- becoming more energy efficient and replacing fossil fuels with renewable energy options that have lower costs of production.

2.3.2. Energy Return on Investment (EROI)

EROI is an important metric as it accounts for costs expended to deliver energy from extraction to the consumer. EROI is defined as the ratio of gross energy output ($E_{gross,t}$) obtained from an energy production activity, such as drilling for oil, mining for coal, or building wind turbines, to energy input ($E_{input,t}$) for the energy production process during a period of time (*t)* (Heun and de Wit, 2012):

$$EROI_t = \frac{E_{gross,t}}{E_{input,t}} \qquad (2.2)$$

By this definition, the break-even point for energy production is when EROI = 1. Thus a process with EROI > 1 is an energy source and a process with EROI < 1 is an energy sink (Heun and de Wit, 2012). Furthermore, for energy production processes, it is apparent that the higher the EROI, the more energy is supplied to society – this can be visualised in Figure 2-1 Figure 2-2.

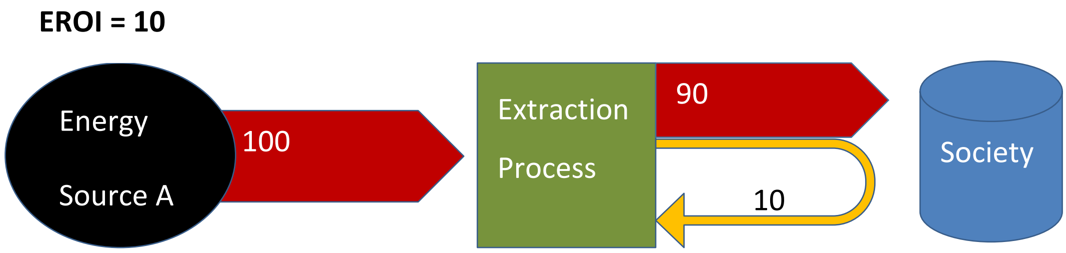

Figure 2-1: Energy Source with EROI = 10

Source: Adapted from Heun and de Wit (2012) and Roberts (2017)

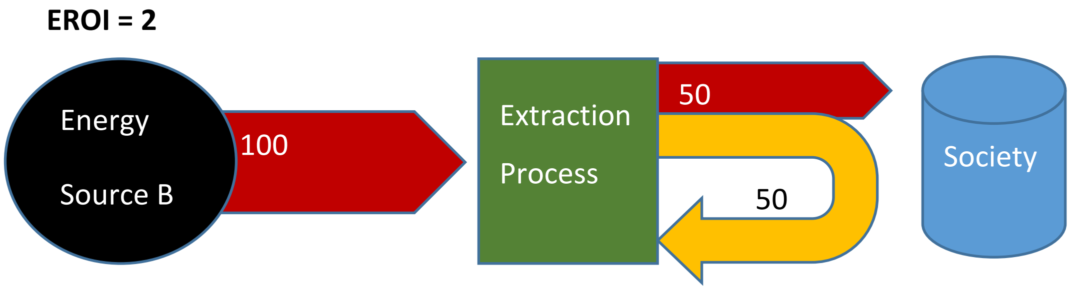

Figure 2-2: Energy Source with EROI = 2

Source: Adapted from Heun and de Wit (2012) and Roberts (2017)

As the EROI of energy sources decrease, the market price of the energy increases (King, 2011), and statistical models have been developed in an attempt to predict the market price of energy, given an energy source's EROI (Heun and de Wit, 2012). Since EROI has been shown to dictate energy prices, it is an important to energy policy and energy sources with the greatest EROI should be used when deciding on a country/city's energy mix.

As oil supplies continue to become depleted, there is a tendency to extract energy from energy sources with a lower EROI. The EROI values for various energy sources can be plotted against the net energy efficiency in order to guide energy policy and energy developments (Murphy & Hall, 2011) - see Figure 2-3. The most important concept provided by this figure is that when EROI values decline below 10, the net energy provided for society decreases exponentially. Unless society reduces its reliance on fossil fuels, which have a rapidly decreasing EROI, the globe will move towards a "net energy cliff" (Lambert *et al.*, 2014).

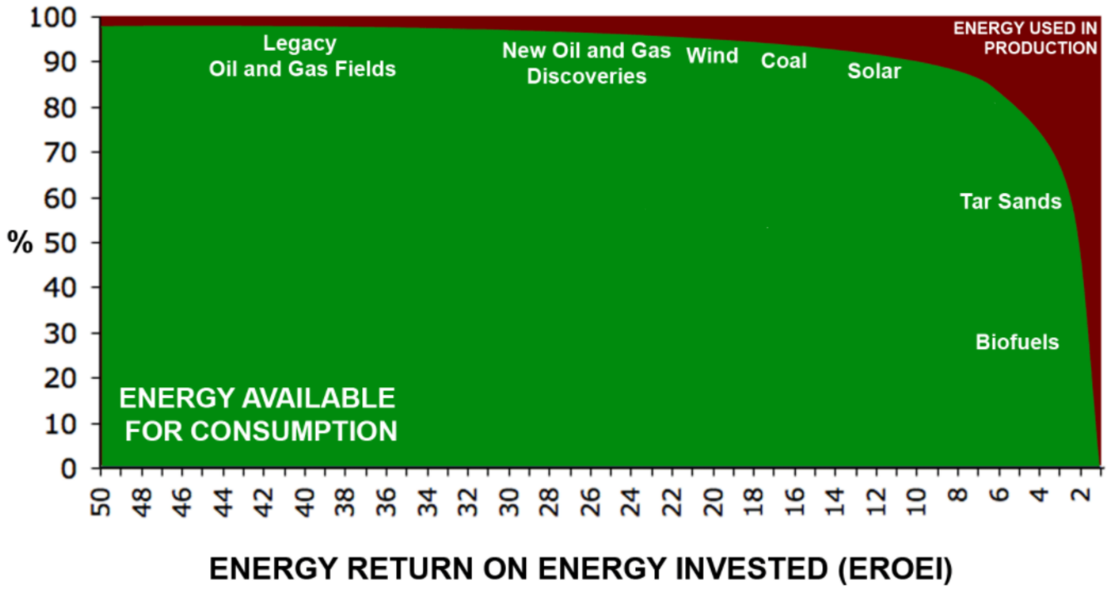

Figure 2-3: The Net Energy Cliff (Murphy and Hall, 2010)

A comprehensive comparison between world economic and net energy metrics has been carried out using data from 1978-2010 for 44 countries that contribute to 90% of global GDP (King, Maxwell, & Donovan, 2015). This revealed that the costs of energy are an important factor in economic growth; and global energy cost share is significantly correlated with the one-year lag of the annual changes in GDP (King et al. 2015). However, it is noteworthy that the correlation coefficients calculated in this study were mostly not statistically significant; which may have been due to a lack of accurate time series data available and the short time period in which this data has been recorded. An alternative explanation is that energy prices play little role in influencing economic growth – it is only when energy expenditure reaches an upper threshold, that it starts to restrain the factors contributing to economic growth such as labour and capital (Bashmakov, 2007; Aucott & Hall, 2014). This also alludes to the use of critical energy cost share thresholds as being a more important metric than general correlation coefficients (Roberts, 2017).

It is important to note that these energy cost share thresholds may be different from country to country, depending on whether it is a net importer or exporter of energy, and will likely change with time. Establishing these thresholds, if any, and determining a correlation between economic growth and critical energy expenditures once these thresholds have been exceeded is of utmost importance since it indicates the level of investment in energy beyond which there will be little economic benefit. These thresholds can then be used to guide the expansion and mix of the national energy supply system, using a range of energy supply options with different EROI.

2.3.3. Energy Intensity

Energy intensity can be defined as "*the ratio of energy use to a relevant measure of activity or output*'' (Schipper & Grubb, 2000), or the energy consumed per unit of GDP (IEA, 2003). Essentially, a high energy intensity translates to a high cost of converting energy into economic growth; while low energy intensity indicates a low cost of converting energy to economic growth. In summation, a lower energy intensity means a higher amount of energy efficiency.

From the foregoing definitions, several aspects are important in understanding energy intensity in developing countries- the rapidly growing energy demand; the security of energy supply in terms of quality, reliability and continuity; the capital intensiveness of energy industry; and the overall economic development path of the country (Jamasb, Newbery & Pollitt, 2005).

The Human Development Index (HDI) published by the World Bank validates that economic development is an urgent issue in developing countries. However, evidence shows that there can be no significant economic development without affordable energy (Priddle, 2002). A large part of the underdevelopment issues in sub-Saharan Africa are related to an energy shortage. For instance, Nigeria, with a population of over 140 million people, can only produce about 1600 MW of electricity, while Ireland with a population of about four million people produces over 4000 MW of electricity (Fufore, 2012). In terms of human development, it is no wonder then that, while Ireland ranks 5th on the United Nations Development Program's (UNDP) HDI, Nigeria is ranked 158th (UNDP, 2007).

There exists a trend in the energy intensity of developing countries which seems to follow the same pattern as developed countries historically, where energy consumption and intensity grew considerably with economic growth during the industrialisation era, but began to decline significantly as the economies shifted to secondary and tertiary industries (Metcalf, 2008; Shipper et al., 1993; Zhang, Feng & Sun, 2009). However, energy use continued to increase until after the oil crisis of the 1970s when "a phenomenon known as 'decoupling' was been observed" (Stage, 2002) where energy use is grew at a much slower rate than economic growth. This can be attributed to a shift to secondary and tertiary industry and higher prices promoted the use of energy-efficient technologies (Stage, 2002). Studies indicate that energy intensity first increases as a consequence of escalating economic growth and development, but consequently drops as a result of a shift to a service-based economic structure (Medlock III & Soligo, 2001).

A simple way to reduce GHG emissions originating from fossil fuels is to increase the amount of economic output per unit of energy consumed (efficiency). Understanding the drivers of the intensity of energy demand is therefore an important stage from an energy policy making viewpoint, since it is a combined measure of economic output and energy consumption (Zhang et al., 2009). It is thus crucial for the policy makers to grasp how energy demand will vary with a structural change in the economy (Markandya et al. 2006). A pattern of energy intensity and economic growth can be seen from a historical viewpoint of development. When industrialisation commenced, energy consumption rapidly increased with economic growth. However, later on the path of industrialisation, energy consumption was reduced while economies continues to grow as a result of gradually switching from primary to secondary and tertiary industries. There are some apparent inconsistencies to this trend in countries like Brazil, Philippines, Argentina and Colombia, where energy intensity has been shown to be “superficially” low compared to the level of economic development. This phenomenon can be explained by examining the inequality between the rich and the poor. A considerable gap between the two social classes means that wealthy people drive the GDP of the country up, while energy consumption remains low since the majority of the population is poor and thus unable to consume a substantial amount of energy to balance the GDP and national energy consumption (Suehiro, 2007).

2.3.4. Decoupling

The term 'decoupling' has been promoted as a term to describe the efforts to break the link between economic growth and the depletion of resources and the degradation of environments (UNEP, 2011; Swilling *et al.*, 2013). A prime focus of sustainable development is thus to decouple economic development from the increasing use of energy and natural resources. Global resource consumption and economic production is now concentrated in cities, with 80% of global GDP now associated with cities (Grubler *et al.*, 2012). By 2005, approximately 75% of global energy and material were consumed in cities, which covered a mere 2% of the land. Given the predicted growth of cities and the important role that cities will have in influencing economic growth, there is an urgent need to understand how this growth can be achieved in a sustainable manner.

One approach is to decouple economic growth from resource use and environmental impacts (UNEP, 2011). There are two types of decoupling. The first is resource decoupling (strong decoupling) or 'dematerialisation' which involves reducing the rate at which resources are used per unit of economic output. In other words, resource decoupling refers to growing the economic output while decreasing the resource use. The second type is impact decoupling (weak decoupling) which refers to increasing economic activity while decreasing negative environmental impacts; such as pollution, greenhouse gas emissions, and biodiversity loss. Both are illustrated in Figure 2-4.

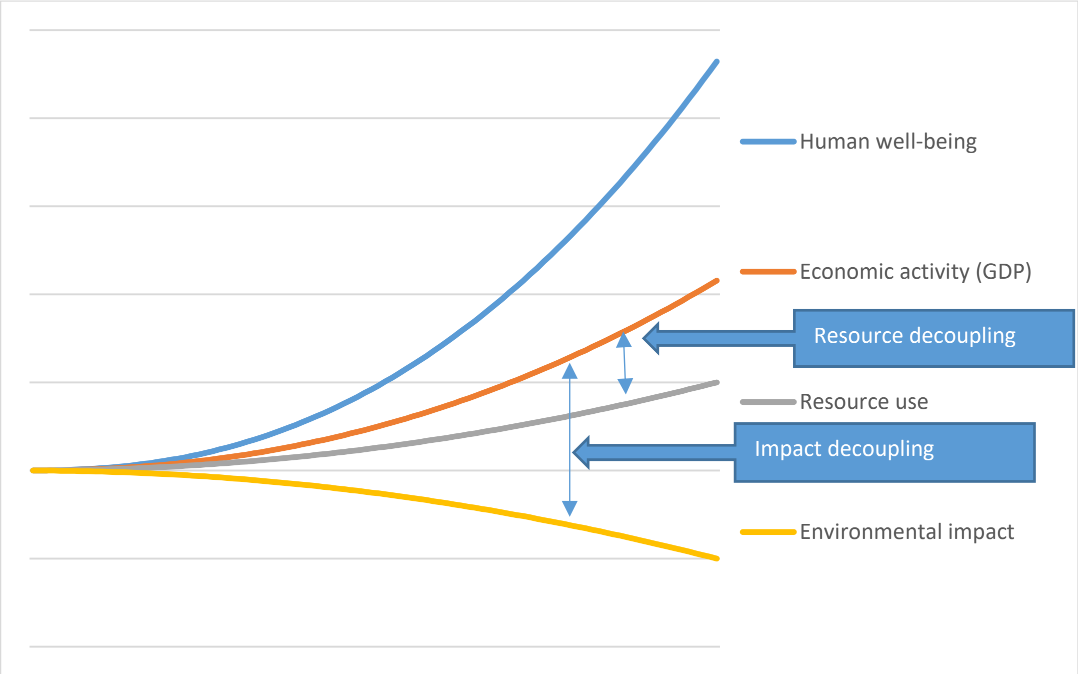

Figure 2-4: The two aspects of decoupling

Source: Adapted from UNEP (2011)

Understanding the relationship between energy consumption and economic growth is fundamental to decoupling economic growth from resource use (resource decoupling), while an increased understanding of the environmental impacts of energy supply options is needed for impact decoupling.

Furthermore, the concept of 'absolute decoupling' vs 'relative decoupling' is crucial to monitor the environmental pressures of an economy. Figure 2-4 has shown that decoupling occurs when the growth rate of an environmental pressure is less than that of its economic driving force (e.g. GDP) over a given period. Absolute decoupling is said to occur when the environmentally relevant variable is stable or decreasing while the economic driving force is growing. Decoupling is said to be relative when the growth rate of the environmentally relevant variable is positive, but less than the growth rate of the economic variable.

Decoupling indicators, like all other types of indicators, shed light on particular aspects of a complex reality but leave out other aspects. For example, the decoupling concept lacks an automatic link to the environment's capacity to sustain, absorb or resist pressures of various kinds (deposition, discharges, and harvests). In the case of renewable natural resources, a meaningful, interpretation of the relationship of environmental pressure to economic driving forces will also require information about harvesting rates compared to renewal rates.

2.3.5. Economic Metric

In order to measure the relationship between energy consumption and economic performance, an economic metric needs to be identified. For more than a half century, the most widely accepted measure of a country's economic progress has been changes in its Gross Domestic Product (GDP) (Costanza *et al.*, 2009).

GDP is an estimate of market throughput, adding together the value of all final goods and services that are produced and traded for money within a given period of time. It is typically measured by adding together a nation's personal consumption expenditures (payments by households for goods and services), government expenditures (public spending on the pro- vision of goods and services, infrastructure, debt payments, etc.), net exports (the value of a country's exports minus the value of imports), and net capital formation (the increase in value of a nation's total stock of monetized capital goods).

Economists have warned since its introduction that GDP is a specialised tool, and treating it as an indicator of general well-being is inaccurate and dangerous (Costanza *et al.*, 2009). Other metrics that incorporate health, education and poverty levels are more suitable for interpreting the overall well-being of a society. Furthermore, as explained in the following section, 2.4, the unrecorded economy and volunteer services are not accounted for in the GDP of an economy. Therefore a society should not become overly fixated on the GDP metric.

It is of particular concern that GDP measurement encourages a depletion of the earth's resources by stimulating energy consumption (Costanza *et al.*, 2009; Xue, 2010). Therefore, it is most appropriate that this study utilises GDP measurements to evaluate whether a rising GDP does indeed cause an increase in energy consumption for cities. Alternatively, the impact of an energy conservation policy on a city's GDP can be evaluated. Since this study is not aimed at evaluating the relationship between energy consumption and well-being, but rather the linkages between energy and economy, the GDP metric proved to be suitable.

2.4. Key Considerations in Urban Energy Systems

This section looks into some of the key focus areas that are expected to have considerable effects on the urban energy-economy relationship, but whose influence is uncertain, namely: energy efficiency, the importance of local governments, the unrecorded economy, city boundaries, and finally, energy accounting methods (Karanfil, 2008; Warr, Schandl and Ayres, 2008; Kohler, 2013; Aucott and Hall, 2014).

Whether a city can be truly sustainable is debatable. This is due to the varying priorities with which cities contend, the manner in which their boundaries are delineated, and the challenges in identifying and measuring appropriate indicators of urban sustainability (Currie, Musango and May, 2017). In addition, the vision of a sustainable city as a utopian entity is potentially unhelpful, as it may impose a contextual or unrealistic development pathways on the city (Campbell 1996). For example, a sustainable city that externalises its resource use and impacts to locations outside its boundaries cannot be considered sustainable from a multi-level perspective. Arguably, cities are not either sustainable or unsustainable, but rather encompass various socio-economic and socio-ecological processes "*that negatively affect some social groups while benefiting others*" (Allen, 2001). Therefore, political considerations are important to address the inherent trade-offs or contradictions in addressing the social, environmental and economic aspects of sustainability simultaneously.

There is also a need for urban energy policy to focus primarily on demand management, such as energy efficient buildings, structuring urban form and density conductive to energy efficient housing forms, high-quality public transport services, and the integration of urban energy systems. This demand-side focus at the urban scale represents a paradigm shift compared to the traditional, more supply-side energy policy focus at the national scale; and offers opportunities for a more efficient use of energy in urban environments may have a considerable effect on the economy of the city (Grubler *et al.*, 2012).

2.4.1. Energy Efficiency

Increasing energy efficiency has been broadly considered as the most cost-effective way to mitigate greenhouse gas emissions and is one of the most important ways to reduce the threat of increased global warming (European Parliament 2009, IPCC 2007). Without efficiency improvements since 2000, the world would have used 12% more energy than it did in 2016 – equivalent to adding another European Union to the global energy market (IEA, 2017). Energy efficiency is the "*least expensive, most benign, most quickly deployable, least visible, least understood, and most neglected way to provide energy services*" (Lovins 2005).

This is most important in countries rapidly building infrastructure, where efficiency opportunities lost now lock in wasteful energy use for decades. As IEA member nations' absolute energy use shrinks from its 2007 peak, developing countries' rising share of global energy use offers important opportunities to leapfrog to the best technologies, in which they could even seek and achieve market dominance (Lovins and Browning, 1992; Cagno *et al.*, 2013; IEA, 2017).

With energy efficiency as its cornerstone and needing its pace redoubled, climate protection depends critically on seeing and deploying the entire efficiency resource. This means extending modern net-zero or net-positive and deep-retrofit building-design philosophies—examples of integrative design—into industry, vehicles, mobility, and their links to IT and urban form; broadening our climate-change-mitigation analytic framework from components or devices to whole systems; and replacing theoretical assumptions about efficiency's diminishing returns with practitioners' empirical evidence of expanding returns (Lovins, 2018).

Table 2-3: Benefits of increasing Energy Efficiency and Renewable Energy

Public Benefits	Private Benefits
Employment and market growth in energy efficiency and renewables	Cost reduction, energy affordability, low energy prices
GDP growth, productivity and competitiveness, reputational benefits from reduced environmental impacts	Productivity, competitiveness, product quality, employee comfort and satisfaction
Energy system resilience and security, reduced reliance on imported fuels, reductions in emissions	Reputational benefits from reduced environmental impacts
Improved air quality, reduced public health costs	Health and wellbeing, comfort, reduced respiratory illness

Source: Adapted from IEA (2017)

2.4.2. The Importance of Local Governments

There is growing global, national and local awareness of the role of urban and local management as being key to many areas of sustainable energy development and climate change mitigation. If a municipality is going to have an impact on transition to a green economy in the area under its jurisdiction it must influence change amongst its broader constituency – the residents and businesses of the city or town. There are principally two ways of influencing the behaviour of citizens and businesses: through regulations and policies, and by providing support and information (Sustainable Energy Africa, 2017).

A green economy is defined as one that results in “*improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities*” (UNEP 2010). In its simplest expression, a green economy is low-carbon, resource efficient, and socially inclusive. In a green economy, growth in income and employment are driven by public and private investments that reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services. While the idea behind a green economy is spreading fast, much of the current discussion centres on national developments (ICLEI, 2012).

Due to an increasingly active network of local leaders – supported by organizations such as ICLEI - Local Governments for Sustainability – a consensus is emerging that the notion of “think global – act local” is imperative to find sustainable solutions to the challenges of resource scarcity and climate change (ICLEI, 2012). When pursuing a sustainability agenda, local governments have certain ‘tools’ at their disposal, such as governing by authority (e.g. acting as a regulator); governing by enabling (e.g. promoting certain policies towards relevant stakeholders such as a national ministry); governing by provision (e.g. giving financial support to specific activities such as the purchase of solar water heaters); self-governing (e.g. being a role model in energy efficiency projects in public buildings) (ICLEI, 2012).

Each city is unique, so combining analysis on the global level with constant ‘deep dives’ into local and regional strategies can assist cities to find the most suitable individual strategies. Collaboration with higher levels of government is essential if cities and networks of cities are to overcome regulatory barriers and access funding. It is thus crucial that higher levels of government support city-level innovation for resource efficiency (Swilling *et al.*, 2017).

City governance has a central role to play in managing energy consumption and GHG emissions. City governance can incentivize energy efficiency, and promote renewable energy use and public transport. Indirectly they can influence city energy use through urban planning and economic development (Sustainable Energy Africa, 2014).

2.4.3. Unrecorded Economy

The definition of an unrecorded economy is that of an underground or shadow economy, which is the “*market-based production of goods and services, whether legal or illegal that escapes detection* *in the official estimates of GDP*" (Smith, 1994). Developing countries have the highest unrecorded economies accounting for 44% in African economies and 39% in Latin American countries. Concerning transition and developed countries, the unrecorded economy is estimated to account for 20% in Middle Eastern and Eastern European countries and 12% in OECD (Organisation for Economic Co-operation and Development) countries (Gërxhani, 2004). Thus, the investigation of the linkage between energy consumption and the official economy may not give reliable results in such countries. It would appear that a country's energy input is not transferring to economic output due to the scale of the unrecorded economy.

However, energy input may not be an essential factor of production in the *unrecorded* economy (Karanfil, 2008). This is alleged to be due to unrecorded economic activities having low energy inputs, such as peddling or hawking. These results may not be a true reflection of the situation, since estimating energy demand is a difficult task in informal settlements, as households that do not have legal land tenure are not entitled to public services provision (Payne, 2001). Unrecorded economies should be included in future energy-economy studies, especially in developing countries, in order to build comparative research to ultimately form a generalizable conclusion (Karanfil, 2008). The intricacies of the relationship between energy consumption and economic growth has been of much interest to researchers for years, despite the fact that there is yet to be an agreement on the direction of the causality. It is expected that the varying size of the unrecorded economy will play an important role in evaluating the true size of an economy, and how it interacts with energy consumption.

2.4.4. City Boundaries

City energy assessments should also include clear definitions of the system boundary used. Currently, many urban energy assessments, in effect, arbitrarily choose the system boundary to reduce the reported energy use or GHG emissions; for instance by claiming their electricity comes from different sources than the average regional mix, or by excluding certain energy uses that are, nonetheless, central to the very functioning of cities, such as airports or a large tourist population (Grubler *et al.*, 2012). Arbitrary, or ill-defined, system boundaries defy the very purpose of urban energy assessments: to guide public and private sector policies and decisions and to allow comparability and credibility of the entire process.

The seemingly easy question of "How large is the energy use (or associated GHG emissions) of a city and what can be done to reduce it?" can vary enormously as a function of alternative geographic and system boundaries chosen. In a modification of an old adage that only what gets measured gets controlled, this chapter postulates that only what is measured correctly and transparently at an urban scale is useful for policy guidance. The manner in which urban boundaries are delineated also has direct bearing on how governments administer their cities, and changes to these administrative boundaries also have implications for how urban growth is measured (Swilling *et al.*, 2017). This is largely why studies of resource flows have typically been undertaken at national level, where boundaries are clearer and data is more available (Grubler *et al.*, 2012).

For the case of a city analysis, the urban or metropolitan jurisdictional boundary is the generally accepted boundary (WRI, C40 and ICLEI, 2014; Swilling *et al.*, 2017). Importantly, the boundary should be chosen independently of the location of any buildings or facilities under municipal—or other government—control, such as power generation facilities or landfill sites outside of the city's geographic boundary (WRI, C40 and ICLEI, 2014). Furthermore, the boundary should be kept consistent in order to allow for comparison with studies in the future.

Since the vast majority of liquid fuel is used to fuel transport (petrol and diesel), which frequently cross city boundaries, the question of which area should be accountable for the energy consumption and greenhouse gas emission becomes a complicated one. There are a number of ways to report liquid fuel data, and each present unique advantages and disadvantages. These methodologies have been well documented by the Global Protocol for Community-Scale Greenhouse Gas Emissions Inventory (GPC) - 2014.

These methodologies for estimating transport emissions can be broadly categorized as top-down and bottom-up approaches. Top-down approaches start with fuel consumption as a proxy for travel behaviour. Here, emissions are the result of total fuel sold multiplied by a GHG emission factor for each fuel. For this approach the assumption is that the amount of fuel purchased outside of the city boundary and brought in cancels out with the amount of fuel purchased inside of the boundary and taken out. The bottom-up approaches begin with detailed activity data. Bottom-up approaches generally relate travel activity, the mode of travel, energy intensity of each mode, fuel, and vehicle type, and carbon content of each fuel to total emissions. These details and exceptions to these methodologies are explained in the Global Protocol (WRI, C40 and ICLEI, 2014).

2.4.5. Energy Accounting Methods

Generally, urban-energy assessments must be oriented either to physical energy flows (a 'production' perspective) or, if trade effects are included, follow economic exchanges linked to energy use (a 'consumption' perspective). The two methods discussed are classified using two main criteria: the basis of the data and the definition of energy users.

The 'final energy' method uses physical data, such as energy statistics from utilities or fuel sales, as the data basis. Users are defined as energetic end users within the city boundaries. Energetic end users are the "consumers" of final energy (such as electricity, heat, gasoline, or heating fuels). It is important that both producers and consumers (i.e., firms and households) use final energy. By disaggregating the final energy use by sector, one can differentiate between residential, commercial, and industrial uses. These sectorial accounts of urban final energy use also allow comparisons with national level data or data of other cities and can serve as a useful guide, e.g., for energy-efficiency 'benchmarking' that can guide policy.

Energy input-output, or 'Energy I-O', accounting approaches are based on national economic I-O tables, which measure (usually in monetary terms) all sales and purchases of goods and services among the producing sectors and to final demand. These tables can be extended to account for physical energy flows or emissions. Based on I-O tables, the 'embodied' energy (i.e., the energy used throughout the whole production chain to produce the final goods and services) can be calculated. This approach allows allocation of energy use to specific sectors of economic activity.

The indeterminacy in defining 'urban energy' should not be misinterpreted as a flaw in the urban systems perspective. It reflects that the data are approaching the actual final-decision level at which the purpose of the decision, to some degree, can resolve many of the statistical and data ambiguities. For example, administrative boundaries and a production perspective are appropriate system boundaries if the decisions are to be undertaken by local administrations. Final energy-use data remain an essential and useful tool for analysis of energy efficiency and for crafting policies for improved efficiency. Conversely, a 'consumption' perspective on urban energy and GHG use helps to raise awareness that, ultimately, urban energy and GHG management cannot be relegated to an energy optimization task, but equally involve changing lifestyles and consumption patterns.

2.5. Time Series

Fundamental to this study is the analysis of a potential causality between energy consumption and economic performance. Many different methodologies have been employed in previous studies to analyse this causality (Karanfil, 2009; Ozturk, 2009). This section aims to review these methodologies and explore previous studies' recommendations in order to provide the most comparable results, and to contribute to the overall understanding of the energy-economy nexus. The different types of data are examined, and the fundamentals of time-series data are examined. Thereafter, the data analysis methodology is explained step-by-step. The section then closes with some conclusions on data analysis and names a few important considerations that should be treated with caution in this type of study.

Much criticism has been expressed towards the existing methodologies used to analyse the energy-economy relationship. Table 2-4 gives a brief comparison of empirical results from causality tests between energy consumption and economic growth for three countries: India, Turkey and USA (Karanfil, 2009). From Table 2-4 it can be concluded that, for the countries involved, almost all types of results (uni- or bi-directional causality and neutrality) have been reported in the literature. The results reported in Table 2-4 also raise some other concerns related to the reliability of the policy implications that can be drawn from such analyses and the necessity to develop of new methods (or improvement of existing ones) (Karanfil, 2009).

Table 2-4: Overview of studies on the energy-income nexus in three selected countries.

Countries	Results*			
	E→Y	E←Y	E↔Y	E~Y
India	Asafu-Adjaye (2000)	Paul and Bhattacharya (2004)	Soytas and Sari (2003)	
Turkey	Soytas and Sari (2003)	Lise and Van Montfort (2007)	Erdal, Erdal and Esengun (2008)	(Jobert and Karanfil, 2007)
USA	Stern (2000)	Kraft and Kraft (1978)		(Chontanawat, Hunt and Pierse, 2008)

*E and Y denote energy consumption and economic growth, respectively. → and ← indicate direction of causality, while ↔ means bi-directional causality and ~ means no causality in any direction.

