SMART URBAN DEVELOPMENT SUITABILITY ANALYSIS BASED ON POWER UTILITY INFRASTRUCTURE CAPACITY: A CASE OF CITY OF JOHANNESBURG

Minor Dissertation

by

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Declaration

I hereby declare that this thesis is my own original work, and to the best of my knowledge has not been presented or published in any other institution. All materials obtained from other sources are duly acknowledged.

Signed: ________________________________ Date: ________________________

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Abstract

The assessment and understanding of spatial energy patterns play a critical contribution for the overall planning of smart-energy efficiency solutions within cities. This study therefore seeks to project a model that structures the City of Johannesburg's planning efforts to practice smart spatial energy initiatives of optimization and efficiency regarding the power utility sector in relation to the city growth. In doing this, the background pertaining to the city's efforts in adopting smart energy principle was key in overseeing the general status quo and exertions. Overlapping from this was the assessment of the synergy between land use and form with spatial energy. Using three time-series satellite scenes (Landsat TM (2000 and 2008) and ETM+ (2017)), clarification pertaining to how the city had developed in relation to the spatial energy was possible and key as the projection of where future growth was most likely to take place, was invigorated and to an extent, informed the subsequent modelling analysis. The analysis of the data revealed the efforts of the city in attaining smart energy principles, however, these efforts lack institutional support across all spheres. Additional analysis regarding the synergy of land use and built form in relation to the city's spatial energy point out to how the majority of the built form within Region F is under-capacitated. Most of the densified land uses are central – with Region D accounting the most. This has serious implications regarding future energy supply and demand dynamics that the city has to address. The model with the urban growth projection for the year 2047 was generated using the IDRISI software. This served as a functional framework for the model and the growth generated was predominantly densely central and located towards the northern regions where access to power was abundant and efficient. The overall findings of the research seek to provide contributions to the field of urban planning in understanding the dynamics between spatial energy and urban growth.

Key words: Urban growth, smart energy, remote sensing, urban development, urban growth projection.

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Analytic Hierarchy Process	AHP
Carbon Dioxide	Co2
City of Johannesburg	CoJ
Fourth Industrial Revolution	4IR
Geographic Information Systems	GIS
Growth Development Strategy	GDS
Internet of Things	IoT
Information and communications technologies	ICT
Multi-Terminal Substation	MTS
Open Street Map	OSM
Relative Operating Characteristic	ROC
Remote Sensing	RS
Spatial Autoregressive Model	SAR
Spatial Autoregressive Model	SAR
Sustainable Development Goals	SDG
University of Johannesburg	UJ
Urban Energy Systems	UES

Contents

Chapter 1: Introduction

1.1. Background

The concept of a smart city has relatively dominated the urban sphere and is rapidly being adopted in developing countries like South Africa, Kenya, Brazil, Nairobi, Botswana, Nigeria, Rwanda etc. Most of the initiatives cut across a variety of fields and are generally interlinked with a common idea of smartization - with reference to dealing with challenges associated with urbanization and the ever-incremental population growth, climate change, and energy supply and demand.

The overall smart city initiative aims at the optimization of available resources while significantly offering a considerably high quality of life to city inhabitants (Jain and Subbaiah, 2007). Dirks et al. (2010) note how the concept is innovatively-linked to tenets such as Information and Communications Technology, Integrated Operations, Big Data development, and overall analytical software related to Geographic Information Systems and Remote Sensing.

Such innovation aims to bridge urban issues experienced; particularly the occurrence of urbanization at a rapid pace. Consequently, energy deficiency and increased environmental degradation suffice as demand remains exponential. According to research by Seto et al. (2017), modern cities have become the major giants responsible for the overall global energy consumption – standing at two thirds of the total production. Ultimately, expectations regarding shifts in the energy production and consumption is high as each development has its own demand and carbon footprint contribution.

With this, cities are, according to Haase and Nuissl (2010) regarded as "*economic engines*" of each nation. Because of this, policies should not only focus on urbanization and ways to curb it but should also look into how the electrical utility sector balances out with development. Although this would be a good initiative, Giarrusso (2003) notes how the integration poses challenges as urbanization far outstrips the expansion of utilities along with the planning processes and facilitation of infrastructure.

It is then of prime importance that urban growth projections along with informed utility assessments are conducted on a regular basis to facilitate sustainable urban growth policies and strategies as a mode to mitigate chronic developmental impacts. This is key to planners as tools that can assist in measuring and monitoring the electrical utility sector with reference to suitable future developments to result in improved understanding and rationalized decision-making.

1.2. Problem Statement

The City of Johannesburg is experiencing a growth rate of 3.11% with an estimated population of 5.63 million for the year 2019 (Statistics South Africa, 2019; United Nations World Urbanization Prospect Report, 2019). The population has increased by 650,000 from 4.98 million in 2015 despite the population growth having decreased by 0.13% (United Nations World Urbanization Prospect Report, 2019).

The city is largely facing some burdens in Urban Energy Systems (UES). This is reflected by load-shedding issues being experienced as the ever-increasing urban growth demand strains the limited energy services of coal production. According to the United Nations Human Settlement Program (2019), the aggregate energy demand by global cities can go as far up as 70% in the next 40 years. This is likely to happen given the high consumption of UES; contributing to a non-surprising figure of 80% regarding global carbon emissions (European Commission, 2019).

The high level of urbanization and haphazard developments play a critical role in fostering climate change (Bai, 2007). The recently adopted New Urban Agenda (NUA) does outline on issues of sustainability, particularly the theme on energy and resilient, sustainable cities, however, lacks the road map on the overall implementation of the agenda.

Additional roadmaps and strategies have been suggested (*see* Local Agenda 21) on themes such as renewable energy usage, distributed energy production, and area energy network to mention a few, as initiatives for smart energy production and consumption. However, most of these themes at a city level are not spatially harmonious as some address the energy issue differently (e.g. Waterfall City solar roof initiatives), signifying a lack of synergy in the image of the city at an institutional level.

Most of these issues, as observed, are commonly addressed and understood from a framework that enables regional competition instead of combined growth. This results in various energy initiatives and development approaches being adopted irrespective of exclusivity and compatibility. It is thus, the purpose of the research to study and evaluate how future developments can benefit from structured and planned urban electrical utilities.

1.3. Preliminary Review

1.3.1. GIS applications on overall land and power utility suitability studies

Urbanization and the subsequent development have always been the issue world cities experience due to economic and population growth (Britter and Hanna, 2003; Burgi et al., 2004) – birthing an argument between conservation and development as the ecological aspect of the environment is substituted for developmental growth.

Given this dire situation, policies and strategy formulation have come and go, however, not much is done as the demand remains uncapped. But then, there lies no purpose if infinite development is based on finite resources (Baynes and Bai, 2009). The policies and strategies are long-term based and the setback within their framework is their independence on a variety of sectoral issues. Usually, the application of technological tools (GIS, Remote Sensing etc.) and sets are utilized to address this problem in the linkages of various concepts.

The linkages have opened up opportunities on the simulation/projection of urban growth patterns in city regions and has thus become an important component in developing settlements in a sustainable manner (Ramachandra and Uttam, 2004). This opportunity requires a variety of factors and disciplines (i.e. urban planning, geography, energy etc.) to be understood to provide a holistic picture.

Crosetto et al. (2000) refer suitability analysis as an important aspect for understanding urban growth. Delgado and Sendra (2009) refer to it as a technique that involves multiple locations suitable for development to select from. All this is based on the type of criteria and weight stipulated in the suitability model that reflects the compatibility index of the region. This is done through GIS and other techniques, which assist in successfully monitoring and controlling potential changes and impacts of developments on the environment.

Dietzel et al. (2005) for instance, applied the statistical tool of the binary logit model to help project the likeliness of certain land use types on an overlaid utility grid network. This was done to assess the compatibility of land uses and is similar to Doygun et al. (2008)'s study on the analysis on residential land use change with reference to the electrical grid system with the application of the logistic model. The techniques are similar; however, most are statistically based to assess the chance of achieving certain results.

In summary, the literature reviewed indicates that suitability studies for urban growth has specific and detailed site prerequisites. However, issues of data acquisition that goes into the model for other specific regions may pose a problem and as such, the employment of different conditions suffices. In this case, other studies (Benke and Pelizaro 2010) apart from the statistical indices, utilize themes such as urban facilities with reference to urban utilities (power stations, sub-stations etc.) as well as the Bid-Rent theory as essential variables that inform urban growth projections regarding urban development.

1.3.2. Urban development growth forecast studies

Similar to the power utility suitability, urban growth forecast studies take into consideration future related aspects of the overall growth of cities. As such, Giarrusso (2003) posits how a detailed spatiotemporal analysis is key in the evaluation of various urban growth typologies at both local and regional levels.

This evaluation assists local planning initiatives to oversee active areas prone to rapid urbanization. With this, policies regarding urban growth can be drafted as a mechanism to regulate upcoming developments to be aligned within the power utility and resource carrying capacities. This information is essential in the allocation of fiscal capacitation as well as adherence to the overall concept of sustainability through modelling (Burgi et al., 2004).

In modelling future urban growth, a variety of expansion metrics are employed. For instance, Glaeser and Kahn (2004) conducted a study in Mangalore, India, using the city's built-up density, patchiness as well as entropy facilitated by regression analysis to forecast the urban sprawl the city will face. Similar to this, Hayek et al. (2011) equally utilized entropy, however, focused on site metrics to project the city expansion of cities in

Ajmer. The site metrics as compared to regression analysis differ as one is statistically-inclined whereas site metrics consider spatial features.

The implication of the scholars' findings indicate that projected growth is most likely to be located near existing city centers where high density fosters. This makes sense given the spatial attributes being used in the model structure. With this, an assumption can be drawn that there is a direct spatial-correlation to land use and utilities. Coppin et al. (2004) presented a similar study using the spatial autoregressive (SAR) model to justify this assumption.

The assumption was validated; however, the setback is that the variables selected are not random and renders the parameters estimated to have consistency. Geymen and Baz (2008) suggest the appropriate formulation and integration of external variables to avoid bias on the parameters estimated. Also, with reference to the electrical grid network having direct influence on the overall urban development, it is therefore imperative to incorporate it as the explanatory variable in urban growth projections.

1.3.3. Smart energy utility in cities

Energy utilities are pivotal in any city formation and development. However, constantly rising energy prices, depletion of resources due to urbanization, land mismanagement, and incremental carbon footprints are major issues local authorities struggle to curb in their discourse towards smart cities.

Recent studies (Dirks and Keeling, 2009) indicate that the adoption of smart energy principles provide the potential to manage the above challenges. This relates to the usage of innovative measures like smart sensors, smart meters, renewal energy sources, automation, and optimization of energy that is distributed throughout the urban grid.

In this case, this reflects smart energy as initiatives that meet the urban energy demands in the most environmentally (clean) and economically (cost-effective) sustainable manner. This is critical in future developments as Al-Hader et al. (2009) note the potential of smart energy infrastructure relative to microgrids, energy storage, automated demand response, electric vehicles, and virtual power plants.

These are smart energy elements that local authorities need to take into consideration in conjunction with urban growth. They offer a multitude of intelligent energy distribution across the urban grid and provide features such as the visualization of energy consumption patterns (Bai et al., 2010). This can assist in formulating interactive-based energy monitoring systems that seek to improve power utility efficiency in the city.

Smart Grids as a smart energy infrastructure according to Al-Hader et al. (2009) are already being distributed and implemented in developing and transitional countries. For instance, India (Dirks et al., 2009) has a Smart Grid project that is inclusive of street light automation, outage management system, virtual demand response, as well as advanced metering that can detect faulty lines and wastage. Associated benefits relate to lower maintenance costs, energy optimization and efficiency, managed transmission and distribution, informed load forecasts, low carbon footprint, renewal energy source compatibility, and energy conservation.

1.4. Research Aim

To project a model that structures the City of Johannesburg's planning efforts to practice smart spatial energy initiatives of optimization and efficiency regarding the power utility sector.

1.5. Research Objectives

- Reviewing smart energy infrastructure development at a city level;
- Determining the relationship between urban land use, built form, and energy consumption;
- Assessing the city's past-current urban development and growth pattern in relation to energy demand and supply dynamics; and
- Extrapolating an urban development suitability growth model based on the power utility infrastructure 30 years from the year 2017.

1.6. Research Questions

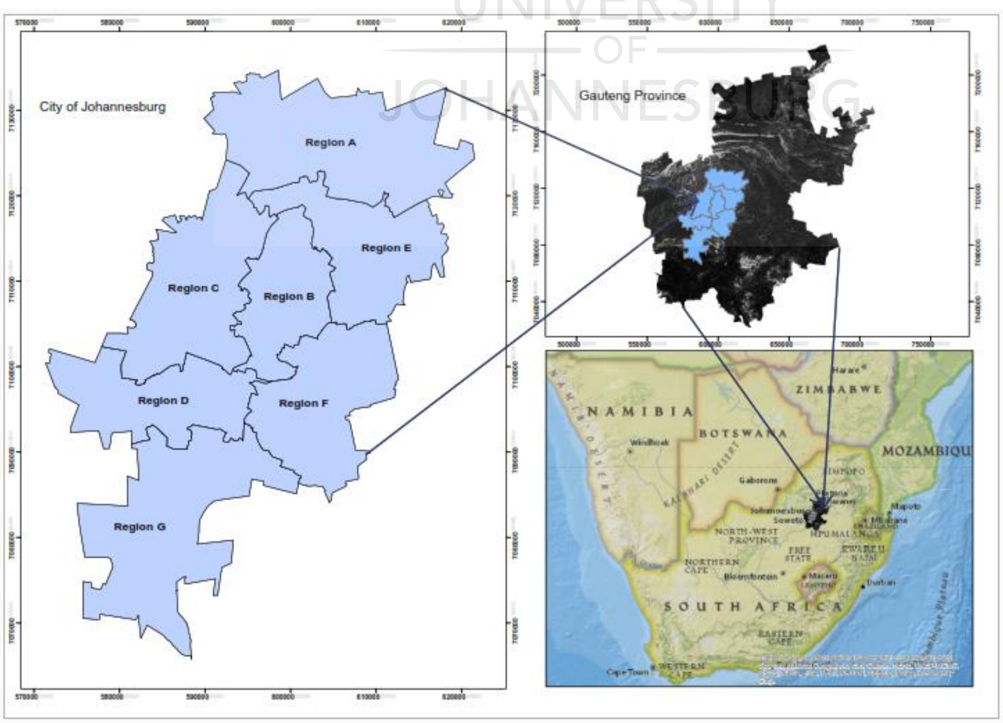
- What forms of smart energy infrastructure exists in CoJ?

- What is the demand and supply dynamics in energy sector for the city looking like?
- What is the overall influence of the energy utility in relation to the residential, commercial, and industrial land uses within the city?
- How is the nature of CoJ’s development with reference to its spatial energy over the period of 17 years?
- Where will the desired future urban growth stem from considering the power infrastructure in relation to other growth elements?

1.7. Study Area

The City of Johannesburg, according to the 2018/2019 Integrated Development Plan, has an approximate population of 4.9. million with a population growth of 2.3%. The city has a population density of 2900 sqm and is mostly characterized by temperate weathers. The city is a metropolitan with major economic activities focusing on financial and business sectors. Because of the incremental population growth, smart city initiatives regarding efficient energy usage and growth need to be aligned and resourcefully managed in a sustainable manner.

Figure 1: The City of Johannesburg



1.8. Research Design

A research design, according to Okoto (2016) can be defined as the conditions for which data is collected and analyzed with an objective to relate the purpose of the research with the adopted procedure. In this sense, the study involves a variety of methods to collect and analyze the information.

With regards to the designs available (case study, experimental, statistical, modelling, evaluative), a cross-multiple synergy between them can be established. The research employed both the modelling and evaluative design to conduct the research.

The hybrid approach was a prevalent method in carrying out this research as it encapsulated both Remote Sensing and GIS with spatial and satellite data as units. The modelling design relates to the formation of logical deductions and results stemming from the numerical data collected, ordered, and analyzed. The evaluative design addressed the limitations experienced from employed quantitative techniques through the provision of an ability to understand interactive conditions through the perspective of the researcher (Winner, 2009; Yin, 1984).

1.9. Research Methodology

The research employs both quantitative and qualitative aspects of research to conduct the study. Quantitative analysis provided an atmosphere where statistical and mathematical modelling of the urban growth forecasts was done whereas qualitative analysis informed the elements/attributes behind the modelling. This expanded further into the type of prognostic strategy that was used to project growth, i.e. (theoretical Analytic Hierarchy Process).

1.9.1. Data Collection Methods

This refers to the tools employed in the process of collecting information specific to the inquiry of the research (Okoto, 2016). GIS and RS data for Johannesburg on urban development and power utility within the city was obtained from government departments and associated online institutions (e.g. OpenStreetMap data, Digital Globe, Johannesburg City Power, and Johannesburg GIS Department). Secondary information regarding the evaluation of energy consumption in comparison to the land uses will be employed from credible sources such as the University of Johannesburg Library, scholarly articles, and published reports, and journals.

1.9.2. Data analysis

The utilization of the GIS software ArcGIS 10.5 and the Remote Sensing application IDRISI 17.00 was used in the analysis of data. Modelling in conjunction with the theoretical Analytic Hierarchical Process was key in understanding the desired growth projection. This provided a platform for both qualitative and quantitative multi-criteria data interpretation. The data presentation was adequately visualized as the software provided such capabilities through overlaying functions and presentation of critical information.

1.9.3. Data Validity

Data validity denotes to the procedures taken to validate whether the data collected is factual and reliable (Winner, 2009). In assuring data validity, GIS and Remote Sensing data collected was from recognized physical and online intuitions such as the CoJ municipality, Digital Globe, and Johannesburg City Power. The data was further checked to determine the correctness of the location by checking the georeferenced details whether the data procured corresponded to the urban features present on the map as per the IDRISI validation process.

1.10. Limitations

The only power utility used in the analysis is the available electrical infrastructure for the year 2017 provided by Eskom. By this, the study does not look into other sources of energy such as solar, wind, or hydro. The urban growth forecast under which the projection of the future development was entirely based on municipal-owned land. This was to align the findings and deductions to be under the metropolitan's jurisdiction and ownership.

1.11. Chapter outline

Chapter 1: Research proposal

An overview of the proposed research at hand is presented. The intention of the research is to portray a variety of analyses that range from land use analyses to urban modelling in relation to urban energy within the City of Johannesburg. The planned approach on how to attain the set objectives of the research are briefly are highlighted along with the framework of the preliminary literature that guides chapter 2.

Chapter 2: Literature review

A comprehensive review of brief scholarly literature looking into the existing knowledge base found to be relevant and significant to the overall study is discussed. The knowledge referred to reflects multiple disciplines centered on urban energy systems, forecast studies, urban growth and development, land-use/development synergy, urban form, energy pattern dynamics, and techniques involved in urban growth forecasting. Overall, the topics covered are guided by the established research questions set in chapter one to outline the key issues and discussions in the field.

Chapter 3: Research design and methodology

A central role in the establishment of the salient components that comprises of both the primary and secondary data collection procedures followed in carrying out the research analyses is played by chapter 3. The study's adopted research design and methodology and the the logic behind broad methods and techniques used in this research is highlighted.

Chapter 4: Analysis

The analytical discussion of the city's efforts in the adoption of the smart power utility infrastructure throughout its regions is discussed in this section. A broad status quo on the smart power application at a city level is provided. This is followed by a review of key primary legislations that influence smart energy utility development along with the key energy authority responsible for the city's power sector. The discussion on the empirical energy initiatives undertaken within the city is also addressed.

The following subsection discussed the synergy between different land-uses and the power utility within the city. The analysis is centered on density, form, demographics, use, spread, and form to assess the overall relationships.

The third subsection provides a brief overview of how the power coverage has spatially spread out throughout the city from the period 2000 to 2017. The main goal was to provide a basis for the model formulated and offer a broad understanding of how development in relation to spatial energy has evolved through time during the 17 years under focus.

The final section touches on aspects of suitability analysis in which the city's urban growth is projected from the year 2017-2047 (30 years) in relation to the power utility. The future growth was derived, followed by a suitability analysis that was theoretically generated. This subsection is therefore pivotal and assess how the city's growth is like in the future to realize where the desired suitable growth should take place relative to the considered factors.

Chapter 5: Conclusion

An overview and summary of the minor dissertation is presented, which is then followed by recommendations directly linked to the findings on the preceding chapters. In wrapping up the paper, a review of the main methodology that was adopted is discussed along with its implication for the study.

1.12. Conclusion

This research aims to highlight the importance of geospatial energy in the forecast of potential urban developments within the confines of sustainable development. In doing so, the intention of the research is to present a variety of analyses that range from land use analyses to urban modelling as planning sustainable developments primarily depends on the utilization of urban energy data which provide a scientifically-inclined framework for the overall design of resilient urban infrastructures and policies as aligned with SDG-11 and other agendas.

Moreover, the accuracy in modelling assists in providing policy makers and urban planners an overall depiction of suitable urban development aligned with sufficient energy provision in the attainment of clean and sustainable UES (Hu et al., 2012; Mohammadi et al., 2018). In doing so, systematic approaches provide an input for informed decision-making in urban developments.

Chapter 2: Literature Review

2.1. Introduction

A comprehensive review of literature that revolves within the existing knowledge base found to be relevant and significant to the overall study is presented. The knowledge extracted cuts across multiple disciplines of urban planning, energy systems, and smart city concepts. The themes covered are directly linked to the established research questions set in chapter one with the aim of provisionally outlining the key issues and discussions in the fields. In a nutshell, the literature review focuses on urban energy systems, forecast studies, urban growth and development, land-use/development synergy, urban form, energy pattern dynamics, and techniques involved in urban growth forecasting.