Source: Adapted from Karanfil (2009)

Based on the literature review in Table 2-4, the causal relationship using the same country data could be different due, in part, to differences in research periods or in research methods. The most probable reason for the discrepancy is the insufficient number of observations in the data. It manifests from the literature that most data are in the 30 to 40 years span. For the unit root or Johansen co-integration test, the 30–40 data points are few and as such, low statistical testing power is expected (Huang, Hwang and Yang, 2008). Thus, the inconsistency in results is not unexpected. A second reason for divergent results is due to the diversity of methods and testing procedures employed in the analyses (Asafu-Adjaye, 2000).

2.5.1. Time Series Analysis and Time Series Data

Time series analysis in the social sciences is the application of statistical models to time series data to examine the movement of social science variables over time (e.g., public opinion, government policy, judicial decisions, educational outcomes, socioeconomic measures), allowing analysts to estimate relationships within (over time) and between variables in order to test causal hypotheses, make forecasts about the future, and assess the impact of policy changes.

To clarify exactly what time series data are and are not, it is useful to compare such data to other types of data. For many, the most familiar type of data is cross-sectional data. Typically, cross-sectional data are from a random sample of cases. For example, a variable Y is a collection of observations on randomly selected cases:

$$Y = \{y_1, y_2, y_3, \dots, y_N\}, N \; is \; number \; of \; cases \qquad (2.3)$$

Each observation y_i is from a different case, all from the same point in time. If the cases are selected by simple random sampling, each value of y_i is roughly independent of the others. Cases can be a random selection of individuals, countries, firms, and so on.

Time series data have a separate observation for each time point, and each observation is for the same case—for example, GDP (gross domestic product) of a country. The time between observations can be years, months, days, hours, and so on. However, as we shall see, the measurements are assumed to be (roughly) evenly spaced. A time series variable Y_t is a non-random sequence of observations for an individual case ordered over time:

$$Y_t = \{y_1, y_2, y_3, \dots, y_T\}, T \; is \; number \; of \; time \; points \qquad (2.4)$$

Another type of data, which is neither cross-sectional nor purely time series, is panel data. In panel data, we have more than one case. The same set of cases is observed at multiple time points. The panel data approach is used in the literature to investigate the causal relationship between energy consumption and economic growth in different groups of countries (for example, low, middle and high income groups) instead of providing country-specific results (Karanfil, 2009). In order to compensate for the deficiency in an inadequate sample size, the panel data approach groups similar countries together. The advantage of using the panel data approach is the increase in data points and hence the power of statistical estimation. In the case of this study, the panel data approach was used to group cities with a similar economic profile together. This approach allowed for a larger sample size, which increased the power of the statistical analyses.

There are a number of assumptions included in time series analyses. One of the most important of these assumptions is that the observations are independent. Usually, the cases in a cross-sectional data set are assumed to have been selected randomly, and therefore, the value of any case for a given variable will be independent from the value of any other case for the same variable. In time series data, we have measures of the same variable for the same single case at different time points. Therefore, time series data, such as those used here, are usually not independent, especially if the sampling time interval is small. Observations close together are often more alike than those far apart. For example, energy consumption in 2016 is more closely related to energy consumption in 2015 than it is to energy consumption in 2005

If not accounted for in our analysis, one of the problems the violation of independence can lead to is a problem called serial-correlated errors. This is the problem of correlation across the estimated errors in the data model.

2.5.2. Correlation

Correlation helps explore relationships in data series, and thus discover interesting and useful patterns. Such information may facilitate the formulation of causal hypotheses, with the proviso that the systems in question are sufficiently familiar and — even better — understood (Perdicoulis, 2013).

The calculation and expression of correlation between data sets involves an elaborate study, both in the original fields — for instance, the natural or social sciences — and statistics. Correlation can be sought in scatter graphs or in statistical measurements such as the correlation coefficient ‘r’.

The idea of the correlation coefficient ‘r’ is simple and elegant, with values of ‘+1’ indicating a perfect positive (or direct) correlation, ‘−1’ a perfect negative (or inverse) correlation, and zero indicating no correlation at all. In practice, however, for many different reasons and purposes, there are many versions of ‘r’. Covariance, for instance, is a fairly common measure of correlation (Fowler et al., 1998, p.135):

$$Covar_{x,y} = \frac{\sum(x-\bar{x})(y-\bar{y})}{(n-1)} \quad (2.5)$$

Improving on this idea, the product moment correlation coefficient 'r' compensates the covariance for different units of measurement between the 'x' and 'y' variables (Fowler et al., 1998, p.135):

$$r = \frac{\frac{\sum(x-\bar{x})(y-\bar{y})}{(n-1)}}{s_x \times s_y} \quad (2.6)$$

Overall, the data analysis and search for patterns facilitated by correlation can be quite involving, insightful, useful, and even entertaining. However, the utility of correlation does not go as far as identifying causality, and most textbooks will acknowledge this (Hammond and McCullagh, 1978, p.219; Haynes, 1996, p.114; Fowler et al., 1998, p.130).

2.5.3. Causality

The idea of causality is utilized not only in economics, but in many different fields such as physics, philosophy, etc. In economic analysis, the aim is to find a relation between variables. On the other hand, when a correlation is found between two variables the immediate question which should be asked is *what is the reason for this correlation?* Or *is there a reason at all?* These questions led Granger (1969) to develop a new technique, which exploits the interrelationships between multiple time series in a dynamic system. In the literature this is known as *Granger's Causality*.

In this framework, Granger premised that the future cannot cause the present or the past. Thus, if event *A* occurs after event *B*, then *A* cannot cause *B*. At the same time, when *A* occurs before *B*, it does not necessarily mean that *A* causes *B*. This causal framework is not that which is logically assumed in real life, but it is related to observing time series. The statistical test is given by:

$$y_t = \sum_{i=1}^{k} a_i y_{t-i} + \sum_{i=1}^{k} b_i x_{t-i} + \varepsilon_t \quad (2.7)$$

where y_t and x_t are time series.

Then, series x_t fails to be the cause of series y_t in the sense of Granger's causality, if the regression estimates of $b_i = 0$, for all $i = 1,2 \ldots k$.

Thus Granger's approach to the question whether x_t causes y_t, is determined by examining how y_t is affected by its past values (y's) and by adding the past values of x's. It should also be mentioned that Granger's causality is more related to the word *precedence*, since all that is tested is whether a certain variable *precedes* another, and that it does not test a causality *as it is usually understood.*

Causal enquiry is naturally qualitative, as it attempts to describe 'how things are' in dynamic situations — i.e. those characterised by activity and change — or 'how things happen' in terms of cause-and-effect explanations (Perdicoulis, 2010, p.46). Drawing on information from observations and/or case descriptions, people use various heuristic techniques (e.g. precedence, proximity, 'sine qua non', causal mechanisms) to discover and/or verify causal relationships (Perdicoulis, 2010, pp.51–55).

Being of qualitative nature, causal hypotheses can be formulated immediately, without a need for long or heavy investment in data collection. Proceeding without quantitative data may appear 'non-scientific', but in fact it is perfectly acceptable: science is concerned with the methodical testing of hypotheses, leaving considerable liberty for their formulation (Perdicoulis, 2013d). So, technically it is possible to formulate causal hypotheses relatively quickly, at least to explain a phenomenon tentatively.

Causal enquiry is creative work, based on knowledge and understanding, and can be aided by (a) studying similar phenomena in different contexts, whose causal model is [thought to be] known, and (b) drawing on information provided by correlation, even though this cannot be always trusted — for instance, causality is known to remain undetected by data correlation in cases of time delays (Sterman, 2000, p.697).

2.5.4. Time Series Conclusions

While correlations tend to give information about 'what' is happening, 'how much' and 'where', understanding and knowledge do not come before the causes are determined — at least tentatively, as hypotheses or mere suspicions. However, when correlation substitutes or overrides causal reasoning, very odd claims can be supported — as John Sterman demonstrates in his famous and purposely exaggerated 'ice cream and murder' example (Sterman, 2000, pp.141–142).

There are two stages in explaining phenomena: (a) study measurements and establish correlations through deductive thinking; and (b) establish causality through study and inductive thinking. The two can be performed one after the other, in that order. The former option is less 'scientifically risky' than the latter, dealing mainly with numerical data and performing all kinds of statistical tests. The latter is more creative, difficult to prove, but far more interesting as an explanation — in fact, it is the only explanation: correlation is merely an exploration.

Granger's methodology (which is widely used in energy economics) has received strong criticism in literature (Lütkepohl, 1982; Karanfil, 2009) It has been demonstrated that theoretically, and in practice, it is difficult or impossible to draw conclusions concerning the relationship between a few economic variables solely on the basis of a time series model for these variables (Lütkepohl, 1982). The structure of the relation can only be derived by including all 'important' variables in the model. Consequently, since many economic variables are important in the sense that they interact, high dimensional time series model-building seems to be required.

It appears that in order to work safely with data and correlations, one must have an understanding of causality, or 'how things work' — i.e. at least a tentative explicit causal mental model of reality. The suggestions of correlation can 'prove' just about anything that can be demonstrated with numbers, if not checked for against the mental model of reality: 'does this make sense?' 'Is this relationship causal, as expected?' Once again, without proper understanding we may be informed but 'remain in the dark' (Perdicoulis, 2012a). Most likely this would not be satisfactory for anyone, even for statisticians.

Econometric analysis proves to be a useful method for forecasting potential policy simulations and considerations; it is concerned with building statistical models that link economic variables (Granger, 2004).

2.6. Conclusion

This section concludes chapter 2 and summarises the findings of the literature review. This section then shows how the first two objectives of this study were achieved.

Energy plays a vital role in economic and social development. As a result, many studies have endeavoured to establish the direction of causality between energy consumption and economic performance; however the evidence still remains controversial. Conclusions of these studies are varied, ranging from unidirectional or bidirectional to no directional causality. Kraft and Kraft's (1978) pioneering work on the USA energy-economy nexus over the period 1947 to 1974 provided the stimulus for several studies on the subject with some studies confirming and others contradicting Kraft and Kraft's conclusion.

One of the explanations for the contrasting and frequently differing empirical results on this relationship lies in the diversity of approach and testing procedures used in the investigation. Although Granger-causality is the most widely used definition, different methodologies have been employed, largely due to the development of new econometric and statistical techniques. For example Feng et al. (2009) used co-integration analysis for China, Asafu-Adjaye (2000) employed co-integration and error correction model for eleven Asian countries, while Metcalf (2008) utilised decomposition methodology for the USA. Considering the different approaches and the different sets of data and periods covered, no consensus has arisen with any clear direction for policy makers. As revealed above, conclusions in these studies have been varied and the empirical evidence on this issue seems to have diverged rather than converged.

The recommendations of previous studies were used as important guidance for this study. Karanfil (2009) highlights the repetitive methodologies used in the energy-economy field. He criticises the inconsistent and conflicting results in the existing literature on the subject of the energy-economy nexus, and provides recommendations for future studies in the energy-economy nexus as follows (Karanfil, 2009):

- The importance of keeping the policy maker and their interests in mind when performing a study in energy economics.
- The policy maker is neither concerned about the time period considered in the study nor the methodology employed by the researcher - he or she is only interested in the robustness and the consistency of the results.
- If energy economists would like to influence energy policies so that they may be designed in accordance with the policy implications of the findings, there should be a more coherent understanding of the energy-income nexus and find better ways to do so.

Karanfil's (2009) view is that future research may achieve this objective by focusing more on the new approaches and perspectives rather than by employing usual methods based on a set of common variables for different countries and different intervals of time.

2.6.1. Objective 1: Examine the approaches for correlation and causality analysis in an urban context

The need for rigour, objectivity and transparency in reaching conclusions from a body of scientific information is evident in many areas of policy and practice (Popay, 2006). Systematic reviews are the recognised standard for accessing, appraising and synthesising scientific information, and are particularly valuable where science can inform policy and decision-making (Popay, 2006). This objective followed a systematic review process in order to reveal and synthesize the best available evidence in order to inform policy makers.

This objective was met by the critical analysis of chapter 2. It was found that studies examining national energy-economy relationships did exist, however, very few studies had focussed on examining the *urban* energy-economy nexus. The literature review found that a range of approaches and methodologies had been used. Much criticism has been expressed towards the existing methodologies examining the energy-economy nexus. Section 2.5 reviewed the approaches used for correlation and causality analysis. The divergent results were alarming and largely due to a lack of sufficient data points to allow for statistical power. A second reason for the inconsistent results is the use of varying methodologies and test procedures employed by these studies. Revealing these inconsistencies in results proved to add importance to Objective 2 of this study – determining the most appropriate approach to analyse an urban energy-economy nexus is crucial in gaining accurate results.

2.6.2. Objective 2: Determine the appropriate approach for the correlation and causality analysis for cities

In order to investigate a city's relationship between energy consumption and economic performance, time-series data was analysed to find potential correlations and causalities. However, finding the most appropriate methodology to perform this analysis proved crucial to the accuracy of the results. Section 2.5 addressed this objective. A thorough review of the available literature was performed in order to find the most suitable methodology for an analysis of this kind.

It appears that in order to work safely with data and correlations, one must have a considerate understanding of causality, or 'how things work' — i.e. at least a tentative explicit causal mental model of reality. It was shown that the suggestions of correlation can 'prove' just about anything. It was therefore vital to have an understanding of the variables and how they interact before attempting to perform a correlation analysis.

Econometric analysis proved to be the most useful methodology to gain insight into the causal relationships of an urban energy system. Econometric analysis was shown to be useful in forecasting various policy simulations. Section 3.5 further documents the methodology followed to analyse the relationship between a city's energy consumption and its economic growth.

Chapter 3 Research Methodology

3.1. Introduction

This chapter offers insight into the methodologies used in the realisation the third objective. A mixture of qualitative and quantitative methods was used in this research study. This chapter formulates a robust and clear methodology to analyse whether a correlation and/or causality exists between selected cities' energy consumption and economic performance. The methodology is based upon using time series data to investigate potential correlations and causal relationships.

The first step of the research strategy, after reviewing the literature, was to select cities on which to perform an analysis. The second step was then to acquire data for the selected cities. The nature and sources of the data was an important consideration and is documented in this section. The process for obtaining the data and the way the data was treated to be useful for analysis is also documented here. The section ends by explaining how the data was analysed.

3.2. City Selection

The three cities that were selected for investigation are Cape Town (South Africa), Wellington (New Zealand) and Barcelona (Spain). Initially, the goal was to find economically comparable cities, to enable intercity learning. However, eventually, the cities were selected based on the availability of data for a statistical analysis, and the ease of communication with the city councils.

These three cities share a number of similarities, which make them highly comparable cities. They are port cities that have a service-orientated economy (Infometrics, 2016; Western Cape Government, 2016; Giampietro *et al.*, 2017). Although the cities had similar economic profiles, their energy consumption patterns were vastly different. This meant that the cities would be able to relate on an energy-policy level, since their economies required similar inputs. Thus these three cities were selected in order to allow for inter-city learning.

3.3. Source of Data

This study used annual and quarterly data on energy consumption and GDP between 1990 and 2015. The nature and sources of data used play central roles in determining the overall accuracy, authenticity and reliability of the findings (Bergman, 2008). The nature of data used was largely affected by the availability of data. The study thus focused on secondary data rather than primary data.

The data that was required was:

- Total Energy Consumption for each city. In order to compile the total energy consumption of a city, the various forms of consumption were required. These were found to be:
  - Electricity consumption
  - Liquid fuel consumption (petrol and diesel)
  - Aviation fuel
  - Liquid Petroleum Gas (LPG)
- GDP data for each city

The time frames if this data was also an important consideration. Since a correlation analysis was performed, the GDP data and the Energy consumption data needed to be of the same time intervals. Monthly data was the first preference, since it allowed for more data points. However, it was found that GDP data was very seldom available on a monthly basis. Therefore quarterly or annual data was used.

3.3.1. Cape Town Data

Cape Town's energy consumption data was sourced from the most recent State of Energy Report (City of Cape Town, 2015) as well as from South Africa's publicly available Department of Energy website. Cape Town's economic performance data was sourced from the City's Economic Research Unit.

The State of Energy Report provided energy data for the years in which it was published (2002, 2007 and 2012), but provided very little for the years in between. However, the State of Energy reports did prove very helpful in that the framework and methodology for the gathering of the data was in place.

For the case of Cape Town, the energy consumption consisted of two separate datasets that had to be combined in order to calculate the total energy consumption. The first dataset was the electricity consumption of the city, and the second the liquid fuel consumption of the city. There are a number of ways to report liquid fuel data, and each present unique advantages and disadvantages. These methodologies have been documented in section 2.4.4.

The most suitable methodology for this study was the Fuel Sales Method (WRI, C40 and ICLEI, 2014). This methodology simply assumes that the fuel purchased within the city is used within the city. The assumption is that the fuel taken out of the city and the fuel brought into the city roughly balance out. This methodology should be used with care, and is not suitable for all cases. An interesting exception to the Fuel Sales Method is when a city serves as a 'stopover' for international ships. The city would then sell large amounts of liquid fuel to the ships, and be held accountable for the consumption and emissions, but would not benefit economically from the ships since the ships carry cargo to another destination. Another consideration for the case of liquid fuels in Cape Town was the fuel used to generate electricity within the city boundaries. The City has limited generation capacity and its three power stations (Steenbras pumped storage facility and the Athlone and Roggebaai gas turbines) are used for load management, rather than being base-load generators (City of Cape Town, 2015). The electricity generated by the power plants is already accounted for in the electricity sales of the city, so in order to avoid double counting this fuel, it was necessary to subtract the liquid fuels used by these power stations.

The liquid fuel data provided by the Department of Energy was divided by Magisterial District (MD). In order to calculate the fuel sales within the municipality, a scaling methodology was used based on the proportion of an MD's area that fell within Cape Town Municipality. For example, if 50% of MD A fell within the municipality, then only 50% of the liquid fuel sales of MD A were assigned to the municipality. Table 3-1 shows the approximate proportions of the various MDs that fall within Cape Town Metro's municipal boundary. The proportions were calculated by Sustainable Energy Africa for the State of Energy Report (City of Cape Town, 2015). They used maps of the magisterial districts and maps of the municipality to find the overlapping areas and calculated the approximate proportions.

Table 3-1: Proportion of Magesterial Districts that fall within Cape Town Municipality

Municipality	Magisterial District	Approximate proportion of Magisterial District in Municipality
Cape Town Metro	Bellville	100%
Cape Town Metro	Cape Town	100%
Cape Town Metro	Goodwood	100%
Cape Town Metro	Kuils rivier	95%
Cape Town Metro	Malmesbury (south of 33°30' latitude)	50%
Cape Town Metro	Mitchell's Plain	100%
Cape Town Metro	Simon's Town	100%
Cape Town Metro	Somerset West	95%
Cape Town Metro	Strand	100%
Cape Town Metro	Wynberg	100%

Source: Personal communication with Sustainable Energy Africa

In terms of Cape Town's GDP, the annual data was easy to come by and freely available in the public domain. The quarterly GDP data was more challenging to find. Therefore, in order to obtain the quarterly GDP data, some extrapolation was required. Based on the annual data, Cape Town's contribution to the Western Cape's GDP was known for each year. Since the quarterly GDP of the Western Cape was known, the assumption was made that Cape Town's quarterly contribution to the Western Cape was constant throughout the year. Hence, Cape Town's quarterly GDP data was extracted from the provincial data.

3.3.2. Wellington Data

Wellington's energy consumption and economic performance was sourced from the Community Greenhouse Gas Inventory for Wellington City and the Greater Wellington Region 2000-2015 (AECOM, 2016). This report was aimed at reporting the emissions of the city, thus converting the emissions data to energy consumption data, which is required for the analysis here, was required. The emissions report for Wellington reports annual emissions data as well as emissions intensity of each energy source. It was then possible to divide the annual emissions by the emissions intensity and be left with the annual energy consumption. Table 3-2 shows the emission-intensity factors for each fuel type in Wellington for the year 2000.

Table 3-2: Emission-intensity factors for Wellington for the year 2000

Category	Fuel	Unit	2000
Coal	Bituminous	kt CO2/PJ	88.97
Coal	Lignite	kt CO2/PJ	94.03
Coal	Sub-Bituminous	kt CO2/PJ	91.64
Liquid Fuels	Aviation Gasoline	kt CO2/PJ	65.89
Liquid Fuels	Biodiesel	kt CO2/PJ	67.26
Liquid Fuels	Bioethanol	kt CO2/PJ	64.2
Liquid Fuels	Bitumen	kt CO2/PJ	76.97
Liquid Fuels	Bunker Fuel Oil	kt CO2/PJ	73.79
Liquid Fuels	Diesel	kt CO2/PJ	69.69
Liquid Fuels	Exported Naphtha	kt CO2/PJ	63.91
Liquid Fuels	Heavy Fuel Oil	kt CO2/PJ	73.4
Liquid Fuels	Jet Kerosene	kt CO2/PJ	68.43
Liquid Fuels	Light Fuel Oil	kt CO2/PJ	72.31
Liquid Fuels	LPG	kt CO2/PJ	60.43
Liquid Fuels	Premium Petrol	kt CO2/PJ	66.96
Liquid Fuels	Regular Petrol	kt CO2/PJ	66.26
Natural Gas	National Weighted Average	kt CO2/PJ	52.27

Source: Adapted from AECOM (2016)

Wellington’s GDP data was freely available and easily accessible in the public domain.

3.3.3. Barcelona Data

The vast majority of energy consumption data for Barcelona was acquired from the city’s Energy, Climate Change and Air Quality Plan Report (Ajuntament de Barecelona, 2011). This report provides an extensive review of Barcelona’s energy consumption patterns, and zooms into each sector’s consumption patterns. The downfall of this report is that it only provides data until the year 2008. Therefore, the data does not reveal how the city recovered from the global recession in 2008/2009. This public report also shared data on Barcelona’s economic performance, which was used in this study.

3.4. Data Input

In using secondary sources, the focus was on obtaining quantitative data required to develop an understanding of cities’ economies in order to reveal the factors stimulating energy consumption. Time-series data was required for a comparative analysis of energy consumption and economic growth across cities from a historical viewpoint. Secondly, data was required to perform a regression analysis of energy consumption and economic performance. Thirdly, data was required for the identification and analysis of hurdles which prevent the decoupling of economic growth from energy consumption. Granger causality tests formed the basis for the analytical framework of the study.

In order to perform the regression analysis and the Granger causality tests, time-series data was required. Furthermore, in order to make the data comparable, it was required that all the data be in the same units. Since the Joule is the only recognised SI unit to measure energy (United Nations Statistics Division, 2011), it was decided that all energy units be converted to Joules. Table 3-3 shows the energy conversion factors used to convert the energy data to Joules.

Table 3-3: Energy Conversion Factors

Energy Carrier	Energy	Unit	Density (kg/ ℓ)	MJ/kg
Aviation gas	33.9	MJ/ ℓ	0.73	46.4
Coal (general purpose)	24.3	MJ/kg		
Diesel	38.1	MJ/ ℓ	0.84	45.4
Electricity	3.6	MJ/kWh		
Heavy fuel oil	41.6	MJ/ ℓ	0.98	42.3
Jet Fuel	34.3	MJ/ ℓ	0.79	43.3
Liquid petroleum gas	26.7	MJ/ℓ	0.54	49.4
Natural gas	41	MJ/m3		
Paraffin illuminating	37	MJ/ ℓ	0.79	47
Petrol	34.2	MJ/ ℓ	0.72	47.3

Source: Adapted from Department of Energy (2013)

At times, using the log of the data was found to be appropriate. The log-returns are stationary and also second-order stationary (their variance does not increase over time), so they are ideal for investigation with time series regression.

3.5. Data Analysis

The secondary data was examined using regression analysis. Regression analysis, which is a form of inferential statistics, is a test of statistical significance which indicates how confidently one can infer unknown population parameters from the measured sample of that population. This is done by comparing the recorded and inferred values and accepting or rejecting the Null (H_0) or Alternative (H_1) hypothesis. The data collected through the course of this study was subjected to regression analysis and used to test the hypotheses using appropriate statistical tools of analyses.

The null and alternative hypotheses for the tests may be written as:

$H_0: \alpha = 0$

$H_1 : \alpha < 0$

In the analysis, the study utilised unit root panel data as explained by Levin, Lin & Chu (2002), who assumed that there is a common unit root process so that ρi is identical across cross-sections. The tests employed a null hypothesis of a unit root. Levin, Lin and Chu (2002) considered the following basic Augmented Dickey-Fuller specification:

$$\Delta y_{it} = \alpha y_{it-1} + \sum_{j-1}^{k} \beta_{ij} \Delta y_{it-j} + X_{it}\delta + \epsilon_{it} \qquad (3.1)$$

Under the null hypothesis, there exists a unit root, while under the alternative, no unit root exists.

For the lag condition of co-integration analysis, the lag order k was predicted using a model selection procedure based on the Schwarz (1981) information criterion. Once the order of integration was established for each variable, the second step was to investigate the co-integration properties of the data. The necessities for co-integration are that the variables are integrated in the same order and that their linear combination is stationary. In order to test for co- integration, the study utilised the residual-based test of Engle and Granger (1987). It is a two-step procedure involving:

- An ordinary least square estimation of a specified co-integrating regression to attain the residuals
- A unit root test of the residuals. The null hypothesis of non-co-integration is rejected if the unit root *statistics falls below certain critical values. The Engle-Granger (1987) co-integration test is based o*n an investigation of the residuals of a spurious regression accomplished using first-order ($I(1)$) variables. If the variables are co-integrated then the residuals should be stationary ($I(0)$). Conversely, if the variables are not co-integrated then the residuals will be $I(1)$.

The process that was followed to perform the statistical analysis can be seen in Figure 3-1. The first step in the process was to check the time series for stationarity using the Dickey-Fuller unit root test (Dickey and Fuller, 1981). Non-stationary time series were differenced for further analysis, while stationary time series are investigated through the use of a linear model. After which, the Durbin-Watson test was used to check whether the residuals were random, uncorrelated white noise (Watson and Durbin, 1950). Figure 3-1 shows the steps followed to generate an autoregressive–moving-average (ARMA) model.

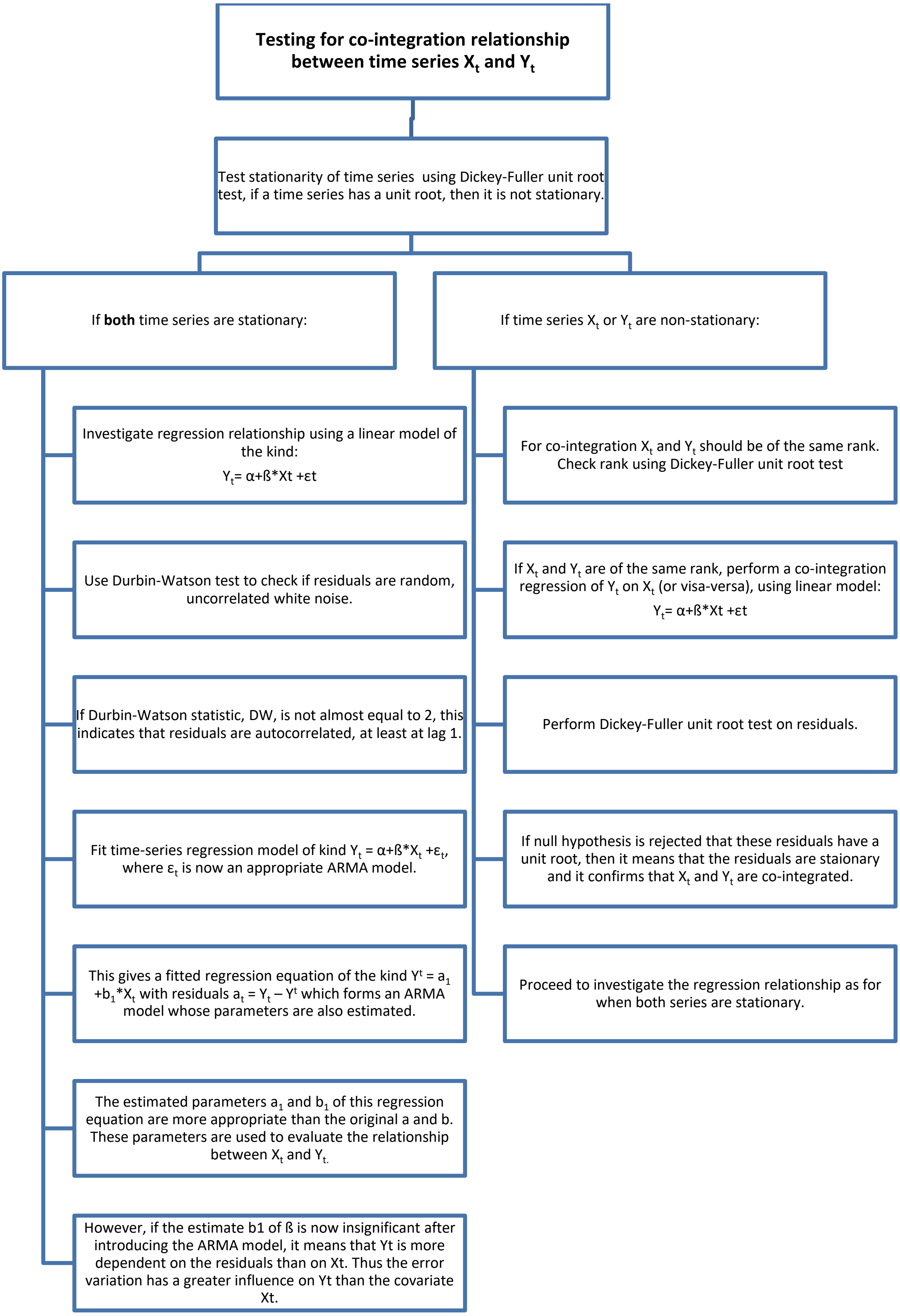

Figure 3-1: Flow diagram showing procedure followed to test correlation between two time series

Chapter 4 Results

4.1. Introduction

This chapter provides the results of the econometric analysis. The relationship between energy consumption and economic performance has been shown to be a crucial indicator in making a successful transition to a green economy. Firstly, each city's energy profile is reviewed in terms of supply and demand, carbon emissions, and price of energy. Each city's energy consumption and economic growth is then plotted on a simple line graph; these indicate general trends in the data. Thereafter, the results of each city's regression analysis is given.

4.2. Cape Town Results

The city of Cape Town faces vast and compelling challenges when it comes to energy (Sustainable Energy Africa, 2007). Almost all the energy consumed in the city comes from outside the city's boundaries or control. The main sources supplying to Cape Town are high in carbon emissions (City of Cape Town, 2015). In the light of climate change, this is not sustainable (Sustainable Energy Africa, 2007; Winkler, 2007). At the same time, Cape Town's economic growth is constrained by energy supply limits (Sustainable Energy Africa, 2007). This may explain why some key actors are seriously considering investing in renewable energy and energy efficiency (Sustainable Energy Africa, 2007; Fufore, 2012; City of Cape Town, 2015).

4.2.1. Cape Town Energy Profile

Cape Town consumed 158 685 055 GJ of energy in 2012, which translates to 21.3 megatons of CO_2 equivalent in greenhouse gas emissions (City of Cape Town, 2015). Cape Town has a comprehensive State of Energy Report (City of Cape Town, 2015) which shows a breakdown of energy generation by energy carrier and energy use by sector, shown in Figure 4-1. Transport needs are clearly the most energy intense aspects of Cape Town, consuming 64% of the city's energy. Addressing transportation energy is a large undertaking as it requires multiple socio-technological intervention points. By contrast, Government energy consumption, which was at 1% of total energy use in 2012, is possibly the easiest point of intervention as it is housed under a single administrative entity (Mahomed 2016). In this way, implementing energy efficiency programmes or renewable energy generation in civil structures may not have a significant impact on Cape Town's overall energy use, but stand as a strong symbol for what is possible for the city's energy system.

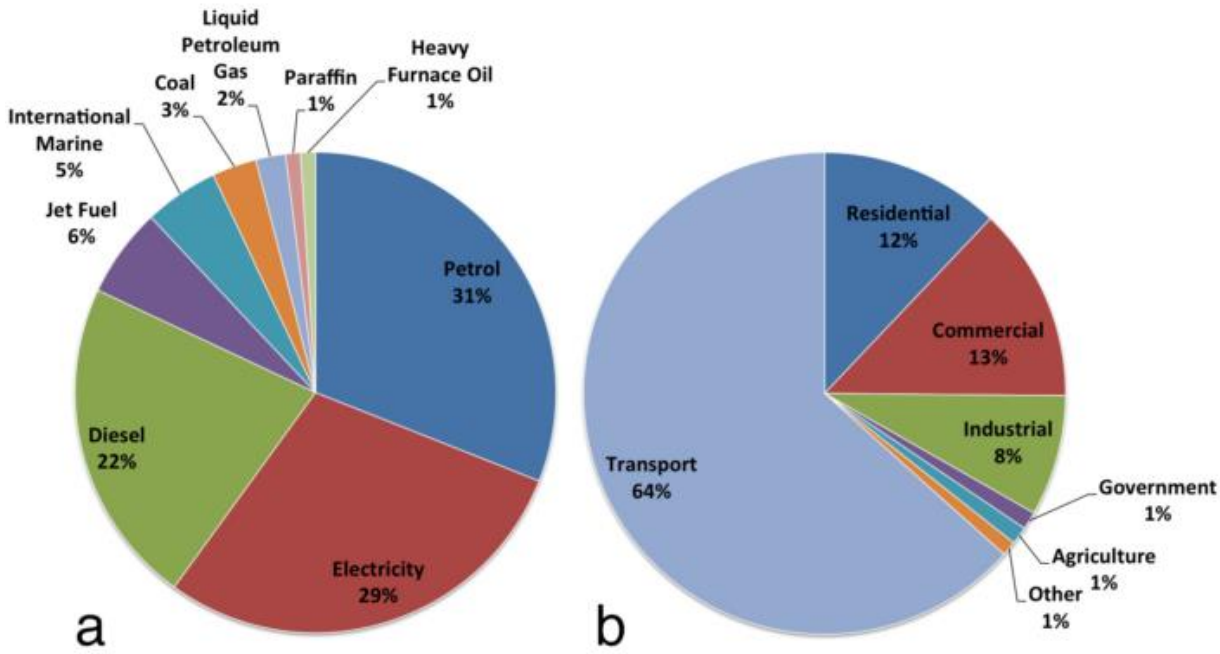

Figure 4-1: Energy consumption by energy source (a) and energy consumption by sector (b)

Source: Adapted from City of Cape Town (2015)

The largest energy carriers in Cape Town are petrol, electricity and diesel. The majority of petrol and diesel usage is tied to transportation, while electricity usage tied to industry, commerce and residential patterns of consumption (City of Cape Town 2015b). South Africans also tend to be most reliant on electricity to meet the majority of their domestic needs, such as lighting, cooking, and space and water heating (Stats SA 2011a). This has implications for resilience, should the electricity grid come under stress, as well as for sustainability, given that the vast majority of South Africa's electricity is coal-thermal generated.

4.2.1.1. Energy Supply

Cape Town's energy supply is dominated by electricity provided from the national grid, liquid fuels (mainly petrol and diesel, refined locally from imported crude oil), and a small amount of coal used by industry. Coal-fired electricity provides 85% of electricity fed into the grid, which means that the average carbon emissions attributed to electricity supplied to Cape Town are high – around 1 tonne of carbon dioxide (or equivalent) per MWh of electricity.

The primary energy supply of South Africa continues to be dominated by coal: More than 70% of primary energy, more than 90% of electricity and a third of liquid fuels are derived from coal. Due to this heavy reliance on coal, South Africa is the 15th-largest emitter of CO2 from combustion of fuel sources, despite a far lower ranking in terms of its weight in the global economy (City of Cape Town, 2015).

These coal-fired power stations are 2000 km from the city, which results in significant losses enroute. The 1800 MW Koeberg nuclear power station, just outside Cape Town is also part of the national mix. To supply peak demand and for emergencies, Cape Town uses two open cycle gas turbines (1327 MW and 171 MW) and a pumped-storage station (400 MW). Cape Town's electricity demand is 2 400 MW, 6% of a total installed national grid capacity of 40 000 MW (City of Cape Town, 2010).

There is considerable potential around Cape Town for wind, concentrating solar and solar photovoltaic electricity generation. These renewable energy technologies are made more attractive by the increasing costs of new coal plants, the decreasing cost of wind and solar, the likelihood of significant cost reductions in solar photovoltaic energy, and the need to decrease carbon emissions (City of Cape Town, 2010).

4.2.1.2. Energy Demand

Transport accounts for almost two thirds of energy consumption in Cape Town, while the residential, commercial and industrial sectors roughly share the other third of demand (City of Cape Town, 2010). Almost all transport energy is supplied by petrol (gasoline) (60%), diesel (39%) and aviation liquid fuels. Residential and commercial energy is supplied by electricity (at least 90%), and the industrial sector uses a diverse supply of energy sources. Although 95% of households are connected to grid electricity, paraffin is still used by poor households (including electrified households), and is associated with fires, poisoning and poor indoor air quality.

4.2.1.3. Carbon Emissions

Despite electricity only accounting for 29% of Cape Town's total energy consumption, electricity consumption accounts for 64% of carbon emissions. This reflects the high emissions of South Africa's electricity production. Most of this electricity consumption is attributable to the residential and commercial sectors (which jointly account for 83% of electricity consumption).

Cape Town's energy supply, consumption and carbon emissions profile differs significantly from the rest of South Africa's. Industry and mining account for 55% of energy consumption nationally, while, in Cape Town, industry accounts for only 14%. Nationally, residential and commercial demand account for only 13%, while, in Cape Town, these sectors account for 34%. This very different profile, combined with the tight supply situation, a large services sector and tourism industry, its pursuit of the reputation as a green city and its distance from coal mines and power generation, presents Cape Town with a different set of strategic challenges, such as the need to shrink the city's carbon footprint and to localise energy supplies.

4.2.1.4. Electricity Prices

Due to cheap coal, South African electricity prices have historically been among the lowest in the world, with little attention being paid to energy efficiency and conservation (City of Cape Town, 2010). In early 2008, South Africa experienced the first of a series of highly disruptive outages and load-shedding episodes that came at an enormous cost to the economy (Deloitte, 2017). The electricity supply crisis, prompted decision-makers to respond with greater urgency to the capacity shortage that had been threatening to emerge for some time, and Eskom was given the go-ahead to embark on a massive investment programme. However, in the 20 years since Eskom had last invested in base load capacity, real electricity tariffs had declined to such an extent that it became apparent that Eskom would not be able to finance the new build programme on the basis of its existing low tariffs and inadequate revenue. In the 5 years between 2008 and 2013, electricity prices more than doubled in real terms, rising by a cumulative 114%, as the national energy regulator (NERSA) granted Eskom tariff increases to help it raise debt for the new build (Deloitte, 2017). However, the sharp increases in real electricity tariffs over this period prompted a public outcry, and NERSA took a decision to limit the increase in real electricity tariff to ~2% per year for the 5-year period from 2013 to 2018.

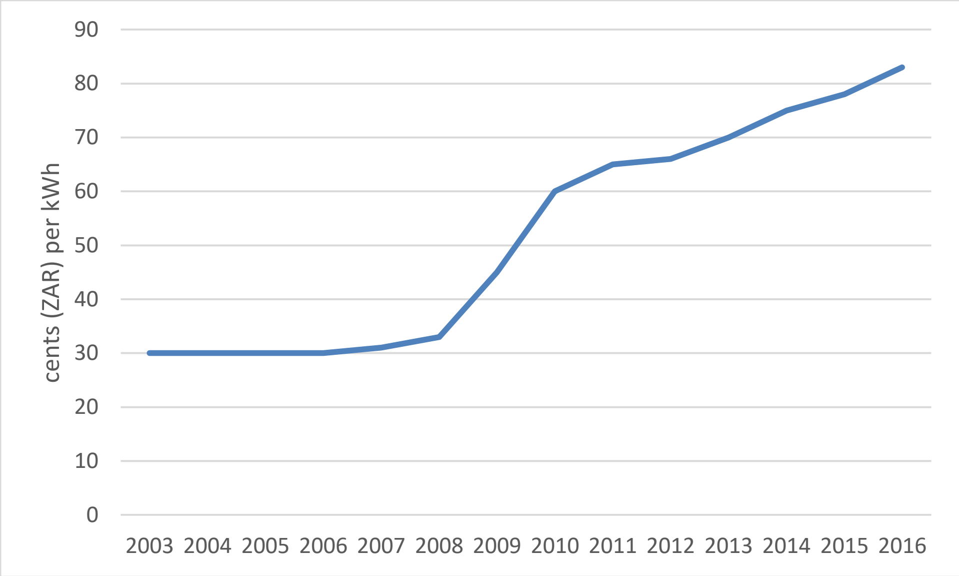

Figure 4-2: Average Real Electricity Price in South Africa (constant 2016 values)

Source: Cape Town State of Energy Report (City of Cape Town, 2015)

While a further increasing electricity price does have a negative impact on households and economic activities, it also offers an opportunity to explore local production of energy from renewable resources, and invest in energy efficiency rather than expand supply. These options are likely to lead to significant co-benefits, such as cheaper energy services, reduced environmental damage, local economic development and a more liveable and economically competitive city.

4.2.1.5. Liquid Fuel Prices

Liquid fuel prices increased dramatically between 2002 and 2008. The prices then dropped significantly in 2009, as can be seen in Figure 4-3. Since 2009, the prices of liquid fuels have steadily been increasing. The role of inflation has been removed by keeping the prices constant in 2005 monetary values. This large increase in liquid fuel prices has significant implications for Cape Town's road-based transport system, where average commuting distances are greater than 25 km (City of Cape Town, 2010).

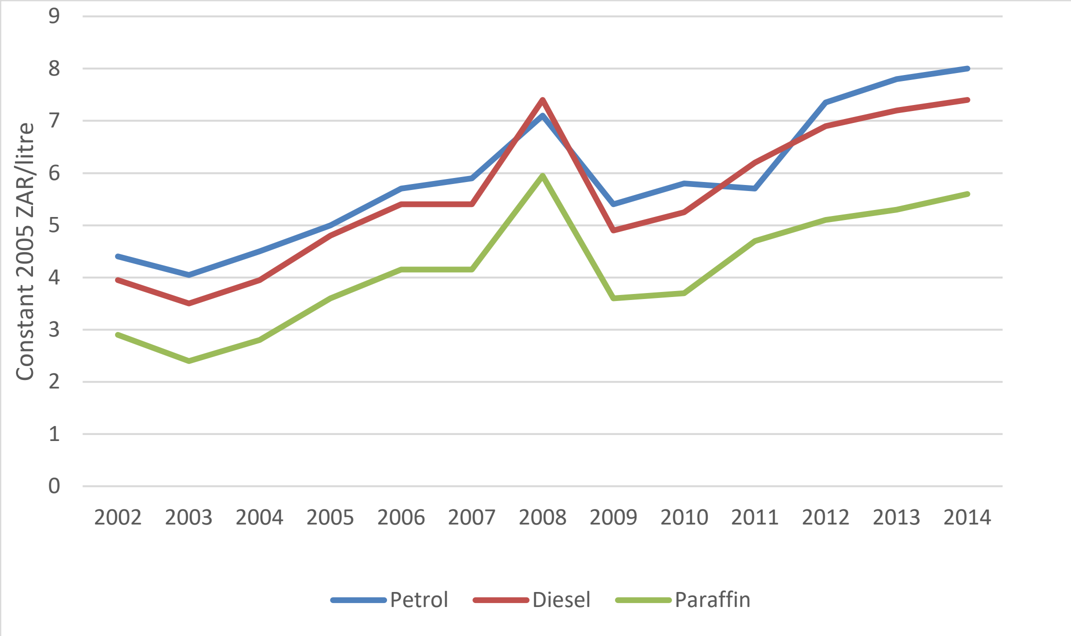

Figure 4-3: South Africa liquid fuel prices (ZAR constant 2005/litre), 2002-2014

Source: Cape Town State of Energy Report (City of Cape Town, 2015)

The likelihood of greenhouse gas emission constraints playing a role in the medium- and long-term future of South Africa's economy can no longer be ignored. The country is both emissions- and energy-intensive, and mitigation presents South Africa with a fundamental economic challenge that will require a well-planned, long-term and co-ordinated response.

4.2.2. Cape Town Energy-Economy Nexus

Figure 4-4 shows Cape Town's annual total energy consumption plotted against the city's GDP for the period of 2006-2015. The most obvious thing one notices is how large the reduction in energy consumption was between 2007 and 2010. An associated decline in GDP took place between 2008 and 2009. Although this decline in GDP growth between 2008 and 2009 appears to be small on this figure, it is a significant amount of money; in the order of 3 billion Rand in 2009. Further along the timeline, the total energy consumption of the city then reduces notably again between 2011 and 2014.

From Figure 4-4 it can be seen that the reduction in total energy consumption preceded the decline in GDP of late 2008 and into 2009. Cape Town's reduction in energy consumption occurred from the end of 2007. This trend shows the potential involvement of energy prices in the great recession of 2008/2009. Looking back at Figure 4-2 and Figure 4-3 which show the various prices of energy in Cape Town, the influence of energy prices on overall energy consumption can be seen. It can be seen that there occurred above 30% increases in electricity prices in both 2008 and 2009. The year 2008 is also when the price of liquid fuels peaked. Furthermore, early 2008 is when Eskom implemented its load-shedding program to deal with the supply crisis they were experiencing – this too had negative effects on the economy (Deloitte, 2017).

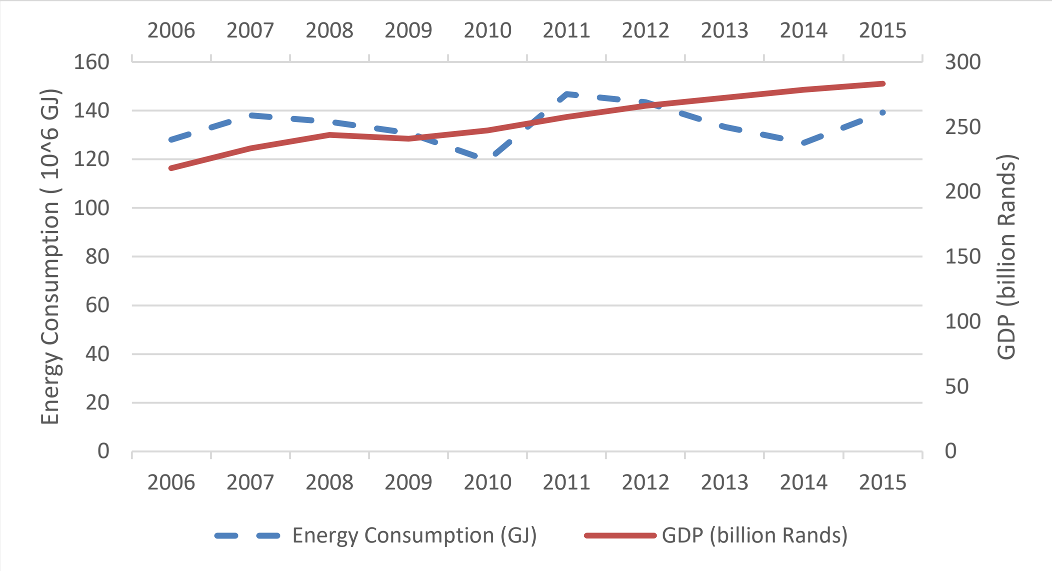

Figure 4-4: Cape Town Annual Total Energy vs GDP

There exists a theory that attempts to explain the Global Recession of 2008/2009. It states that the increasing prices of oil leading up to 2008 (caused by booming demand and stagnant production) placed the financial pressure on the economy which *caused* the recession (James D. Hamilton, 2009; Heun and de Wit, 2012). In looking at Figure 4-4, it can be seen that the reduction in energy consumption preceded the economic downturn, which eludes to the effect of energy on the economy. The similarities between precedence and causality are so compelling that Granger's well-known theory of causality is based on searching for precedence (Granger, 2004).

Conversely, the reduction of energy consumption in the period 2011-2014 has had little effect on the economy. Bashmakov's (2007) proposal that a correlation exists only when the energy cost threshold of an economy is exceeded may play a role in the lack of correlation of this period. Since there was a large reduction in energy prices after the 2008/2009 period (see Figure 4-2 and Figure 4-3) the energy cost share may have decreased below the threshold, eliminating a correlation.

Alternatively, the reduction in energy consumption may also be due to the increasing efficiency of machines, heating systems, and lighting. This coupled with society's increasing awareness of sustainability concerns, and the effects of energy consumption on the environment, may have played a part in reducing energy consumption over the 2011-2014 period.

The drastic rise in energy consumption in 2011 is startling. Looking at the detailed data, it shows that this increase in consumption is primarily due to an increase in petrol and diesel consumption. Petrol consumption increased by 31% from 2010 to 2011, while diesel consumption increased by 51%.

Quarterly data, which provides a more detailed view of trends than annual data, is not as well recorded as annual data. Hence Figure 4-5 shows only 2010-2015 quarterly changes on both GDP and total energy consumption. It is important to note the two different axes for each metric. The change in energy scale is an order of magnitude larger than the change in GDP axis.

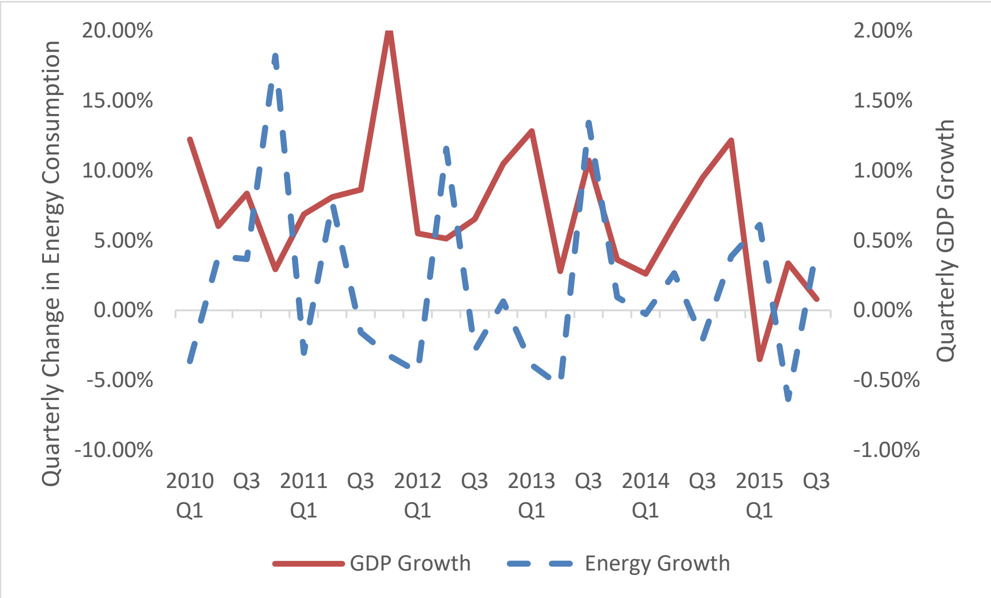

Figure 4-5: Cape Town Quarterly GDP Growth vs Change in Total Energy Consumption

A more comprehensive data set that was available is that of electricity consumption within the City of Cape Town. Figure 4-6 shows quarterly GDP growth plotted against electricity consumption. Electricity consumption accounted for almost a third of Cape Town's total energy consumption in 2012, so it does give good insight into the overall energy picture of Cape Town. The undulating nature of the electricity consumption line is due to the seasonal demands for electricity.

Figure 4-6 paints a positive picture for Cape Town for the period of 2007 onwards. Electricity growth first levelled and has since declined, whereas economic growth has continued to grow. The decline in electricity consumption in Cape Town from 2007 is led by decreasing demand in the residential sector in particular. During this period, there were steep price increases, an economic downturn, active electricity-saving campaigning by both the City and Eskom, and a roll-out of prepaid electricity meters across the city (City of Cape Town, 2015). Electricity demand from commerce and industry, although not showing absolute decline, does also flatten out during this period. The growth in Cape Town's financial and service sectors may also be a contributing factor. These sectors are not only less energy-intensive, but may well have a more elastic demand in relation to price changes.

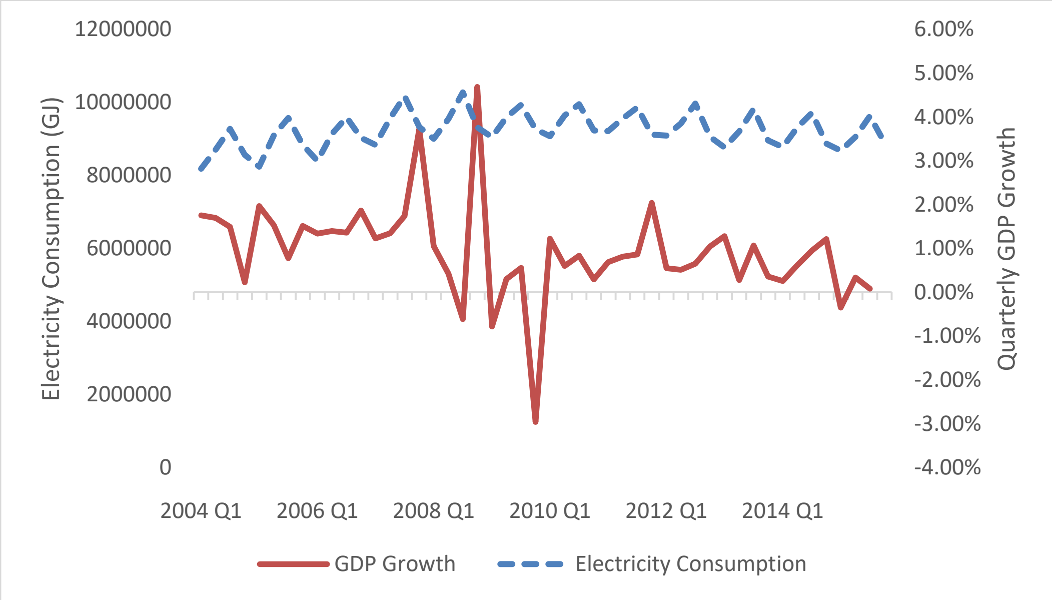

Figure 4-6: Cape Town Quarterly GDP Growth vs Electricity Consumption

The usefulness of evaluating the energy cost share of an economy was explained in chapter 2. It was explained how thresholds may exists for an economy's ECS, above which recessionary pressures cause a reduction in demand for energy, thereby forcing the price of energy down. It was argued that when the ECS exceeds the energy affordability threshold, economic growth becomes highly dependent on fuel expenditure. Figure 4-7 shows Cape Town's ECS between 2006 and 2015. It can be seen that the ECS has risen slightly over the decade to a value of around 10%. This can be interpreted as Cape Town spending 10% of total GDP on energy.

The ECS of Cape Town dropped by one percent between 2008 and 2009, at the time of the recession. This correlates with the reduction in total energy consumption in the same period, as can be seen in Figure 4-4. Since the GDP of Cape Town has continued to grow throughout the ECS reporting period, the conclusion can be made that the energy affordability threshold of Cape Town has not been exceeded in this period.

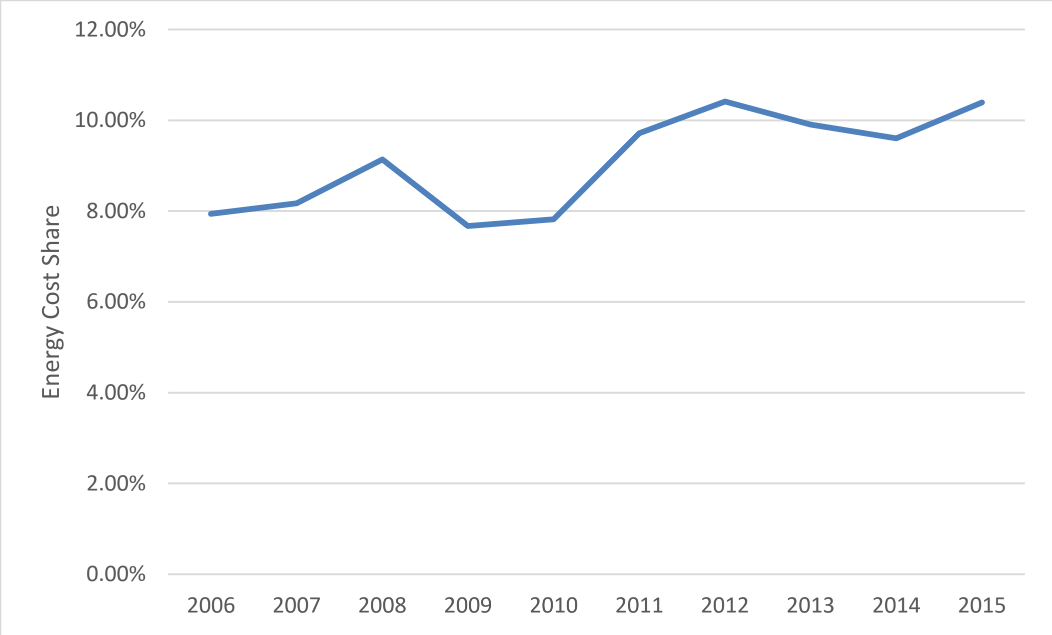

Figure 4-7: Cape Town Energy Cost Share

The data indicates that Cape Town's economy has become more energy efficient. The concept of energy intensity was explained in section 2.3.3. It was defined as the energy used per unit of GDP. Figure 4-8 shows a plot of Cape Town's energy intensity for the period 2004-2015. The figure shows that Cape Town has reduced its amount of energy used per Rand of GDP by 17% between 2004 and 2015.

The lower the energy intensity, the more resistant the economy is to price increases and shocks within the sector. Furthermore, during times of constrained supply, greater energy efficiency in the economy can act as 'freeing-up' of energy (liquid fuel or electricity) needed elsewhere in the economy (City of Cape Town, 2015).

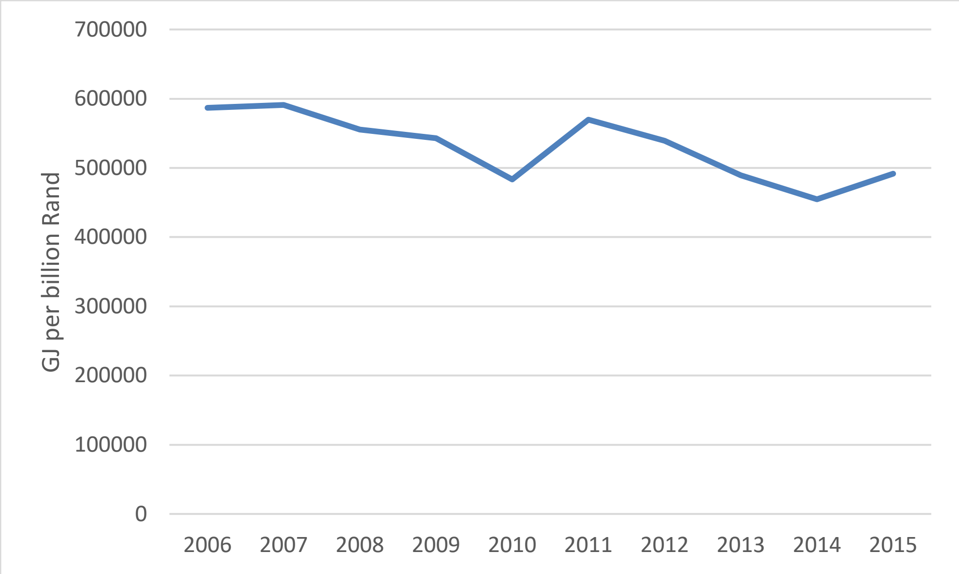

Figure 4-8: Energy Intensity of Cape Town

Figure 4-4 through Figure 4-8 show plots of Cape Town's energy consumption and economic performance over time. Much can be learned by deconstructing these figures, however, the question remains: Are these metrics correlated? Will a conservation of energy cause a downturn in economic growth? These questions are further investigated in the following section where a statistical analysis is performed on the data.