2.2 Urban development dynamics

Overview of Urban development, past and current scenario patterns

The multiple dimensions of urban development

The process of urban development involves various features influenced by multidisciplinary theories, approaches, and literature based on key academic sectors such as demographic studies, geoscience, economics, and sociological analogies (Glaeser and Kahn, 2004). The primary focus is mostly involved on the urban scale expansion and nodal concentration of human activities along with the factors behind the growth or decline.

Much benefits from an economic and sectorial view (i.e. concentration of labor and skills) have been recorded and stipulated. Although benefits can be observed, climatologists (David, 2007) and conservationists (Williams, 2016), however, discuss the negative aspects (radiation residues, energy imbalance, habitat destruction etc.) of urban development while transportation planners (Bai, 2007) seek to address external anomalies (e.g. traffic congestion and strategies that aim to reduce high-dependence on private vehicles) as a result of projected and unexpected growth.

Literature (Burton, 2002; Crookston and Clark, 1996) also cuts across the environmental sphere as patterns (e.g. waste) pertaining to the generation at source and distribution within the urban system are studied. The sociological element, according to Britter and Hanna (2003) and Burgi et al. (2004) touch upon the complex relationship and social structures within the city based on their intra- and interactions with various urban fabrics (i.e. land use, city functions, administration etc.) and their associated challenges (e.g. poverty, informal housing, unemployment etc.).

Musakwa and Van Niekerk (2014) observe urbanization as a consequence of urban growth with increased energy use and demand for a constant supply system from external, usually remote settlements. The four themes (geoscience, sociology, economics, and demographics) on urban development, according to Anthopoulos and Fitsilis (2010) can assist in understanding the influential factors behind the urban energy demand. Using the given perspectives, urban growth with urbanization as a catalyst can be described as the subsequent change of rural populations becoming modernized as a result of urban influence (Brown et al., 2009; Ewing, 1997; Haase and Nuissl, 2010).

This implies the transformation of the population along with its urban setting from being classified as basic to advanced. That is, an increase in population numbers and activities undertaken. A different explanation involves the gradual loss in the features associated with a rural setting while an increase in features associated with an urban setting is experienced.

That is, the presence of agricultural and monofunctional land uses decrease and more exposure on landscape transformation (built-up impervious surfaces, densification, and Information and Communications Technology (ICT) is experienced (Hayek et al., 2011). From an economic perspective, urbanization involves an area’s structural economic shift in activities from primary (e.g. agriculture and mining) to secondary and tertiary levels. This would result in multi-functional economic activities that involve manufacturing, servicing, processing, and other advanced functionalities.

2.3. Urbanization and urban growth trends

According to Giarrusso (2003), Haase and Nuisssl (2010), and Hayek et al. (2011), there is a considerable amount of uncertainty regarding the accurate projection of urban population and development. With this, much efforts are being facilitated in producing assessments that do not sway further from understanding the dynamics of urban development. Frank and Engelke (2001) record how the growth of populations within urban centers have experienced an insurmountable growth over the past century.

For the period 1950-2005, the United Nations Department of Economic and Social Affairs (DESA) (2010) provided an estimation of how urban populations in both Middle Eastern and African countries were exposed to a drastic increase in population numbers (i.e. from 44 million to 478 million). Further linked, Asia saw a population boom from 175 million in 1950 to 1.3 billion in 2005 while the Caribbean and Latin America regions saw the least growth from 68 million to an approximate figure of 429 million people.

These figures indicate a rapid level and demand for development that has addressed the needs of the population in terms of housing and service provision. Additional trends in population and urban growth indicates ageing (i.e. more in China with a life expectancy of 90+ years) demographic groups and a demand for infrastructural upgrades and extensions for newer developments. Glaeser and Kahn (2004) note how population increase as a direct cause of urban growth is mostly experienced in developing (e.g. Surat in India with a rate of 4.99%) and transitional countries.

For developed countries prone to economic reform (e.g. Eastern Europe), a population decline is anticipated with the UN DESA (2010) report noting a decrease from the year 2005 (404 million people) to 365 million by the year 2050. Part of the reasons apart from the economic reform involves the deindustrialization approach and more attention on the Forth Industrial Revolution and automation of city functions which could impact employment trends.

For southern regions, a projection in population numbers increasing has been set. Additionally, these regions, which have been prone to low fertility rates, are expected to indulge in more development and have their populations increasing due to various factors such as technological innovation, migration, young populace, and foreign investments.

Given this background, the global population (7.7 billion people) is set to experience an increase by a figure between 2.7 and 3.2 billion people by the period 2050 (World Population Clock, 2019). Much strain on the existing infrastructure is anticipated and a call for sustainable initiatives can be traced by the United Nations (UN) reports on sustainability (i.e. Brundtland Report and Agenda 21). This growth is largely set to be conjectured in the less developed countries as they seek to industrialize (i.e. Kenya) and urbanize.

2.4. Variations in urban development

According to Geymen and Baz (2008), patterns in urban development and the associated urbanization vary across regions. Regions, to a number of factors (economic opportunities, governance, safety etc.), experience growth which can be regarded as rapid, slow, stagnant, or negative/declining. Urbanization as a factor is frequently associated with the ultimate growth of large cities.

These megacities e.g. Kolkata, India, according to Glaeser and Kahn (2004) house populations of more than 10+ million people and symbolize experienced urban challenges (e.g. urban blight and poverty, informal and slum settlements, under-capacitated infrastructure etc.) interlinked with urbanization. The reality of urban growth and current settlement sizes as indicated below on table 1 is often dominated by cities within the developing countries.

Table 1: Urbanization trend for developing and developed countries

Global Ranking	Countries	City	Total Area (Km^2)	Density (Km^2)	2018/19 Population (M - Million; K - Thousand)	Growth Rate (%)
1	China	Beihai	3337	460	484K	10.6
2	India	Ghaziabad	133	3954	2.8M	5.2
3	Yemen	Sana	126	15 000	3.9M	5
4	India	Surat	326	14 000	4.4M	4.9

5	Afghanistan	Kabul	1023	4500	4.6M	4.7
6	Mali	Bamako	245	5300	1.9M	4.4
7	Nigeria	Lagos	1171	6871	21M	4.4
8	India	Faridabad	741	2442	1.4M	4.4
9	Tanzania	Dar es Salaam	1500	3100	6.3M	4.3
10	Bangladash	Chittagong	168	18 757	3.9M	4.2
11	Mexico	Toluca	2436	904	2.2M	4.2
12	Congo	Lubumbashi	747	949	1.6M	4.1
13	Uganda	Kampala	189	9429	1.6M	4
14	Bolivia	Santa Cruz	150	1400	1.5M	3.9
15	Angola	Luanda	116	4300	2.6M	3.9
16	India	Nashik	2681	6200	3.5M	3.9
17	Congo	Kinshasa	150	949	7.7M	3.8
18	Kenya	Nairobi	696	4859	3.1M	3.8
19	Bangladash	Dhaka	302	116	10.3M	3.7
20	Madagascar	Antananarivo	86	10 266	1.3M	3.7

Source: City Mayors Statistics (2019), Population Statistics (2019), World Population Review (2019)

2.5. Land use and built form in relation to energy consumption

The built environment

The built urban environment, according to Deng et al. (2009) is comprised of various land uses and functions such as commercial units, residential, governmental, recreational, and industrial plots that are spatially spread out throughout the urban landscape. Urban growth, therefore, results in an increase for advanced infrastructural features such as transportation, energy utilities, water and sanitation, and waste management.

Hayek et al. (2011) highlight the importance of understanding the dimensions of the urban environment as it assists in providing key components that outline the urban energy utilization patterns from a localized to a regional level. This understanding can shine light on how the built environment interacts with the city's urban system by looking at the production, distribution, and consumption patterns of various city sectors. With this, an understanding of which sector that requires more energy can be delineated and assist in the draft of policies and guidance of upcoming development.

Design of residential buildings

Cole and Kerman (1996) note the integrity of designing and integrating thermal concepts of insulation in residential buildings as a critical element in the management of energy for cooling and heating purposes. This approach is aligned with recent efforts by the northern European countries in attempting to reduce energy output as a factor of buildings with poor cooling systems.

For countries within the middle latitude region, efforts seek an equilibrium between cooling and heating systems as aligned with seasonal changes. In most cases, Rey et al. (2013) observe how newly established residential developments (e.g. European residential typologies in tropical settings with poor ventilation and shading) are equipped with standardized thermal systems however, performing poor due to the lack of adaptation to localized climatic conditions.

Apart from the ability to adapt to foreign climate, another factor that contributes to increased energy output involves dilapidated buildings that have been exposed to a lack of renovations that seek to adhere to established building energy standards. Cowan (2008) notes how the influence of technological innovation in the building sector remains pertinent in a sense that energy regulation is maintained.

For instance, European residential sites are subjected yearly to have a space heating within an extent of 15-kilowatt per hour per square meter (kWh/m^2) floor area. For low-energy demand residential sites, a value within 50 kWh/m^2 is subjected as an approach to avoid energy utilization for space heating within the capacity of 200-400 kWh/m^2. This is done to avoid poor thermal insulation. In the regulation of urban energy consumption, Golany (1996) asserts how regular maintenance and refurbishment of building sections should be taken into cognizance to assist in the effective energy assessment protocols.

For buildings with over a 50-year lifespan, Crabtree (2005) and Dhakal et al. (2003) report an embodied energy (5-10%) that ranges between 2.5-5 years of the buildings' lifespan based on the factors of construction materials, decommissioning, and functional energy utilization. The inclusion of solitary and multi-family presents a different scenario.

A review of Cole and Kerman (1996) literature indicates an embodied energy that oscillates between 4-15% for the total lifespan of the building in the consumption of energy. A different analysis for energy-efficient buildings with low operational usage portray an embodied energy within 25 and 29% with power values typically ranging from 20-30 kWh/m^2 floor area per year.

Buildings typology and function

Building typology influences the type of function space will portray to the city inhabitants. When considering the energy features of a building and its surrounding, Guneralp et al. (2017) conclude that the determination of urban energy use can be facilitated. A generic understanding of a city's urban setting is its ever-growing demand for power utilities as a result of growth that transforms ordinary spaces into densified blocks that constantly require maintenance and upgrading.

The overall efforts invested in improving the structural elements of a building to reduce both heating and cooling demands according to Dhakal (2009), involve increasing a construction's floor area. Although a solution, a challenge anticipated points to affordability as floor area per capita has been justified to positively correlate with the inhabitants' source of income (Banister, 1996).

Like South Africa (30 m^2), Japan's national floor area is averaged between 30-50 m^2 per person as compared to Canada (55 m^2) and the United States (80 m^2). These figures can be a challenge in often dense, populated urban centres as a result of land/space positively corresponding with dwelling prices. Coppin et al. (2004) present an evaluation of a modelled energy assessment of two housing typologies in Australia: detached housing and urban apartments.

In the study, the conclusion drawn is that both typologies have similar embodied energy and similar heating and cooling rates on an annual basis. Secondly, the lifespan for urban apartments was much lower (10-30%) as compared to detached housing due to a low-floor area occupied per person. Dhakal et al. (2003) applied the lifecycle methodology to evaluate energy consumption and production of greenhouse gases by peripheral residential land uses in contrast to dense, centralized sites for the city of Toronto.

The findings indicated that low-density settlements had a higher (1.5 kWh) embodied energy as compared to the densified residential sites based on the floor area factor. Correspondingly, in a study revolving around the spectrum of Paris' urban morphologies, Golany (1996) outlined the relationship between heat energy and morphology, asserting the less-dense an urban setting is, the higher the demand of energy needed for heating.

2.6. Urban form and functions

Literature has indicated that patterns of urbanization have a direct influence on the overall extent and locality of city functions within an urban setting along with the provision of infrastructure. A variety of urban form typologies (corridor city, compact city, edge city etc.) exist and all have various advantages and disadvantages associated with them. Because of this, strong views have been set against each other regarding the pursuit and adoption of sprawling or densified cities.

For urban energy, densification is best preferred as Ogra and Ndebele (2014) posit how densified settlements have proved to be viable in the facilitation of public transport, infrastructural distribution networks, social cohesion, and localized heating and cooling urban energy systems. With this said, high density developments play a critical role in curbing urban energy (Ewing and Rong, 2008). Additionally, functional and cosmopolitan proximity is promoted.

This extends within the transport sector with the quest of smart cities pursuing multi-modal transportation systems accompanied by non-motorized initiatives within the city space (Cervero and Kockelman, 1997). As a smart city aspiration, Cheng et al. (2006) assert how densified cities play a critical role in reducing automobile dependency and demand for conveyance energy per capita. This is in contrast to low-density settlements where per capita energy consumption and production has significantly increased at a rate equal to sprawling developments (Musakwa and Van Niekerk, 2014).

This phenomenon according to Steemers (2003) portrays low-dense urban forms as major contributors to the utilization of energy. On average, Adolphe (2001) observes how inhabitants within a 15-kilometer distance from the urban center utilize twice as much of transportation energy as compared to a group within a 5-kilometer distance from the central district. Additionally, there exists a relationship between income and vehicle ownership.

This suggests that the owners portray an inclination to commute lengthier distances influenced by energy-demanding modes. Adequate policy coordination between land-use and for instance, the transportation sector, will be pivotal in attaining energy efficient multi-modal transport systems. According to Banister and Watson (1997), location efficiency plays a significant role in providing city inhabitants the accessibility to nodes of opportunities.

This is an efficient concept to integrate in policies as variation can be best accomplished. For improved results, the application of location efficiency is best suited in densified urban settings to reduce energy consumption and production. With this, adequate infrastructure supplements this approach as traffic volume can be controlled – ultimately leading in decreased levels of energy output.

The accomplishment of this vision would involve an integrated, multi-disciplinary decision-making system aligned with a city's fiscal, energy, and inhabitants' demand. An additional element to be factored in involves consumer behavior. For instance, Japan, according to a publication by World Data (2019), is experiencing lower per capita energy consumption levels (7 458 kWh) due to the established consumer behaviorism of the rail-based system being efficient. Barrett (1996) and Ewing (1997) observe the adoption of a type of urban energy system as another critical factor. For instance, both regional heating and cooling infrastructure are best suited for highly densified urban centers where apparent and intensive demand is experienced.

Should this not be the case, projected benefits such as the presence of large economies of scale and energy co-generation will not suffice as such an infrastructural approach requires fiscal-intensive investments. Linked to this, Banister and Watson (1997) assert how the density of urban form plays a role in the level of energy consumed by buildings.

Golany (1996), for instance, observes how buildings characterized as studio apartments portray the ability of generating urban settings influenced by large economies of scale when compared to single-house dwellings. The only setback in this situation is the lack of apartments in assimilating reduced energy-consumption design principles such as decentralized ventilation systems, devolved solar panel systems, and natural illumination.

In all, trade-offs will be experienced, and decisions may need to be made as to whether to adopt energy-efficient transport systems that come with increased urban density versus the adoption of densifying urban centers that will be prone to higher energy utilization due to a number of people in the city. In a nutshell, the argument boils back down as to whether urban planners should pursue densification or spread-out developments.

2.7. Energy development pattern dynamics

Urban development and energy patterns have played a huge role in influencing policies related to the power utility regulation sector. Cities over time have become centralized spaces within which more than 50% of the world population reside within (World Bank, 2018). With this, the direct consumption of energy at a global level is perceived at three-quarters (Richardson et al., 2010) and this signifies the demand for additional energy services along with alternative solutions.

Such a drastic demand challenges the notion of sustainability as adequate access to energy sources will be central to having vibrant cities. According to Musakwa and Van Niekerk (2013), future developments should be aligned with the explicit understanding of dynamic urban changes occurring at local levels. As such, urbanization is an element to consider along with the factors behind it.

The delineation of the synergy between energy systems and future growth assists in anticipating challenges and specific opportunities interlinked with them. For instance, larger population densities are often attributable to hyper economic activities. Based on this assertion, the consumption of energy significantly confines the application of consistent sustainable energy practices.

As a challenge, future expansions may postulate upon smart energy management systems such as smart grids, electricity cogeneration, and application of renewable energy sources for small-scale urban land uses like single-dwelling residential units (Howell et al., 2017). The understanding of future density (preferably ranging between 60-140 city dwellers/ha) can provide a platform for diversity to suffice and this will be pivotal as energy can be articulated throughout the grid efficiently through: integrated utility systems, resourceful and dense residential units such as apartments, and the promotion of mixed-use to co-locate urban activities with the aim of reducing automobile dependence (Boardman, 1993).

Based on the availability and typology of energy systems, the nature of future developments can be projected. Cohen et al. (2005) provide a broad sight that low-dense settlements (Waterfall City) are usually characterized by renewable energy sources (Solar) as compared to large-scale (coal) urban centers (City of Johannesburg). The success of the development therefore relies heavily on the provision of energy as services like water and sewer reticulation systems, security, transportation, and communication services indicate an intrinsic attraction to power.

Although difficult to power all services with renewable energy sources, efforts in the integration of the systems is gradually taking course as advancements from coal-powered systems is being aspired (Bravo et al., 2008; Rey et al., 2013). As such, the urban growth's future infrastructure should not be provided from an isolated perspective. Instead, a sectorial approach with energy efficiency as a common theme will assist in identifying patterns of vulnerabilities, relationships, and potential gains. From this view, institutional frameworks and clarity on roles (i.e. three spheres of government) and stakeholders will be key in the facilitation of energy-efficient cities.

2.8. Urban energy systems dynamics

Research indicates that the electrical utility industry in South Africa, and other transitional countries in Africa (Nigeria, Egypt etc.), has continued to experience unparalleled levels of change. Howell et al. (2017) notes ageing urban power utility infrastructure, customer choice and affordability, innovation, and sectorial shifts as leading factors influencing the rapid change within the power utility sphere.

Because of the nature of change; the production, delivery, utilization, and consumption of the power utility is remarkably distorted. Societal challenges that continue to pest involve the inhabitants as the end-users and not proactive citizens involved in the participation of planning, coordinating, and operating the power utility sector (Howell and Saltelli, 1996).

With challenges come modernized modifications to the existing urban energy systems with alterations influencing the distribution nature of transmission power systems in a manner that locates them closer to residential units.

From one perspective, urban energy systems have reduced transmission costs and have become smarter as new processors have smaller chips embedded within them that allows the systems in place to function with better capacity as compared to larger, traditional ones. The American Physical Society (2010) notes how the modernized urban energy systems incorporate elements of renewable resources in which the possibility of efficient and manageable micro smart grids and net-zero energy structures can occur.

This transition according to Bhattacharrya (2010) is significant as cities are within the strategic position to draft energy policies aligned with sustainability principles that are invigorated by informed, factual, and rationalized forecast studies. Furthermore, these policies will be fundamental in influencing how the distribution of energy in relation to growth is done. This will tackle centralized distribution to cater for alternative nodes that are based on a sectorial background – significantly inducing the application of direct current.

According to Louis (2009:18) cities can thus be regarded as transitional from a centralized supply of power to *"one-way consumption modes to open systems of distributed, ubiquitous providers and users of renewable and other energy streams"*. Such benefits offer an advantageous acumen in light of resulting issues associated with densified high urban population and constantly varying economic activities. Ciupuliga and Cuppen (2013) present opportunities (i.e. electricity heat cogeneration and cascades) that can be deduced from urban energy systems and offer ways in which city functions can forage on energy flows that result from conversion and industrial use.

Furthermore, aspects such as functional cosmopolitanism and densified development can be crucial in the utilization of energy across the urban setting in which multiple energy utilities can arise i.e. reduced transport distances and net-zero energy buildings. It is thus paramount that the plan for sustainable urban energy systems, according to Howell and Saltelli (1996) requires the efficient usage of energy models to scientifically craft (i.e.

through GIS, RS, and other methods) urban growth forecasts aligned with potential energy policies.

Such crafts are additionally important in providing a framework of reference for urban planners as crafted scenarios would assist in the harmonious attainment of sustainable urban energy systems for the power utility sector. Li and Wen (2017) recognize the importance of factual and reliable data sources for urban energy systems in forecasting growth. Within this context, the integration of GIS, Remote Sensing, and urban energy models would provide valuable tools as the agents of change.

As an element, Koch and Girard (2013) think of transparency and accountability across the government tiers as critical requirements for scientific policies. Frayssinet et al. (2018) however, realize that a variety of urban energy systems in place lack transparency within its structures as input data can be fabricated and unreliable due to data collection and validation constraints. As a result, on the one hand, Fonseca and Schlueter (2015:45) argue about how the *"non-transparency of both urban energy system models and data hinders public participation, limits scientific evaluation and impedes discussions and public debate".*

On the other hand, Alhamwi (2017) observes the existence of incremental interest in the modelling of urban energy systems through the adoption and application of open source and data tools. This sparked curiosity cuts across various knowledge domains that particularly involve legal, science, and urban planning.

For instance, Germany has had all its grid operations obliged (Renewable Energy Act) to have the level of transparency (i.e. activities involving new renewable energy installations) increased and subsequently published for scrutiny and analysis by all involved stakeholders of the country since 2004 (Bundesminisrterium for energy, 2016). One salient application due to the legislative obligation involves the upload of data on a database functional of collecting information from energy systems and subsequently making it accessible to the public.

The company/institutional data captured presents information pertaining to the form of energy produced, the source, locality, production, and overall consumption (*see*

EnergyMap.info). Similarly, however, on a larger scale, Europe has a commission centered on energy science and production of knowledge in the power sector (American Physical Society, 2010). Subsequently, this resulted in an interactive and open source database (Urban Data Platform) that allows data sharing and visualization of urban energy systems across European cities and associated districts.

The database cuts across multifaceted dimensions of knowledge disciplines and is shown by the nature of the data (urban growth, population statistics, environment, and resources) available. Although Howell et al. (2017) appreciate the idea in which "*relevant data is relatively and speedily available online*", Alhamwi (2017) acknowledges the institutional credibility and copywrites of the data as explicit licensing cannot be facilitated.