4.2.3. Statistical Analysis

Cape Town's energy-economy nexus was analysed using EViews (Econometric Views) software and Statistica software. These analyses were performed with the assistance of the Centre for Statistical Consultation at Stellenbosch University. The main outcomes of the statistical analysis are summarised here, while the full results of the statistical analysis can be found in Appendix A.

The process followed to test for co-integration relationships between the data can be found in Figure 3-1. However, no statistically significant correlations were found between Cape Town's energy consumption and economic growth. The relatively small dataset (10 years) along with the presence of decoupling meant that no correlations were found between energy consumption and economic performance.

There are two main occurrences during the period of analysis. The first notable occurrence occurred between 2007 and 2009 when energy consumption was reduced. This reduction was accompanied by an economic downturn, and a reduction in a reduction in GDP, in 2008 and 2009. Therefore, this period would lead researchers to view the reduction in energy consumption as possibly causing the reduction in economic growth. The second noteworthy occurrence is the phase of decoupling between 2011 and 2014, where energy consumption was reduced significantly while the GDP continued to grow. These two occurrences are opposite in their direction of causality, and thus a single causality could not be identified through the statistical analysis. Section 5.3 provides recommendations for how this changing direction of causality should be analysed.

4.2.4. Cape Town Conclusions

Cape Town's electricity consumption has decreased continuously since 2007. This reduction was led by the residential sector. The residential sector was exposed to steep price increases, an economic downturn, active electricity-saving campaigning by both the City and Eskom, and a roll-out of prepaid electricity meters across the city. Electricity demand from commercial and industrial sectors also flattened out since 2007, which seems to be a result of the growth of the financial and services sector of Cape Town, which are less energy-intensive than other sectors.

Cape Town’s biggest challenge is its high energy consumption in the transport sector. Road congestions have risen significantly over the last 10 years, with Cape Town being South Africa’s most congested city (TomTom Traffic Index, 2017). Cape Town has low densities compared to other cities across all global regions (City of Cape Town, 2015). This makes public transport development enormously challenging. At the same time, the majority of Cape Town residents (58%) rely on public transport. Experts note that it is very difficult to get commuters out of private vehicles and back into public transport once the modal switch has been made. This means it is extremely important for the City of Cape Town to upgrade and enhance public transport in the city, thus retaining current public transport users.

4.3. Wellington Results

The following section provides results of the analysis of Wellington, New Zealand. An important distinction to make is that between Wellington City and Wellington Region. Wellington City accounts for 41% of the region’s population, while it accounts for 60% of the regions employment (Wellington City Council, 2016). This difference indicates the high number of people that live outside the city boundaries and commute into the city on a daily basis. In 2015, Wellington City accounted for 65% of the region’s GDP while it produced 32% of the region’s GHG emissions (AECOM, 2016; BERL, 2016). Some of the data that was required to perform the required analysis was only available at a regional level, and therefore this was an important consideration while analysing the energy-economy relationship of Wellington.

4.3.1. Wellington Energy Profile

In 2017 the population of Wellington city was 212,700 (Infometrics, 2018). It is the administrative and judicial capital of New Zealand. Most of the energy consumed in the city comes from outside the city's boundaries or control, besides for the two wind farms on the outskirts of the city (AECOM, 2016). New Zealand's renewable energy resources are amongst the best in the world. In 2015, more than 80 per cent of New Zealand's electricity was generated by hydro, geothermal or wind resources (MBIE, 2017a). New Zealand has significant bioenergy, solar and marine energy potential. In this respect New Zealand is well ahead of other countries. However the electricity system only represents about 25% of consumer energy demand, and 6% of gross emissions (MBIE, 2017b). The majority of the other energy is sourced from fossil fuels such as oil, coal and gas, which is why the gains to be made lie beyond electricity generation (MBIE, 2017b).

4.3.1.1. Energy Supply

In 2015, Wellington consumed 17 869 736 GJ of energy. In the same year, New Zealand sourced 40% of its total energy from renewable resources. This is the fourth highest renewable primary energy supply in the OECD after Iceland, Norway and Sweden (MBIE, 2017a). Most of this renewable energy is used to produce electricity - the rest is mainly wood fuel used to produce heat for industrial processes and home heating. Hydro and geothermal energy are the largest contributors to renewable energy supply. New Zealand has coal- and gas-fired electricity generation plants that act as a backup for periods when renewable generation is low. In wetter years, where hydro generation is high, the coal- and gas-fired plants generation decreases significantly. Retirement of thermal plants in the last decade as well as the growth of geothermal and wind generation has seen generation from thermal sources fall to historical lows (MBIE, 2017a). With a continued investment in renewable energy generation, New Zealand's electricity renewable percentage has been trending up over time.

4.3.1.2. Energy Demand

Transport accounts for around 36% of New Zealand's energy use and 17% of New Zealand's gross emissions. New Zealand's transport system relies almost entirely on fossil fuels to power cars, trucks, aircraft, rail networks and ships. Ninety per cent of transport energy is used in road transport.

Process heat makes up one-third of New Zealand's overall energy use and contributes 9% of gross emissions. Most of the process heat is supplied using fossil fuels, mainly coal and gas. The large contribution of process heat is due to New Zealand's large meat and dairy industry, which use the heat to sterilise equipment, as well as New Zealand's colder climate, which leads to heating being required in most buildings.

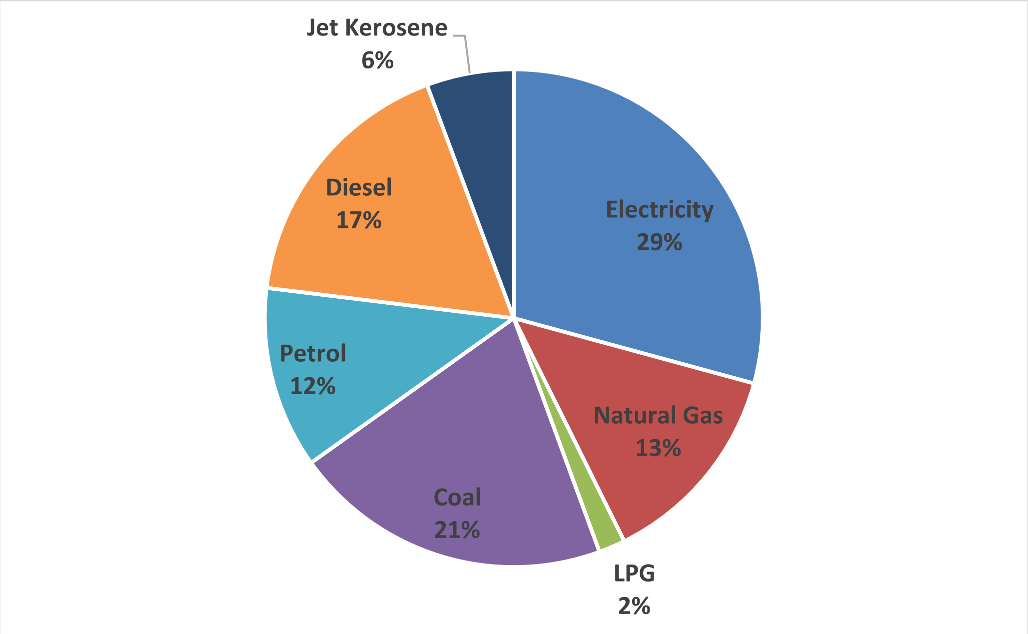

Figure 4-9: Wellington Energy Consumption by Fuel Source

Source: Adapted from AECOM (2016)

4.3.1.3. Carbon Emissions

Figure 4-10 demonstrates the contribution of individual emission sources to total city gross emissions. Liquid fuels dominate the city's emissions, and are the source of a combined 64% of Wellington's GHG emissions. Electricity, which is largely renewable, accounts for 15% of the city's emissions. Natural gas, which contributes 11%, is a noteworthy source of GHG emissions. Industry gasses and solid waste disposal account for the final 10% of the city's GHG emissions.

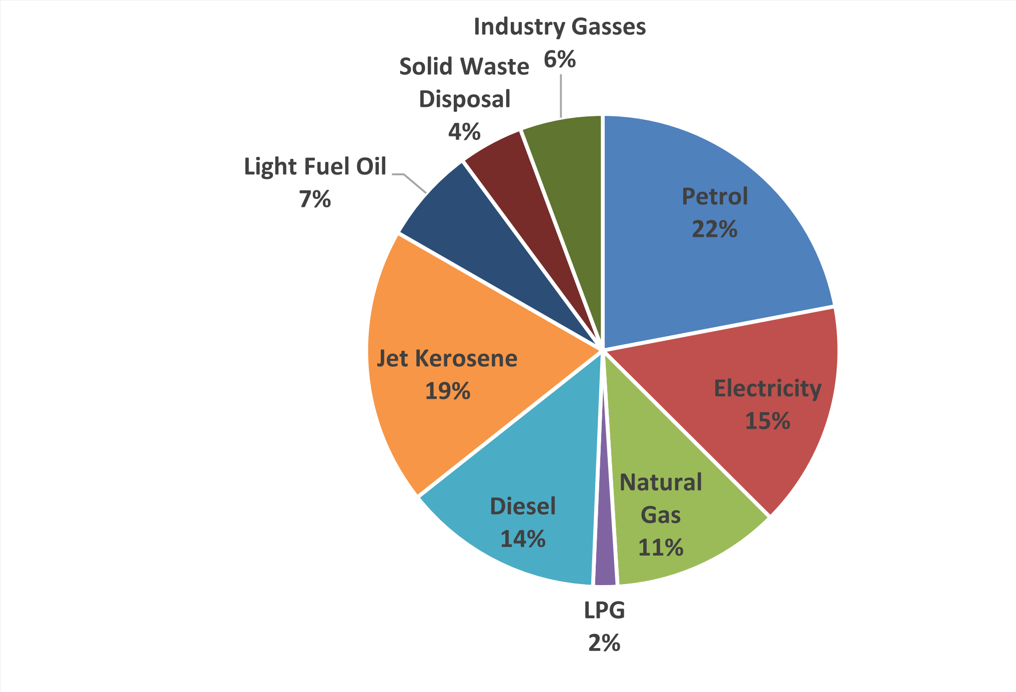

Figure 4-10: Wellington City GHG Emissions by Source

Source: Adapted from AECOM (2016)

4.3.1.4. Electricity Prices

Wellington city is supplied with electricity from the national grid, and the price of electricity is thus beyond the control of the city. As can be seen from Figure 4-11, the electricity prices have constantly risen between 2004 and 2015 at somewhere between 1-4% annually. In 2016 the price of electricity dropped by 2%. Since more than 80% of New Zealand's electricity is generated by renewable sources, the price of electricity can be volatile. In a year with low rainfall and low wind, where associated hydro and wind generation would be low, electricity prices may be driven up.

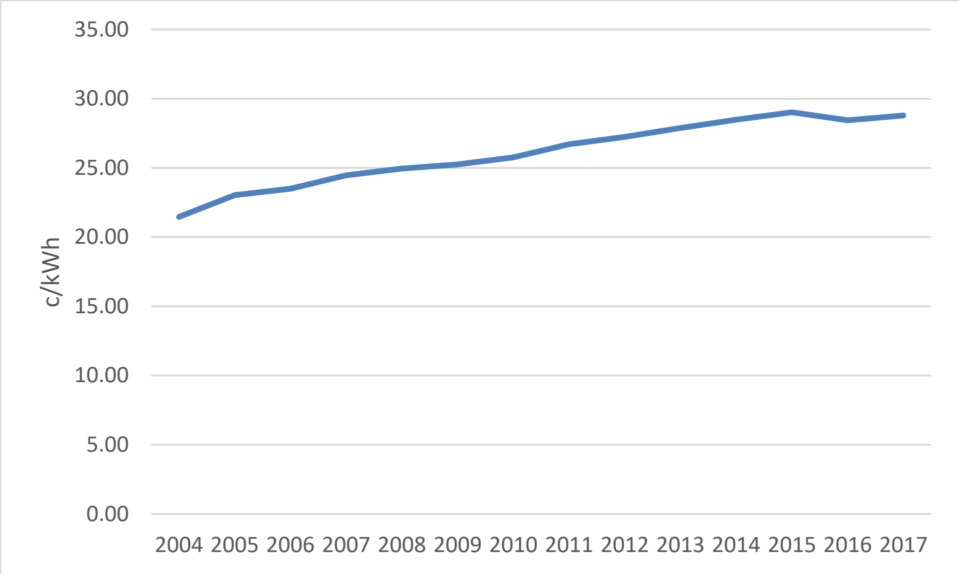

Figure 4-11: New Zealand Electricity Prices (Constant March 2017 monetary values)

4.3.1.5. Liquid Fuel Prices

Figure 4-12 shows the last 14 years of liquid fuel prices in New Zealand. It can be seen that the prices started rising from 1998, until the prices decreased significantly in 2009, again at the time of the global recession. Thereafter, the prices rose again, but have started decreasing sharply since about 2011. New Zealand has some of the cheapest liquid fuel prices in the western world (MBIE, 2017a).

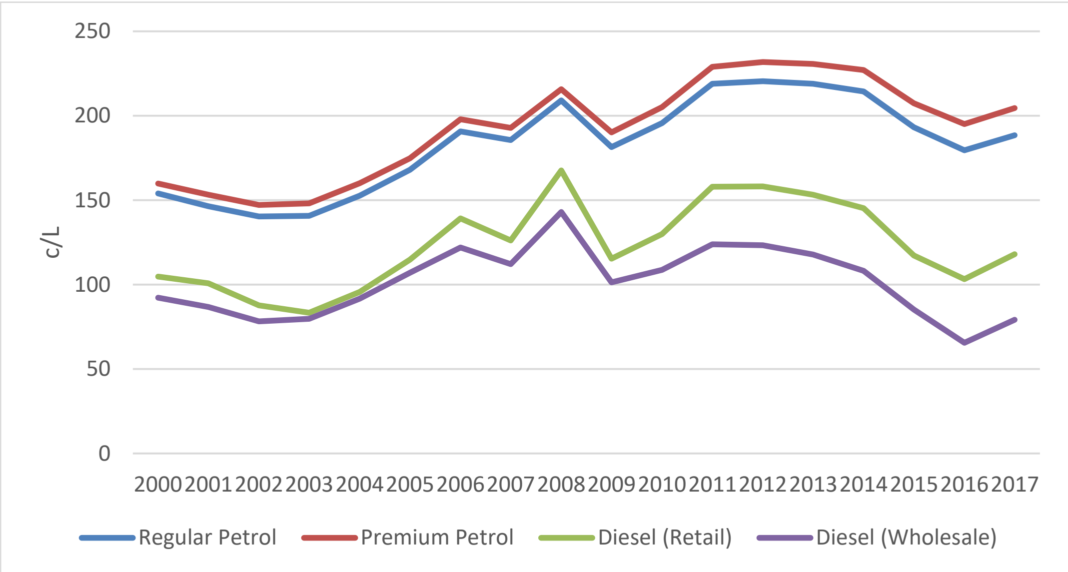

Figure 4-12: New Zealand Historical Petrol and Diesel Prices

4.3.2. Wellington Energy-Economy Nexus

This section interprets the relationship between energy consumption and economic growth in Wellington. Figure 4-13 shows Wellington city's total energy consumption plotted against the GDP of the city. The energy consumption rose continually until 2004, where the consumption began to plateau. The energy consumption of the city then began to decrease steadily from 2008 through 2014. Through this same period, the GDP of the city rose constantly, indicating absolute decoupling. This decrease in consumption was a result of the efficiency improvements, weather variations and the economic growth of the commercial sector, which is far less energy intensive than other sectors (MBIE, 2017b).

The greatest contribution to the reduction in consumption came from electricity and petrol consumption. Electricity consumption in 2012 was 3.5% less than in 2011, while petrol consumption was down 2.5% in the period. Although their absolute contribution was less significant, noteworthy reductions came from Av Gas, natural gas and coal which were down 17.7%, 10.6% and 6.4% in 2012 respectively. Diesel consumption and jet kerosene consumption rose slightly towards the end of the reporting period. However, the overall energy consumption reduction is greatly positive for the city.

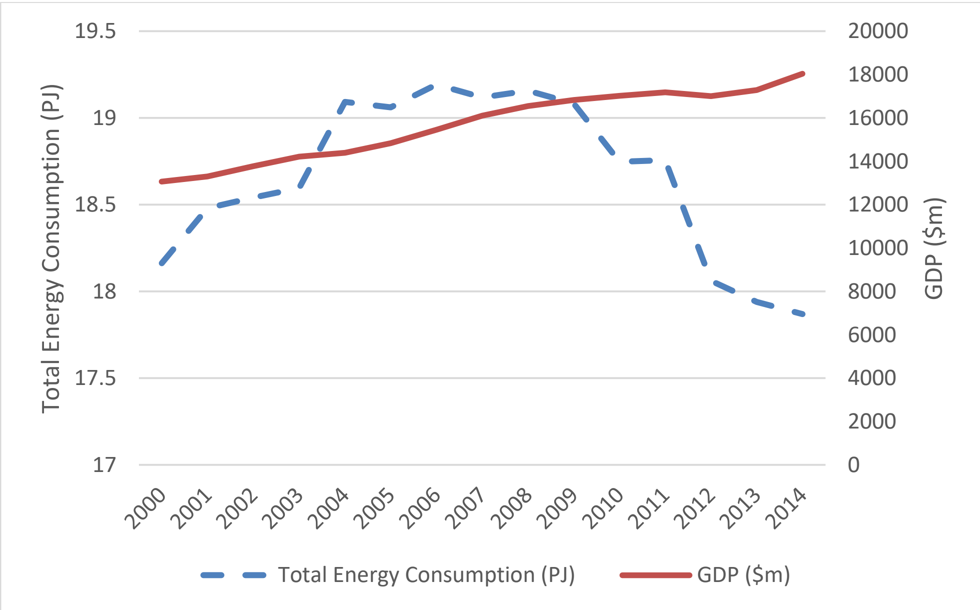

Figure 4-13: Wellingon City Total Energy Consumption vs GDP

Narrowing the focus, Figure 4-14 shows Wellington city’s electricity consumption plotted against the city’s GDP. The figure shows that the city’s electricity consumption increased until 2009 where it started to decline. Since 2011, the city has drastically reduced its electricity consumption. Throughout the time period of the figure, 2000-2014, the GDP of the city continues to rise and it seems unaffected by the changes in electricity consumption. This decrease in electricity consumption can be attributed to a number of factors, of which, the growth of the city’s commercial sector, and the increasing energy efficiency, are two major ones.

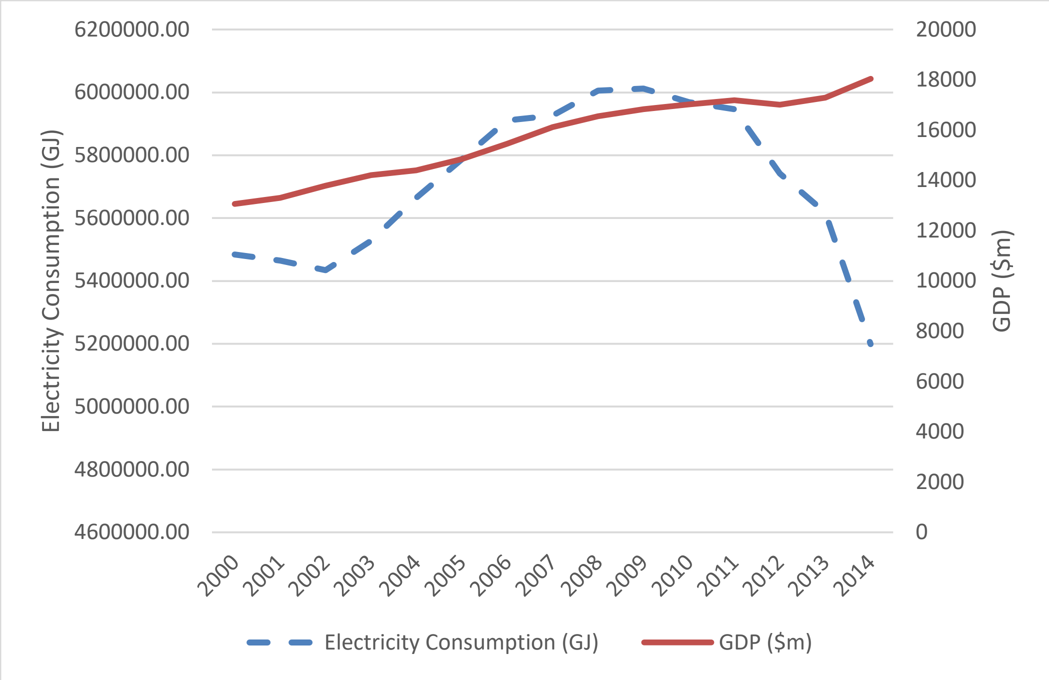

Figure 4-14: Wellington City Electricity Consumption vs GDP

In terms of what proportion of income is spent on energy, Figure 4-15 looks at Wellington's ECS. The spike in ECS during the 2008 recession can be seen. There has been a steady reduction in Wellington's ECS since 2011. As explained in the literature review, a high ECS can have detrimental effects to an economy. This downward trend is therefore a positive indicator for the city.

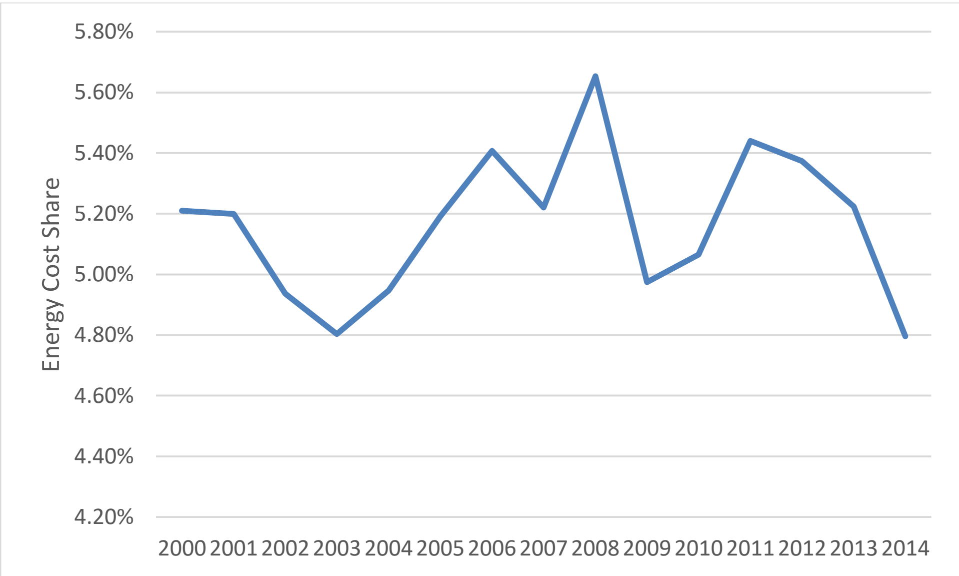

Figure 4-15: Wellington City Energy Cost Share

Wellington's energy intensity has been steadily decreasing over the last 15 years, as can be seen from Figure 4-16. The city reduced its energy consumption per dollar GDP by almost 30% between the years 2000 and 2014. However, New Zealand still has a national energy intensity that is 20%

higher than the OECD average, and is the 7th highest in the OECD (MBIE, 2017a). Therefore, the downward trend will need to continue if New Zealand is going to reduce its national energy intensity to that of its peers.

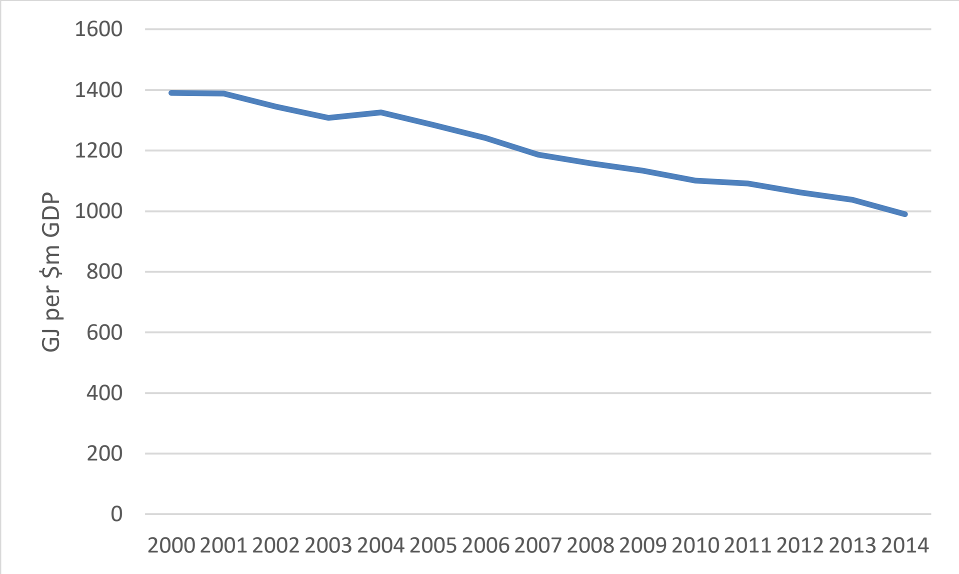

Figure 4-16: Wellington City Energy Intensity

The regression analysis allows for a statistical investigation of the dynamics between energy and economy. The following sections provides the results of the regression analysis on Wellington city's energy-economy nexus.

4.3.3. Statistical Analysis

Wellington's energy-economy nexus was analysed using EViews (Econometric Views) software and Statistica software. These analyses were performed with the assistance of the Centre for Statistical Consultation at Stellenbosch University. The main outcomes of the statistical analysis are summarised here, while the full results of the statistical analysis can be found in Appendix A.

The Spearman's rank order correlation test was used to test for correlations between Wellington's energy consumption and GDP and Wellington's electricity consumption and GDP. When looking at the period 2000-2014, no statistically significant correlations were found between Wellington's energy consumption and economic performance. This is due to a significant period of decoupling started in 2008. This decoupling has meant that Wellington's energy consumption has decreased while the GDP has continued to rise. For the period leading up to 2008, the energy consumption and economic performance grew hand-in-hand and this may have lead policy makers to believe there is a causality between energy consumption and economic growth. However this premise has been disproven since 2008.

4.3.4. Wellington Conclusions

New Zealand's Emission Trading Scheme (ETS) was introduced in 2008, which correlates with the start of the period of reduction in consumption for Wellington. The ETS, along with a strong environmental campaign by the Fifth Labour Government (1999-2008), led to an environmental awareness among much of Wellington's population. This caused an increased adoption of energy efficient technologies. The city has also seen a strong push for public transport, coupled with no significant investment in road infrastructure, which incentivised the modal switch from private cars to public transport. Furthermore, the city's tertiary sector, which has a lower energy intensity than other sectors, has also seen growth.

Much of the energy consumed within the Wellington region is outside of the direct control of councils, particularly in terms of activity levels. However, city councils can influence consumption in a number of ways. For example, infrastructure decisions have a significant impact on consumption patterns. Road transport represents an area where local and regional councils can influence the consumption profile, with electric road transport gaining interest nationally and internationally, including electric passenger vehicles and electrified public transport. Given New Zealand’s largely renewable electricity generation this represents a unique emissions reduction opportunity. A focus on electric bicycle infrastructure may also represent an opportunity to shift passenger transport away from fossil fuel based private motor vehicle travel.

Electric vehicles, and other technologies, such as solar panels and battery storage, provide new opportunities to make use of renewable resources. This priority area also reflects the potential to make more of New Zealand’s renewable electricity advantage through opportunities for greater electrification of sectors that have, to date, relied on fossil fuels (e.g. from internal combustion engines to electric vehicles in the transport sector and substituting coal and gas use for electric technologies in the manufacturing sector). The Government’s Electric Vehicles Programme and the new process heat action plan are planned to explore this potential.

4.4. Barcelona Results

Barcelona is Spain’s second most populous city, in 2011 the city was home to 1.6 million inhabitants (Ajuntament de Barecelona, 2011). The greater Barcelona urban area has a population of over 6 million, making it the sixth most populous urban area in the European Union (EU). Barcelona is a transport hub, with the Port of Barcelona being one of Europe's principal seaports and busiest European passenger port (Statistics Service, 2014), an international airport, Barcelona–El Prat Airport, which handles over 40 million passengers per year (Port Authority Aviation Department, 2012), and an extensive railway network.

4.4.1. Barcelona Energy Profile

In 2008, Barcelona consumed 17,001.78 GWh of final energy (Ajuntament de Barecelona, 2011). This figure can be divided almost equally between the services sector, with 29.9%, the residential sector, with 27.9% and the transport sector with 24.1%. 17.2% of the remainder was consumed by the industrial sector and 0.8%, other sectors (primary, energy, construction and public works).

By energy source, 44.5% of consumption was electricity, 31.8% natural gas, and the remainder diesel (15.4%), petrol (7.0%) and liquefied petroleum gases or LPG (1.4%). Barcelona's energy consumption represented 1.38% of all the energy consumption of Spain in 2008.