Noticeably, a widely popular open source database is the OpenStreetMap (OSM) database, which, according to Barrn et al. (2014) can be utilized for various urban and non-urban-related purposes. General urban applications relate to: demographic studies, population forecasts, re/routing and triangulation systems, and last but not least, the extraction of built-up features across the globe. Due to the nature (accessibility and credibility) of OSM data, various urban energy systems have been simulated and resulted in power grid models representative of both high and low power levels across cities (Ather, 2009; Medjroubi, 2017).

Additionally, there is a growing academic interest in the application of OSM data to model energy systems that range across a spectrum of sectors (from electricity, heating, to transportation). In Bennet (2010), the utilization of OSM datasets were applied to stipulate urban energy system requirements to model production and distribution substations in Germany, Oldenburg. The findings indicated that the city's urban energy system can be reproduced through the utilization of OSM; significantly portraying open source and easily accessible data reliable and as an alternative for usually costly, commercial data.

Another urban energy system model (Medjroubi, 2017) involves the geometrical measurement (i.e. used infrastructural parameters) and extraction of residential features from OSM to assess the potential level of district heating across commercial and light residential units. Moreover, Ather (2009) applied georeferenced OSM data to project the viability and production of power generation on urban settlements based on the installation of biomass, electrical, and photovoltaic structures for the optimization of informed urban and regional planning of smart energy across different regions.

2.9. Urban Energy System Challenges

Energy access and affordability

The literature before this theme presents energy as a basic need in human settlements, hence observations can be drawn on how energy poverty saliently presents itself in both developing and transitional countries across the globe. Alhamwi (2017) notes the percentage household income spent on the electrical power utility as an indicator of measuring urban energy poverty in a city, however, Fonseca and Schlueter (2015) argue against this indicator's efficiency especially with regards to middle-to-low income nations whose household incomes are primarily spent on food and other basic needs other than electricity; which ranges between 50-75% of monthly income.

This poses an observative understanding of a shift in priorities that differs across households based on income size and accessibility. The two most occurring implications of urban energy poverty according to Akbhari and Konopacki (2005) involves affordability (i.e. ability to afford power along with the utility) and accessibility to the electrical utility itself. Socially, Boardman (1993) observes how middle, frequently low-income households are prone to allocating lesser fiscal investments for food and other necessities in relation to the money allocated for purchasing power to process the food and other interrelated household aspects.

Studies (Richardson et al., 2010) also link households with home-based initiatives with having high power purchases. This relationship can be practicalized from an informal-settlement view in which increased risks of fire outbreaks and burns (i.e. accidental) through various factors (e.g. overcrowding, illegal connections, unorthodox power generating sources, housing material, lack of emergency services etc.) can be seen.

These issues highlight the challenges in relation to purchasing and accessing electricity and is profoundly experienced in low-income communities. Although community efforts are in place to improve the accessibility index, much initiatives are unsafe due to a lack of fire prevention and emergency services in highly densified informal settlements; projecting a time-bomb waiting to explode by a minor trigger (i.e. candle, gas stoves).

Energy use dilemma in low and middle-income countries

General statistics have been presented on the functionality and typology of urban energy use within cities as well as extending to levels of accessibility by the inhabitants (Arsanjani et al., 2015). As pivotal as this achievement is, Cohen et al. (2005) argue that there is a lack of statistical data that assesses the level of power utilization and accessibility within various cities with reference to the income group. This issue can be aggregated to the generalization of results from a national perspective which at most, assumes homogeneity across a country/city.

With this, the statistical publication presents the data as an average figure – significantly ignoring discrepancies of minor, local areas with little influence on the final data. Bravo et al. (2008) provide a possible reason as to why localized energy data is often published; attributing this issue to the power utility sector not receiving the same level of attention as compared to other competing sectors (i.e. water, waste management, housing etc.).

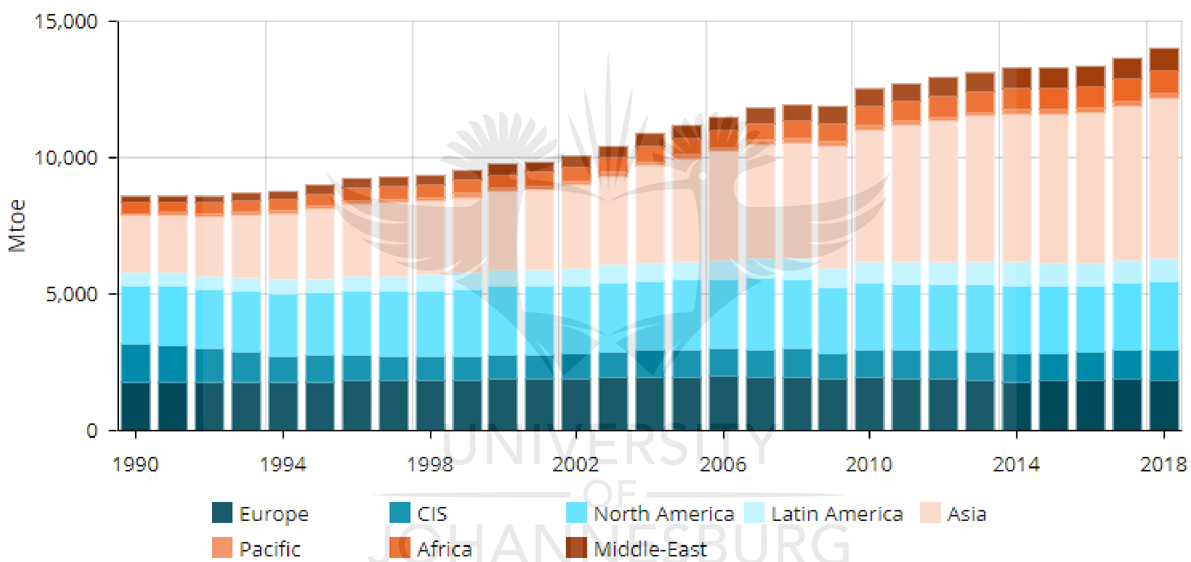
Energy use dilemma low-to-developing countries

Much publication, observably, involves the hazardous effects of energy on the health and environment – with the majority of this literature usually focusing on rural populations. According to Banister (1996) half of the urban population within the sub-Southern Africa region proved to have access to electricity. Additional literature (Akbhari and Konopacki, 2005) also indicates that Asian and African countries are most likely to have a fusion of different energy sources i.e. coal, wood, candle etc., most likely due to seasonal factors, governmental subsidy programs, energy availability, and most arguably, preferences (Bravo et al., 2008).

Florides et al. (2002) provides further understanding regarding the differentials in the scale of the utilization of energy for both low- and high-income households. According to the United Nations (2019), China (1.42 billion) and India (1.37 billion) stand as the two countries with the highest populations – together accounting for more than a quarter of the planet’s human population.

For India, fossil fuel dominates the scene in the urban space where high-income groups reside while biomass relevantly accounts for the lower income populations (Bai et al., 2010). Minor trends in the adoption of electricity have been witnessed since 1990 as shown below in figure 2. Contrary to China, electricity dominates the urban populations, however, legislative policies (i.e. Energy Conservation Law of 1998 and Renewable Energy Law of 2006) have seen to cause a direct shift from coal-powered electrification to more energy-efficient alternatives as a result of human and environmental hazards experienced.

Figure 2: Energy development patterns since 1990-2018



Source: Global Statistical Energy Year book, 2019

Like India, most developing nations (e.g. Rwanda) portray a pattern of poor urban households with a limited purchasing power along with increased needs to keep the spending on power utility low (Batty, 2008). An analysis drawn from this analogy is that the utilization of power highly depends on the average price and availability of different urban energy systems i.e. electricity.

Constraints in supply and reliability

It is without doubt that modern cities highly depend on extended and integrated energy systems across their urban fabric and power outages/failures occurring on a city to national-wide scale has proved to have problematic outcomes for the dwellers at large. This can be attributed to the recent Eskom power outages in which load-shedding stage levels have gradually increased over time and significantly impacted businesses and other sectors within the city.

Apart from energy generating sources failing to provide power as a result of fiscal investments in old plants, software failure can also occur and render most of the sophisticated power-generating distribution systems vulnerable to the Fourth Industrial Revolution (4IR). Additional factors are geographical as Ather (2009) notes how solar or wind energy sources may ultimately influence an urban energy system's reliability profile in terms of efficiency and trade.

Favorably, the power outages as a result of these renewable sources may be minimal as they usually operate on a small-scale as compared to an urban settlement that is nuclear powered. Conversely, a hybrid form of power generation can transpire due to the variability of power supplied (Bravo et al., 2008). With this, a larger plant assumes responsibility on day-to-day activities until a power outage occurs while the renewable sources support the critical sectors within the city instead of experiencing an all-out holistic darkness.

The 4IR comes with increased innovation, simplification, and automation of urban activities. With this in place, a trend highlighting increased dependence on urban power to support the revolution can be sketched. The implication for urban energy systems is diverse as they need to accommodate a new form of technological development that requires constant and stabilized power input to support critical city functions and operations.

A proposed solution (Florides et al., 2002) in the realization of the 4IR through reliable power generating sources is through the parallel operation of urban energy distribution systems. This renders localized plants as the primary distribution sources within cities and surrounding villages while the national systems provide a form of back-up. This practice can be seen in gated communities utilizing microgrids with the main neighborhood's power supply acting as back-up during sudden blackouts.

Although a good initiative, microgrids might be subjected to one dominant form of electrification with renewable, clean energy sources usually coming in second. Reference can be made to the European winter season during the 2008-2009 cycle in which the gas supply plants could not meet the demand-side of the population. The advantage is that this source can be stored in the both specialized storage facilities and gas mains and is multifunctional i.e. transit-systems, household use, power generation etc. (European Commission Report on Renewable Energy, 2014).

Conversely, setbacks relate to market trades and global natural resources' economics as liquified natural gas is a worldwide trade resource and fiscal fluctuations may be influenced by various factors (e.g. emergencies, recession, scarcity etc.). A favorable move, according to Barron et al. (2014), would involve the market liberalization of gas and coal sources of power generation. Richardson et al. (2010) are against this neoliberal shift as *"the effect will incentivize producers to sweat their existing assets".*

With the two extremes, perhaps, as attributed by Cohen et al. (2005) - it will be beneficial to find a midpoint and present structured complexities such as strategic tariffs that will seek to incentivize resource investments and ultimately assist in the reflection of the actual value to the consumer i.e. showing the lost load.

2.10. Current urban energy utilization

Urban energy consumption as other sections above indicate that a high level of complexity exists within urban settings. Multiple factors come into play and each of them have different energy utilization outputs (O'Malley et al., 2014). The World Energy Outlook (2008) by the International Energy Agency (IEA) in collaboration with the International Institute for Applied Systems Analysis (IIASA) provided two methods (i.e. upscaling and downscaling) for analyzing and estimating both regional and world urban energy utilization estimates.

As a result of a lack of an integrated and updated database with a statistical catalog of energy performance, the upscaling method estimates global energy consumption by the extrapolation of regional energy data (Vigna et al., 2018). The alternative method involves the application of a GIS system in which regional energy consumption levels are estimated based on broad national data downscaled to grid level cell size to spatially depict the energy zones of interest (Howell et al., 2017).

Regions under which the report applied the techniques involved the European union, United States of America, and China. Within these regions, the United States recorded a value of 80% of regional energy consumption as compared to the European union (69%). Seto et al. (2012) attributes such high scales due to the level of development sophistication and urbanization. Contrary to this assertion, China recorded 75% irrespective of experiencing low rates (41%) of urbanization.

Apart from these results, an extrapolation of the global energy utilization stood at 69% - which was equivalent to 330 Exa Joules (EJ) for the year 2006. The analysis' working environment assumed the major utility primary mix for cities worldwide was equivalent to the regional average with cognizance of electricity as the main source of energy.

The results, although providing a generic understanding on the overall understanding of the global energy usage, seemed difficult to accept (Richardson et al., 2010). The argument is based on the view that both African and Asian countries at the time were characterized by low urbanization rates as a result of a lack of development due to poor income generating sources. With this assertion, average rural-energy utilization structures depicted discrepancies when compared to the national/regional averages.

The difference remains too vast and heterogeneous across the spatial realm to formulate a conclusive, holistic average for the concerned country. Another criticism involves the report failing to see how it, according to Seto et al. (2011:177), "*diminishes the plausibility of the study's scenario projections by primary energy carrier to 2030 ... where total urban primary energy use is projected to grow by some 56% from 2006 to 2030*".

In the IEA report, projections regarding the energy consumption levels (67%) for the year 2030 are dominated by urban centers. The IIASA's conclusions on global energy consumptions are a little bit far behind (76%) as the study adopts a different methodology comprising of different datasets (i.e. urban extents, global population, and Greenhouse Gases) to process the projections.

The subsequent processes involved the integration of national biomass and electrical data in relation to active sectors such as industries, estates, and transportation. With this integration, the method downscaled the datasets to grid-cell level in line with geographical variables such as the population data based on the United Nation World Urban Prospects (UNWUP), Gross Domestic Product (GDP), light aperture etc.

This was followed by overlaying the extent map of the study area to project the direct energy utilization output for urban centers. On a global scale, the energy use output according to the IIASA report variates between 180 and 250 EJ with 240 EJ being the median. These results are aligned with the global assertion that cities are responsible for three quarters (240 EJ) of the world's total energy utilization.

Taking in consideration the industrialized regions, discrepancies can be observed – especially in the developing countries such as the Saharan Africa in which projections indicate that 80 percent or 4 EJ of commercial uses can be rendered as urban. Similarly, Asian regions also depict this understanding – with 8 EJ of commercial activities being regarded as urban. Other developing countries according to Anderson (2006) portray minor differences as "*little noncommercial energy continues to be used in cities*".

Richardson et al. (2010) outline the relationship between commercial energy, household income, power accessibility and associated infrastructure. The synergy concludes that higher levels of electricity consumption is most likely to occur in urban areas should the above factors positively correlate with each other.

However, both the IEA and IIASA reports provide a sense of confirmation for intergovernmental policy-intervention: *"50% of the world's population is urban ... urban energy already dominates global energy use"*. For policy-makers, this implies proactive energy-efficient strategies that address sustainability initiatives in the context of urban energy systems.

Factors behind urban energy use

Factors behind energy consumption and demand have traditionally been studied at a national level. Seto et al. (2017) note the following list below as broad direct/indirect categories of energy drivers:

- Local environment: geographical location and climate conditions;
- City socioeconomic status quo: household features, economic output, and demographic dynamics;
- Local/regional city interrelationships: city role, labor, skill set, and production and consumption synergy;
- Urban energy and institutional system: governing structure, power supply system, and cost; and
- Urban morphology: built urban environment, density, housing typology, land use variation, and transportation infrastructure.

These factors, according to Rey et al. (2013) are interrelated and influence each other directly/indirectly within the city as a system. Output results are not homogeneous throughout individual cities as variations as a result of density and city-function play an active role in energy consumption.

For instance, an industrial city will consume more energy as compared to a residential-driven city. An additional factor (i.e. history) as put by Li and Wen (2017) and Mohammadi et al. (2018) portray dynamism and path independence e.g. energy use being liable to a city's historical fabric. This point is key as a city's historical path may provide an understanding of its current morphology and growth pattern.

Relatively, a city's economic activity originates from its historical establishment, whether as a major port like Durban and Amsterdam, an industrialized node like London and Lagos, or a market and service center like Johannesburg and New York. These developments are aligned with the factors above, i.e. Nature – Cape Town's coast, and therefore have a perpetual influence on how urban energy will be consumed in the future.

Socioeconomic features

A positive relationship between household income and energy consumption output has been recorded on multiple literature involving various countries across the globe (*see* Dhakal, 2009). In a study by Cabtree (2005) in Australia, Sydney, the authors highlighted the synergy between income and energy consumption. In the study, the factors behind the energy embodiment involved the type of household goods and services (i.e. furniture, appliances etc.), and housing typology (i.e. features like area per square meter and building structure).

Cowan (2008) however, argued that household income alone does not delineate incremental energy consumption. To invigorate this assertion, Shanghai recorded a higher average energy use in comparison to Tokyo irrespective of having a lower per capita income (Cotton and Devine-Wright, 2013).

Additionally, demography also plays a critical role in the determination of overall energy utilization. Dey et al. (2007) reports how households with more than 2 people result in increased economies of scale – ultimately influencing the energy utilized per person. This singularity can be derived in India (Dhakal et al., 2003) however, Japan portrays the opposite - with larger households being attributed to high energy consumption.

2.11. Urban energy demand and supply dynamics

London and Tokyo in comparison to low, densified urban centers such as the city of Osnabruck in Germany, have a high level of density. With reference to Seto et al. (2012), urban energy demand in cities (e.g. Curitiba and Lagos) spans from 10-100 Watts per square meter (W/m^2) across their spatial density.

The main factors behind this involve population growth and affluent income groups. For smaller cities (e.g. Beihai), an energy demand value oscillating within 1000 W/m^2 is expected. Rey et al. (2013) asserts three factors of significance that suffice as a result of an increased urban energy demand levels. These are: high emission levels due to higher spatial energy densities; innovative opportunities that involve recycling (i.e. waste-heat, bio-fuel regeneration etc.); and provision of light energy-related services through renewable sources.

According to Louis (2009), this ranges between 0.1-1 W/m^2 of energy supplied – potentially rendering the approach as a city demand/supply mismatch. From an alternate perspective of energy systems, Ogra (2019) acknowledges the importance of aligning city infrastructure within high-density urban settings with different energy systems to address a variety of sectorial energy demands experienced.

According to Seto et al. (2011), the statistical representation of the disparity between urban energy supply and demand with Tokyo and London as examples can be done. With this, a normal operational/consumption of urban energy oscillates within the 10-18 (EJ) region. For Tokyo, the reported urban energy consumption stood at 0.6 EJ as compared to London (0.6) and New York (0.8 RJ).

The recorded mean value for the energy densities for Tokyo stands at 28.5 W/m^2 while London records 27.4 W/m^2. The mean values are almost similar – with a difference of 1.1 W/m^2 separating the megacities. Results can also be improved with the integration of localized renewable urban energy systems that can be employed to provide power to low-density buildings as their efficiency in megacities remains questionable (i.e. local renewables provide a minute fraction of energy less than 1%).

With this scenario, a study by Battle (2007) based on aerial survey methods assessed the efficiency and relevance of local renewable energy systems in Osnabruck, Germany. The study area at the time had a population of 272,000 with a density of 23 people per hectare receiving solar radiation equivalent to an approximate value of 983 kWh/m^2.

The study identified suitable Photovoltaic (PV) roof area (2 million m^2) in correspondence to the city's total area of 119 km^2 that if utilized adequately, the PV could make an electrical provision equivalent to 249 million kWh/m^2. This provision will meet the entire residential area's demand (235 million kWh/m^2) for power. Because of this, conclusions can be drawn on how this supply system can assist in providing a fraction (3.3 GJ/capita) of Germany's energy output (154 GJ/capita) per capita.

This study provides a critical understanding of the interrelationship regarding population density and energy demand/supply dynamics. Further linked, it portrays the potential localized urban renewable energy systems have. The delineation that suffices is that lower density areas harness greater potential for renewable energy systems to thrive as compared to high-density urban centers like Tokyo (130 people per hectare). Another study that aims to understand the disparities experienced regarding urban energy demand and supply involves the International Institute for Applied Systems report for Western Europe.

The research found a mismatch regarding the energy demanded and the energy supplied. Implicated with this, the region's demand fell short far behind the supply density that was recorded at 1 W/m^2. Irrespective of the results, a conclusive understanding outlines that regions classified as dense and modernized receive less attention from a supply of renewable energy sources as compared to sprawled, low-dense urban settings.

2.12. Density, morphology and operational energy

According to Cowan (2008) the operational power within buildings can be attributed to factors such as heating and cooling times. With this, external parties such as consumer behavior and climate for instance come to play. A study by Bai et al. (2003) and David (2007) concluded that the climatic condition of an area influences the type of building structure to be erected.

With this thought in place, structures within moist or hot temperatures often seek to regulate and reduce high temperatures as opposed to structures within cool zones where the function is to avoid heat loss through conservation and storage. Aligned with this, a delineation drawn according to Coppin et al. (2004:43) is that "*the warmer the climate the lower the overall operational energy required*" as heating serves as the significant catalyst of energy consumption, for instance, in cooling and preservation.

Apart from how climate influences structural typology, linkages between the density of an area's urban form, behaviorism, and other factors associated to energy consumption can be assessed. Density as put by Cole and Kerman (1996) can be increased through the extension of the depth of the building, higher building height, and densifying the existing morphology (i.e. advancement from single-housing to apartments).

Based on the assumption of moderate access to natural features (e.g. sunlight and air), Golany (1996) calculated a ratio of 2:1 for operative energy to transportation energy. The rationale is enforced by the assertion that transportation energy declines as building density is increased - further encouraging the concept of densification (Barter, 2000; Ogra, 2019). Practical benefits involve greater access to multi-modal transport systems and proximity to the urban center with its opportunities.

Catering these opportunities (Dey et al., 2007), commercial sites have been noted to have higher power consumption when compared to the residential land-use. This conclusion factors in the space heating floor per unit area. As a conclusion, Dhakal et al. (2003) found out that 60% of energy utilization in residential sites accounts for space heating. The figure increases as floor area increases, indicating the time it will take to heat the whole space – subsequently playing a key role in the energy demand and supply dynamics.

2.13. Smart city and energy use

Smart city is a concept that is relatively new, fairly adopted, and applied in both transitional and developing countries. With each applicability, various clarifications have been observed to surface based on a city context, challenges, and aspirations. From a collective perspective, the various views (Ebrahim and Irani, 2015; Griffinger and Gudrun, 2010; Ogra, 2019) do portray a common understanding in which the theme of "smartization" results.