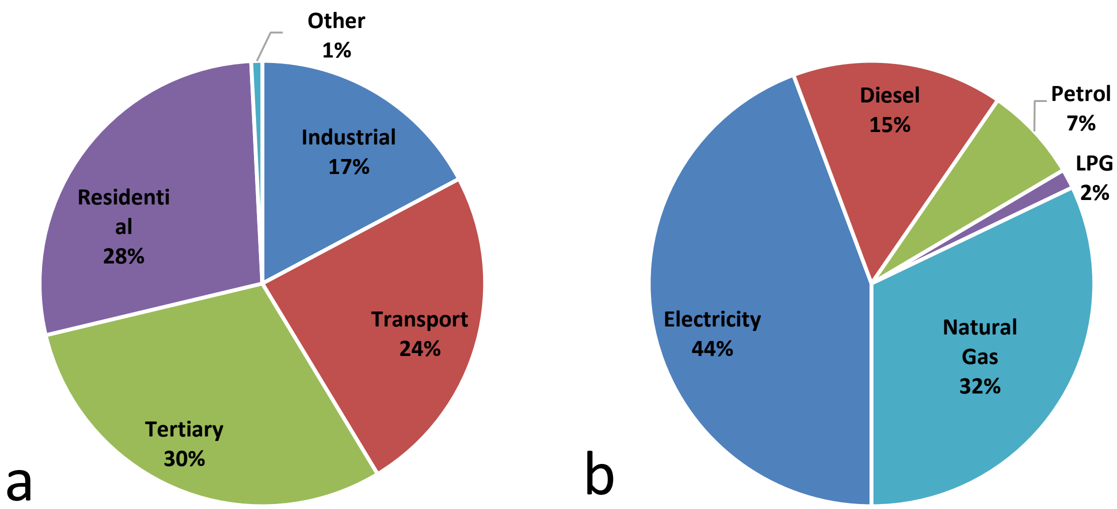

Figure 4-17: Barcelona consumption by energy sector (a) and energy consumption by source (b)

Source: Adapted from Ajuntament de Barecelona (2011)

4.4.1.1. Energy Supply

Considering energy in its origin, during 2008, Barcelona consumed 30,783 GWh of primary energy, with a contribution (considering the mix of electricity generation in Catalonia) of 44.8% of nuclear energy, 32.3% of natural gas, 12.3% of liquid fuels, and 3% of hydro power and renewable energy among other sources of less importance. According to the annual balance of 2008, 68% of the electricity consumed in Barcelona and was generated by electric generation facilities located in the Barcelona region.

4.4.1.2. Energy Demand

Barcelona's energy consumption is distributed as follows: 29.9% in the tertiary sector, 27.9% in residential, 24.1% in transport, 17.2% in the secondary sector and 0.8% in other sectors such as the primary sector, energy, building and public works. Similarly, in terms of energy sources, electricity prevails with 44.5%, followed by natural gas with 31.8%, gas oil with 15.4%, and oil with 7.0%, and LPG (butane and propane) with 1.4%.

4.4.1.3. Carbon Emissions

With regard to greenhouse gas emissions it is confirmed that, in 2008, 4,053,766 tonnes of GHG were emitted (Ajuntament de Barecelona, 2011). Among greenhouse gas emissions, the transport sector was the main emitter (26.2%), followed by residential (20.6%), commercial and service sectors (19.4%), the secondary sector (13.5%), as well as other sectors (0.5%) such as the primary, energy, building and public works. Some 8.1% of the GHG emissions was also caused by municipal solid waste treatment, and 11.8% was due to the Port of Barcelona activity as well as these related to Barcelona Airport which has a direct impact on the city.

Figure 4-18 shows Barcelona's annual CO_2 emissions. Barcelona has managed to reduce its annual CO_2 emissions by an average of -1.72% per year. This reduction has occurred despite Barcelona's increasing population during the same period. Barcelona has reduced its CO_2 emissions per capita by an average of -2.5% per year.

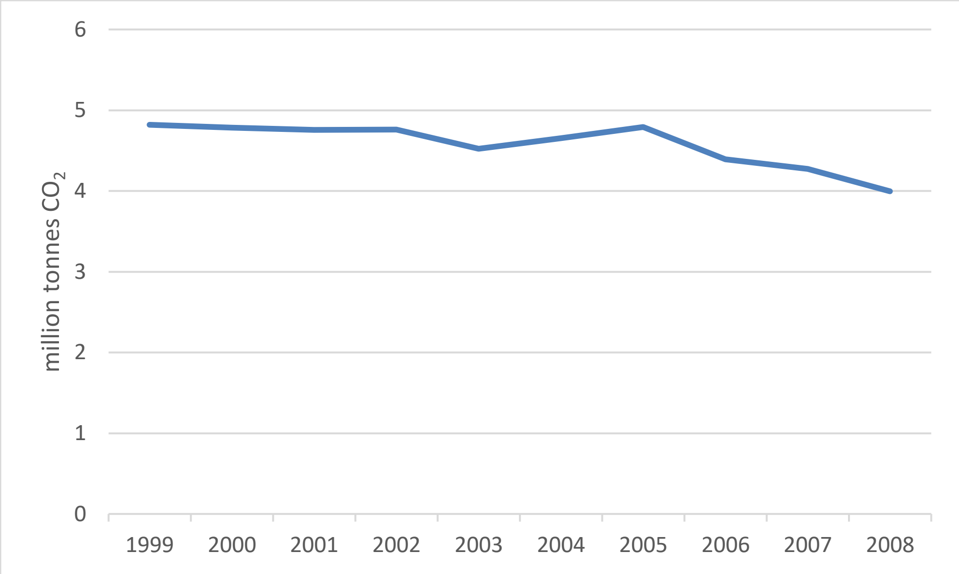

Figure 4-18: Barcelona's annual CO_2 emissions

4.4.1.4. Electricity Prices

Spain's electricity prices showed a steady reduction between 1993 and 2005. The price of a kWh of electricity then rose rather sharply between 2005 and 2008, as can be seen from Figure 4-19. Despite the increase in demand of electricity, Spain managed to reduce the price of electricity during the reporting period, which is a great feat, and definitely a factor which contributed to Spain's economic growth during this time period.

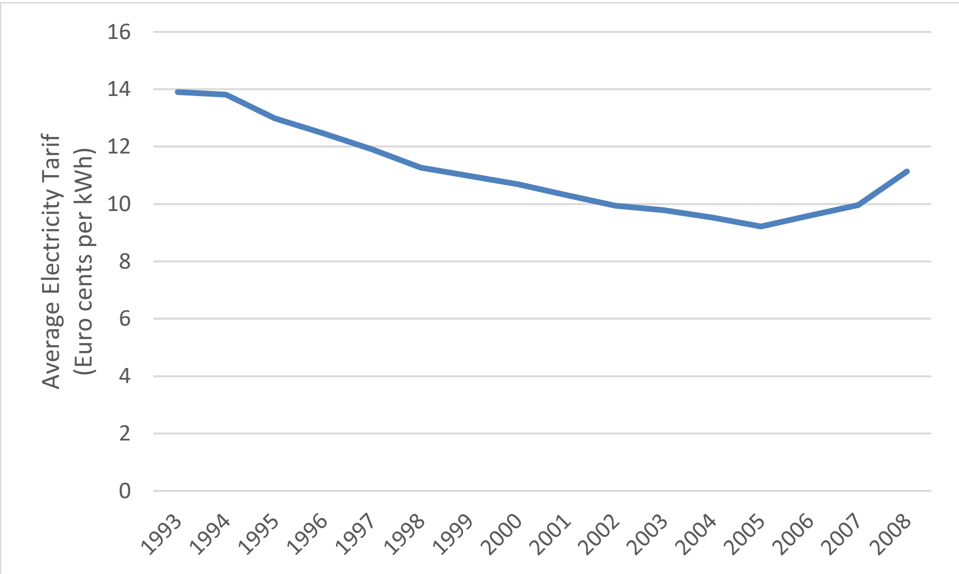

Figure 4-19: Average Electricity Prices in Spain

4.4.1.5. Liquid Fuel Prices

Figure 4-20 shows Barcelona's liquid fuel prices between 2000 and 2018. It can be seen that the prices rose continually from 2000 until 2008, where global the recession took place. The prices then dropped significantly into 2009. When the world economy stabilised in 2009, and demand for oil returned, the liquid fuel prices started rising again. Since 2013, the liquid fuel prices have gradually decreased.

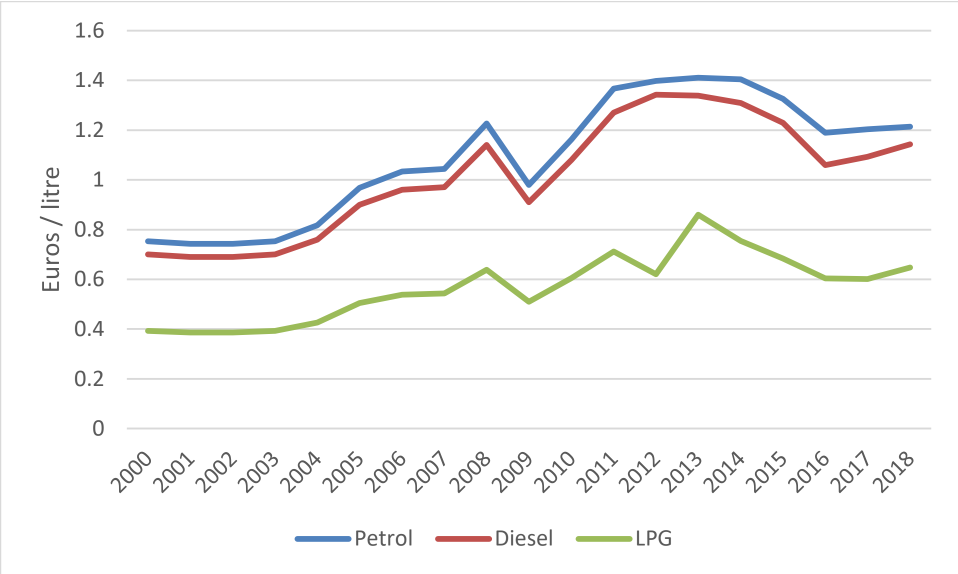

Figure 4-20: Barcelona Liquid Fuel Prices

Source: Adapted from Ajuntament de Barecelona (2011)

The following section evaluates how Barcelona's energy consumption and economic performance have interacted. It is hypothesised that the prices of energy (both electricity and liquid fuel) will affect the consumption of energy as well as the economic performance.

4.4.2. Barcelona Energy-Economy Nexus

Figure 4-21 shows Barcelona's annual energy consumption plotted against the economic performance (GDP). It can be seen that a sharp decline in the total energy consumption occurred since 2005. The economy has continued to grow throughout the reporting period, between 1999 and 2008, and has shown to be unaffected by the decline in total energy consumption since 2005. It is a positive indicator for the city, and it seems that the economy has managed to decouple its performance from energy consumption.

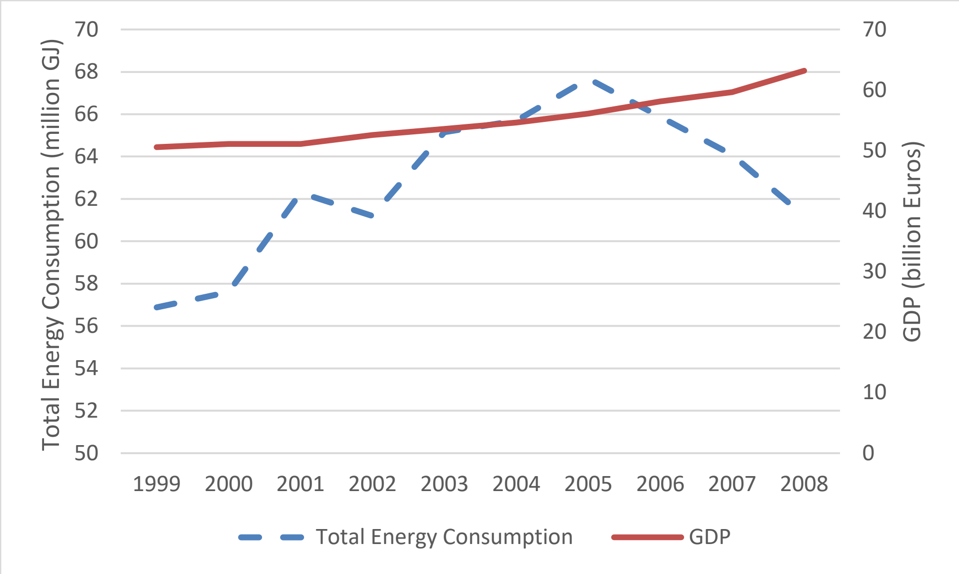

Figure 4-21: Barcelona Annual Energy Consumption vs GDP

The total annual electricity consumption can be seen from Figure 4-22. It can be seen that the electricity consumption has grown throughout the reporting period, along with the GDP. However, it should be noted that the rate of increase in electricity consumption has decreased towards the end of the reporting period. This is a positive sign for the city.

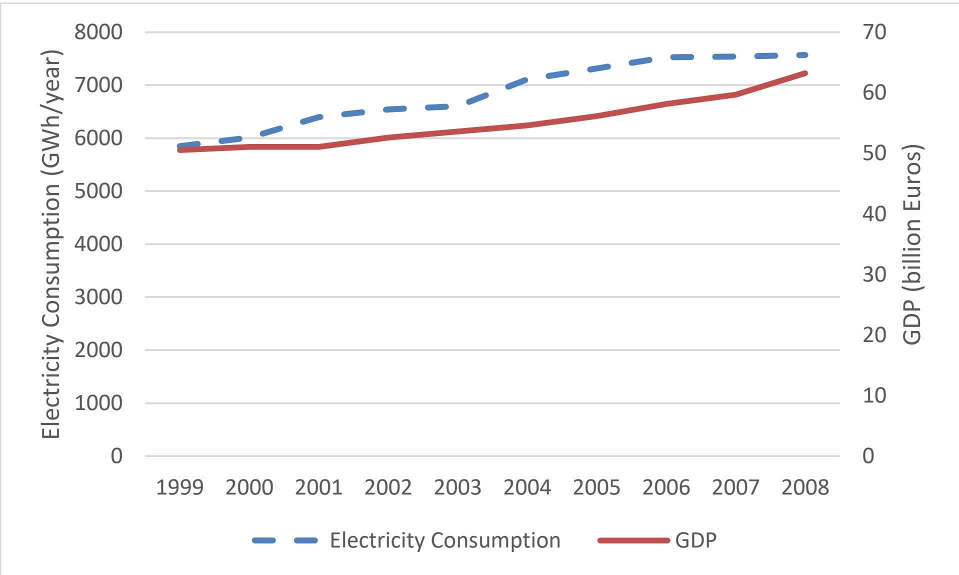

Figure 4-22: Barcelona Annual Electricity Consumption vs GDP

In order to understand how much of a financial expense energy is to the city, the energy cost share (ECS) of the city was calculated. Figure 4-23 shows Barcelona’s energy cost share for the period 2000-2008. It can be seen that the ECS hovered around the 6% mark for the first 4 years of the period of analysis, thereafter it rose constantly to a maximum of 8.2% in 2008.

A high ECS means that a high percentage of income is spent on purchasing energy. Therefore less disposable income remains to cater for other needs. There is a body of research that connects a high ECS to recessionary pressure (Hamilton, 2012; Heun and de Wit, 2012). Barcelona's increasing ECS leading up to the global recession of 2008 shows that perhaps an increasing ECS is an indicator of an imminent recession. Unfortunately the data was not available to investigate how the city's ECS reacted after the global recession, and throughout the economic crisis which has Spain has been suffering from since 2008.

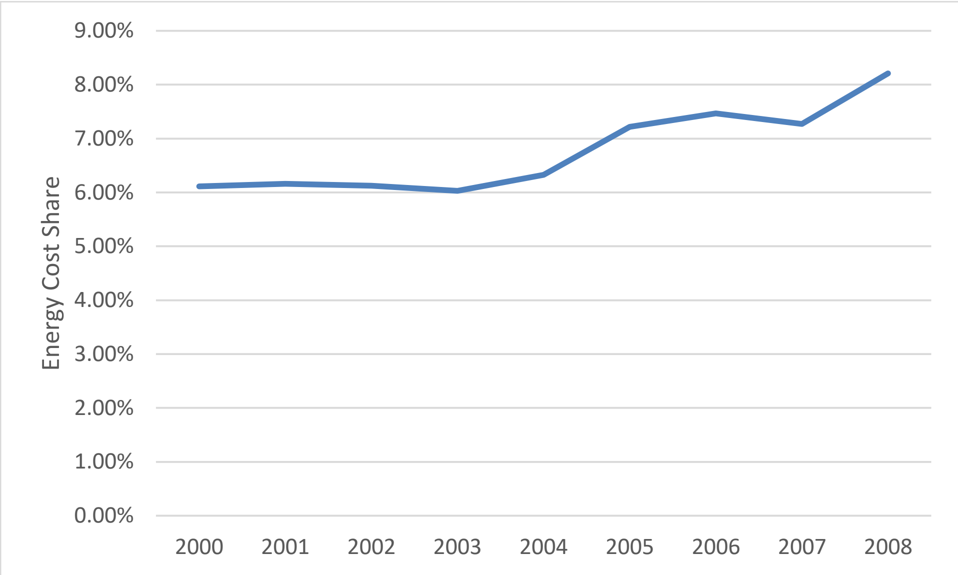

Figure 4-23: Barcelona Energy Cost Share

Barcelona's energy intensity can be seen from Figure 4-24. It can be seen that the city has continually managed to decrease its consumption of energy per unit of economic output. The city's energy intensity fell at an average annual rate of -1.11% between 1999 and 2008. This reduction was chiefly connected with the fact that GDP rose significantly during these years. This is a highly positive rate, and is higher than Spain's average (-1.01%), and it is also higher that Europe's average as a whole (-1.03%). The city has decreased its energy intensity by 20% between 1999 and 2008. This is a positive indicator for the city, since it means that more economic output can be generated from the same amount of energy production.

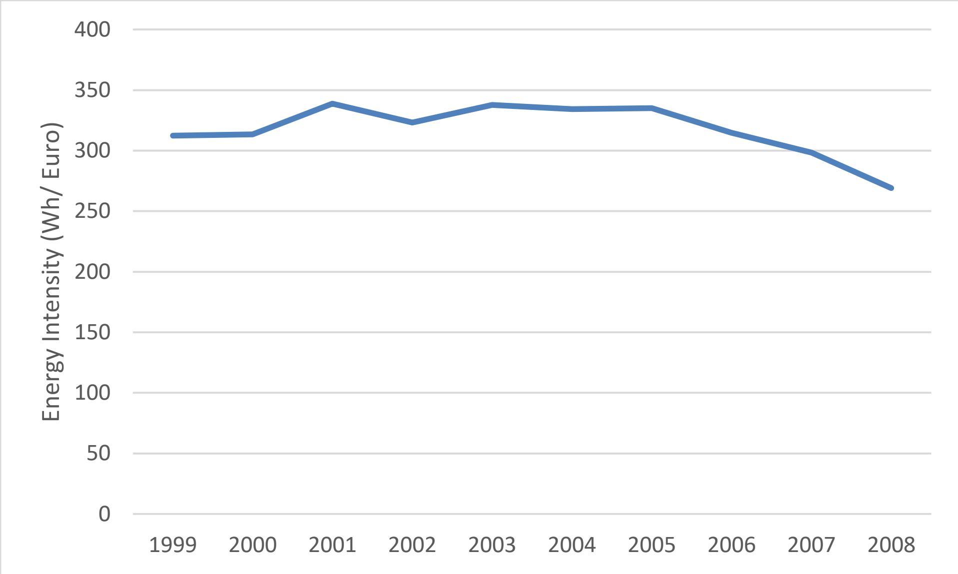

Figure 4-24: Barcelona Energy Intensity

To evaluate whether there are causal mechanisms between Barcelona's energy consumption and economic performance, a regression analysis was performed on the data. The results of the regression analysis are presented in the following section.

4.4.3. Statistical Analysis

Barcelona's energy-economy nexus was analysed using EViews (Econometric Views) software and Statistica software. These analyses were performed with the assistance of the Centre for Statistical Consultation at Stellenbosch University. The main outcomes of the statistical analysis are summarised here, while the full results of the statistical analysis can be found in Appendix A.

The period of analysis, based on the data availability, was 1999-2008. For this period, a correlation between electricity consumption and GDP was indeed found. The Spearman Correlation Coefficient, $r_s = 0.997$ which indicates a strong positive correlation between GDP and electricity consumption. This means that the higher the GDP of the city has been, the higher the electricity consumption of the city has been.

As a result of governmental policies, there was an increase in the number of users of electric means of transport (metro, train and tram) and thus the electricity consumption of the city has continued to rise. However, no correlation was found between total energy consumption and GDP. By looking at the figures of total energy consumption and electricity consumption (Figure 4-21 and Figure 4-22), it can be seen that total energy consumption started to decouple from economic growth in 2005, whereas electricity consumption continued to rise with GDP through until the end of the reporting period in 2008.

4.4.4. Barcelona Conclusions

The correlation that was found between electricity consumption and GDP is noteworthy. The data shows that as GDP increased, electricity consumption increased. However, it should be noted that the period of analysis is only until 2008, which means that the data does not show the effects of the global push for energy efficiency, which has gathered momentum in the last 10 years. The other two cities, Wellington and Cape Town, also showed an increasing trend of electricity consumption until 2008, but the decoupling of electricity consumption from GDP pursued after 2008.

Barcelona has seen a noteworthy reduction in the consumption of automotive fuels, petrol and diesel which is attributed to two factors: less private transport road traffic in the city and enhanced energy efficiency of the vehicle population in circulation.

The economy become more energy efficient, producing more Euros per GJ, however the economy has spent a higher percentage of its income on energy, shown by the increase in energy cost share. This increase in ECS should be a concern for the city, as an increased ECS could be indicative of an imminent recession, as explained in section 2.3.1.

4.5. Comparative Analysis

This section compares the three cities' energy-economy nexuses to each other and finds ways in which the relationships might be similar, or conversely, ways in which the relationships might differ. Through a comparative study, these cities can find ways to learn from each other.

4.5.1. Energy Intensity

The efficiency of the cities' economies were evaluated through calculating their energy intensities. For the sake of comparison, the monetary units were converted to US Dollars. The three cities' energy intensities were plotted on together in Figure 4-25. It can be seen that Barcelona has the lowest energy intensity, meaning it produces the most USD (GDP) per GJ of energy consumed. Second is Wellington, which has shown an impressive reduction in energy intensity. Cape Town has the highest energy intensity. It should be noted that this figure considers the GDP in USD, and thus exchange rates are a factor. Cape Town's energy intensity, when measured in GJ per Rand is decreasing, but Figure 4-25 shows how much the currency has weakened against the USD.

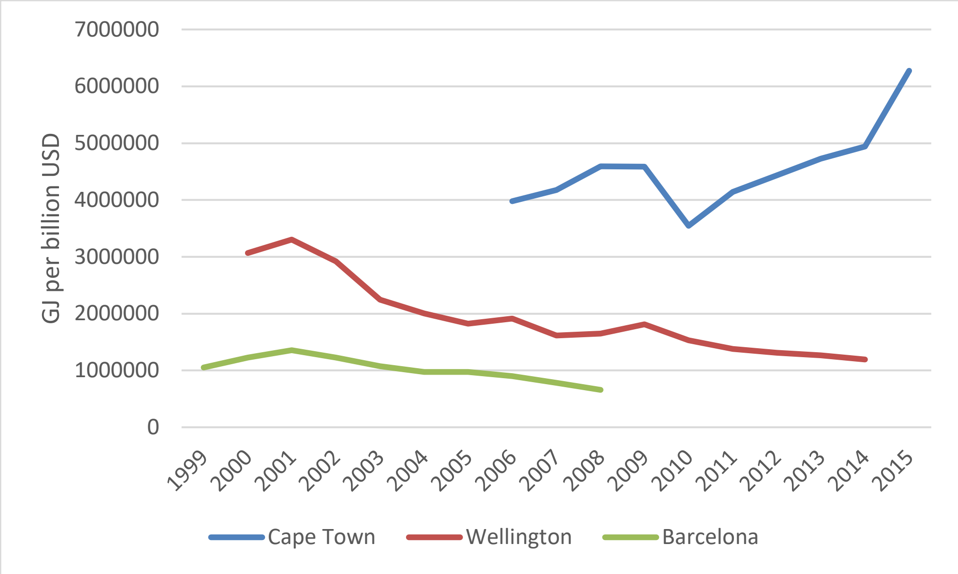

Figure 4-25: Energy Intensity Comparative Analysis

Cape Town has low densities compared to other cities across all global regions (Western Cape Government, 2016). This means that daily commuting distances are long, and it makes public transport development enormously challenging. At the same time, the majority of Cape Town residents (58%) rely on public transport (City of Cape Town, 2015). Experts note that it is very difficult to get commuters out of private vehicles and back into public transport once the modal switch has been made. This means it is extremely important for the City of Cape Town to upgrade and enhance public transport in the city, thus retaining current public transport users.

Although Wellington, and New Zealand as a whole, has a positive trend in terms of its energy intensity, New Zealand still has an energy intensity which is 20% higher than the OECD average (MBIE, 2017a).

Transport, since it is an enormous energy consumer, plays a large role in a city's energy intensity. Cape Town's combined petrol and diesel consumption accounts for 53% of the city's total energy consumption. This figure sits at 37% for Wellington and 22% for Barcelona. Since Barcelona is a compact city with a comprehensive and well-adopted public transport network, its transport energy use is far lower than Cape Town, and well-below that of Wellington too. This metric magnifies the importance of focussing on improving transport efficiency.

4.5.2. Energy Expenditure

To understand how much of an economic burden energy costs are, this section compares the energy expenditure of the three cities. Section 2.3.1 showed that a high energy expenditure can cause recessionary pressures to reduce the energy demand, thereby reducing energy prices, which in turn reduces the total energy cost share to its earlier (equilibrium) value (Heun and de Wit, 2012). An increasing energy cost share is therefore potentially an indicator that a recession is imminent.

It can be seen from Figure 4-26 that all three cities' ECS increased during 2007, which may have been an indicator that a global recession was imminent. Both Wellington and Cape Town's ECS dropped during 2009; perhaps this is an indication of a stabilising economy. Unfortunately, Barcelona's data for the 2008-present time period was not available and thus an analysis of the current economic crisis in Spain is not possible.

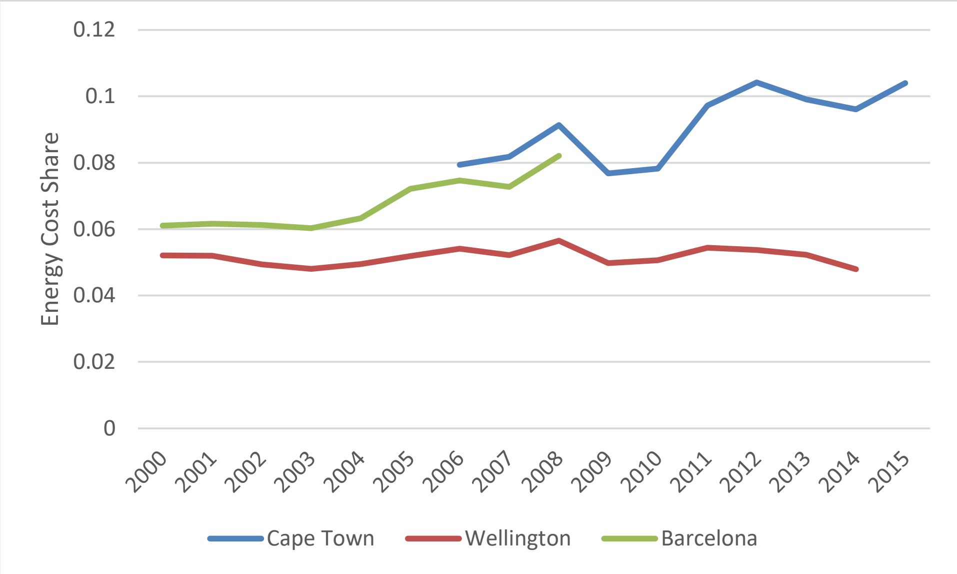

Figure 4-26: Energy Cost Share Comparative Analysis

Wellington's ECS has continued to remain stable, and even decrease, since the 2008 recession. Wellington has seen the highest percentage of economic growth since 2008, and it seems that a decreasing ECS might be linked to stimulating an economy. Conversely, Cape Town's ECS has increased to alarmingly high rates. Figure 4-26 shows that as much as 10% of Cape Town's GDP is spent on energy. Furthermore, since energy costs have a ripple effect through the economy, as explained in section 2.3, a high energy cost can slow economic growth.

Cape Town should therefore focus on reducing its ECS, if at all possible. Similarly, Barcelona, should focus on stabilising its ECS and prevent further increases.

4.5.2.1. Carbon Emissions

City greenhouse gas emissions reflect the structure of a city, its energy sources, and its residents' lifestyles(World Bank, 2010). The impact of cities is proportional to the level of output and the combination of energy sources they use. Richer cities, less dense cities, and cities that depend predominantly on coal to produce energy all emit more greenhouse gases. Figure 4-27 shows the carbon emissions of the three cities under consideration. It can immediately be seen that Cape Town has by far the highest total emissions. Barcelona's emissions are decreasing, which is positive, and Wellington's emissions appear to be very low. However, this figure only considers absolute emissions, and does not cater for the population of the cities.

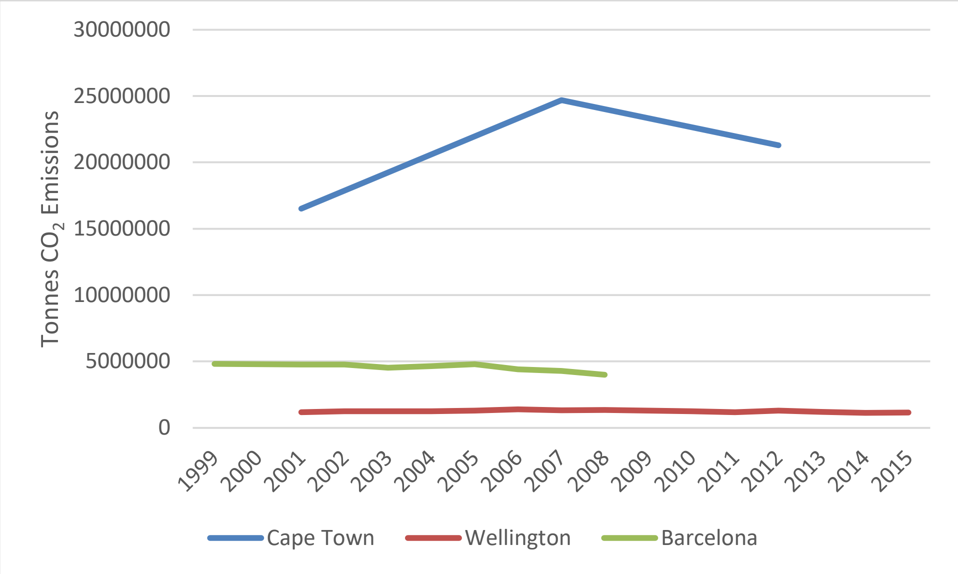

Figure 4-27: Carbon Emissions Comparative Analysis

Taking account of a city's greenhouse gas emissions per capita is vital, because city per capita emissions often differ greatly from regional or national per capita emissions. Although cities are responsible for high total greenhouse gas emissions, per capita emissions can be comparatively low in cities that are efficient and well planned. In order to compare the three cities, the emissions per capita were calculated for the year 2008. These results can be seen in Figure 4-28. The results paint a completely different to that of the previous figure (Figure 4-27).