This is entirely focused on the aspects of rapid city urbanization and uncharted population growth. Interlinked to it is the initiative of sustainable development that seeks to optimize the city's capital forms for an improved quality of life for its inhabitants (Dirks and Keeling, 2009; Lewis and Ogra, 2010). This optimization is through the integration of advanced Information and Communications Technologies (ICT), big data development, and Internet of Things (IoT) in the city's operational systems (Dawes et al., 2009; Hayat, 2016; Joshi et al., 2016).

With this optimization, the main challenge aligned with rapid growth is the excess demand for power utility with a need for a strategy in place to address energy shortage. It is within this context that the application of concepts such as the Smart (Dirks et al., 2009; Kwele, 2016) and Digital city (Borja, 2007) have been widely adopted to address issues that negatively influence urban energy systems (Anthopoulos and Fitsilis, 2010; Meijer and Bolivar, 2015). With growth comes the establishment of strategic visions in which futuristic cities are adopting the significance of urban energy-efficient models in their existing planning framework.

Smart city concept application

Urban cities have advanced their strategic planning frameworks to attain the aspiration of digitalized smarties. For instance, the "*Malaga Smart City*" plan in which urban energy is optimized through renewable energy sources being integrated within the city's power grid. The grid is capacitated with systematic innovation that enables the management and storage of energy that integrates urban transport (i.e. electric vehicles) and other city sub-systems (Malaga Smart City Plan, 2018).

On the one end, the "*Amsterdam Smart City*" planning framework takes into cognizance various domains that cut across the urban energy utility sector. This is supported by 52 city-wide projects that seek to balance the energy supply with the inhabitants' demand taking multiple factors such as electrical vehicles, the cooling and heat system of the city, and the overall building structures (Structural Vision Amsterdam 2040, 2015).

The end goal is the utilization of ICT to digitize city functions and optimize resources with special attention to decreased carbon footprint levels, improved energy-maximization, and the integration of smart-grids as outlined above to portray positive outcomes for urban planning and future expansion.

Smart energy interventions

Existing research indicates that cities serve as giant sponges given how responsible they are in relation to the global consumption of primary energy (Alvarez et al., 2013). In addition to this, new patterns of urban energy consumption can be assessed from a sectorial perspective. With this, Alhamwi (2017) observes Japan's industrial sector for the year 2014 declining (i.e. by 6.8%) while its residential sector saw an increase of 6.6%.

From this observation, the major shift experienced realizes a new demand for urban energy with the inhabitants and working class being held accountable for two thirds of the city's carbon footprint. This unorthodox sectorial energy shift indicates upcoming issues concerning the city's socioeconomic output as more effort will be directed towards its human capital for energy sustenance.

Linked to this involves environmental concerns as other means of energy may be utilized to address the surging demand. Dirks et al. (2009) and Alhamwi (2017) observe the adoption of Net-Zero energy residential buildings as an effective strategy that seeks to address the energy needs on the demand side.

The Net-Zero energy residential building strategy encompasses features such as improved energy utilization efficiency, adoption of renewable energy, and effective management of power utilities in urban expansion while taking into cognizance existing residential conditions (i.e. density, spread, dominant use, etc.), fiscal feasibility, and the city's infrastructures' ability to accommodate the change (Dawes and Pardo, 2002; Dawes et al., 2009; Dirks et al., 2010).

This change will need to be resilient and flexible as the demand and supply theme of urban energy as put by Al-Hader and Rodzi (2009) is an intricate system composed of multiple factors of both the present and future urban life. It takes into consideration multiple residential expansion blocks and their facilities as to how they will fit in the existing system in a most amicable and financially feasible manner.

As such, policies on ground should therefore be based and structured on interrelated energy features such as the infrastructure of the city (supply of energy to the demand side from generation source), presence of power utility distribution systems, and the city's urban structure (future infrastructure maintenance and development). Given the mandate of sustainable development, urban energy along with a city's expansion should be smart and multifaceted in dealing with the upcoming environmental degradation that will arise with the growth (United Nations, 2015).

The smartization of developmental expansion will enable a framework of adopting ICT to effectively collect, manage, and examine implications associated with growth aligned with the city's urban energy system. Of this, Al-Hader et al. (2009) emphasizes a smart community as an integral part of this framework as they will be the sole custodians of the development from a citizen-centered perspective.

With citizenry emphasized, informed inhabitants will be capacitated to rationalize decision-making on matters that revolve around urban energy infrastructure utilization.

This will significantly assist in attaining linked smart energy initiatives such as "*distributed energy generation, renewable energy utilization, Net-Zero energy residential buildings, and Area Energy Network*" (Al-Hader and Rodzi, 2009; Belissent 2011).

2.14. Urban growth forecast studies

Proactive monitoring strategies for urbanization have proved to have an influential outcome for sustainable urban development initiatives. This monitoring involves the preparation and selection of appropriate land for future development within the carrying capacity of existing city resources and facilities. Hayek et al. (2011) posits how urban areas have then been assessed and concluded to be relatively heterogeneous in most of the developing cities.

This, according to Giarrusso (2003) makes a holistic approach of monitoring and prediction of urban growth based on a common set of city-scale indicators quite difficult. In addition to these existing problems, misinformation regarding urban setting dynamics have continued to result in misguided spatial planning and land use management, poor allocation of scarce resource, farfetched policies that are yet to be implemented, and large infrastructural projects that lack fiscal capacitation to suffice.

Previous urban forecast studies for land-use change and cover assessments involved the utilization of cadastral maps at a standardized scale of 1:4000. The 20th century had come with advancements as a result of innovation that saw a shift from cadastral mapping, aerial photography to multispectral satellite imagery from different sources (Bagheri et al., 2012). Conversely during the early 21st century phase, urban growth assessments improved from being basic to rather progressive as new digital image processing had been introduced and fused with mathematical methods that seek to improve accuracy in the output results.

Spectral techniques involved supervised and unsupervised pixel classification, however, supervised classification is mostly preferred as the latter provides overlapping signatures of varying classes of land use (Khamaisi, 2006). As a counter measure, digital image enhancement (Image rationalization, image differencing, Normalized Difference Vegetation Index etc.) can be applied for improved visualization and infographic extraction. However, Battle (2007) posits how a correct assessment and projection of urban growth as envisioned is not always the case as information based on spectral information lacks detail when it comes to mapping out solid urban structures (roofing, road, paving etc.).

Because of this, the Applied Research Institute-Jerusalem (2007) suggests an analytical classification scheme that is grounded on texture and image differencing that is based on a spectral structural manipulation to ultimately improve the accuracy of urban growth forecasting techniques. Additional improvements were primarily centered on detection and extraction methods to monitor transitional site changes in the past (Geyman and Baz, 2008). Increased levels of uncertainties in the output results still display dependencies on spectral elements such as satellite resolution data, data radiometry, and localized spatio-climate characteristics.

The accuracy in the remote sensed output results, therefore, remains a continuous challenge more-or-so in the most developing countries where GIS is still in their initial phases. Newer methods *(i.e. “landscape metrics, knowledge based expert systems, agent-based modelling, Cellular Automata based algorithms, artificial intelligence and machine learning based techniques”)* according to the European Commission (2016) have been applied to increase the overall phenomena understanding of urban growth forecast studies.

The most common factors that are integrated within urban growth forecast studies as literature indicates involve both imperious and built-up areas. The quantification of urban growth is mostly experienced in developed countries to cater for stable progression as compared to developing and transitional countries where legislation is in place, however, not fully implemented (Geymen and Baz, 2008). This is a detrimental outcome as the morphological measurement of growth is a significant exercise for an effective land use and management system to transpire.

Commonly applied, GIS and Remote Sensing have served as the go-to tools for local authorities, however, output legitimacy highly depends on the credibility and availability of input data for reliable spatio-temporal and strategic regional planning results. Various publications (Doygun et al., 2008; Haase and Nuisssl, 2010; Issac and Hilal, 2011) have successfully quantified the forecast of urban settlements over time and systematically mapped and projected future developments through the utilization of primary ground data.

Remote sensed data has been applied to monitor growth on a larger scale across an urban landscape and is enforced by its ability to draw analysis from past periods in time. Because of this, multiple studies (Angel et al., 2011; Bagheri et al., 2012) have been observed with similar findings based on various urban growth forecast techniques such as image differencing, image rationalization, masking etc. From a broad perspective, undertaken studies have concluded that urban elements such as demographics and socioeconomic (i.e. businesses, housing, opportunities etc.) to be the most influential factors in driving urban development.

In line with this, typical methodologies integrate these empirical elements with the regression models to assist in the analytical description of the historic spatial orientation of an urban area along with its population dynamics (Hayek et al., 2011). Within the context of urban energy systems, research can be undertaken to oversee the influence it has regarding certain sectors (residential, business, industrial etc.) of a city.

The influence needs to be properly understood as studies revolving on the expansion of the power utility has a direct impact on the city's political, environmental, social, and economic structures. Additional areas of concern, as put by Glaeser and Kahn (2004) involve fiscal constraints on residential developments in the medium-to-long term range as power is a necessity and basic right in some countries (i.e. South Africa).

As a framework for strategic urban growth forecasts, studies pertaining to the power utility sector received incredible attention from recognized institutions (European Commission, Restore 2050, RES Project Consortium), however, Issac and Hilal (2011) note how although most of the studies (i.e. Greyman and Baz, 2008) focused under the theme of urban growth forecasting and power utilities, much effort was neglected on how different themes interact as published research focused on independent themes in isolation e.g. renewable energy, urban energy systems, electrical grid expansions etc.

Besides these issues, underlaying factors commonly considered under technical published literature involve the operational structure of the grid system, stabilization, consumption, production, and integration. According to Khamaisi (2006), some of these elements are critical in urban forecast studies involving urban energy systems. Moreover, Geymen and Baz (2008) substantiates the assertion of forecasting with the generic acceptance from the public as transparency is a critical trait between the public and the local government for projects to be successfully endorsed and completed.

Like regular forecasting, the power utility grid models depend on the availability and technical quality of the electric grid representative of the urban landscape. According to Doygun et al. (2008), the transmission grid should be interconnected to delineate a systematic pattern for forecasted urban developments.

Of these, two forms of models are widely used: electrical grid system and grid simulation models. For grid simulation, the technical and actual performance of electrical grids is assessed whereas the electrical grid focuses on the management, planning, and overall extension of electrical power systems (Angel et al., 2011).

In most integrative studies, the single-node model is mostly preferred as it assumes an unrestrained grid widely applicable in economic models (Haase and Nuisssl, 2010). This perfectly aligns with the urban planning aspect of forecasting irrespective of the heterogenous landscape of land-use functions across an urban space.

Urban growth and suitability forecast techniques

Zielinksi and Jankowski (2008) categorically classify two studies pertaining to land suitability as detailed analysis and simplified analysis. The detailed analysis is primarily concerned with a remote geographical region or area whereas the simplified analysis is undertaken from a global perspective. From a regional perspective, Homma and Saltelli (1996) note how the binary logit model has been widely applied to assist in the overall estimation of the likeliness of a particular land use across the urban space.

Saltelli et al. (2004) applied the logistic regression model and conducted a study in Elbe for the period 1990-2000 under the environmental setting of 250×250-meter grid system. The explanatory variables within the settings involved the regulatory practices pertaining to the land use, transportation infrastructure, as well as the autoregressive spatial factors expressed by the urban landscape's land use patterns.

The validation of the output results was through the Relative Operating Characteristic (ROC) and the analysis indicated that Elbe over the 10-year period had its land use proportional across the grid cells. Using additional variables (distance to transport facilities, environmentally regulated zones, urban facility index, and landscape attractiveness), Deng et al. (2009) performed a suitability analysis of 6 different land cover uses for Netherlands during the 1996-2008 period using the grid system of 100×100-meter.

The results indicated that development was likely to be approved in areas where urban facilities are proximal to the land where the intended development will be undertaken. Although good, this forecast remained questionable as facilities within the urban space were a direct component of land use; therefore, resulting in tautology; also, key autoregressive elements pertaining to the land cover were not used in the study.

Similar studies with analogous criticisms indicate the application of the bid-rent as an external factor. Delgado and Sendra (2009) regard such an approach as a way to increase accuracy in the findings, however, Greyman and Baz (2008) regard forecasted models without bid-rent to be "*50%*" when reference of degree is made to its correspondence. The integration of the bid-rent presents the technique as an endogenous element influenced by the land market's demand and supply.

In the sphere of urban growth forecasting according to Hayek et al. (2011), the bid-rent needs to be estimated and integrated with other techniques. For instance, Benke and Pelizaro (2010) fused it with the multinomial logit model to forecast the locality of future urban settlements. In this study, the explanatory variable involved the spatial autocorrections reflective of the land-uses.

The maximum likelihood technique was adopted to set the parameters within the technique along with additional household attribute variables (transportation infrastructure, proximity to the rail station, urban land value, commercial building presence, household income, and ownership patterns regarding vehicles) within the working environment based on the model. On the one end of techniques, Seto et al. (2017) applied GeoMod to estimate the urban expansion at a global scale from the period 2000-2011 with a grid cell resolution of 5 kilometers.

The variables utilized in the study involved the density of the population and the landscape slope. The location of the expansion was influenced by the study's findings concerning the areas' land grids with the highest suitability index. The restriction was on environmentally sensitive and protected areas; however, statistical assessments were not discussed under the findings. As such, a similar model (UrbanMod) – derived from the main model (GeoMod) by Kordi (2012) forecasted the global urban expansion for the year 2000 and 2030 using the 25-kilometer global grid system.

The model is integrated with the Monte Carlo technique to simulate the possibility of global urban land use. The results indicate that the global land use will triple during this 30-year period. The variables used involved the slope, proximity to the road network, and the population density from the year 2000. The model was exposed to criticism as the computational and mathematical methods adopted were not recorded and as a result, the validity and credibility of the model was not given much international attention.

An additional global urban forecast study by Seto et al. (2011) indicated that demarcated zones (i.e. protected areas) will be prone to urbanization. In an integrative effort, the Analytic Hierarchy Process (AHP) can be applied as an external technique that assists in the identification of a strategic criteria that can be adopted along with a set of weightages that scales the explanatory variables on a scale of importance. Crosetto (2010) acknowledges the AHP's ability to measure the level of urban growth suitability through the hierarchical decomposition of the compatibility analysis into structured units.

In a brief manner, urban forecast techniques on regional areas highly depend on detailed site-specific explanatory variables. However, Benke and Pelizaro (2010) note how the juxtaposition of the models on other geographical terrains is not an obvious exercise. Reviewed studies have applied urban facility intensity approach along with bid-rent as primary variables with Kordi (2012) positing how these factors are in nature, "*essential endogenous components of urban land use*".

As an advancement, detailed forecast studies should have these elements factored within the working environment and seek integration with various other suitability models that rely on autoregressive spatial elements. This is because most of the global urban forecast studies discussed have neglected autocorrective factors and thus renders the results almost inconclusive. The most common factor utilized is the nearest distance to transportation facilities.

Homma and Saltelli (1996) suggested the incorporation of autoregressive elements such as urban city agglomeration due to the factor having an effect on the prime essence in the growth of an area. The implication of this suggestion is that new settlements are likely to be developed nearby an existing urban center other than a non-urbanized locality. For this reason, autocorrelation within the working environment can be assumed and computed through the spatial autoregressive (SAR) model.

Delgado and Sendra (2009) support the SAR approach as this technique is inclusive of endogenous elements – thereby rendering the estimated parameters to not portray consistency, significantly avoiding bias in the results. Another suggestion worthy of attention by Crosetto (2010) is the utilization of the transport infrastructure as an autocorrective factor.

The main reason is that the transportation network significantly influences urban development. Consequently, transport nodes have been rapidly developed where demand is highly experienced; therefore, transport factors can be attributable for urban expansions in the future, however, Kordi (2012) realizes how the endogeneity nature of this variable may result in bias within the estimated parameters.

2.15. Conclusion

The process of urban development is complex and influenced by multidisciplinary factors that span across academic disciplines such as demographics, geoscience, economics, and sociological analogies to mention a few. The primary focus within the majority of the literature reviewed involves different assessments regarding the urban scale expansion along with its relationship to the nodal concentration of human activities responsible for the overall growth or decline in the specific area.

With the above, this growth or decline indicates a rapid level and demand dynamics for development that needs to address the needs of the population in terms of housing, utilities, and other amenities. Additional trends in population and urban growth has indicated an ageing populace with an increased demand for infrastructural upgrades and extensions for newer developments. Rapid growth in this sense has been observed to mostly take place in developing and transitional countries.

This indicates varying patterns of urban development and can be attributed to a number of factors (economic opportunities, governance, safety etc.) which also are responsible for growth that will suffice (i.e. rapid, slow, stagnant, or negative/declining). This has paved a way to fully understanding the dimensions of the urban environment as it assists in the provision of key components that outline the urban energy utilization patterns from a localized to a regional level. This understanding shines light upon the built environment on how it interacts with the city's urban system by looking at the production, distribution, and consumption patterns of various city sectors.

The integrity of designing and integrating thermal concepts of insulation in residential buildings is therefore a critical element in the management of energy for cooling and heating purposes when looking at the production and consumption levels. Furthermore, building typology influences the type of function space will portray to the city inhabitants. As such, an understanding of a city's urban setting as a result of its ever-growing demand for power utilities transforms ordinary spaces into densified blocks that constantly require maintenance and upgrading.

Urban development and energy patterns therefore play a huge role in influencing policies related to the power utility regulation sector. Future developments should therefore be aligned with the explicit understanding of the dynamic urban changes occurring at local levels. With challenges come modernized modifications to the existing urban energy systems with alterations influencing the distribution nature of transmission power systems in a manner that locates them closer to residential units.

From one perspective, urban energy systems have reduced transmission costs and have become smarter as new processors have smaller chips embedded within them that allows the systems in place to function with better capacity as compared to larger, traditional ones. Although a good initiative, demographics will also need to be addressed so as to be an inclusive system.

This is based on how a large-scale household income is spent on the electrical power as compared to it being primarily spent on food and other basic needs other than electricity. Linked to this is how general statistics have been presented on the functionality and typology of urban energy use within cities as well as extending such figures to the levels of accessibility by the inhabitants.

As pivotal as this achievement is, there however, is a lack of statistical data that assesses the level of power utilization and accessibility within various cities with reference to the income group. This issue can be aggregated to the generalization of results from a national perspective which at most, assumes homogeneity across a country/city.

With reference to generalization, literature has concluded upon factors behind energy consumption and demand. The following below has been classified as broad direct/indirect categories of energy drivers:

- Local environment: geographical location and climate conditions;
- City socioeconomic status quo: household features, economic output, and demographic dynamics;
- Local/regional city interrelationships: city role, labor, skill set, and production and consumption synergy;
- Urban energy and institutional system: governing structure, power supply system, and cost; and
- Urban morphology: built urban environment, density, housing typology, land use variation, and transportation infrastructure.

Such issues are usually addressed through smart city initiatives. The preceding literature regards smart city as a concept that is relatively new, fairly adopted, and applied in both transitional and developing countries. With each applicability, various clarifications have been observed to surface based on a city context, challenges, and aspirations. The end goal is the utilization of ICT to digitize city functions and optimize resources with special attention to decreased carbon footprint levels, improved energy-maximization, and the integration of smart-grids to portray positive outcomes for urban planning and future expansion.

With reference to future expansions, pro-active monitoring strategies for urbanization have proved to have an influential outcome for sustainable urban development initiatives. This monitoring involves the preparation and selection of appropriate land for future development within the carrying capacity of existing city resources and facilities. Literature categorically classifies two studies pertaining to land suitability as detailed analysis and simplified analysis.

With the above synopsis, the literature review section, in overall, has presented a comprehensive review of work that cut across multiple disciplines of knowledge bases. In a nutshell, the literature review focused on themes such as urban energy systems, urban growth forecast studies, urban growth dynamics and development, land-use/development synergy, urban form, energy pattern dynamics as well as the techniques involved in urban growth forecasting.

Chapter 3: Research design and methodology

3.1. Introduction

Chapter three is central to the preceding sections of this research and seeks to brighten the salient components that comprises of both the primary and secondary data collection procedure followed. In an effort to delineate the rigorous research protocols adopted, the examination is structured in a holistic sense that unpacks the research questions set above in chapter 1. This section presents the methodology adopted in the research study and in the process, deliberates and expands the logic behind broad methods and techniques used in this research.