It can be seen that Wellington's per capita emissions are almost as high as that of Cape Town's. According to this metric, Barcelona has the lowest emissions per capita – as can be expected from such a compact and efficient city. According to this metric, both Cape Town and Wellington have reductions to be made.

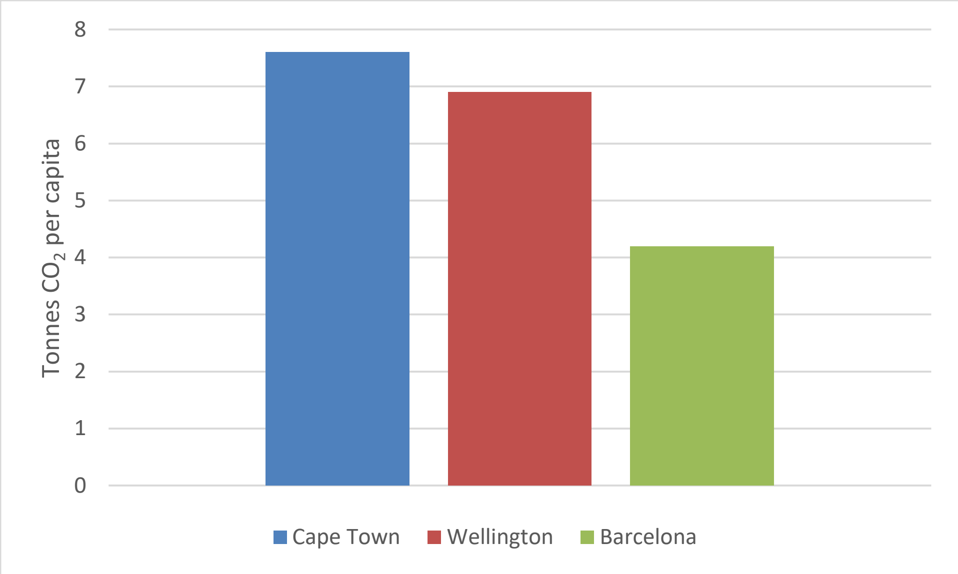

Figure 4-28: Emissions per capita Comparative Analysis

4.6. Results Summary

The statistical analysis was performed on Cape Town, Wellington and Barcelona. Each city's investigation started with a background on the energy profile, which looked at the energy supply and demand, the carbon emissions, and energy prices of each city. To gain an understanding of each city's energy-economy nexus, the energy consumption was plotted against GDP. Thereafter, to further investigate the dynamics between energy and economy, the energy cost share and energy intensity of each city was plotted. Each city's energy consumption and GDP data was then exposed to a statistical analysis to search for potential correlations and causalities. However, it was found that, due to recent decoupling efforts, there were not many correlations or causalities between energy consumption and economic growth. The only noteworthy correlation was between Barcelona's electricity consumption and economic growth. It was found that they were positively correlated, meaning that electricity consumption increased as the GDP increased. Through the analysis, it was found that Wellington had the most notable levels of decoupling. The causes of Wellington's impressive decoupling were of interest, and the city's historical policy interventions and energy price history was used to build a model for decoupling. Finally, a comparative analysis was performed where the three cities were compared to each other using a range of metrics. This comparative analysis is used as the basis for this study's proposal of inter-city learning, where cities are encouraged to share successful policy interventions and learn from each other.

Chapter 5 Conclusions and Recommendations

This study examined the relationship between energy consumption and economic performance at a city level. To satisfy the objectives of the study, it was structured into five chapters. Chapter one introduced the study by reflecting on the issues of energy poverty and why this study has an urban focus. The problem statement, objectives and the research strategy were discussed in chapter one. Chapter two then reviewed relevant literature. The literature review was performed in line with the following thematic areas: understanding the dynamics of the energy-economy nexus, key considerations in urban energy systems, and time series data. Chapter three documented the research methodology followed in the course of study. Hence, this chapter described sources of data collection and the method of data analysis. In Chapter four, the results of the study were discussed; each city's energy-economy nexus was investigated, thereafter a comparative analysis was performed where the different cities were compared. Finally, Chapter five contains the summary, conclusion and recommendations for future work.

5.1. Key Findings

This study has developed an understanding of the dynamics between energy consumption and economic performance at a city level. Pressures and potentials to reconcile economic growth and the sustainable use of resources have been shown to be greatest in cities. This study has investigated the urban energy-economy nexus and has answered the research objectives set out for this study. A summary of the study's key findings is given:

a) Reviewing literature to find a way forward

A thorough literature review was performed in order to find context for this study. A keyword search technique was used to scan literature to find the most appropriate literature. This literature was studied to understand the dynamics of the energy-economy nexus. Fundamental concepts such as energy cost share, energy return on investment, energy intensity and decoupling were studied and explained in Chapter 2. These concepts and metrics would later form the backbone of the city analyses. Various economic metrics were considered and their suitability was evaluated. A city's gross domestic product (GDP) was found to be the most appropriate economic metric.

The findings of the literature review were shared in a review article. This article was submitted to the International Sustainable Development Research Society (ISDRS) conference, and was accepted for oral presentation. The paper was presented and well received; feedback from fellow researchers was considered and taken into account for the remainder of this study.

b) City-level data collection

Collecting the required data to perform the analyses on the cities' energy-economy nexus proved to be a challenging task. Thus, the collection of the three cities' data is a key outcome of this study. The data was collected through communication with city councils, communication with independent energy consultants, communication with fellow energy researchers, from city energy reports, and from greenhouse gas emissions reports. Since most studies and policies are made on a national level, obtaining the city-level data, and performing analyses on the city-level data was a novel approach.

It was found that each city had a vastly different energy profile and a unique energy-economy relationship. Studying cities' energy-economy relationship is thus an important step in ensuring economic growth throughout the transition to more sustainable energy sources. Furthermore, city-level data collection is a vital step in order to understand a city's energy-economy relationship.

c) City council interaction

Through performing an analysis on three different cities, this study allowed for a comparative analysis through which these three cities can learn from each other. In this study, Wellington has shown the most impressive levels of decoupling. The study then investigated how Wellington achieved this impressive reduction in energy consumption while maintaining economic growth. It was found that Wellington's government of 2000-2008 had a strong environmental campaign and an increased budget for sustainability. This government created an increased environmental awareness, which is thought to be linked to the increased adoption of energy efficiency, and the associated technologies. New Zealand's Emissions Trading Scheme (ETS) which was implemented in 2008 is also an outcome of this government. The ETS, coupled with reduced investment in private roads – which led to an increased modal shift to public transport – as well as the increased environmental awareness in Wellington has created a model of decoupling which other cities can learn from.

d) Energy-economy correlations and causalities

This study set out to perform statistical analyses on the cities' energy-economy data in order to determine whether correlations and causalities exist between energy consumption and economic performance. Of the three cities analysed, the only correlation that was found was for Barcelona's electricity consumption and economic performance. However, this does not mean that energy and economy are not linked for the other cities. City energy systems are dynamic, and simply searching for a correlation coefficient will not actually assist is understanding the energy system any better. Rather, analysing how cities reacted to various policy interventions is a more useful way to develop an understanding of a city's energy-economy nexus.

There is no doubt that energy consumption and economic performance are linked. Economic growth requires energy input. However, the causalities of whether energy consumption causes economic growth or whether economic growth causes energy consumption are not fully understood. Since the Granger causality test is merely a search for precedence, looking at which of the metrics (energy consumption or economic growth) precedes the other is a way to tentatively search for causalities. Through performing this type of visual analysis, it was seen that the direction of causality changes every few years. For example, during the time of restricted energy supply in Cape Town (load-shedding) the reduction in electricity consumption preceded ("caused") the reduction in economic growth. Conversely, during the global recession, the reduction in economic growth preceded the reduction in energy consumption. Therefore, this study shows that it is very difficult to discern whether economic growth 'pulls' energy supply or whether energy supply 'pushes' economic growth. Furthermore, since this direction of causality is believed to regularly switch directions, performing a causality test will not reveal a direction of causality since it is often changing, and not a fixed causality.

5.2. Conclusion

In order to understand the relationship between energy consumption and economic growth, this study used the Spearman Correlation Test and the Granger Causality Test to measure the relationship between energy consumption and economic performance for three different cities. The three cities that were selected for analysis are Cape Town (South Africa), Wellington (New Zealand) and Barcelona (Spain). These cities were selected based on their similar economic profiles yet contrasting energy profiles. Previous studies on the relationship between energy consumption and economic growth had not focussed on this relationship at a city level.

The analysis of these three cities' energy-economy nexus showed that some level of decoupling (economic growth from energy consumption) was present, with Wellington showing the highest levels of decoupling. The presence of decoupling meant that correlations and causalities were not found between energy consumption and economic growth. For the case of Barcelona, data was only available from 1999-2008, and thus the data was unaffected by the global push for energy efficiency which has gathered steam in the last decade. Therefore, a strong positive correlation between electricity consumption and GDP was found for Barcelona, however as Barcelona improves its energy efficiency this correlation will weaken.

This study performed a comparative analysis where the three cities were compared and ways to learn from each other were identified. Wellington's remarkable decoupling was used to identify the policy interventions that caused and assisted the decoupling. It was found that a carbon tax system, along with a strong environmental awareness campaign and investment in more efficient public transport were the key aspects in bringing about decoupling in Wellington.

Performing the analyses on cities has highlighted the usefulness and importance of certain metrics which link the energy and economic systems of cities. It was shown that monitoring a city's energy intensity (GJ consumption per $ GDP) is a relatively straightforward way to track the energy efficiency of a city. Cities should therefore strive to reduce their energy intensities. Energy cost share (% of GDP expended on energy) was shown to be an indicative method to track the recessionary pressures of an urban society. To elaborate, the cost of energy was shown to have a ripple effect through society; when the price of energy increases, almost everything costs more. Therefore, an increasing energy cost share is an alarming state for a city to be in, as it can be a sign of an imminent recession – as was shown in Barcelona leading up to Spain's economic crisis in 2008.

5.3. Recommendations for Future Work

Improvements in data collection and reporting systems using consistent methodologies on a city and regional basis would contribute to a better understanding of the impacts of specific policies and measures. Improvements in regional and city data collection are particularly needed in the areas of forestry, agriculture and industrial processes as well as international shipping. Similarly, accurate liquid fuels consumption data of cities is often lacking but is needed to improve accurate tracking of city energy consumption.

In order to better understand the dynamics between energy consumption and economic performance, it is recommend that different approaches, such as System Dynamics Modelling, be incorporated. This study was primarily concerned with finding correlations and causalities between energy consumption and economic performance, and it was found that the causality changes direction every so often. To understand how this changing direction of causality affects the system, this study recommends building a causal loop diagram, and modelling the system with a stock and flow diagram.

Energy consumption patterns change over time and varies extensively by nature of economic activities and across cities. This research report was therefore developed on the basis of limited data from a small sample only. For a more comprehensive investigation, expected to ascertain the relationship between economic performance and energy consumption, data collection should be extended to a larger sample of cities. Obviously, accuracy of statistical estimation depends largely on the number of observations and representativeness of cities in both dimensions – development groups and geographical regions. Until a regular and comprehensive international data source on economic performance and energy consumption for all sectors of the economy is available, a direct survey method seems the only alternative to obtain the required data. Presently energy statistics circulated by different international agencies are not congruent with each other in terms of method of categorisation, data sources and target population. This flaw acutely restricts the possibility of data analysis on energy use.

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Appendix A

Wellington Regression Analysis

The analysis started by simply plotting the two variables, energy consumption and GDP, against each other.

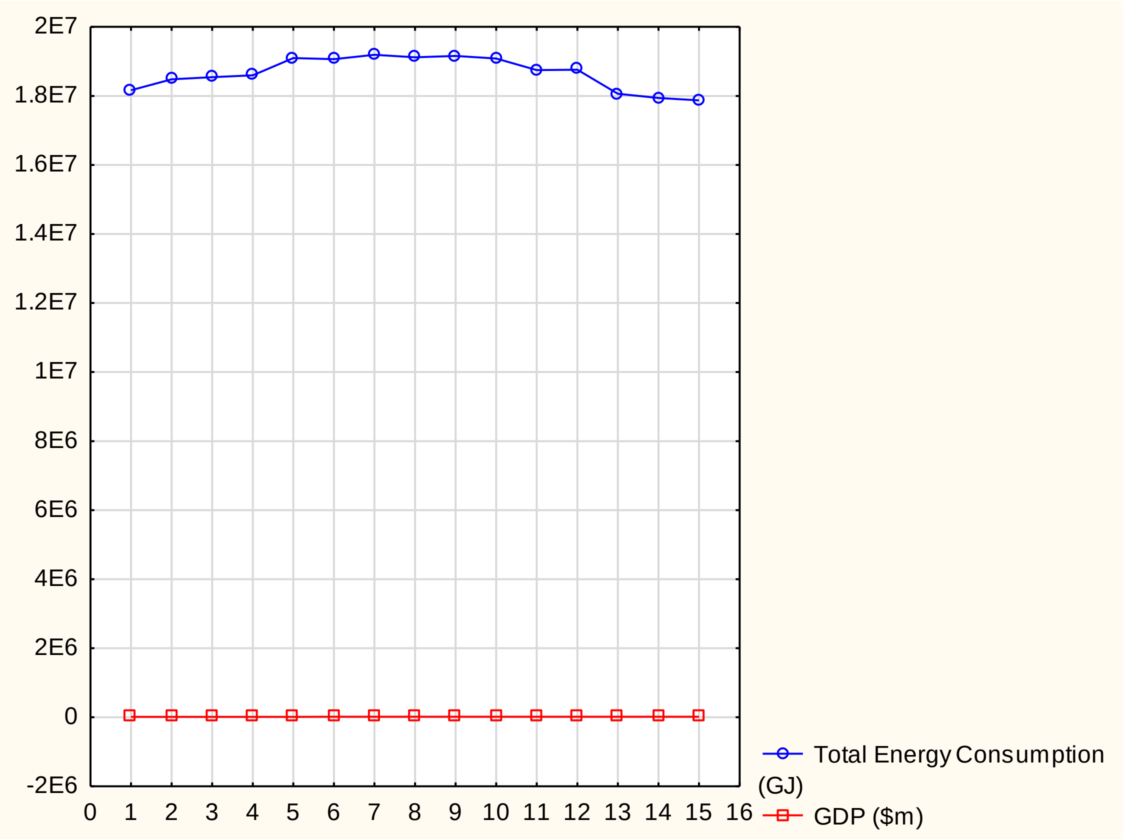


Figure A-1: Wellington GDP vs Total Energy Consumption

Thereafter the percentage change for each year was plotted in Figure A-2 to get an idea of how stable the variables are and how much they are changing.

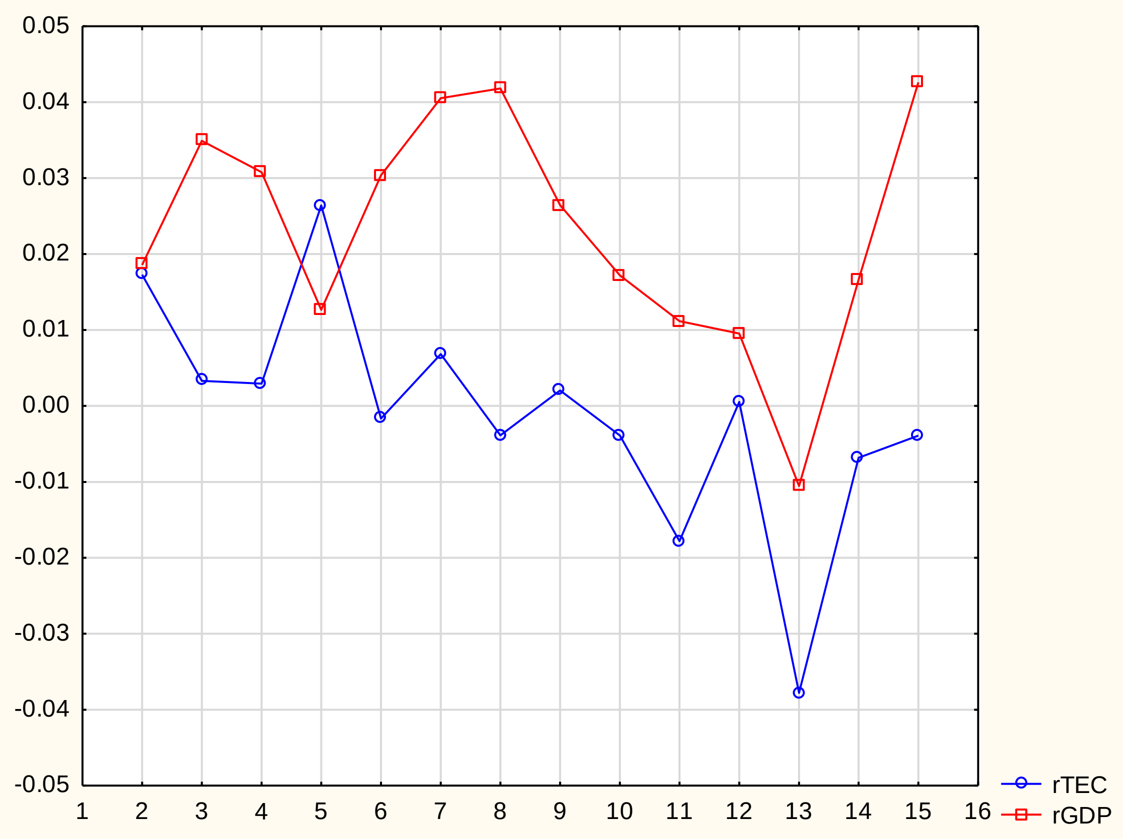


Figure A-2: Percantage change GDP vs percentage change Total Energy Consumption

The analysis then started to search for correlations between GDP and total energy consumption by using a simple Pearson Correlation test, the results are shown in Table A-1. It can be seen that the Pearson Correlation Coefficient is $P = 0.639$, which is not a statistically significant correlation.

Table A-1: GDP and Total Energy Consumption Correlation

	Correlations (Energy-Economy in DATA
Variable	GDP ($m)
Total Energy Consumption (GJ)	-.1320
	p=.639

The annual change was the exposed to a Pearson Correlation test. The results are tabulated in Table A-2. The Pearson Correlation Coefficient is $P = 0.14$ which is also not a statistically significant correlation.

Table A-2: Percentage change Correlations

Variable	Correlations (Energy-Ec rGDP
rTEC	.4154
	p=.140

The second test for correlation that was used is the Spearman Rank Order Correlation. The results of this test are presented in Table A-3. The requirements for a statistically significant correlation is that the p-value < 0.05 and R ≈ 1 or R ≈ -1. It can be seen from Table A-3 that the p-value is far greater than 0.05 meaning that there is no statistically significant Spearman Rank Order Correlation.

Table A-3: Spearman Rank Order Correlation of Total Energy Consumption vs GDP

	Spearman Rank Order Correlations (Energy-Economy in DATA 20180612.stw) MD pairwise deleted			
Pair of Variables	Valid N	Spearman R	t(N-2)	p-value
Total Energy Consumption (GJ) & GDP ($m)	15	-0.164286	-0.600500	0.558497

The Spearman Rank Order Correlation was then calculated for the annual change data. Again it can be seen from Table A-4 that no statistically relationships were present.

Table A-4: Spearman Rank Order Correlation of Percentage Changes

	Spearman Rank Order Correlations (Energy-Economy in DATA 20180612.stw) MD pairwise deleted			
Pair of Variables	Valid N	Spearman R	t(N-2)	p-value
rTEC & rGDP	14	0.270330	0.972664	0.349919

In order to visualise the Spearman's Rank Order Correlations, a scatterplot of the data was drawn in Figure A-3: Scatterplot of Total Energy Consumption vs GDP, along with a linear line of best fit.

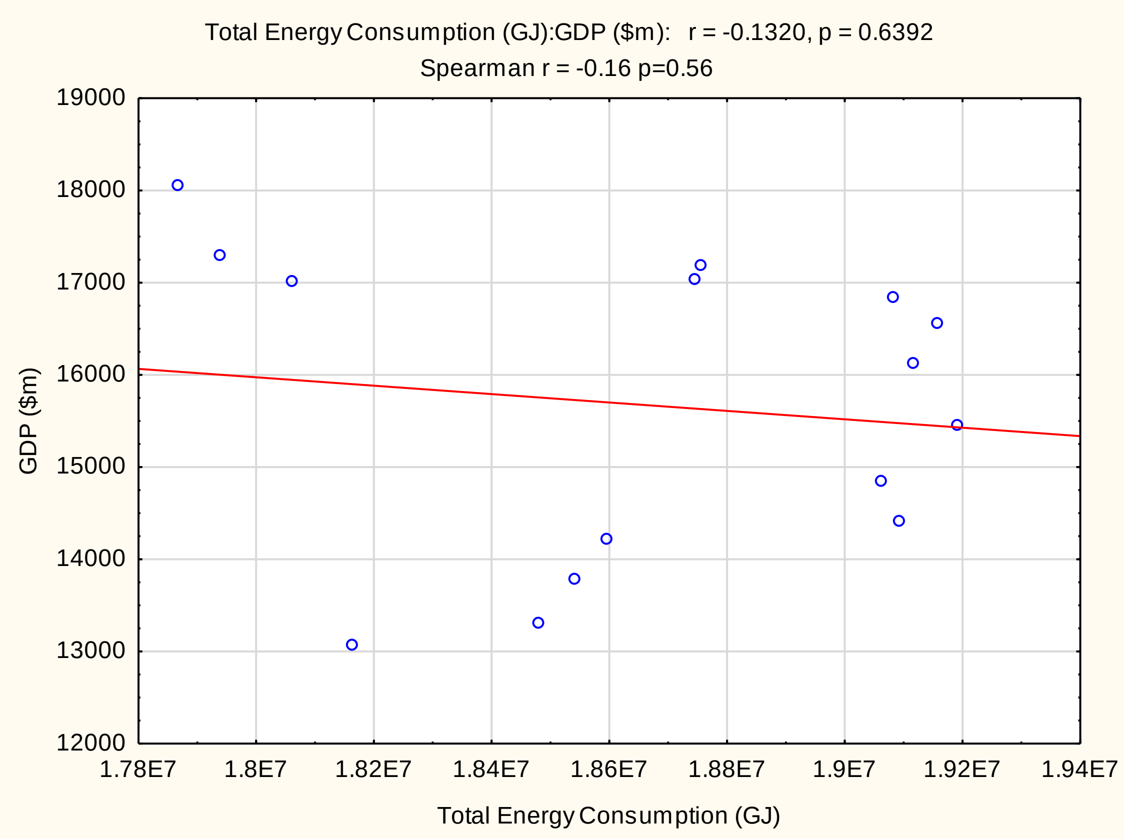


Figure A-3: Scatterplot of Total Energy Consumption vs GDP

Similarly, a scatterplot was drawn of the annual change data, in Figure A-4. The linear line of best fit can been seen on the figure, which shows the low correlation between the data.

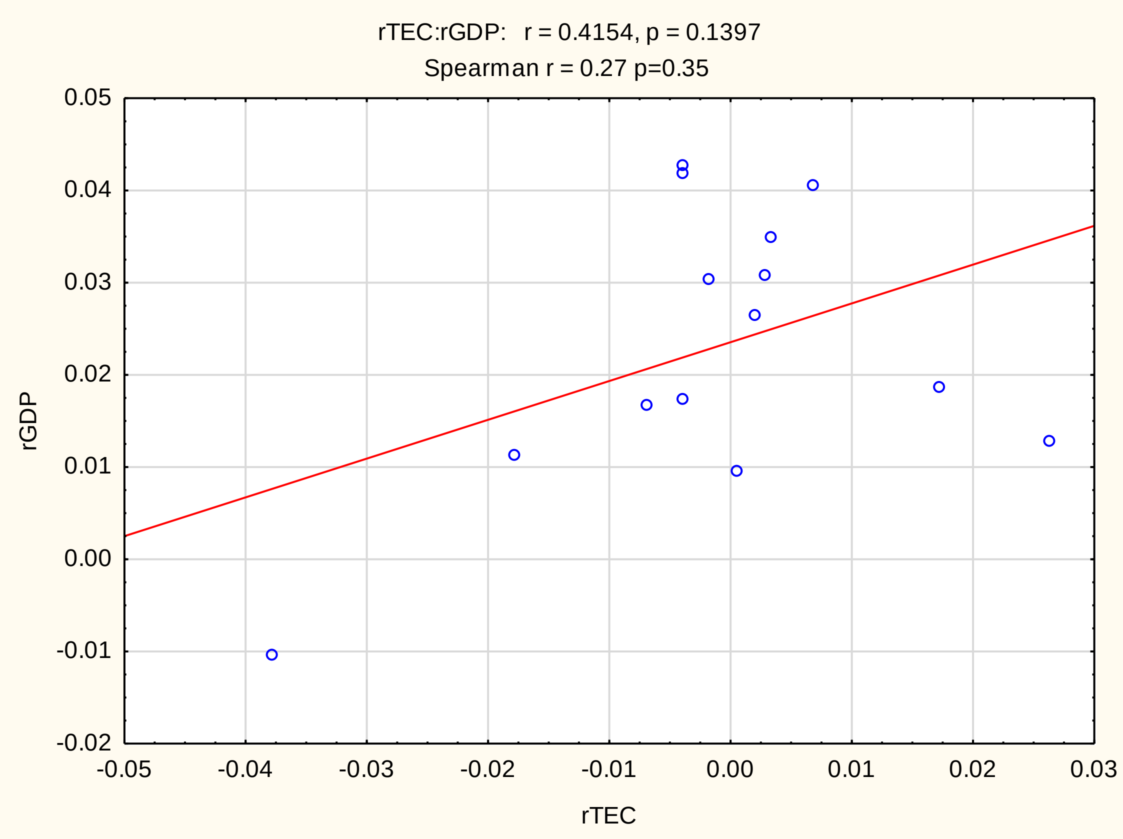


Figure A-4: Percentage change Scatterplot

The second step of the analysis of Wellington's energy-economy nexus was to search for correlations between electricity consumption and GDP. The first step was to simply plot the two variables, electricity consumption and GDP, against each other.

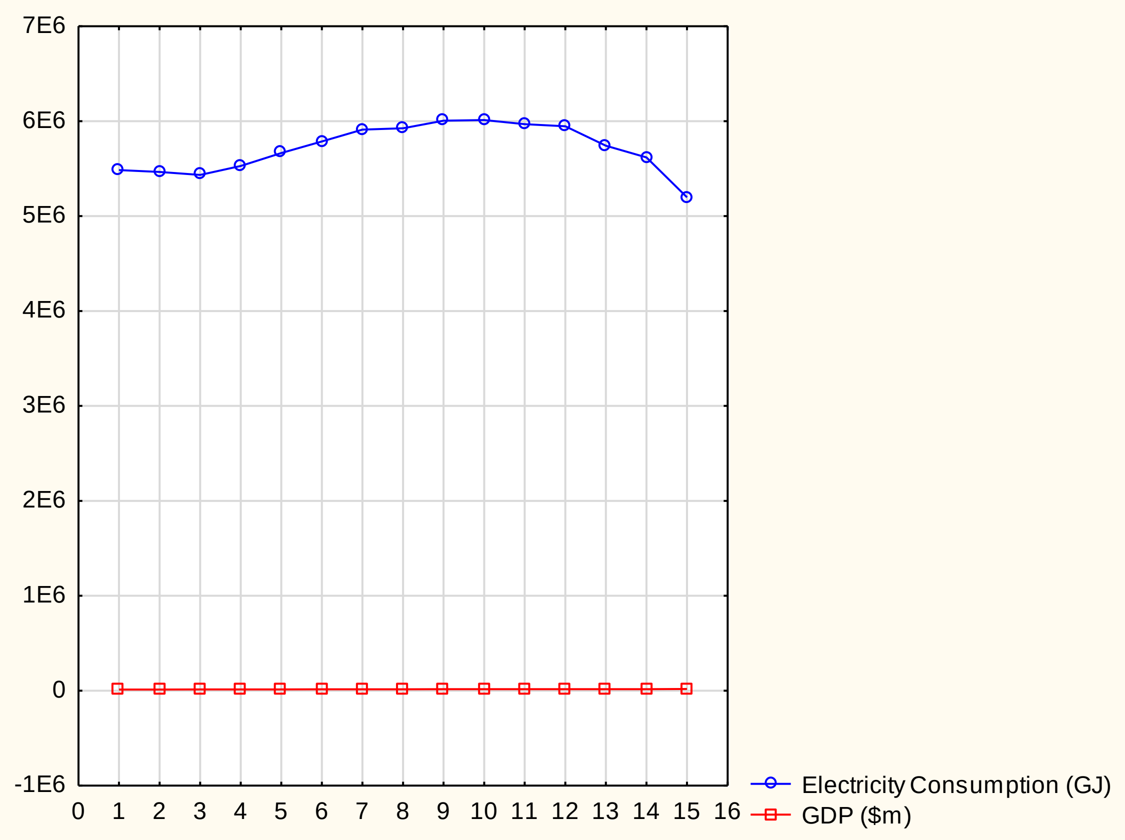


Figure A-5: Electricity Consumption vs GDP

Thereafter the percentage change for each year was plotted in Figure A-6 to get an idea of how stable the variables are and how much they are changing.