3.2. Design Strategy

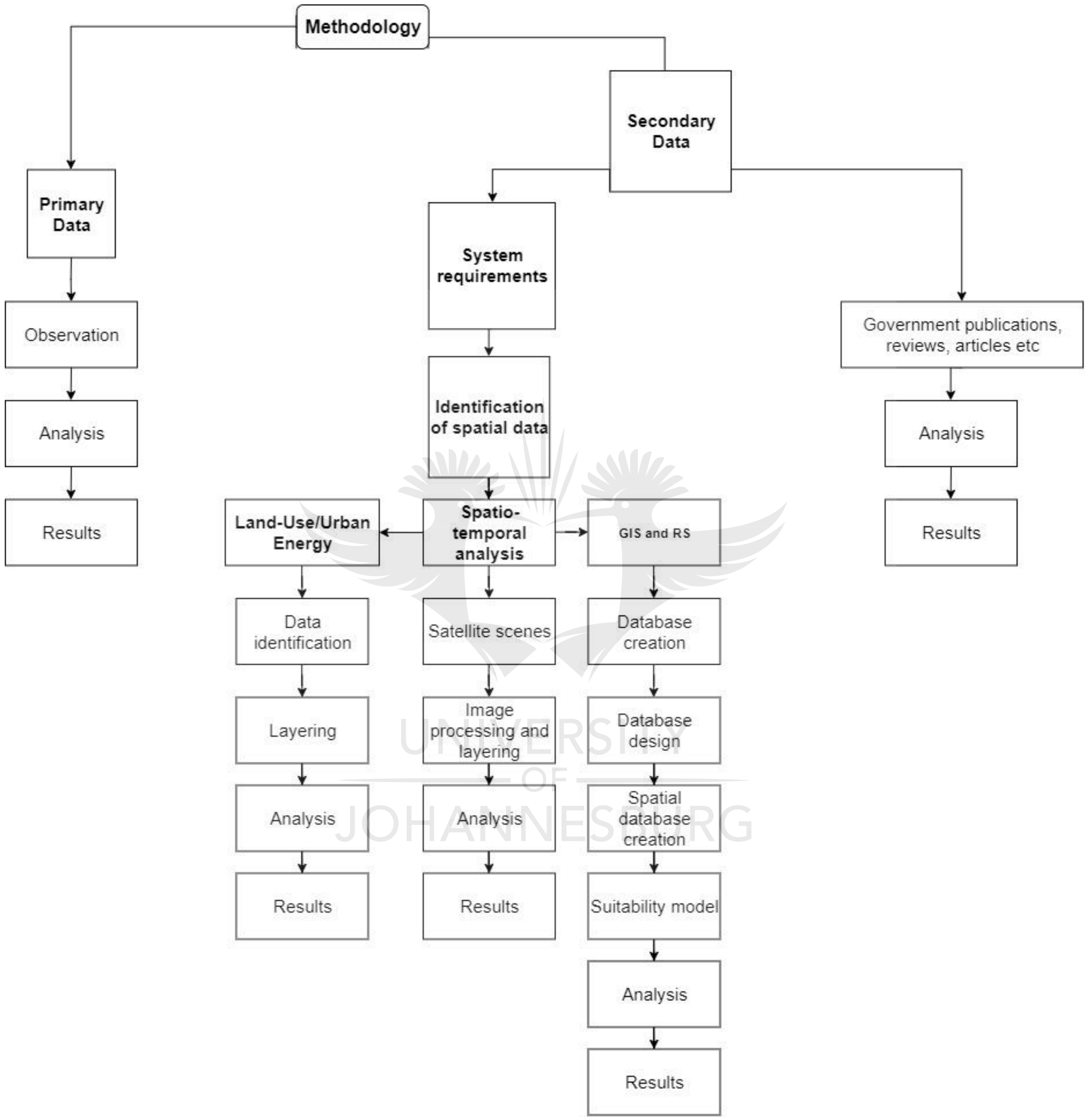
According to Yin (1984), a variety of elements have to be taken under consideration when it comes to the decision-making process of adopting a specific strategy on how to conduct research. From a basic perspective, Winner (2009) and Okoto (2016) divide the methodological data collection process in two classes: quantitative and qualitative methods.

These methods portray a shared goal in a sense that they seek to understand the point of view of the subject at study and provide an outline on the adopted standpoint (Okoto, 2016). Regarding the designs available (case study, experimental, statistical, modelling, evaluative etc.), a cross-multiple synergy between them can be established. The research applied both the modelling and evaluative design to conduct the research.

This hybrid approach was prevalent in carrying out this research as it encapsulated Remote Sensing and GIS principles with spatial and satellite data as units. The modelling design relates to the formation of logical deductions and results stemming from the numerical data collected, ordered, and analyzed. The evaluative design addressed the limitations experienced from employed quantitative techniques through the provision of the ability to understand interactive conditions from the perspective of the researcher (Winner, 2009; Yin, 1984).

3.3. Methodological research structure

Figure 3: Methodological structure



3.4. Primary data

Qualitative:

Primary data

The utilization of primary data used in the study involved observational analysis throughout the city regions. Much emphasis follows below:

Observation

Winner (2009) describes observation as a primary data collection method that involves the observation of behavior/phenomena in a systematized manner that has no direct control or influence over what is being observed. With this employed, the observational analysis was used as an instrument to broadly perceive smart utility initiatives developments throughout the city. To draw a quick synopsis, Waterfall City was observed to have a wide adoption of PV Solar panels along with smart meters extensively being installed in Fleurhof, Ennerdale, and Westdene.

The University of Johannesburg was observed to utilize PV Solar panels as an external charging point for students. As for Bryanston, Sandton, an increase in the adoption of fiber optic wires was seen with an added advantage of fast internet upload and download speeds. Furthermore, Okoto (2016) subsequently stipulates observation as an activity in which rating scales would be utilized when observing an area.

During this, a naturalistic or laboratory observation would have to be employed. For this study, the naturalistic observation was adopted as it involves the natural observation of behavior in its actual environment (Winner, 2009). With this line, the majority of the city was observed to have active Wi-Fi zones i.e. (Braamfontein, Park Station, Newtown, and Sandton) as a way of governance to report issues such as energy outages etc. Additionally, further smart utility initiatives were observed in Sunninghill Office Park with their adoption of Radio Frequency Identification Devices in their devices.

Similarly, a wide adoption of smart water and gas meters were observed throughout the city. Overall, the employment of this observatory approach was utilized effectively and assisted in providing a sense of enforcement to the experience and analytical background in the field of urban planning. This resulted in detailed observations based on informed understanding and knowledge application of the city initiatives.

3.5. Secondary data

Johnston (2014:620) defines secondary analysis as "*any further analysis of an existing dataset which presents interpretations, conclusions or knowledge additional to, or different from, those presented in the first report on the inquiry as a whole and its main results".* The majority of scholarly studies begin by reviewing literature on what is already known/established as well as providing potential paths of what could be learned about a certain theme or area of interest. For the study, the secondary data that was utilized is briefly explained below:

Government publications, reports, and articles

According to Creswell (2009) and Doolan and Froelicher (2009), various research studies provide an investigative overview regarding a theme/topic undertaken. This is inclusive of relevant literature data that may or already exist in providing the assistance in answering the adopted research questions (Dale et al., 1988).

In the case of this research work, an in-depth review of secondary data resources of relevant interest was effectively conducted through the examination of both previous and present work of scholars within the field of urban planning, urban growth forecasting, and urban energy systems. Further review of literature identified additional government agencies (i.e. Statistics South Africa, City Power, Department of Environmental Affairs, Department of Energy etc.), local agencies (Eskom, NERSA, SAICA, etc.), policy papers, global organizations (United Nations, World Bank, American Physical Society), Statistical report centers (Global Statistical Energy year books, City Mayor statistics) and research centers (CSIR, Applied Research Institute-Jerusalem).

3.6. System requirements

Studies involving the utilization of urban energy, spatio temporal, and suitability analysis data traditionally often involve statistical registrars, shapefiles, and other forms of representation. Issues in obtaining the specified themes comprise of information being big and dispersed, accurate, available, sensitive, better resolution, different formats, and sensitive i.e. classified information not available for public.

It is because of this that an adoption of a technical/systematic approach to assist in accessing and analyzing the statistical data is done. Given this context, the analytical capabilities made available by GIS are taken as invaluable tools to effectively satisfy parts of the research objectives. A plan for using it to formulate a GIS based spatio-temporal and urban suitability model is theorized with the goal of generating a GIS database of satellite scenes and land use with the aim of inducing accuracy in analyzing the urban energy in relation to land uses and subsequent forecasting.

GIS requirements

Software requirements

The following Software and Hardware required for the study were used in the study:

Software

The following software were used in the study:

ArcGIS Desktop

ArcGIS is part of the ESRI GIS software family. It comprises of four integral frameworks for executing GIS functions.

ArcGIS 10.5

Desktop GIS application with ArcEditor and ArcView functionalities. The list below shows the components of the ArcGIS Desktop which were utilized for the study:

Arc-Toolbox

Utilized for map projection, clipping, transformation, mosaicking, and etc.

ArcCatalog

Utilized for the creation of feature datasets, geodatabase, and overall arrangement of data.

ArcMap 10.5

Utilized for georeferencing, rectification, layering, digitization, and output display of results.

IDRISI 17.00 Software

Utilized to forecast and validate growth change thirty years in the future to serve as a basis for the suitability model in ArcMap.

Land use cover classification and analysis

For this sub-section, pertinent land-use classes were assessed and divided into four major land-use classes: Built-up, vegetation, water bodies, and undeveloped land as per the spectral band combination for Landsat scenes. Maximum Likelihood Classification was then applied to the scenes as per the classes and had the shapefile layers saved for importation in ArcMap. Using the IDRISI software, modules such as: Markov, Validate, and Ca-Markov were critical in the overall projection of CoJ's built-form pattern for the year 2049. The generated growth map was then converted to a GEOTIFF file and imported to ArcMap to inform the suitability model for potential growth points for that particular year.

Identification of spatial data

Based on the system requirements, the identification of relevant spatial data for analysis is key in producing accurate information relative to the research. This is briefly expressed below:

Spatial data

Spatial data relates to geographical sets with locality and shape embedded within. It can either be in polygon, point, or line form. The relevant spatial layers (i.e. electrical lines, land use, 7 city regions, and other datasets) that required systematic incorporation were identified and analyzed in conjunction with the city's satellite scenes. This is explained briefly in the following sections.

Urban land use relation to urban energy

The relationship between land use and urban energy was assessed through the integration of utility data and the city's urban land use and built form. Through this, ArcGIS layering proved critical in being able to delineate the synergy between land use density and energy coverage and as such, conclude on the results. The analysis involved the assessment of the three land uses: Residential, commercial, and industrial in relation to energy coverage and distribution provided by nighttime light and census (2011) data.

Remote sensing/Spatio-temporal analysis

Based on the available data, the city's energy spatio-temporal data utilized in this study were primarily secondary in nature and obtained from various satellite sites and organizations and compared against each other for best resolution and accuracy (i.e. United States Geological Survey and National Oceanic and Atmospheric Administration (NOAA)).

For spatio-temporal analyses, a period of 17 years from the year 2000-2017 (2000; 2008; and 2017) were employed. Landsat satellite scenes of 30-meter resolutions (2 x Landsat 7 Thematic Map and 1 x Landsat 8 Thematic Map) subject to three band combination were used to derive urban growth patterns. The satellite data along with relevant data for the area of study went through digitization as was discussed above and subsequent projection to UTM-Zone 35S with a WGS-84 geographic coordinate system in ArcGIS 10.5.

Night Time Light (NTL) image and data processing by NOAA's National Geophysical Data Center collected by US Air Force Weather Agency were also utilized in this study and provided assistance by tracking the level of energy activity development patterns throughout the city based on the selected periods of time when Landsat 7 and 8 scenes are overlaid with the NTL data.

The images of multi-temporal NTL data for the study period were obtained from the following sensors: F14 and F15 (2000); F16 (2008). The most recent NTL data (2017) was sourced from WorldView earth data. The images portray a 30 arc-second grid spatial resolution presenting local to global average illumination that ranges from brightness (0) to brightest (63).

The chosen composite "*avg_vis.tif*" was preferred as it is inclusive of the light activity from cities across the globe – including small and big towns, and sites portraying consistent lighting within the study area. Another advantage is the elimination of short-lived events relative to fires and flares. This involved the process of identifying and removing background noise (i.e. replacing the noise with values of 0).

3.7. Geographic Information System

3.7.1. Database design

The type of requirements discussed above provided the working space for the database design.

3.7.2. Conceptual and logical design

The two designs were responsible for the determination of the database contents as well as the logical structure behind the organization of the data. Conclusively, the personal geodatabase resulted in the conceptual design answering how the database would work whereas the logical design provided detailed layout specifications with the aim of filling in the conceptual design requirements.

3.7.3. Physical design

This type of design decided which form of data (TIFF, NTL, txt, doc, shp., and jp2) were used for the system.

3.7.4. Database creation

The creation of a database involved:

Assembling the database

The data required for the project was in outsourced from different organizations (i.e. USGS, City Power, Municipal Planning Department, and the DMPS) and in varying formats. The data was sourced and arranged using ArcCatalog to create a viable workspace in which exploration can be effectively conducted.

Preparation of database for analysis

The determination of which layers to utilize as well as the holistic overview of other layers which require additional coloring and processing for application in the overall analysis was done. The common tasks undertook in the preparation of a database for analysis involved:

- Data quality checking to assure accuracy in presentation and dating;
- Data format conversion;
- Data digitization and geolocation;
- Definition of coordinate systems;
- Layer Projection; and
- Merging/mosaicking layers.

3.2.5. Spatial database creation

Georeferencing

General satellite scenes often do not contain accurate locational information and as such, renders the data to not be aligned with other spatial layers. Given this, the datasets were georeferenced to the UTM-Zone 35S with a WGS-84 geographic coordinate system. This assisted in successfully viewing, querying, and examining the data effectively in conjunction to other layers during the creation of a suitability model.

Creation of a geodatabase

A geodatabase can be regarded as a managed file folder comprising of varying types of geographic datasets to be used in the system. It therefore serves as the established data source for ArcGIS and assists in the automation of data. The chosen database for the study was the Personal GeoDatabase as it provides an added advantage of storing multiple Database Management Systems (DBMS) and Informix.

Furthermore, satellite scenes are generally data extensive and such, this database will assist in handling that. Most of the layers (e.g. city boundary, land use, electrical lines etc.) were in shapefile format. The creation of additional layers occurred as a result of the suitability model. The output layers were imported and stored in the relevant geodatabases.

3.8. Creation of a suitability model

One of the key significances involved in the land evaluation process for urban potential development is to compare the desired requirements of each potential element (i.e. power utility, land use etc.) with the features of each kind of land. The output generated provides a certain measure of the potential land suitability parcels encompassing all aspects under consideration. The stages undertaken in the analysis involved the:

- Definition of objectives;
- Collection of relevant data;
- Identification of the physical parameters; and
- Overall assessment of growth suitability.

The definition of objectives was crucial in projecting a relevant suitability map. This involved a projection of urban development aligned with the power utility. Furthermore, the collection of relevant data assists in providing reliable knowledge interlinked with the land characteristics. This was aligned with the consideration process of the variety of data that could be considered relevant in the evaluation of growth.

The attainment of the data proved to be time consuming and complex due to sensitivity issues regarding other data (i.e. locality of power plants). The common methods adopted in procuring the relevant and needed data involved:

- Focusing on data that is available and applicable to the overall evaluation; and
- The maximization of existing and compatible data to the study area.

Below stipulates the variety of physical data considered for the growth suitability analysis:

- Projected urban growth
- Economic nodes

- Electrical infrastructure
- Transportation network
- Built form
- Population density
- Main substations
- Corridors
- Ecological areas

3.9. Overview of process undertaken

A variety of physical factors pertinent for the study were taken in consideration and this included significant elements with the aim of keeping the model compact and operative. Using ArcGIS 10.5, the AHP method was employed to weigh the elementary vector layers. This was done by theoretically ranking the factors in accordance to their importance/relevance to the suitability analysis. The layers were then processed in the generated model from IDRISI, and ultimately, the output map with potential suitable growth points outlining possible areas where urban growth was most likely to occur was produced.

Analysis

The projected urban growth model was analyzed in terms of the most suitable growth points relative to principles such as proximity to transportation routes, amenities, existing land uses, and most importantly, electrical utilities.

Results

Ultimately, the suitability map was generated and attained in a form of a thematic map encompassing of the relevant information of where the anticipated future growth was most likely to occur.

3.10. Research design and methodology summary

This section presented the study's adopted methodology and design. Regarding the designs available, a cross-multiple synergy between the modelling and evaluative design was established. This hybrid approach was prevalent in carrying out the study as it was inclusive of both Remote Sensing and GIS principles with spatial and satellite data as units.

With reference to the primary data, observation was utilized as the tool for perceiving smart utility initiatives throughout the city while the secondary data pertaining to literature and map data, scholarly articles, reports, government institutions, online satellite data sites, and other publications were consulted to carry the research analysis forward.

The adoption of a technical/systematic approach was therefore mandatory to assist in accessing and analyzing the statistical data collected. ArcMap was utilized for the preparation of maps and other necessary steps required for data processing while the IDRISI software was employed to generate the projected urban growth map as well as the facilitation of the validation procedure.

Chapter 4: Analysis and discussion

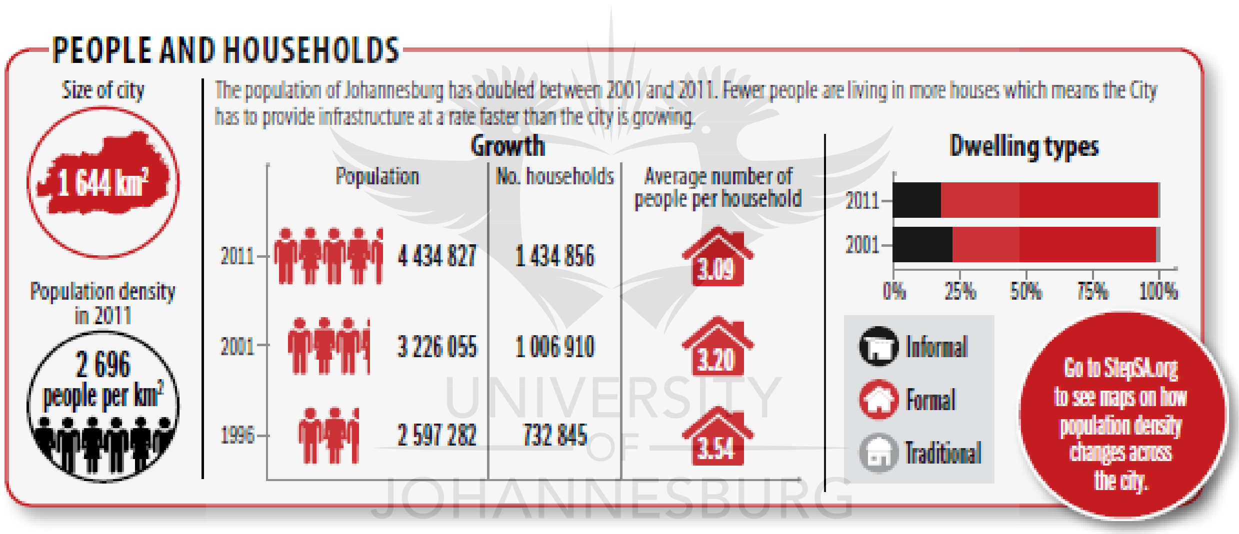
4.1. Reviewing smart power utility infrastructure development at a city level

City Profile: Johannesburg Metropolitan

Spatial Economy

CoJ is the country's largest metropolitan municipality when taking in account factors such as population size, economic output (contributed approximately 15% of the national Gross Domestic Product for the year 2016), and diversity (CoJ Integrated Development Plan 2018/2019). This is visually represented below:

Figure 4: City Demographics

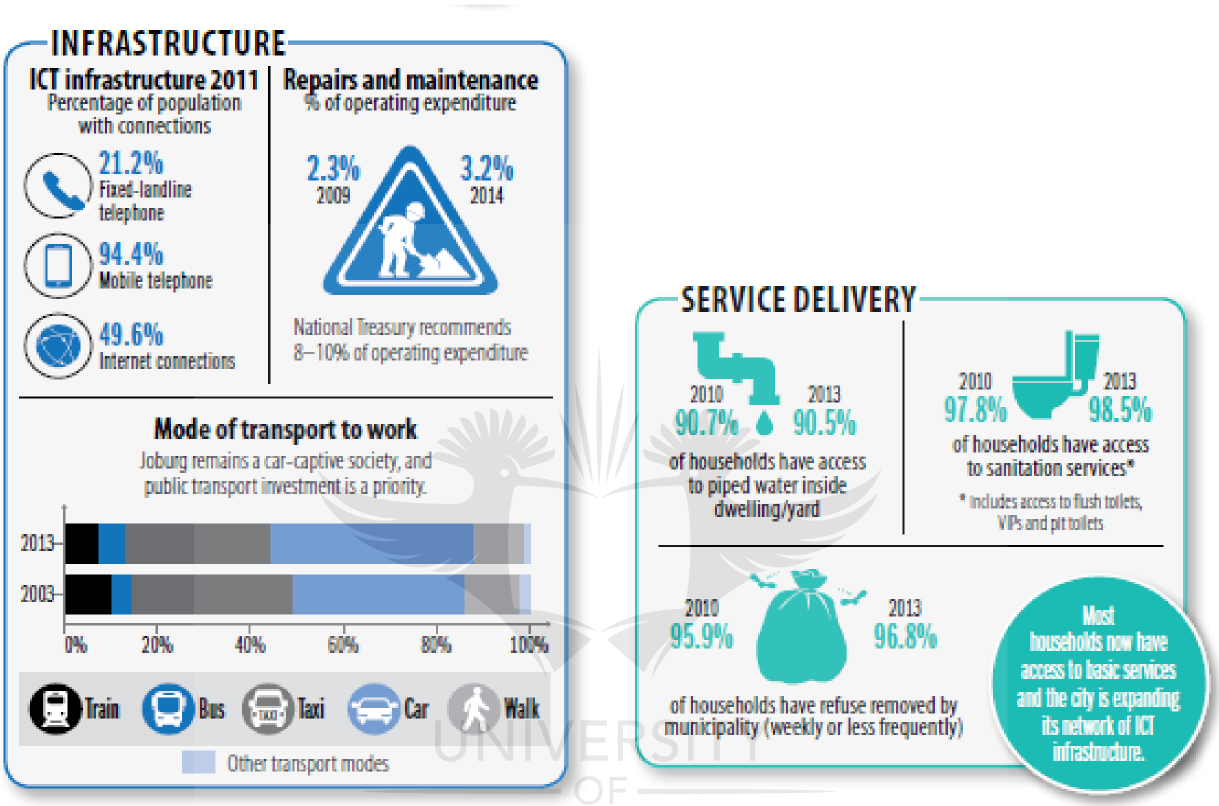


Source: Gregory, 2016

The spatial orientation of the city is divided; with the Northern section of the city comparatively being well-off (i.e. employment opportunities, improved housing standards, efficient waste management etc.) than the Southern regions. According to the GCRO Quality of Life Survey (2015), the bridging point – being the inner city, is closer to the Northern regions and is heavily experiencing an increase in housing demand that continues to outstrip the local authority's supply capacity.

According to the Economic Development Strategy for the City of Johannesburg (2015), the city is an effective economic hub that is well-connected by a variety of multi-modal transportation system that radiates outwards to other major towns and cities. With its infrastructure, service delivery is of its prime importance and is best presented with visual statistics as indicated below:

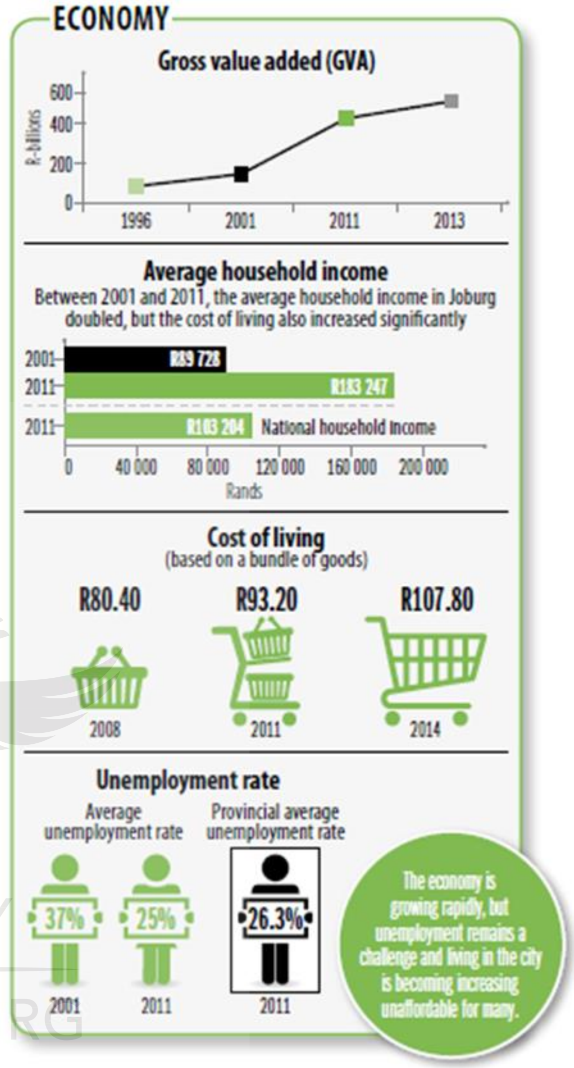
Figure 5: Infrastructure and service delivery status quo



Source: Gregory, 2016

Spatial distribution of the Urban Economy

Over the past years, the UN Habitat (2010) observes how the city's overall economy has accelerated much faster as compared to the country. This is reflected in the official unemployment statistics as shown in **Figure 6: CoJ Economic Stats** as per the Economic Development Strategy for the City of Johannesburg Report (2015).



With the economic indicators positing a stronger stance in the country, major spatial inequalities still persist with specific reference to both the built-form and the opportunities offered. According to the city's Spatial Development Framework (2018), the city's economic output stems outward from the Central Business District to the adjacent regions (E & F) where strong business nodes exist. This synergic output is responsible for halve of the city's economic production, however, houses a low staggering percentage of 23% of the total population.

Discussion: Status quo on smart utility infrastructure in CoJ

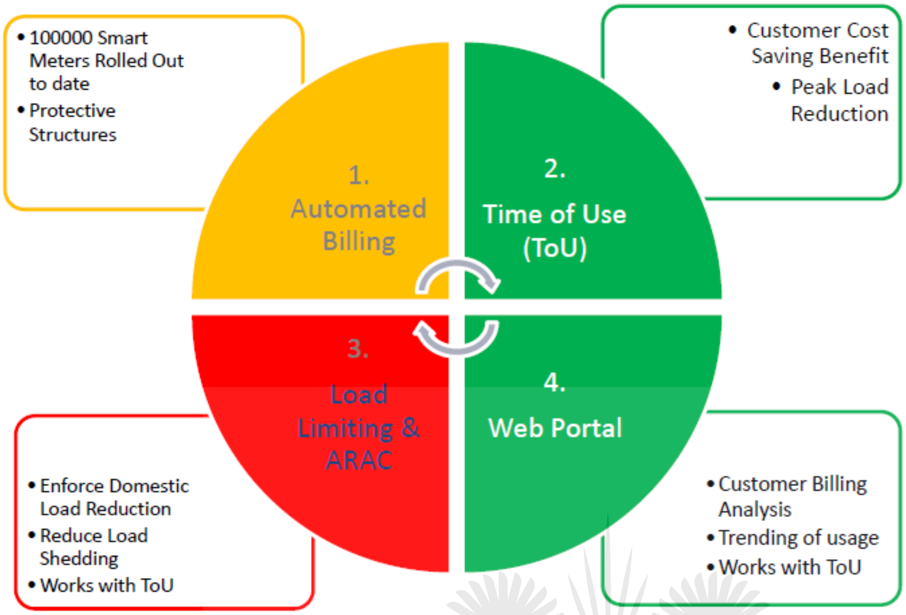
Recent strategic efforts have opened avenues for the city of Johannesburg to rebrand itself as Africa's leading smart and economically competitive city in a quest for improved city life experiences. From a technologically inclined perspective, smart cities are characterized by innovative measures that seek to optimize all forms of capital within the city region. The city of Johannesburg's 2040 Growth and Development Strategy (GDS) emphasizes key themes centered on the provision of world class socioeconomic infrastructure that seeks to transform the city landscape at large.

On a global level, CoJ's governance initiatives comparatively compare better (ranked 35th) in relation to other African countries (i.e. Cairo: 37th; Lagos: 40) as per the ratings by the Ericsson Networked Society City Index (2016). Although a significant progress, there was a slight lag in positionality as it lost its previous 29th position. The ratings are based on global initiatives worldwide by cities pertaining to the level of sophistication and development in the technology sector. Reference is made to sustainable urban growth as well as the Information and Telecommunications Technology sector.

Such advancements in the ICT sector invigorates the city's ambition to pursue themes such as smart utility and other forms of smartness. As a city initiative, the development of smart utility infrastructure has seen the city adopt concepts such as smart meters and smart grids. The rationale behind the project is the attainment of low-carbon energy intensive urban settlements and the maximization of the power utility sector which has shifted its focus on other city dimensions such as gas, pipe, and electrical industries.

As part of the ICT initiatives, the CoJ's power utility system aspires to provide municipal services in the most efficient way. This is made possible by the fusion of governance tactics with smart power utility innovation. Within this system, city dwellers are enabled to assess municipal data in an open and transparent manner with just the use of both software and hardware – both online and offline. The accessibility further allows the dwellers to effectively manage the consumption of household energy, billing, and the subsequent monitoring of live data amongst other features offered as shown below:

Figure 7: Summary of features offered by the smart utility initiatives



Source: CoJ Smart City engagement with World Bank Report (2017:27)

Primary legislations influencing smart energy utility development in CoJ

As part of the research theme, power utility legislation from national to local level which have a direct influence on the smart energy utility development in CoJ is assessed. This looks into insightful sections within the legations and how they play a role in the facilitation of smart energy principles. The energy-related legislation reviewed are as follows:

- National Energy Regulator Act (Act No. 34 of 2008);
- Electricity Regulation Act (Act No. 4 of 2006);
- The Gas Act (Act No. 48 of 2001);
- White Paper on Energy Policy for South Africa of 1998;
- White Paper on Renewable Energy Policy for South Africa of 2003;
- The White Paper on National Climate Change Response of 2011;
- Municipal Systems Act (Act No. 32 of 2000); and
- The Municipal Financial Management Act (Act No. 56 of 2003)

National Energy Regulator Act (No. 34 of 2008)

Pertinent to the persuasion of smart energy principles, the National Energy Act provides an enabling environment for the Minister of Energy to ensure that there is availability of diverse sources of sustainable energy investment. The setback within the Act, however, revolves on the lack of emphasis regarding the typology of energy sources that require the most attention and need for further scholarly research and development. Apart from seeking to alleviate poverty through economic growth, the Act touches upon key energy themes such as:

- Effective energy planning
- Increased supply and distribution of renewable energy for public consumption
- Contingency energy supply i.e. nuclear power plants discussions
- Adequate investment and improved access to reliable energy infrastructure
- The establishment of a credible institution responsible for facilitating energy research and technology.

Aligned with the energy themes, the Acts' objectives do provide an extensive coverage on smart energy initiatives such as the promotion of diversified supply of energy and its sources, energy research, and data collection and information relative to the supply and demand of energy. The aim does extend towards contributing to the development of the country at large in a sustainable manner – however, key emphasis lacks on the exact desired themes of energy research even though it does cater for the commercialization of energy-related technologies irrespective of firm regulatory mechanisms in place.

Electricity Regulation Act (Act No. 4 of 2006)

The Act aims *"To establish a national regulatory framework for the electricity supply industry; to make the National Energy Regulator the custodian and enforcer of the national electricity regulatory framework; to provide for licenses and registration as the manner in which generation, transmission, distribution, trading and the import and export of electricity are regulated; and to provide for matters connected therewith*".

The legislation, though covering an extensive overview of the key themes it aims to tackle, mostly deals with the provision for licensing. Throughout the Act, less attention is given to the theme of smart energy initiatives as only under **Chapter VII** under **general provisions** regarding the new generation capacity, is the theme of smart utility being tainted in a rather obscure form. For instance, **Section 46(1) states that "***The Minister may, in consultation with the Regulator- 45:*

(a) Determine that new generation capacity is needed to ensure the continued uninterrupted supply of electricity;

(b) Determine the types of energy sources from which electricity must be generated, and the percentages of electricity that must generated from such resources".

The section partly touches upon the theme of smart energy, however, lacks specification on how the new generation capacity on Section 46(1)(a) is to be achieved. One may question if it is in the form of new electrical forms or perhaps the synergy of various other sources of energy. This is interlinked with the subsection (b) on the determination of different forms of energy sources. Perhaps this is where smart energy principles will be adhered amidst the broad policy approach adopted.

The Gas Act, 2001 (Act No. 48 of 2001)

The Gas Act, like other forms of Acts, intends to regulate and coordinate its sector in an effective manner. This is done through "*the orderly development of the piped gas industry by establishing a national regulatory framework in which the National Gas Regulator serves as the custodian & enforcer of the national regulatory framework & matters connected therewith*".

The gas industry can arguably be regarded as a development sector within the country and its major cities. The Act does provide for the provision of an "*efficient, effective, sustainable and orderly development and operation of gas transmission, storage, distribution, liquefaction and regasification facilities and the provision of efficient, effective and sustainable gas transmission, storage, distribution, liquefaction, re-gasification and trading services*", however, lacks the structural mechanisms on how to attain this provision (a). It is of this research's opinion that critical themes such as smart gas meters and electrification through gas-powered plants should have been included as sections within this Act.

Aligned with this thought, sub-section (b) offers to "*facilitate investment in the gas industry*". Although a good initiative, details within which sections within the gas industry will require more investment and growth are neglected. The form of investment also needs to be clarified as arguably, monetary, skills, and technological forms of investment will be key forces driving the gas industry based on the 4IR transition where energy will need to be versatile and sustainable.

White Paper on Energy Policy for South Africa of 1998

The White Paper on Energy Policy provides a comprehensive overview of the government's policy relative to the dynamics surrounding the demand, supply, and overall consumption of energy by the country for the next decade. The policy plays a critical role in strengthening the existing policies on energy systems in certain areas of conceptualization and implementation.

This indicates effort regarding the advancement of underdeveloped institutional systems such as the linkages of national policy to both provincial and local levels as interrelated initiatives demonstrate a resolution of extensive transformation in a variety of areas of intervention. The policy is arguably well structured and indicates efforts in addressing a variety of elements (e.g. energy poverty, access, efficiency, technology etc.) relative to the energy sector such as demand and supply, energy efficiency, access to energy and etc.

Although offering a variety of intervention in the energy industry, little attention was paid to the integration of smart power initiatives. However, noticeable efforts are indicated in the policy being able to recognize the lack of development and implementation of related smart energy principles such as renewable energy sources. The proposed intervention nevertheless, aims to take cognizance of the potential other forms of smart energy have in the medium-long term perspective.

White Paper on Renewable Energy Policy for South Africa of 2003

The White paper on Renewable Energy is by far, the most comprehensive legislation that touches upon the aspects of smart energy utilities. Its provisions aim to "*ensure that national energy resources are adequately tapped and delivered to cater for the needs of the nation while the production and distribution of energy remains sustainable to lead to an improvement in the standard of living of citizens*".

As a way of progression, the Act strategically seeks to "*pursue energy security by encouraging diversity of both supply sources and primary energy carriers".* Forms of this aspiration are already in motion as the Government's Integrated Electrification Plan (IEP) has resulted in an integrated scheme relative to the effective provision of solar photovoltaic systems to rural settlements as a plan to alleviate energy poverty. As part of smart energy principles, current policy efforts are being directed to the persuasion of sustainable renewable energy resources (particularly for power generation) as a mechanism to reduce reliance on coal-based power generating systems.

Like other legislation, it is of importance to understand the context under which the legislation will be enforced. The White Paper on Renewable Energy sources, therefore, considers which technologies will be pertinent in the effective stimulation of its market. It seeks to do so by adopting renewable sources as a way to maximize the potential of returns while subsequently minimizing costs associated with traditional energy sources relative to both implementation and operational costs.

More succinctly, the Act plays a good role in academia as efforts are equally being vested in the establishment of technology support institutions that foster smart energy research on themes such as technology, application, and feasibility. The strategic goals aligned with coherent objectives will be key in the proper facilitation of a comprehensive smart energy framework that provides an enabling environment for local authorities to meet the national government's aspiration of promoting renewable energy.

As part of this, the Act addresses four key strategic areas: finance; legal, technology; and capacity building. In its provision, the financial pillar aims to "*promote the implementation of sustainable renewable energy through the establishment of appropriate financial* *instruments*” while technology development seeks to “*promote, enhance and develop technologies for the implementation of sustainable renewable energy*”.

The White Paper on National Climate Change Response (2011)

The White Paper on National Climate Change presents a comprehensive vision of the country’s aspiration to formulate an effective framework that seeks to mitigate climate change and subsequently enforce a long-term transition to an economy characterized by climate-resilience and low carbon emissions. Although offering a comprehensive review on climate-change mitigation, less attention is emphasized on the benefits of smart energy initiatives relative to renewable sources and energy optimization.

Amongst the interventions identified within the policy, good observations suffice as a theme of smart utilities sort of arise – touching upon sub-elements such as the establishment of measures that improve energy efficiency; regulate demand-side management; and the transition to energy sources that promote less emissions during production and supply. From a national perspective, such measures are theoretically effective however, remain disorganized when contextualized in a local municipality setting.

This could be attributable to the lack of direction that empowers local authorities regarding the implementation of the policy irrespective of playing a critical part as stakeholders. This often leads to disjointed frameworks within municipalities in drafting smart-energy policies aimed at combating carbon emission and promoting renewable energy and energy efficiency in a broader context.

The Municipal Systems Act 32 of 2000

The Act relatively plays a good role in empowering municipalities to authorize regulations and guidelines for energy efficiency and renewable energy. The theme of smart energy is however, not fully discussed as it has been assumed under the broad umbrella of energy efficiency.

Another setback identified involves how the municipalities utilize a rigorous model (i.e. developing policies, planning, and strategizing) of going forward irrespective of how these models fail to legally share the same obligation as the by-laws. As such, action plans would be key in the facilitation of smart energy initiatives that are aligned with the models established.

From a national perspective, numerous challenges pertaining to how municipalities should implement smart energy initiatives are unclear. To an extent, the municipal roles in the implantation of energy efficient utilities are not specific due to the lack of specialized coordination.

For instance, few national policies do justice in setting targets pertinent to the implementation of energy efficiency initiatives however, lack stability in the clarification of roles and mandates of local government tiers. This can arguably be improved through comprehensive guidelines that enforce roles and ultimately mandates municipalities to set smart energy Key Performance Areas (KPAs) relevant to the national objectives.

The Municipal Financial Management Act 53 of 2003

The Act seeks to "*Secure sound and sustainable management of the financial affairs of municipalities and other institutions in the local sphere of government; to establish treasury norms and standards for the local sphere of government*". Complex issues relative to the Act boil down to the procurement abilities of the municipalities pertaining to the acquisition of smart utility technology.

Besides this issue, a great deal of the budget-cycle intervention would be necessary in forming a sustainable balance between municipal spending on bulk infrastructure for community development, and the development of smart city initiatives. In such a case, the planning would need to follow a top-down approach in which the actual municipality budget for smart city projects relate to the capacitation and implementation ability at a departmental level while avoiding national sectorial funding in silos.

Profile of the key power supplier within CoJ: City Power

City Power serves as an independent 100% owned municipal entity exclusively owned by CoJ. It was established in the year 2000 and is responsible in conjunction with Eskom for the provision of electricity throughout the city regions. As the main power distributor for

CoJ, its primary capability is to "*purchase, distribute and sell electricity within its geographical foot-print*" (City Power Annual Report, 2018).

City Power, amongst other things, is responsible for the provision of electrical services that relate to:

- The acquisition and supply of electricity;
- Construction of network grids;
- Connecting households to the main power grid;
- Repairing and maintaining power networks; and
- Installing and maintaining public lighting.

As the 4IR scourges over, City Power is determined to adapt to the revolution by revamping its business model to accommodate smart energy initiatives. The drive for transformation involves:

- Improved security in the provision of energy;
- Diversifying electricity generation through the adoption of renewable and alternative energy sources;
- Reducing the total carbon footprint from electricity generation; and
- Strategic application of a variety innovative technologies that seek to maximize the energy sources' output i.e. transitioning to the "Smart City" concept through Smart Grids and meters.

As per the long-term Johannesburg Growth and Development Strategy 2040, most of the institutions within the city feel obliged to align their efforts with the aspiration of "*a resilient, sustainable and livable*" city. The critical element within City Power as aligned with this theme involves the efficient provision of an energy network that seeks to secure sustainable green living while driving economic growth with the opportunities associated thereof.

As a short initiative, City Power had set a target of installing 12 000 Smart Grids for 2017/2018 financial year (City Power Annual Report, 2018). Of this target, 6226 meters were installed – indicating an average progress (51.88%) for the year. Much effort is required if the aspiration is set to be achieved. City Power's envisioned path in improving its performance will need to be systematic and strategic. The city, communities, institutions, organizations, and other key stakeholders' efforts in fostering smart utility development are shown and discussed in the following subsection.

Forms and types of smart energy utility projects undertaken in CoJ

Figure 8: Electric vehicle initiative introduced at Johannesburg motor show.

Source: Ferreira, 2013

Although a good initiative, the city from 2011 had not yet fully transitioned into the theme of smart utilities – more especially one that caters for the transportation sector. Much observations can be made throughout the city and the traditional sector of vehicle fuel stations still precede the new dawn. Much effort and synergy with other sectors i.e. power and transportation, will play a key role in the facilitation of compatible smart energy stations while the planning division of the city assists in curbing development applications aimed at the establishment of petrol stations.

Figure 9: Solar park roofing in GeoSolar premises, Johannesburg

Source: Schneider, 2015

This initiative is highly prevalent in established companies throughout the city. The demand is mostly driven by the number of company vehicular during office hours that are not shielded from the heat. Energy conversion from solar to electricity to power up routine company tasks and activities is also another attributable factor for the adoption of such smart energy utilities.

Figure 10: Solar geyser initiatives

Source: Solar Plumbing, 2014

The initiative of installing solar geysers is mostly prevalent in newly established settlements as a strategy to cut costs associated with attaining electricity from the main grid network. As a pathway to encourage more installation of solar geysers, Eskom recently offered incentives amounting up to R13000.00 based on a criterion of efficiency in conserving energy. This incentive offers a lucrative amount that households can claim when the installation is complete and conforms to the standards that grant the subsidy. This move is critical in combating the energy poverty associated with load-shedding issues when the power grid is overwhelmed.

Figure 9: Smart gas meters, Rooderpoort

Source: Valley, 2015

Smart gas meters help improve accuracy in reading figures concerning utilization rates along with billing. Added advantage relates to City Power being able to attain readings from the signals obtained from the meters and assess information pertaining to hardware being tampered with and etc. This efficiently enables quick responses to theft and racketeering.

Figure 10: Battery demo facility for 2000 Mega-Watts energy storage, Rosherville

Source: Colthorpe, 2017

Renewable sources such as sunlight and wind are naturally free and accessible – more especially for a region like Johannesburg. However, as suppliers of power, much reliance cannot be placed upon them due to the variability-nature they pose. It thus critical that other city utilities are required to provide a constant and balanced supply of energy that responds to the city's demand and supply structure throughout the day. In doing so, addressing power fluctuations will be key in maintaining the energy status quo within the regions and as such, efficient development of battery storages as the one in Rosherville is crucial.

The battery facility in the area is able to store energy up to 2000 Mega-Watts and subsequently assist in rapid response rates to incremental power demand as compared to traditional methods of power generation through turbines. As a smart energy initiative, the city has increased its ability to save excess power generated and utilize it when there is a future need. From a broad perspective, cuts in greenhouse emissions are eminent as more energy storage facilities as part of the electricity grid network will play a significant part as a solution in addressing the carbon footprint of the city.

Figure 11: Solar powered lamps in Doornfontein Campus, University of Johannesburg

Source: Author

Another smart energy initiative undertaken by one of the recognized institutions, University of Johannesburg, utilizes solar-powered lights to effectively channel the sun's energy into electricity to meet its campus needs relative to path illumination. In a long stretch, this initiative when implemented on a city-wide level, would assist in eliminating efforts associated with the wiring of street lights. Interlinked benefits relate to cost efficiency, manufacturing, and construction. Given the sophistication of solar-powered lights in adapting to its surroundings, optimized light performance is guaranteed for citizens during blackouts.