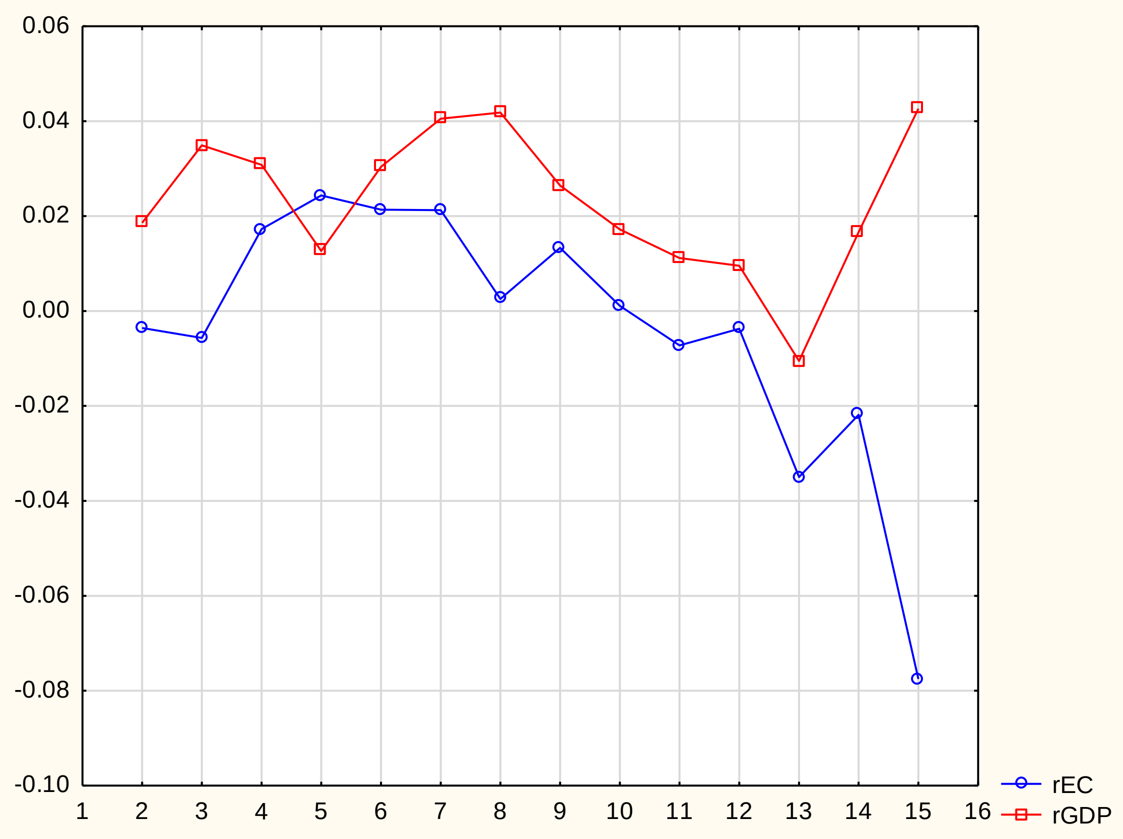


Figure A-6: Annual change Electricity Consumption and GDP

The analysis then started to search for correlations between GDP and total energy consumption by using a simple Pearson Correlation test, the results are shown in Table A-5. It can be seen that the Pearson Correlation Coefficient is $P = 0.202$, which is not a statistically significant correlation.

Table A-5: Correlation between Electricity Consumption and GDP

	Correlations (Electricity-Economy in DATA
Variable	GDP ($m)
Electricity Consumption (GJ)	.3493
	p=.202

The annual change was the exposed to a Pearson Correlation test. The results are tabulated in Table A-6. The Pearson Correlation Coefficient is $P = 0.810$ which is also not a statistically significant correlation.

Table A-6: Correlation between ennual change in Electricity Consumption and GDP

Variable	Correlations (Electricity- rGDP
rEC	.0707
	p=.810

The second test for correlation that was used is the Spearman Rank Order Correlation. The results of this test are presented in Table A-7. The requirements for a statistically significant correlation is that the p-value < 0.05 and R ≈ 1 or R ≈ -1. It can be seen from Table A-7 that the p-value is far greater than 0.05 meaning that there is no statistically significant Spearman Rank Order Correlation.

Table A-7: Spearman Rank Order Correlation between Electricity Consumption and GDP

Pair of Variables	Spearman Rank Order Correlations (Electricity-Economy in DATA 20180612.stw) MD pairwise deleted Valid N	Spearman R	t(N-2)	p-value
Electricity Consumption (GJ) & GDP ($m)	15	0.350000	1.347151	0.200945

The Spearman Rank Order Correlation was then calculated for the annual change data. Again it can be seen from Table A-8 that no statistically relationships were present

Table A-8: Spearman Rank Order Correlation between annual change in Elctricity Consumption and GDP

Pair of Variables	Spearman Rank Order Correlations (Electricity-Economy in DATA 20180612.stw) MD pairwise deleted Valid N	Spearman R	t(N-2)	p-value
rEC & rGDP	14	0.191209	0.674817	0.512584

In order to visualise the Spearman's Rank Order Correlations, a scatterplot of the data was drawn in Figure A-7, along with a linear line of best fit.

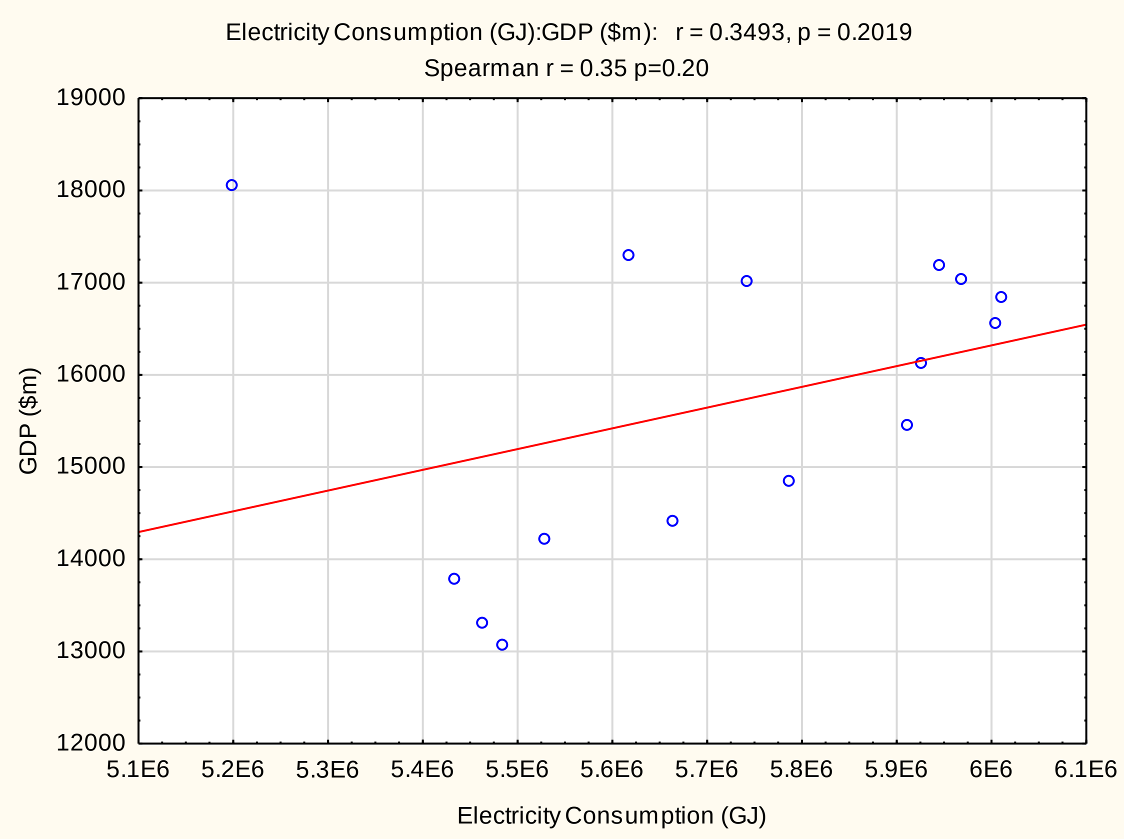


Figure A-7: Scatterplot GDP vs Electricity Consumption

Similarly, a scatterplot was drawn of the annual change data, in Figure A-8. The linear line of best fit can been seen on the figure, which shows the low correlation between the data.

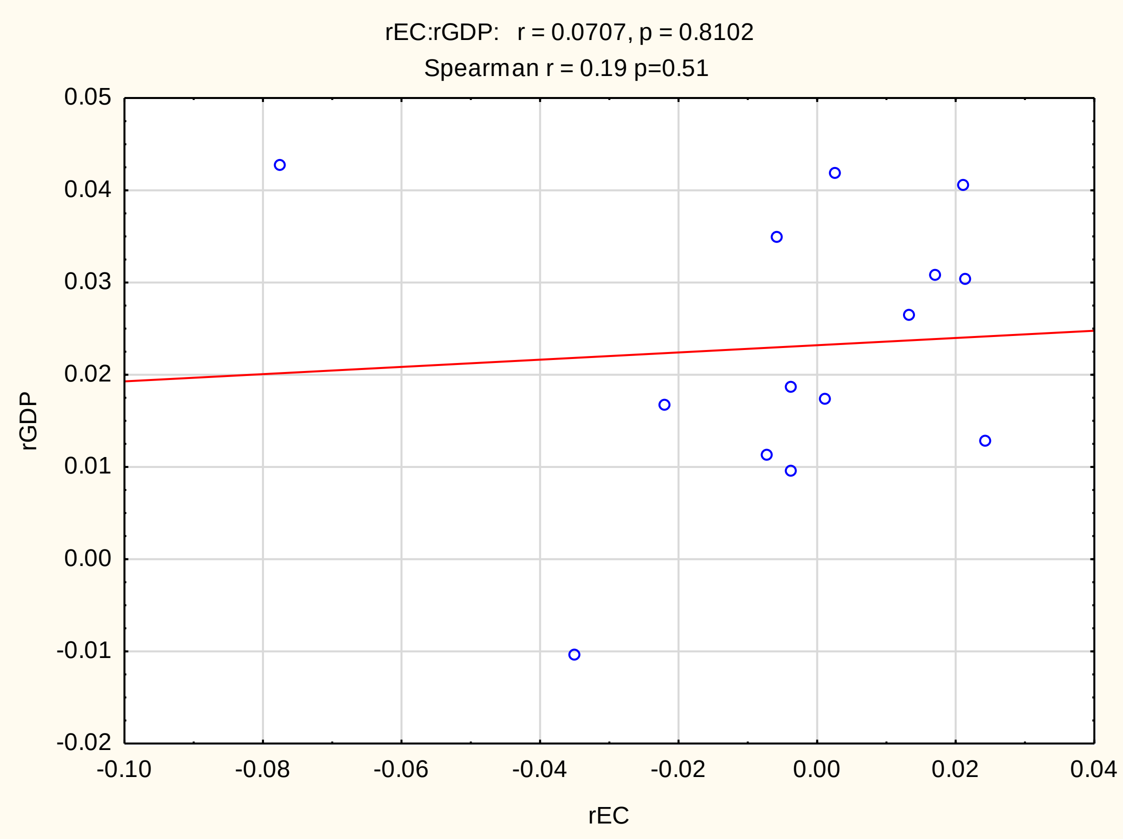


Figure A-8: Scatterplot annual change GDP and Electricity Consumption

<u>Granger Causality Test</u>

Although no correlations were found between Wellington's energy consumption and economic performance, there may still have existed a causality between the two variables. Therefore, the following step was to search for causalities. This was done using the Granger Causality Test. The results of which are presented here.

Table A-9: Granger Causality Tests between GDP and Total Energy Consumption

Pairwise Granger Causality Tests
Date: 06/12/18 Time: 21:01
Sample: 1 15
Lags: 2

Null Hypothesis:	Obs	F-Statistic	Prob.
GDP does not Granger Cause CONSUMPTION	13	5.43903	0.0323
CONSUMPTION does not Granger Cause GDP		0.70047	0.5244

Table A-10: Granger Causality Test between annual change in GDP and Total Energy Consumption

Pairwise Granger Causality Tests
Date: 06/12/18 Time: 21:03
Sample: 1 15
Lags: 2

Null Hypothesis:	Obs	F-Statistic	Prob.
RGDP does not Granger Cause RTEC	12	0.52636	0.6124
RTEC does not Granger Cause RGDP		0.22538	0.8038

Table A-11: Least Squares Test between GDP and Total Energy Consumption

Dependent Variable: CONSUMPTION
Method: Least Squares
Date: 06/12/18 Time: 21:12
Sample: 1 15
Included observations: 15

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	19256608	1253593.	15.36113	0.0000
GDP	-38.20389	79.58417	-0.480044	0.6392

R-squared	0.017418	Mean dependent var	18657815
Adjusted R-squared	-0.058166	S.D. dependent var	469682.8
S.E. of regression	483149.5	Akaike info criterion	29.13761
Sum squared resid	3.03E+12	Schwarz criterion	29.23201
Log likelihood	-216.5320	Hannan-Quinn criter.	29.13660
F-statistic	0.230442	Durbin-Watson stat	0.336829
Prob(F-statistic)	0.639173		

Table A-12: Least Squares Test between annual change GDP and Total Enegry Consumption

Dependent Variable: RTEC
Method: Least Squares
Date: 06/12/18 Time: 21:20
Sample (adjusted): 2 15
Included observations: 14 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.010617	0.007066	-1.502494	0.1588
RGDP	0.410046	0.259209	1.581915	0.1397

R-squared	0.172554	Mean dependent var	-0.001164
Adjusted R-squared	0.103600	S.D. dependent var	0.014903
S.E. of regression	0.014110	Akaike info criterion	-5.552368
Sum squared resid	0.002389	Schwarz criterion	-5.461074
Log likelihood	40.86658	Hannan-Quinn criter.	-5.560819
F-statistic	2.502456	Durbin-Watson stat	2.002577
Prob(F-statistic)	0.139654		

Table A-13: Granger Causality Test between Electricity Consumption and GDP

Pairwise Granger Causality Tests
Date: 06/12/18   Time: 21:26
Sample: 1 15
Lags: 2

Null Hypothesis:	Obs	F-Statistic	Prob.
CONSUMPTION does not Granger Cause GDP	13	0.73345	0.5100
GDP does not Granger Cause CONSUMPTION		3.75445	0.0708

Table A-14: Granger Causality Test between annual change in Electricity Consumption and GDP

Pairwise Granger Causality Tests
Date: 06/12/18   Time: 21:28
Sample: 1 15
Lags: 2

Null Hypothesis:	Obs	F-Statistic	Prob.
REC does not Granger Cause RGDP	12	0.40400	0.6823
RGDP does not Granger Cause REC		0.86586	0.4613

Table A-15: Least Squares Test between Electricity Consumption and GDP

Dependent Variable: CONSUMPTION
Method: Least Squares
Date: 06/12/18   Time: 21:29
Sample: 1 15
Included observations: 15

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4863131.	635290.1	7.654978	0.0000
GDP	54.20632	40.33130	1.344026	0.2019

R-squared	0.122002	Mean dependent var	5712739.
Adjusted R-squared	0.054463	S.D. dependent var	251801.2
S.E. of regression	244848.3	Akaike info criterion	27.77823
Sum squared resid	7.79E+11	Schwarz criterion	27.87264
Log likelihood	-206.3367	Hannan-Quinn criter.	27.77723
F-statistic	1.806406	Durbin-Watson stat	0.410111
Prob(F-statistic)	0.201927		

Table A-16: Results from Regression Analysis between Electricity Consumption and GDP

Dependent Variable: CONSUMPTION
Method: Least Squares
Date: 06/12/18 Time: 21:37
Sample (adjusted): 2 15
Included observations: 14 after adjustments
Convergence achieved after 10 iterations

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3205816.	439692.6	7.291039	0.0000
GDP	171.4509	30.32451	5.653870	0.0001
AR(1)	1.709663	0.207392	8.243632	0.0000

R-squared	0.847096	Mean dependent var	5729062.
Adjusted R-squared	0.819295	S.D. dependent var	252937.5
S.E. of regression	107522.2	Akaike info criterion	26.19619
Sum squared resid	1.27E+11	Schwarz criterion	26.33313
Log likelihood	-180.3733	Hannan-Quinn criter.	26.18352
F-statistic	30.47023	Durbin-Watson stat	1.683683
Prob(F-statistic)	0.000033		

Inverted AR Roots	1.71
	Estimated AR process is nonstationary

Table A-17: Least Squares Test between annual change in Electricity Consumption and GDP

Dependent Variable: REC
Method: Least Squares
Date: 06/12/18 Time: 21:33
Sample (adjusted): 2 15
Included observations: 14 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.006750	0.014130	-0.477712	0.6414
RGDP	0.127253	0.518359	0.245491	0.8102

R-squared	0.004997	Mean dependent var	-0.003817
Adjusted R-squared	-0.077920	S.D. dependent var	0.027177
S.E. of regression	0.028216	Akaike info criterion	-4.166296
Sum squared resid	0.009554	Schwarz criterion	-4.075002
Log likelihood	31.16407	Hannan-Quinn criter.	-4.174747
F-statistic	0.060266	Durbin-Watson stat	0.606233
Prob(F-statistic)	0.810224		

Cape Town Regression Analysis

Cape Town's energy consumption data and GDP data was exposed to a co-integration test to investigate the relationship between energy consumption and GDP.

Table A-18: Result of Regression Analysis of Annual Total Energy Consumption on Annual GDP

Dependent Variable: GDP
Method: Least Squares
Sample: 2006-2015
Included observations: 10

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.71E+11	1.18E+11	1.441516	0.1874
CONSUMPTION	622.7151	880.7556	0.707024	0.4996

R-squared	0.058811	Mean dependent var	2.54E+11
Adjusted R-squared	-0.058838	S.D. dependent var	2.11E+10
S.E. of regression	2.17E+10	Akaike info criterion	50.61369
Sum squared residual	3.76E+21	Schwarz criterion	50.67421
Log likelihood	-251.0685	Hannan-Quinn criter.	50.54731
F-statistic	0.499883	Durbin-Watson stat	0.222868
Prob(F-statistic)	0.499625		

Null Hypothesis: RESID01 has a unit root
(where RESID01 are the residuals from this regression).
Exogenous: None
Lag Length: 0 (Automatic - based on Schwarz Information Criteria, maxlag=1)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-1.136913	0.2132
Test critical values:	1% level	-2.847250	
	5% level	-1.988198	
	10% level	-1.600140	

*MacKinnon (1996) one-sided p-values.

The residuals from the regression analysis are plotted in Figure A-9. From this figure, the stationarity of the residuals can be assessed.

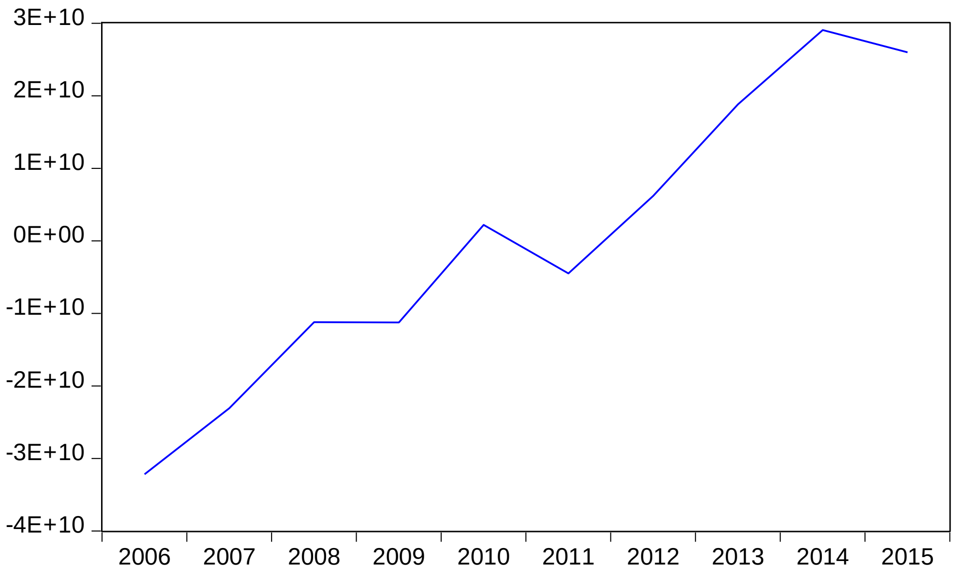


Figure A-9: Plot of Residuals of Regression Analysis 1

Figure A-9 shows that the residuals are increasing, and therefore not stationary, which indicates that the two variables GDP and CONSUMPTION are not co-integrated. The regression is therefore not valid. The regression analysis of log(GDP) on log(CONSUMPTION) was also performed and the results were similar – no meaningful relationship was found. Thus, from the regression analysis, it can be concluded that there exists no statistically significant relationship between the annual GDP and total energy consumption data that was collected.

ANALYSIS 2 (Quarterly GDP vs ELEC):

For this analysis, two regressions were performed. The first regression analysis was performed on the data as it was recorded. The second regression analysis was performed on the log of the data.

Table A-19: : Result of Regression Analysis of Quarterly GDP on Electricity (ELEC) Consumption

Dependent Variable: GDP
Method: Least Squares
Sample: 2004Q1-2015Q4
Included observations: 48

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	90770.00	81711.96	1.110853	0.2724
ELEC	0.015832	0.008834	1.792201	0.0797

R-squared	0.065268	Mean dependent var	237023.3
Adjusted R-squared	0.044948	S.D. dependent var	29574.51
S.E. of regression	28902.21	Akaike info criterion	23.42200
Sum squared resid	3.84E+10	Schwarz criterion	23.49996
Log likelihood	-560.1279	Hannan-Quinn criter.	23.45146
F-statistic	3.211986	Durbin-Watson stat	0.111687
Prob(F-statistic)	0.079679		

Table A-20: Result of Regression Analysis of log of Quarterly GDP on log of Electricity Consumpiton

Dependent Variable: LOG_GDP Method: Least Squares Sample: 2004Q1-2015Q4 Included observations: 48				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.249607	2.442567	0.102190	0.9190
LOG_ELEC	0.735351	0.350689	2.096874	0.0415
R-squared	0.087245	Mean dependent var		5.371334
Adjusted R-squared	0.067403	S.D. dependent var		0.056004
S.E. of regression	0.054084	Akaike info criterion		-2.955798
Sum squared resid	0.134552	Schwarz criterion		-2.877831
Log likelihood	72.93915	Hannan-Quinn criter.		-2.926334
F-statistic	4.396879	Durbin-Watson stat		0.143622
Prob(F-statistic)	0.041532			

with residuals RESID02

A plot of the RESID02 with a Dickey-Fuller unit root test to check the stationarity of the residuals follows.

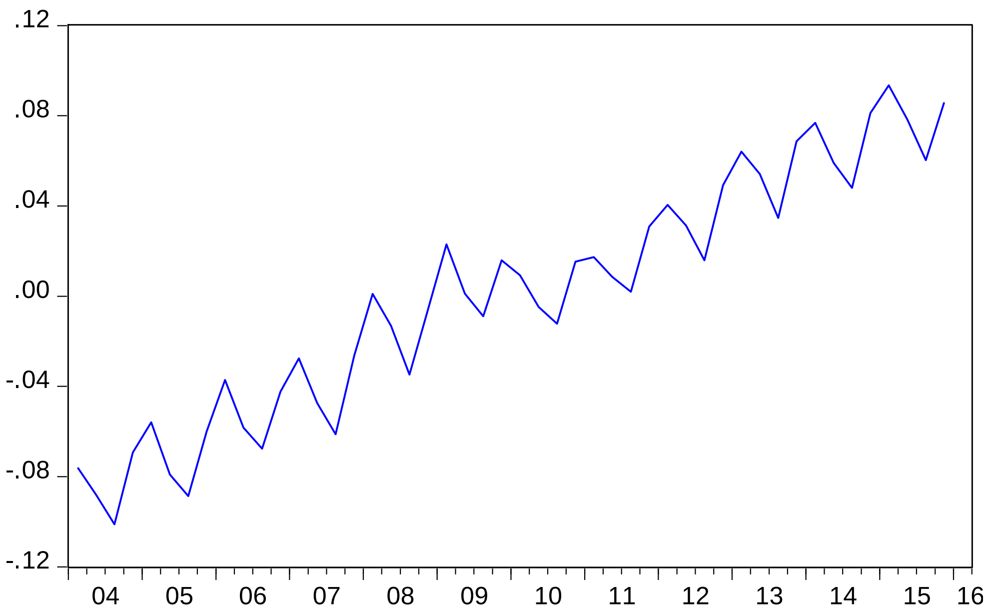


Figure A-10: Plot of Residuals of Regression Analysis 2

Table A-21: Results of Dickey-Fuller unit root test

Null Hypothesis: RESID02 has a unit root Exogenous: None Lag Length: 4 (Automatic - based on SIC, maxlag=9)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-0.470802	0.5057
Test critical values:	1% level	-2.619851	
	5% level	-1.948686	
	10% level	-1.612036	
*MacKinnon (1996) one-sided p-values.			

Both residuals are non-stationary showing that the regressions are not valid. The GDP and ELEC are not co-integrated, and similarly log(GDP) and log(ELEC) are not co-integrated. Thus these regressions are not valid. Therefore the conclusion can be made that no statistically significant relationship exists between quarterly electricity consumption and economic performance, for the period recorded.

ANALYSES 3 (Quarterly GDP VS ENERGY):

Only the log variables are analysed, they are more comparable.

Table A-22: Result of Regression Analysis of log of Quarterly GDP on log of Energy Consumpiton

Dependent Variable: LOG_GDP
Method: Least Squares
Sample: 2010Q1-2015Q4
Included observations: 24

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.416166	0.412018	5.864223	0.0000
LOG_ENERGY	0.396276	0.054441	7.278999	0.0000

R-squared	0.706603	Mean dependent var	5.415185
Adjusted R-squared	0.693267	S.D. dependent var	0.023176
S.E. of regression	0.012836	Akaike info criterion	-5.793507
Sum squared resid	0.003625	Schwarz criterion	-5.695335
Log likelihood	71.52208	Hannan-Quinn criter.	-5.767462
F-statistic	52.98383	Durbin-Watson stat	0.759771
Prob(F-statistic)	0.000000		

The Durbin-Watson test statistic is far from 2, which shows that the residuals RESID02 are autocorrelated and not white noise.

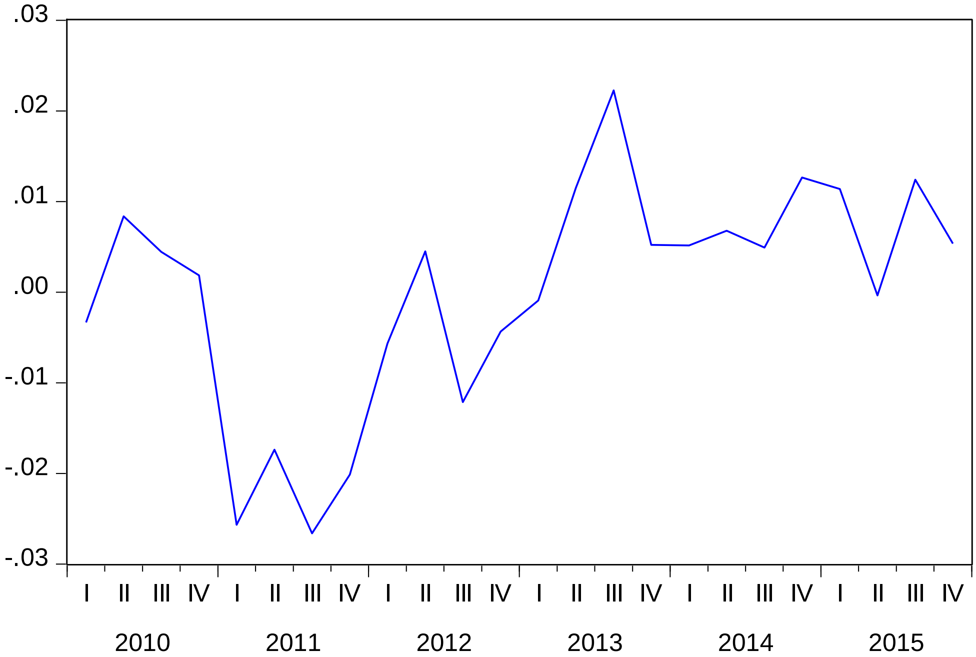


Figure A-11: Plot of Residuals of Regression Analysis 3

A Dickey-Fuller unit root test of the residuals shows that these residuals are stationary, since the null-hypothesis of a unit root is rejected, so the two variables log(GDP) and log(ENERGY) are co-integrated and the regression relationship can be investigated further.

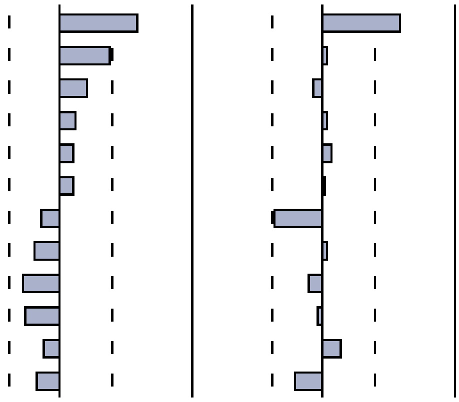
Table A-23: Dickey Fuller test on Residuals from Analysis 3

Null Hypothesis: RESID02 has a unit root
Exogenous: None
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.264425	0.0256
Test critical values:	1% level	-2.669359	
	5% level	-1.956406	
	10% level	-1.608495	

*MacKinnon (1996) one-sided p-values.

To identify the autocorrelations structure of the residuals, a correlogram of the autocorrelations and partial autocorrelations of the residuals RESID02 are given below. This shows a clear indication of a possible autoregressive model, potentially AR(1).