Figure 12: Distribution capacitor bank

Source: Edvard, 2015

Capacitor banks are critical smart utilities for any developing city worldwide and similar to the battery storage in Rosherville, they ensure that storage and fluent flow of energy throughout the city is done successfully. The advantage lies in storing more energy through the overall adjustment of the number of capacitors in a bank/device. With this, a coherent flow of power supply is eminent – subsequently improving the power system's grid in an efficient manner.

Figure 13: Installation of optic fiber lines in Sandton

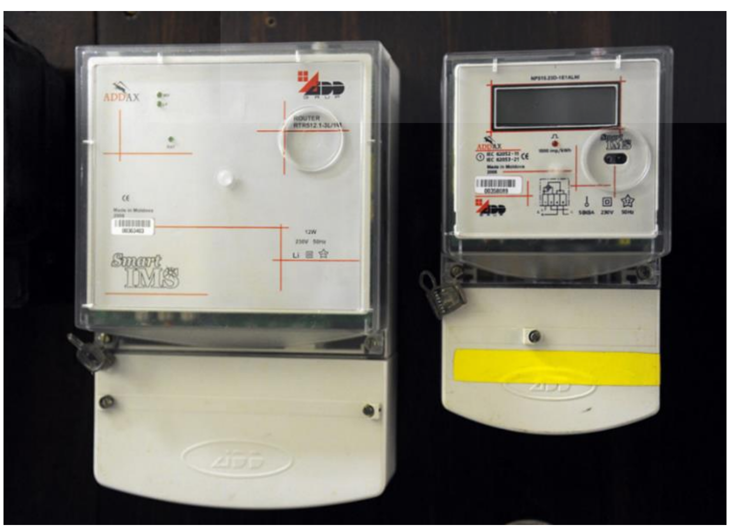
Source: Mokati, 2015

The fiber optics sector plays a significant role in fostering rapid communication network systems and other functions. More recently, the sector has largely moved into the energy sector – serving as the backbone as a mechanism to assess and regulate various factors involved in electrical transmission and distribution throughout the city. This is key as the integration of fiber optics result in complex functions being executed that improve the overall communication networks between power grids and the substations involved within the system.

The installation of optics is mostly prevalent in city neighborhoods that are rather better-off in terms of infrastructural upgrades when compared to other areas where priorities differ. Besides this aspect, newer developments have better chances at having such initiatives being undertaken as the construction of housing will simultaneously be done with the groundworks as compared to metropolitan areas where other infrastructural elements are already embedded within the ground surface.

Although power utilities can install optic fibers anywhere in the city based on the rights-of-way for both transmission and distribution, such an effort could be hindered by higher costs associated with overall construction and remaking of roads, sewer, pavements, etc. As such, this initiative as part of smart utilities can be fostered in newer developments where superstructure construction has not yet started.

Figure 14: Smart power meter



Source: City Power (2018)

Smart-power technology involves the gradual replacement of household analog meters with digital meters to improve efficiency in the recording of power utilization patterns. Additional advantages lie within the rapid data transmission of household energy consumption back to City Power on a much frequent basis as compared to the older system which required manual work i.e. using a meter reader to convey data.

With the smart power meter in place, City Power is able to offer households the ability to monitor their own energy consumption in a precise manner; usually through an integrated cell-phone application so as to make informed decisions pertaining to power usage and billing. Advanced features within the meter such as the recently installed ones offer City Power the administrative power to remotely control the electricity supply such as switching power-consuming appliances off.

Figure 15: Smart Solar PV system

Source: Solar4Life, 2019

Solar panel meters serve as useful smart utilities used for measuring the total solar radiation flux density from a PV system connected to a specific household. The performance of the overall system can be assessed as the collected data provides the yield production as well as the local energy consumption.

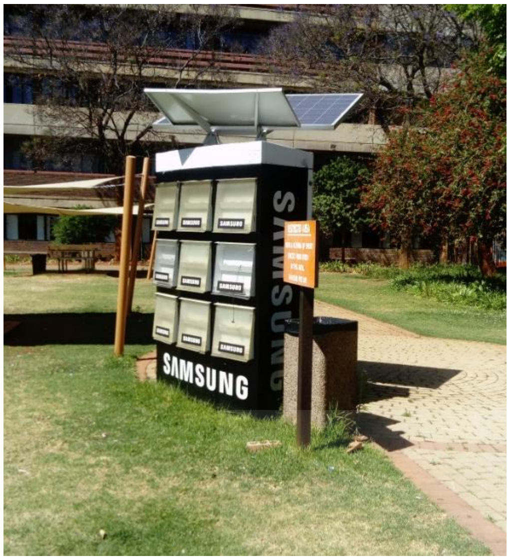
Advanced features, usually in well-developed areas within the city, come with customized settings that perform specific functions such as alerting households of issues relative to the system's performance. This is beneficial for the owners as they are made aware of data pertaining to production, consumption, and savings. This optimizes the overall return on investment.

Figure 16: Solid Dielectric Triple Option Recloser, up to 38kv

Source: Transnet, n.d.

This electrical utility plays a critical role in the provision of an electronic overcurrent protection. This security expands across the system – supplying coverage for single and three phase process on sub-systems that are rated through 38kV. With this in place, smart grid initiatives suffice as the recloser is able to monitor the grid circuit through the application of a multi-ratio internal current transformers and voltage sensors. These sensors then provide information relative to power tripping and overcurrent issues.

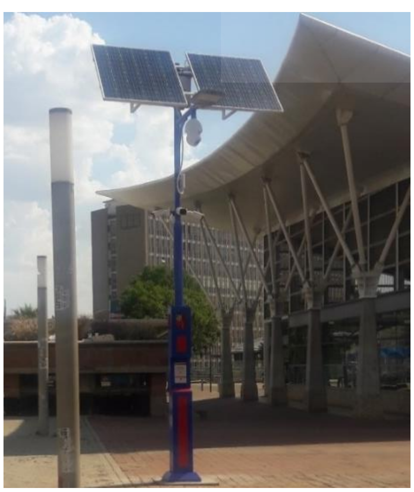
Figure 17: Solar-powered phone and tablet charging points



Source: Author

Small off-grid charging points for smartphones and tablets can be seen around the University of Johannesburg campuses. The decision to adopt these smart utilities was to provide students with an improved health equity and access to power in open spaces without the need of going to the building to power up. On a city-wide context, not much is being done as factors attributable hindering this initiative relate to theft, trust, and other social issues in uncontrolled social spaces.

Figure 18: Solar powered CCTV



Source: Author

This is a new initiative taking place within the city. The majority of these efforts are mostly present within the Gautrain stations around the city. More recently, the Johannesburg park station CCTV-solar powered system has been in effect since the third of November with additional other initiatives being fostered in other Gautrain stations. This is a good initiative and provides a sense of security in the busy multi-transportation node.

Figure 19: Side-walk solar powered street lamps

Source: Author

These are mostly prevalent in well-developed sections of the city such as Sandton City. These lamps are mostly visible in open spaces and this does not only encourage open space at daytime only but also caters for those who prefer to use the space at nighttime. The smart energy initiative is effective in the conservation of power given how large open spaces can be – interlinked to this involves cost-reduction in electrical infrastructure extensions, upgrades, and maintenance.

Figure 20: Solar-powered traffic lights

Source: WorldPress, 2010

The consistent power outages for the period 2007/2008 proved to be critical times for the city. As a result, various industries were affected and most importantly, the transportation sector experienced chaotic traffic patterns throughout the busy intersections within the CBD and other busy neighborhoods like Sandton and Midrand.

As part of the synergy between the transport and energy sector, a budget was allocated in the modernization of traffic lights through the installation of solar-powered remote traffic lights throughout the busy intersections. This was motivated by the urge to maintain consistency in traffic flow during power cuts – subsequently avoiding breaking points such as the one back in the year 2007 which resulted in over 2000 traffic lights in critical roads off.

Figure 21: Solar roofing

Source: Solar4Life, 2019

Residential areas, through solar roofing, can address cost-efficiency in the most environmentally friendly manner. This converted energy is utilized to power up smaller functions within the home and assist in the overall easing off-pressure on the traditional source of energy. In the long run, the carbon footprint is reduced, and associated health benefits can accrue I the household.

Sub-chapter synopsis

Table 2: Summary of the key legislations

Energy legislation	Impact on smart energy	Rationale
National Energy Regulator Act (Act No. 34 of 2008)	Moderate	There is a lack of emphasis regarding the typology of energy sources that require the most attention and need for further scholarly research and development
Electricity Regulation Act (Act No. 4 of 2006)	Low	Mostly deals with the provision for licensing, not much emphasis on smart energy
The Gas Act (Act No. 48 of 2001)	Moderate	Lacks the structural mechanisms on how to attain set provisions within the Act
White Paper on Energy Policy for South Africa of 1998	High	Plays a critical role in strengthening the existing policies on energy systems in certain areas of conceptualization and implementation

White Paper on Renewable Energy Policy for South Africa of 2003	High	Covers extensive areas within the energy sector
The White Paper on National Climate Change Response of 2011	Moderate	Touches upon sub-elements such as the establishment of measures that improve energy efficiency; regulate demand-side management; and the transition to energy sources that promote less emissions during production and supply
Municipal Systems Act (Act No. 32 of 2000)	Low	Challenges pertaining to how municipalities should implement smart energy initiatives are unclear
The Municipal Financial Management Act (Act No. 56 of 2003)	Low	Funding mechanisms unclear

Table 3: Summary of the smart energy initiatives

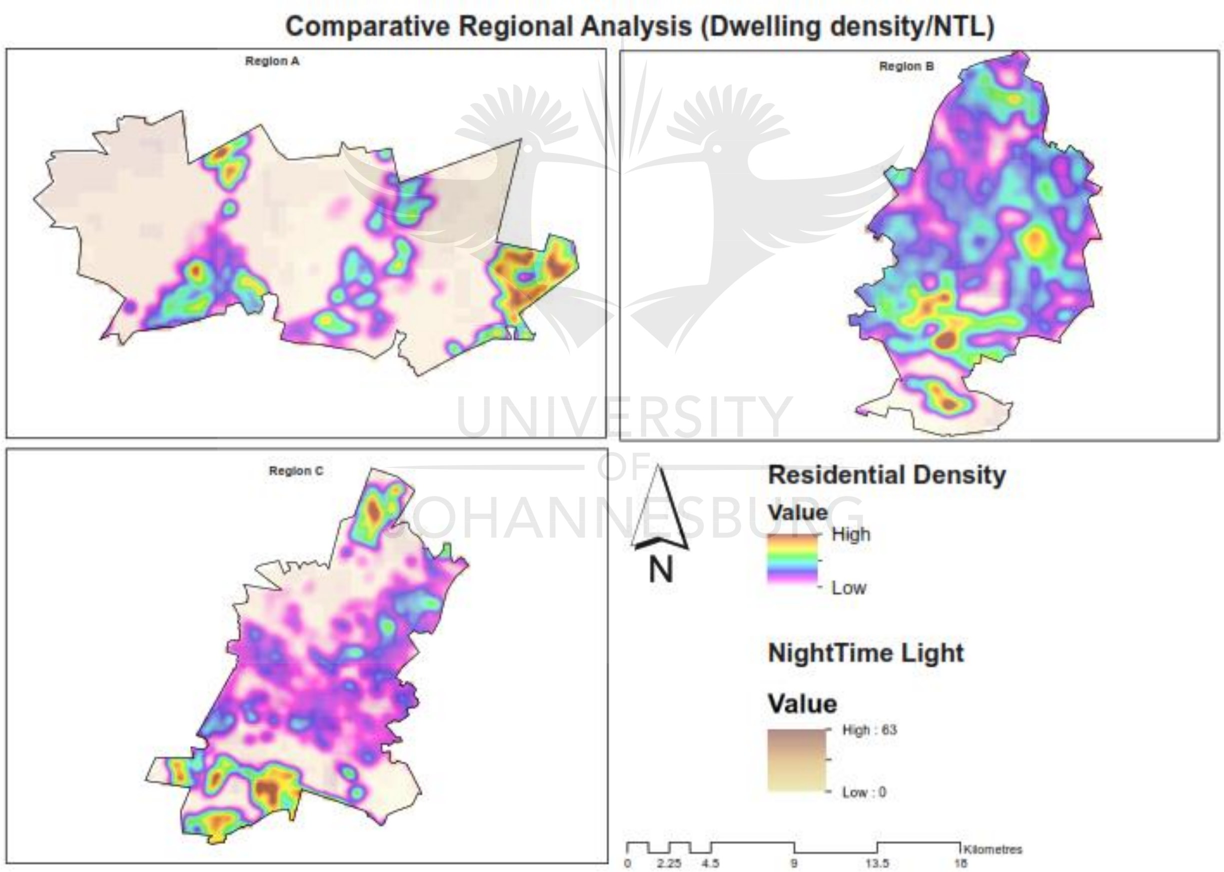
Smart utility efforts undertaken	City Coverage	Initiated city sectors	Key Impact
Electric vehicles	Minimal	Transportation	Reduced carbon emissions
Solar park roofing	Minimal	Parking	Protection from UV rays plus energy generation
Solar geyser	Extensive	Solar	Cost-effective in most income brackets
Gas meter reader	Extensive	Gas industry	Decreased dependence on traditional fossil fuel
Battery demo facility storage	Minimal	Electricity	Reduces pressure on the main power source and stores power
Solar powered lamps	Moderate	Solar	Provides illumination in remote areas
Distribution capacitor bank	Extensive	Electricity	Corrects power lagging and faulting
Fiber optics	Moderate	ICT	Increased speed at which energy is transmitted and distributed
Power meter reader	Extensive	ICT	Real-time monitoring of energy production and consumption at household level
Solar PV system	Moderate	ICT	Real-time monitoring of energy production and consumption
Solid dielectric triple option recloser	Extensive	Electricity	Provides an electronic overcurrent protection
Solar powered charging points	Minimal	Solar	Convenience in accessing charging points
Solar powered CCTV	Moderate	ICT	Back-up power source that assures consistent safety and monitoring
Side walk park street lamps	Moderate	Solar	Energy efficient and aesthetically appeasing
Solar powered traffic lights	Minimal	Transportation	Consistency in traffic flow during outages
Solar roofing	Extensive	Housing	Cost-effective and environmentally friendly

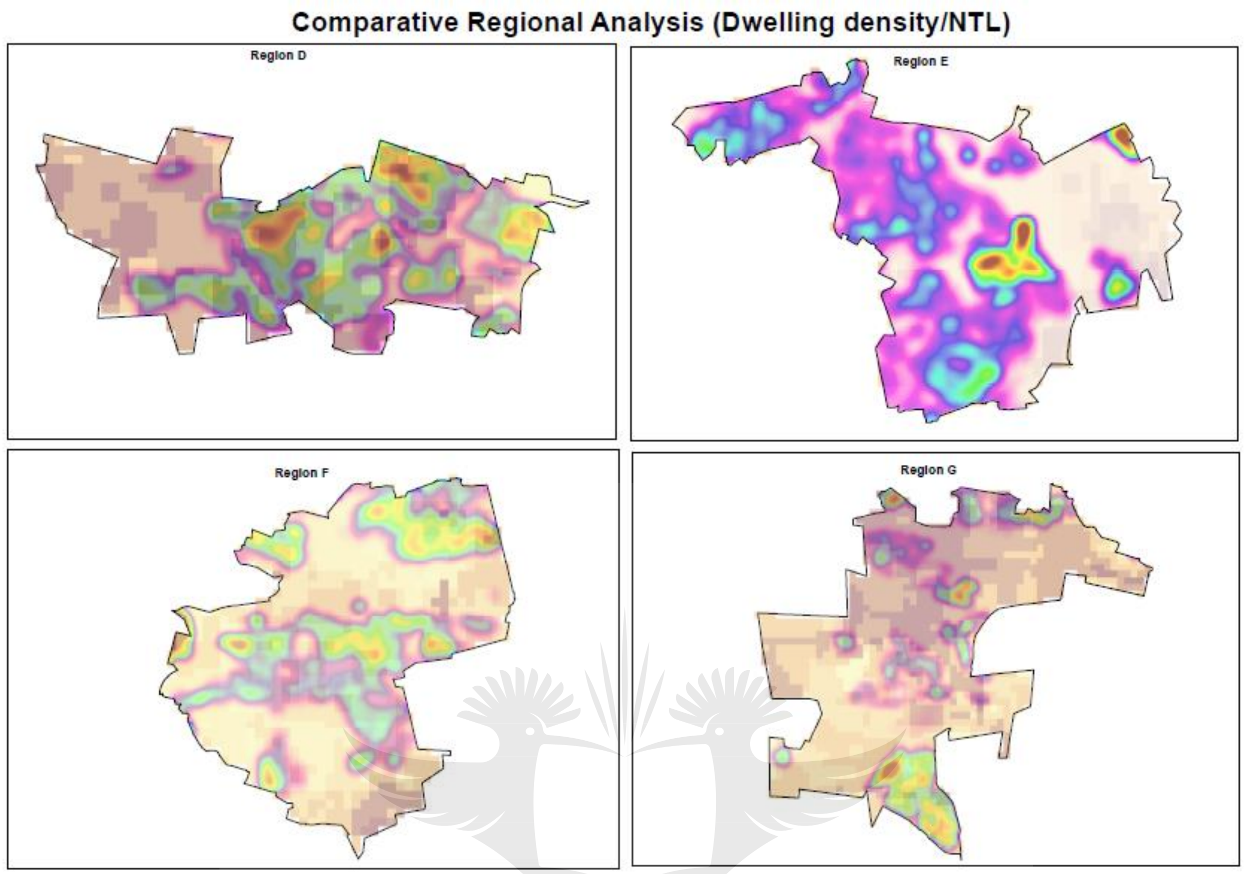
4.2. Assessing the relationship between energy and land use and form

4.2.2. Residential

Due to the data constraint experienced (i.e. sensitivity issues), Eskom data on the City of Johannesburg was utilized for analysis and the results produced regarding the demand for spatial energy for the residential sector of CoJ has resulted in various fascinating energy patterns. A density calculation against the NTL data has been computed for each residential dwelling unit in the CoJ, and a map portraying the regional dwelling density in relation to the NTL can be viewed below on figure 22.

Figure 22: Residential density patterns in relation to power activity





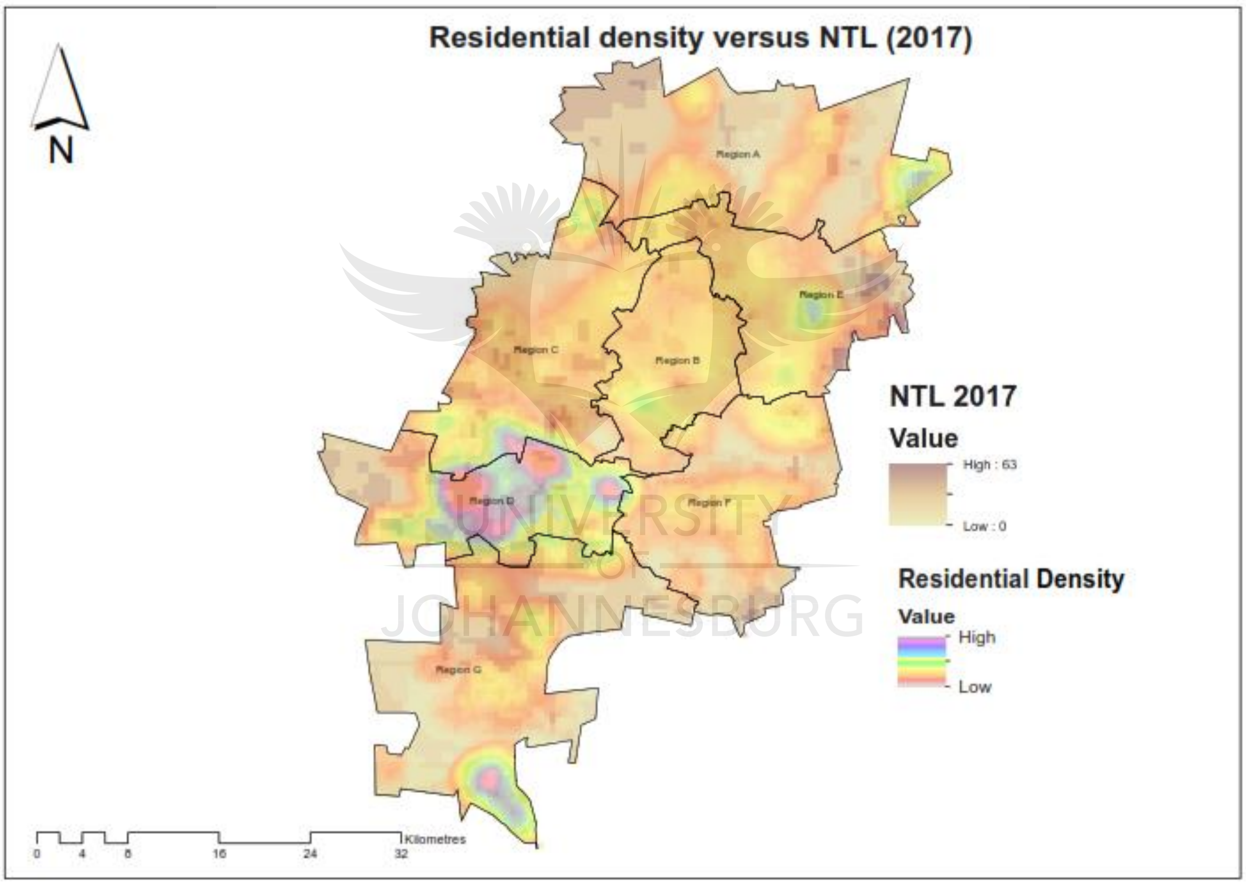
Discussion:

Based on the findings, the highest average residential density relationship to urban spatial energy is within Region D, which is encompassed of areas old, densified residential developments as a result of apartheid planning. This increased density has an inclined strain on energy demand and consumption as existing informal settlements in nearby townships such as Thulani and Joe Slovo Park keep mushrooming on a rapid pace.