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.615	0.615	10.249	0.001
		2	0.400	0.036	14.796	0.001
		3	0.212	-0.077	16.127	0.001
		4	0.127	0.025	16.631	0.002
		5	0.114	0.069	17.059	0.004
		6	0.105	0.018	17.443	0.008
		7	-0.143	-0.380	18.189	0.011
		8	-0.194	0.029	19.661	0.012
		9	-0.281	-0.100	22.955	0.006
		10	-0.268	-0.043	26.162	0.004
		11	-0.132	0.148	26.999	0.005
		12	-0.184	-0.221	28.764	0.004

Regression fitted with AR(1) model:

Table A-24: Least Squares analysis between Energy

Dependent Variable: LOG_GDP
Method: ARMA Conditional Least Squares
Sample (adjusted): 2010Q2 2015Q4
Included observations: 23 after adjustments
Convergence achieved after 6 iterations

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	5.657739	0.135300	41.81626	0.0000
LOG_ENERGY	-0.020149	0.016496	-1.221415	0.2361
AR(1)	0.965172	0.018201	53.02829	0.0000

R-squared	0.992454	Mean dependent var	5.416912
Adjusted R-squared	0.991699	S.D. dependent var	0.022062
S.E. of regression	0.002010	Akaike info criterion	-9.460208
Sum squared resid	8.08E-05	Schwarz criterion	-9.312100
Log likelihood	111.7924	Hannan-Quinn criter.	-9.422959
F-statistic	1315.161	Durbin-Watson stat	2.348603
Prob(F-statistic)	0.000000		
Inverted AR Roots	.97		

Table A-25: Least Squares Analysis between log Energy Consumption and log GDP

Dependent Variable: LOG_GDP
Method: ARMA Conditional Least Squares
Sample (adjusted): 2010Q3 2015Q4
Included observations: 22 after adjustments
Convergence achieved after 11 iterations

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	5.743890	0.149558	38.40589	0.0000
LOG_ENERGY	-0.030456	0.019096	-1.594888	0.1281
AR(1)	0.701473	0.237395	2.954877	0.0085
AR(2)	0.257108	0.229908	1.118312	0.2781

R-squared	0.991786	Mean dependent var	5.418556
Adjusted R-squared	0.990417	S.D. dependent var	0.021090
S.E. of regression	0.002065	Akaike info criterion	-9.364865
Sum squared resid	7.67E-05	Schwarz criterion	-9.166494
Log likelihood	107.0135	Hannan-Quinn criter.	-9.318135
F-statistic	724.4954	Durbin-Watson stat	1.983443
Prob(F-statistic)	0.000000		

Inverted AR Roots	.97	-.27

The latter model's residuals are closer to white noise than the previous mode. The ACFs and the PACFs of this model is included. The Ljung-Box_Pierce test at all lags are insignificant, thus the residuals are white noise indeed. The Schwarz criterion is smaller than for any of the two previous models and thus this is a better fit.

Note that the fitted regression equation is now:

$$ln(\widehat{GDP}) = 5.74389 - 0.030456 * ln(ENERGY)$$

The variation in log_GDP is much more due to the autoregression than its (insignificant) dependence on log_ENERGY. In other words, log_GDP is more dependent on previous values of log_GDP than what it is on log_ENERGY. This means that although a relationship does occur between log_GDP and log_ENERGY, it is not strong enough to base forecasts of future values of log_GDP on. Furthermore, this analysis looked at the log of the variables, which were more comparable than the actual variables. Therefore, it can be concluded that no statistically significant relationship has been found between any of Cape Town's available energy and economy metrics.

Barcelona Regression Analysis

This analysis was concerned with finding potential correlations and causalities between:

1) Energy consumption (GJ) and economic performance (GDP)
2) Electricity consumption (GWh) and economic performance (GDP)

The first step of this analysis was to plot the variables in a scatterplot. The first section allowed for a non-linear regression relationship, whereas the second section only considered linear relationships.

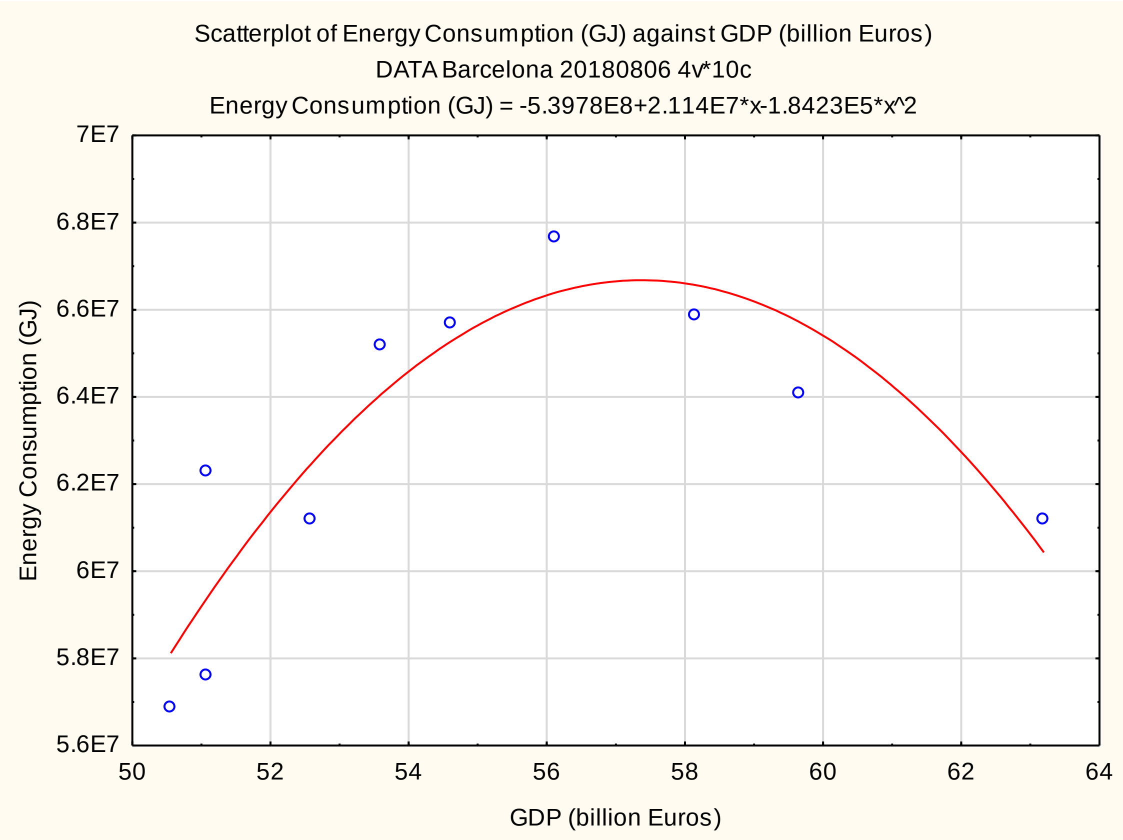


Figure A-12: Scatterplot of Energy Consumption (GJ) against GDP (billion Euros)

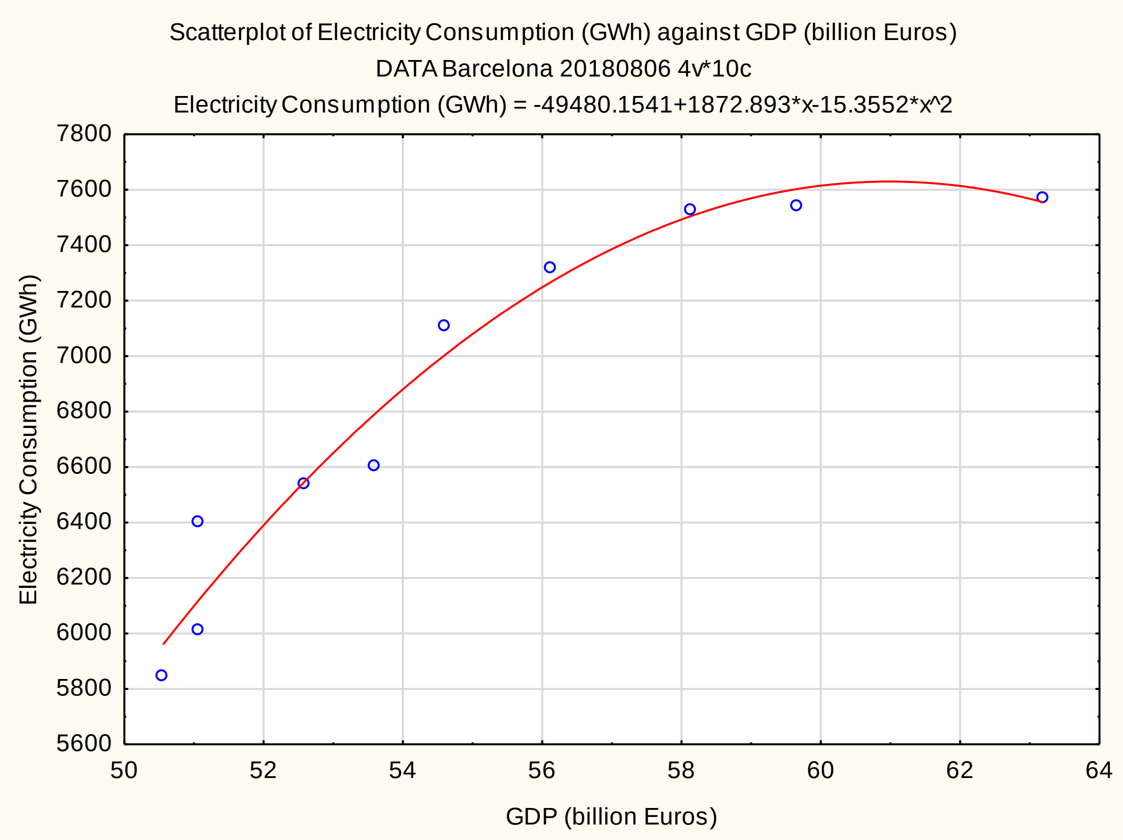


Figure A-13: Scatterplot of Electricity Consumption (GWh) against GDP (billion Euros)

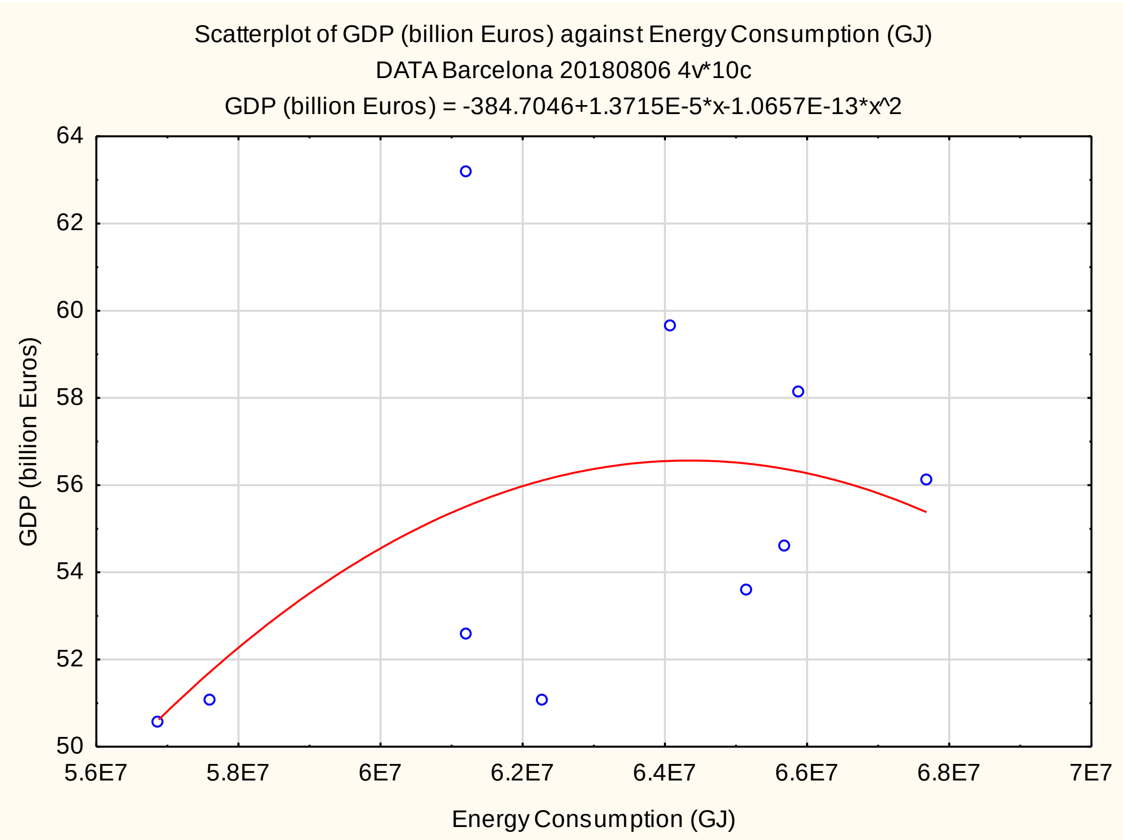


Figure A-14: Scatterplot of GDP (billion Euros) against Energy Consumption (GJ)

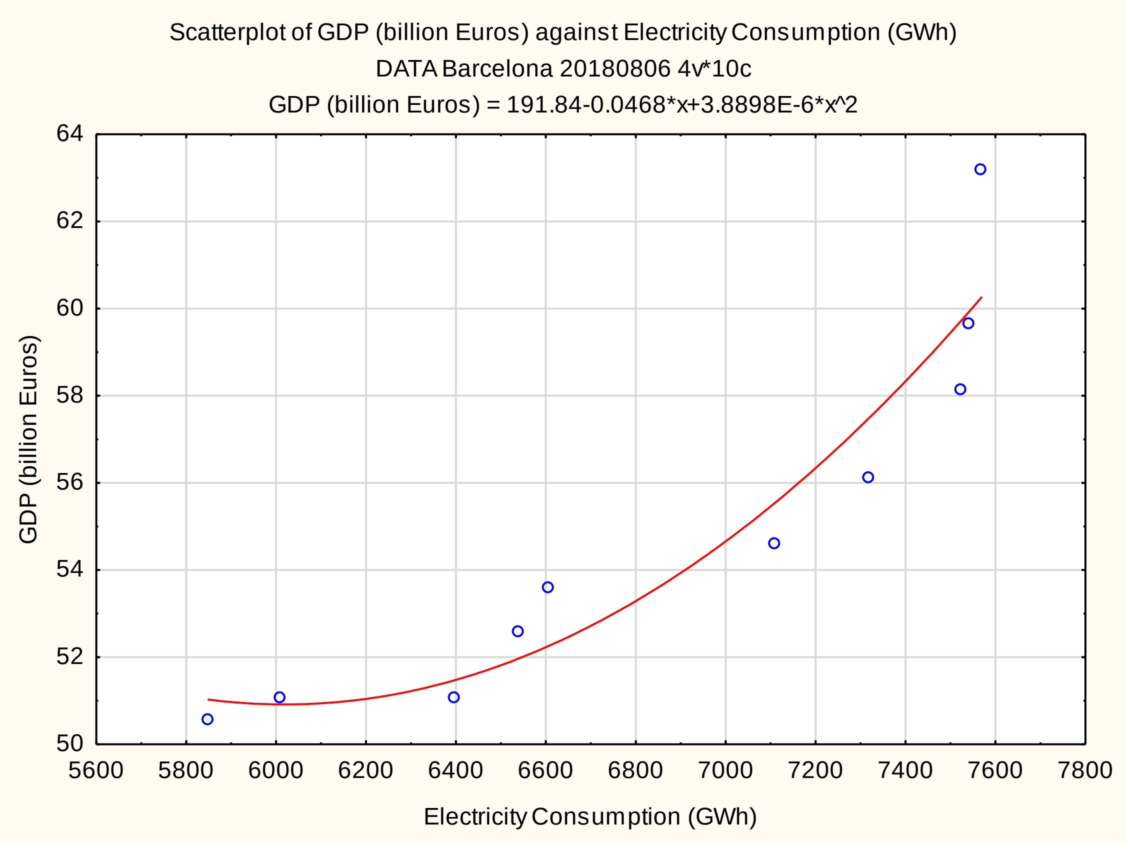


Figure A-15: Scatterplot of GDP (billion Euros) against Electricity Consumption (GWh)

This section plots the linear regression relationships between the variables of interest.

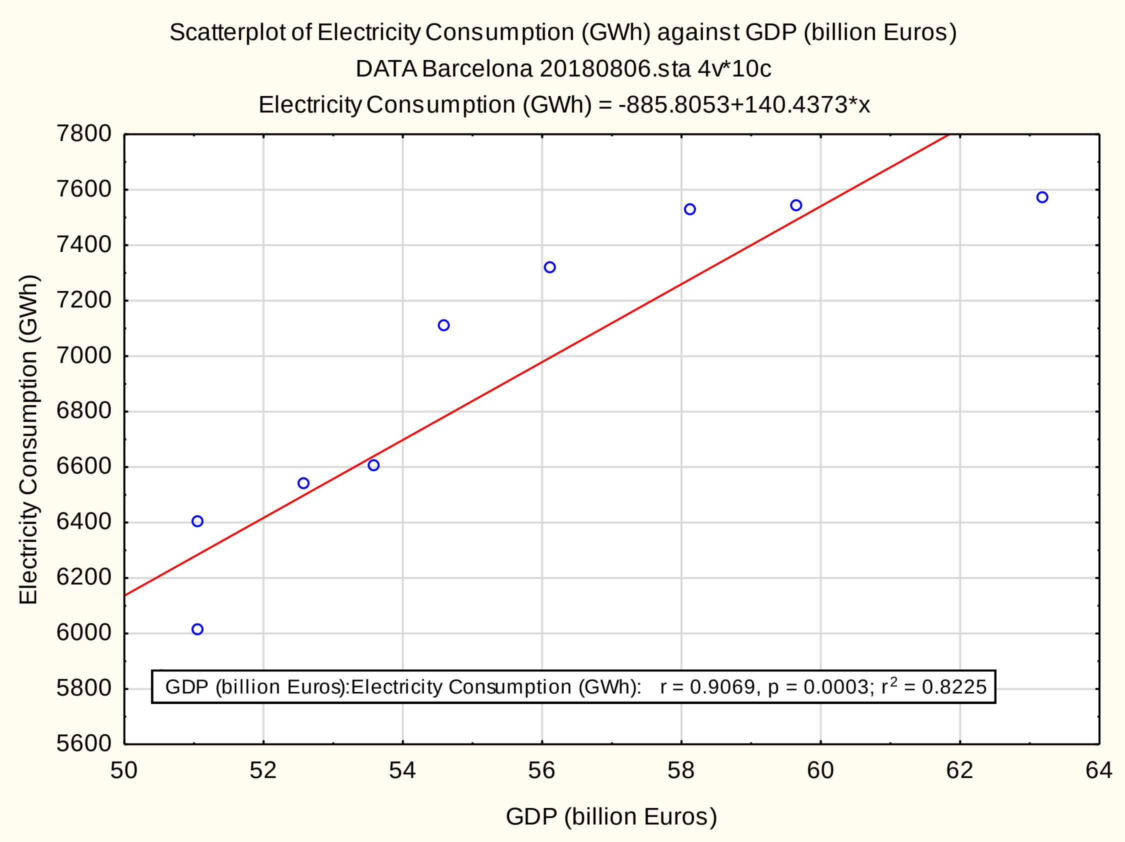


Figure A-16: Scatterplot of Electricity Consumption (GWh) against GDP (billion Euros)

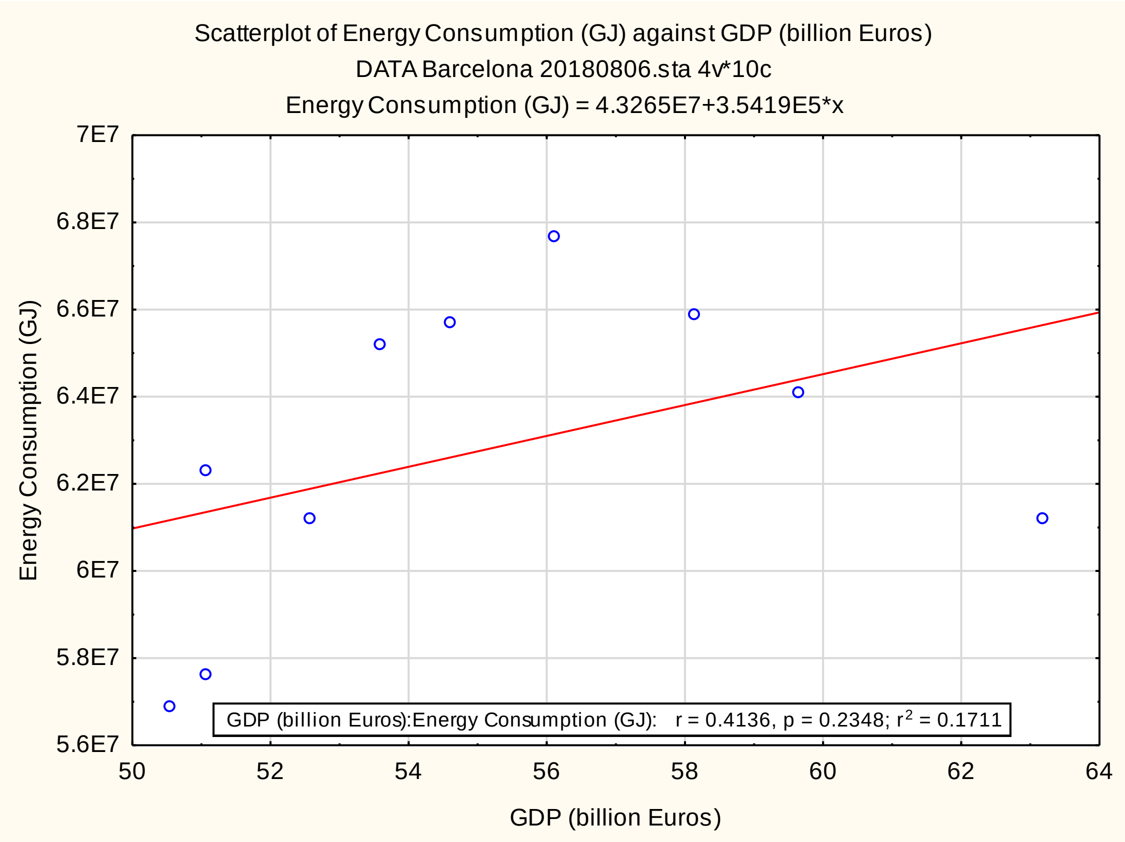


Figure A-17: Scatterplot of Energy Consumption (GJ) against GDP (billion Euros)

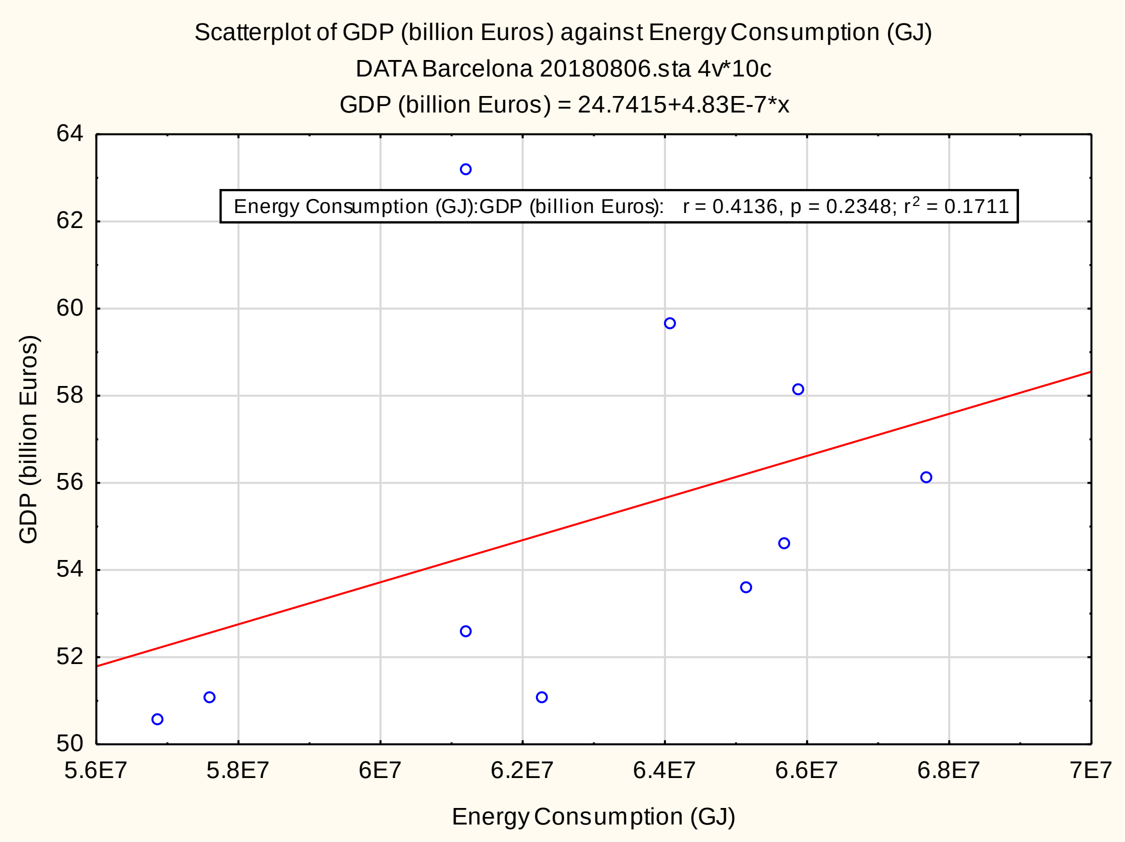


Figure A-18: Scatterplot of GDP (billion Euros) against Energy Consumption (GJ)

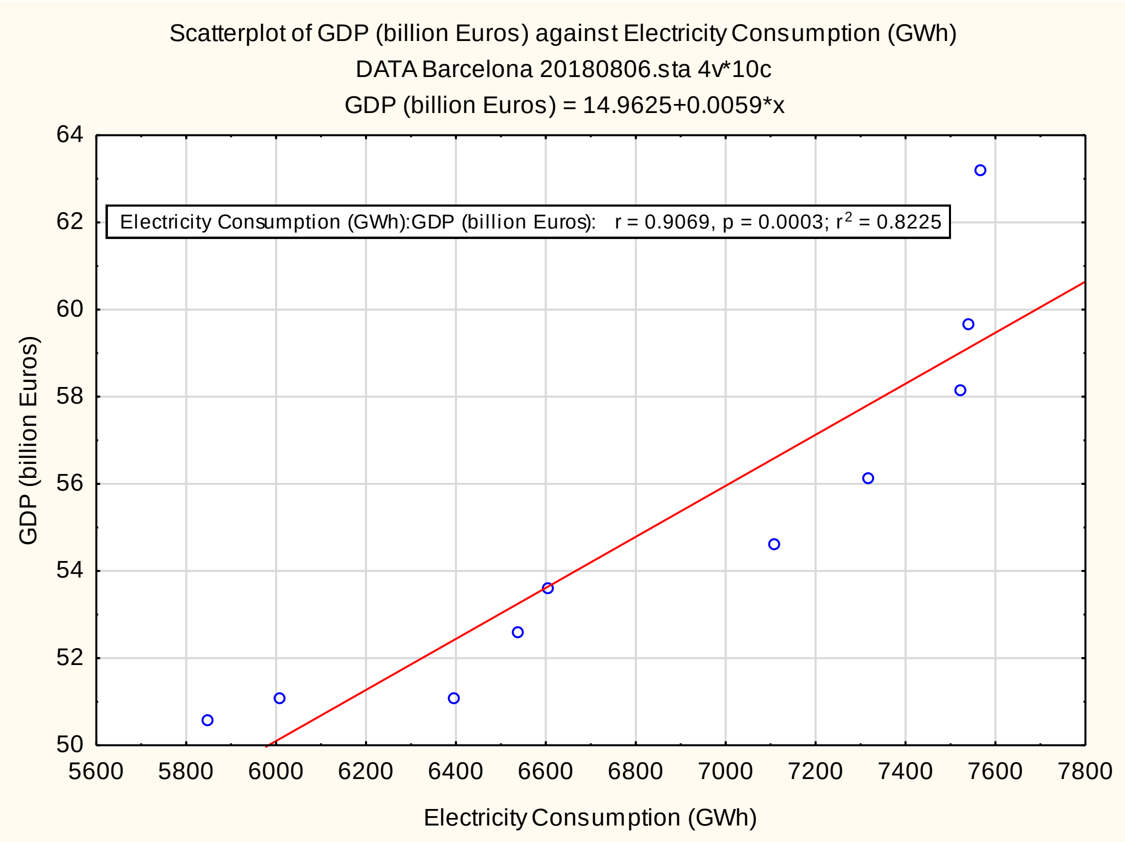


Figure A-19: Scatterplot of GDP (billion Euros) against Electricity Consumption (GWh)

Table A-26: Correlations between Barcelona's Energy and Economy metrics

Variable	Correlations (DATA Barcelona 20180806.sta) Marked correlations are significant at p < .05000 N=10 (Casewise deletion of missing data) GDP (billion Euros)	Energy Consumption (GJ)	Electricity Consumption (GW
GDP (billion Euros)	1.0000	.4136	.9
	p= ---	p=.235	p=.
Energy Consumption (GJ)	.4136	1.0000	.7
	p=.235	p= ---	p=.
Electricity Consumption (GWh)	.9069	.7270	1.0
	p=.000	p=.017	p=

Table A-27: Spearman Rank Order Correlations between Barcelona Energy and Economy

Pair of Variables	Spearman Rank Order Correlations (DATA Barcelona 20180806.sta) MD pairwise deleted Valid N	Spearman R	t(N-2)	p-value
GDP (billion Euros) & Electricity Consumption (GWh)	10	0.996965	36.22154	0.000000
Energy Consumption (GJ) & GDP (billion Euros)	10	0.536585	1.79854	0.109797
Energy Consumption (GJ) & Electricity Consumption (GWh)	10	0.553194	1.87824	0.097169

Table A-28: Granger Causality Tests between Energy consumption and GDP

Pairwise Granger Causality Tests
Date: 08/06/18 Time: 12:13
Sample: 1999 2008
Lags: 2

Null Hypothesis:	Obs	F-Statistic	Prob.
GDP does not Granger Cause ENERGY	8	3.70269	0.1548
ENERGY does not Granger Cause GDP		0.04027	0.9610

Table A-29: Granger Causality Test between Electricity Consumption and GDP

Pairwise Granger Causality Tests
Date: 08/06/18 Time: 12:11
Sample: 1999 2008
Lags: 2

Null Hypothesis:	Obs	F-Statistic	Prob.
ELECTRICITY does not Granger Cause GDP	8	0.95781	0.4768
GDP does not Granger Cause ELECTRICITY		0.05857	0.9442