Closely following Region D is Region E as compared to E which is spatially disconnected from the main city region. The increased dwelling density and demand is mostly experienced in well-established neighborhoods such as Ennerdale and Zakariyya where informal settlements are on a rise and prone to more inefficient socioeconomic conditions as the majority of formalized housing are within the lower-income receiving bracket. The demand is unlikely to be met as the locality makes it difficult for power infrastructure to be properly developed and supplied to the populace.

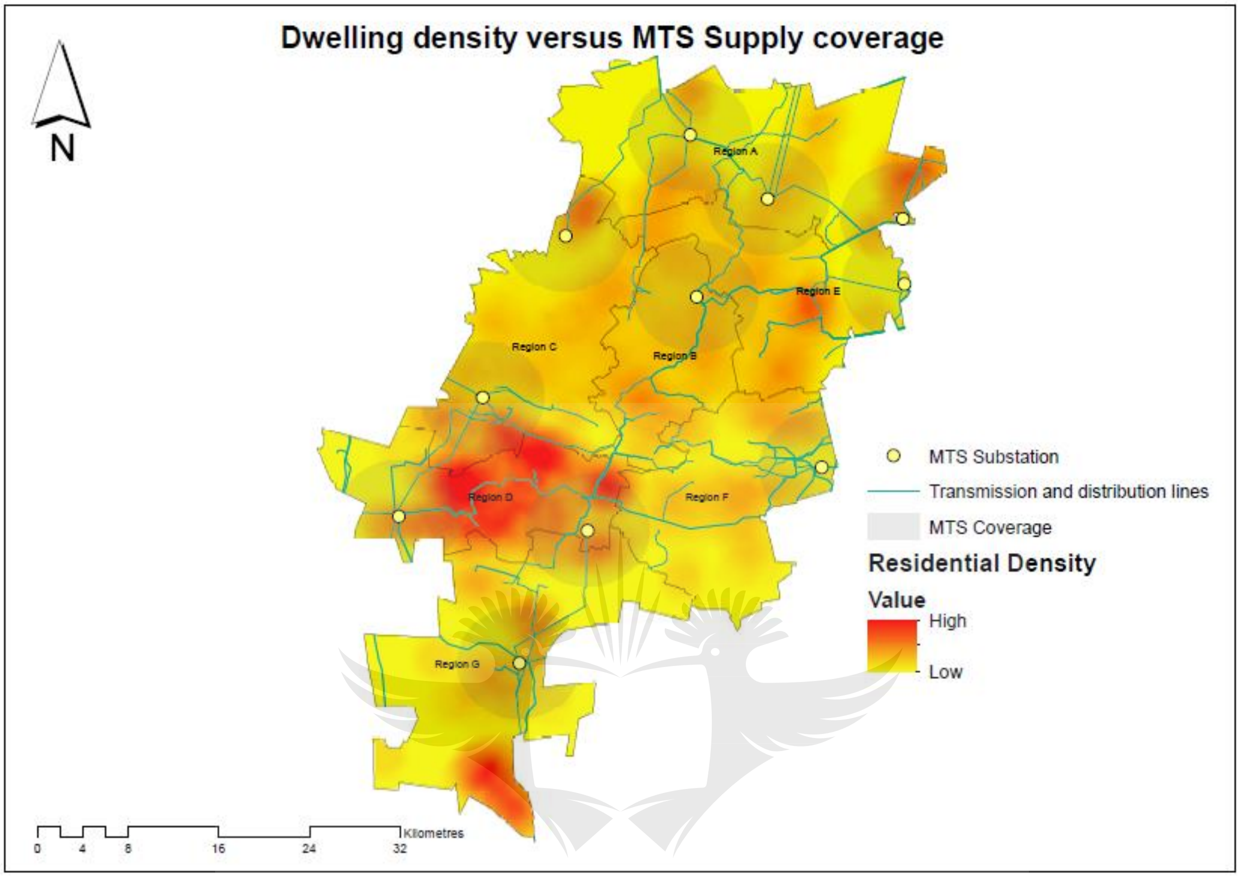
Region E has been observed to involve newer developments along the Louis Botha Avenue. The Alexandra informal settlement is attributable to the high energy demand in the region and further exacerbated by high-to-middle income neighborhoods such as Houghton, Bryanston, Sandton, and Oaklands. The most common residential energy demands are experienced in Region B and F, with some of the areas like Region A averaging a slight demand with influence from the adjacent regions. The overall residential/NTL dynamics at a city level is shown below:

Figure 23: City wide-scale dwelling density/NTL



The question of coverage however, provides an interesting map as shown below:

Figure 24: Supply Coverage by the MTS Stations in relation to residential density



Region F experiences the least coverage of the power supply as it has only one station within the vicinity. Although being under capacitated given that the Region has one supply system, there seems to be a balance as the residential density is in harmony with the energy demand. Perhaps additional sub-station data would have yielded better results.

Region G still lags infrastructural capacity. The majority of the areas under coverage relate to Ennerdale and Zakariyya – leaving the densely populated informal settlements on the south under massive energy poverty. It is contrary to Region E, whereby the majority of the established developments are well-covered except for poor neighborhoods such as Alexandra whereby the density outstrips the coverage.

Such incapacitation provides a burden on communities and increase the likely chances of electrification theft.

Based on the dataset provided, the major stations (NB. Standard supply coverage of 4242 and 4249 mW) have only been considered for this analysis due to sensitivity issues. The statistics attained reflect the following data:

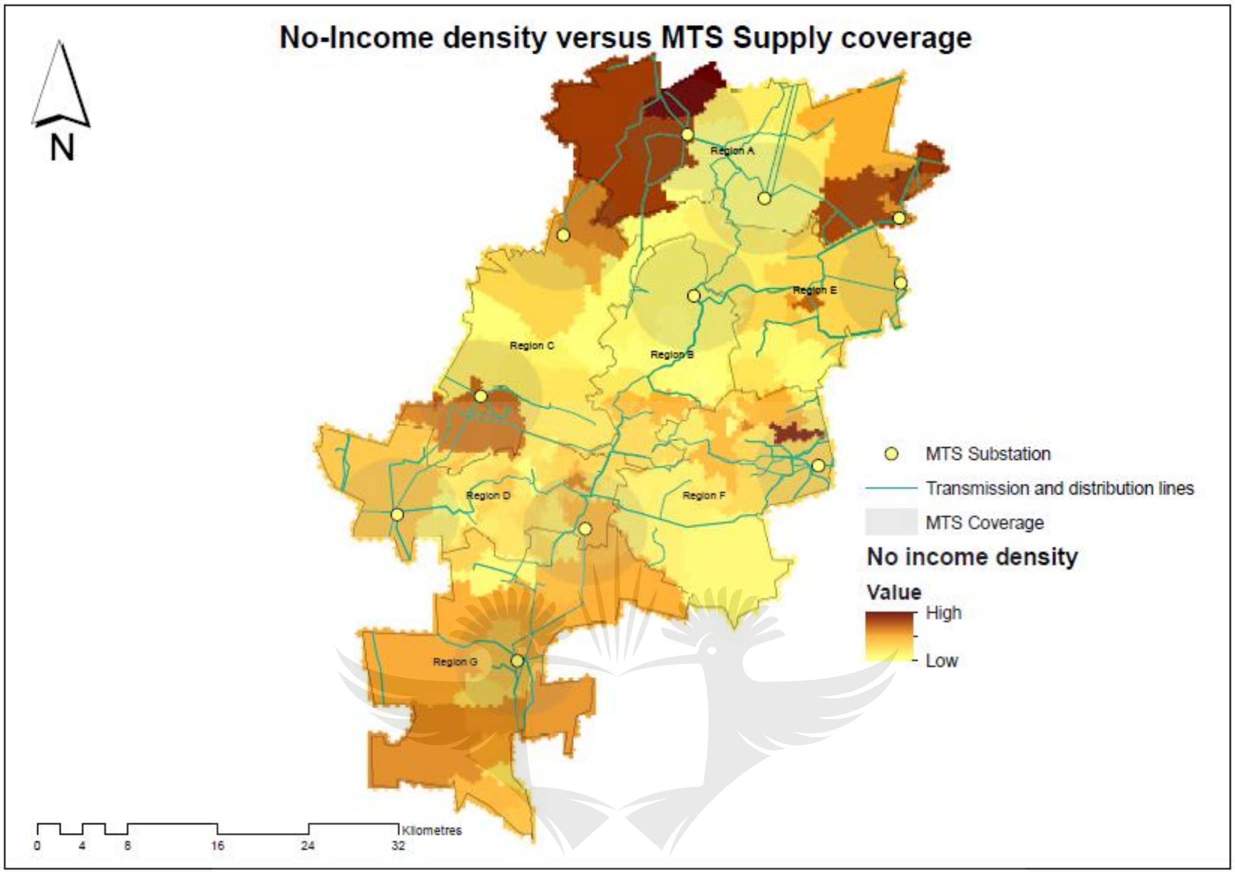
Table 4: MTS Substation technical data

Region Supplied	**Station Name**	**HV Busbar Voltage (kV)**	**LV Busbar Voltage (kV)**	**MV Busbar Connection Capacity (MW)**	**HV Busbar Connection Capacity (MW)**	**Supply Area HV Busbar Steady Limit (MW)**
A	Kyalami	400	132	980	780	4942
	Lulamisa	400	88	926	475	4932
	Lepini	275	88	980	531	4932
B	Craighall	275	88	926	530	4932
C	Demeter	400	88	926	780	4242
	Princess	275	88	926	183	4932
D	Quattro	275	132	980	550	4242
	Taunus	275	132	980	555	4242
E	North Rand	275	132	980	530	4932
F	Jupiter	275	88	529	496	4242
G	Etna	275	88	616	746	4242

Source: Eskom, 2019

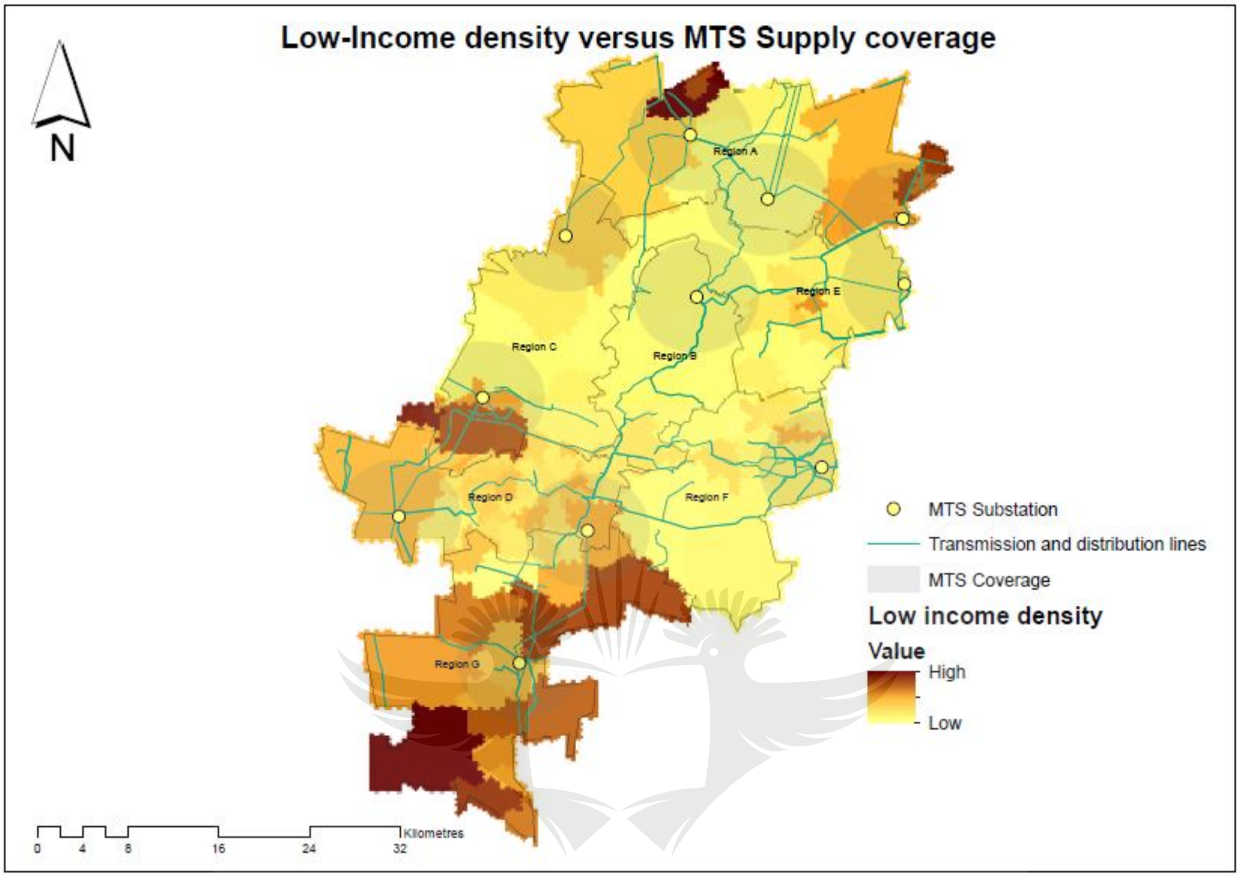
The majority of the areas in Region G are characterized by no-to-low-income earners and the coverage of power is particularly low:

Figure 25: Supply area coverage correlation with No-Income density



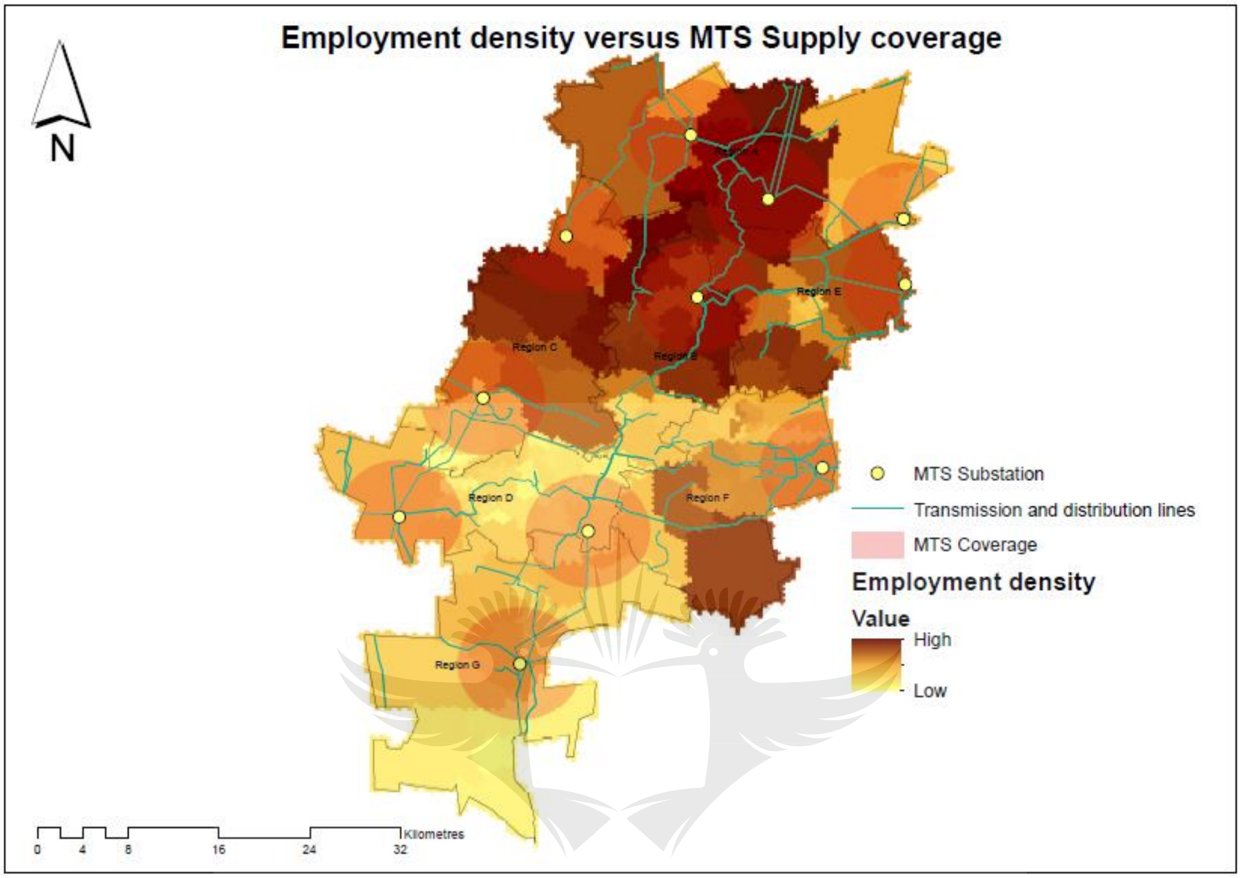
Region A appears as the locale with the most residents that are without income, however, receiving a fair amount of coverage i.e. Diepsloot, Ivory Park, etc. Region G follows suit with the vast majority oscillating between no-income to almost no-income; however, the majority are surrounded by Regions that are well-off with efficient coverage in relation to income levels. The low-income group is shown below:

Figure 26: Low-income group versus residential density (R1-4800)



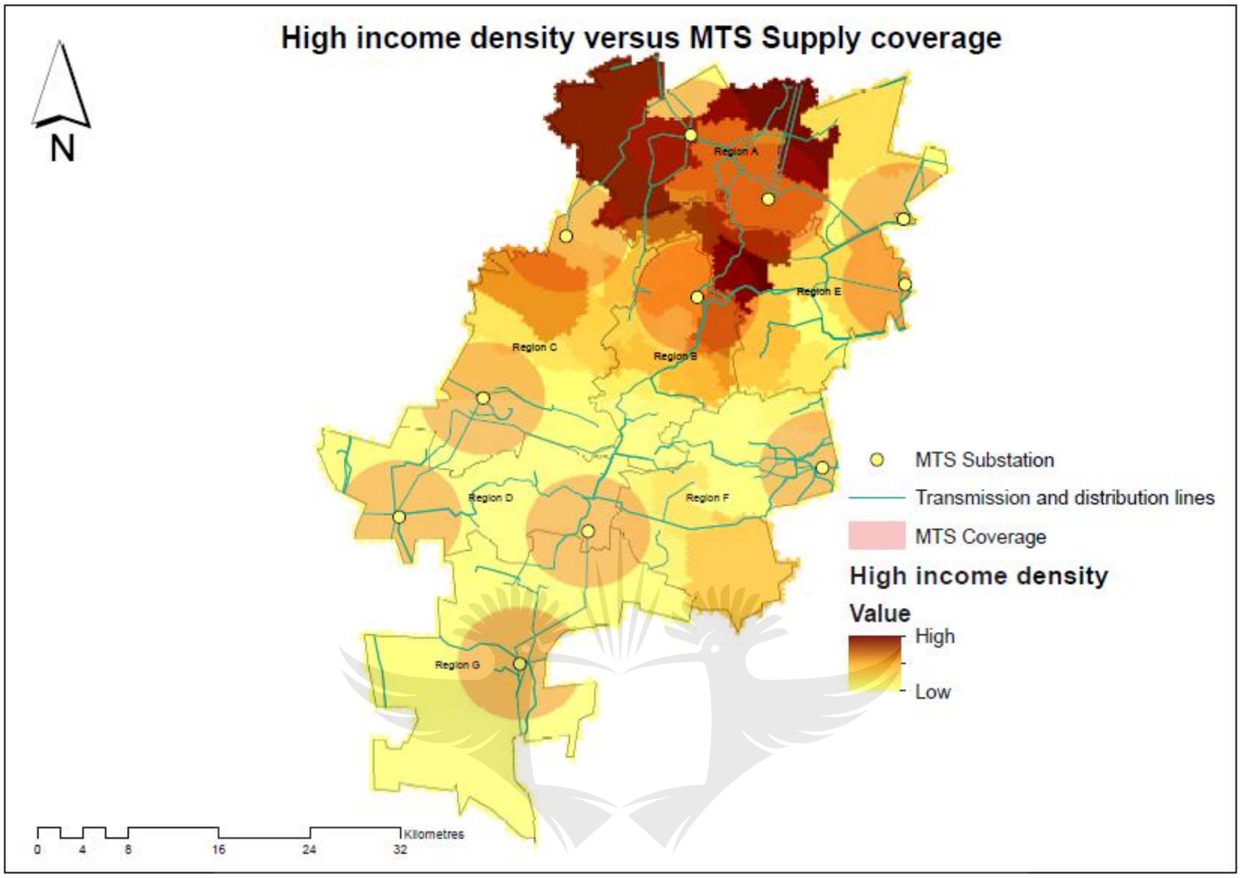
Within this visual, the extreme rate/density of low-income dwellers are prevalent in Region G. Region G presents itself as the locale with the highest number of low-income dwellers – hence power coverage is poor. This can be attributed to affordability issues exacerbating the energy poverty experienced irrespective of the density as the map below assists in understanding the employment/affordability pattern sufficient to purchase electricity.

Figure 27: Supply area coverage correlation with employment density



The assumption taken is that employment influences power purchases – and therefore, access and spending on energy. The majority of the those employed in the city are within the north while the opposite can be observed in Region G while Region C, A, and E face higher employment levels. The relationship established is that the higher the employment rate, the better the access and coverage of power attained. This critically changes the dynamics of income-groups and this may subsequently result in vast income differences that influence how power coverage is spread. This is shown below when taking into consideration the high-income earners.

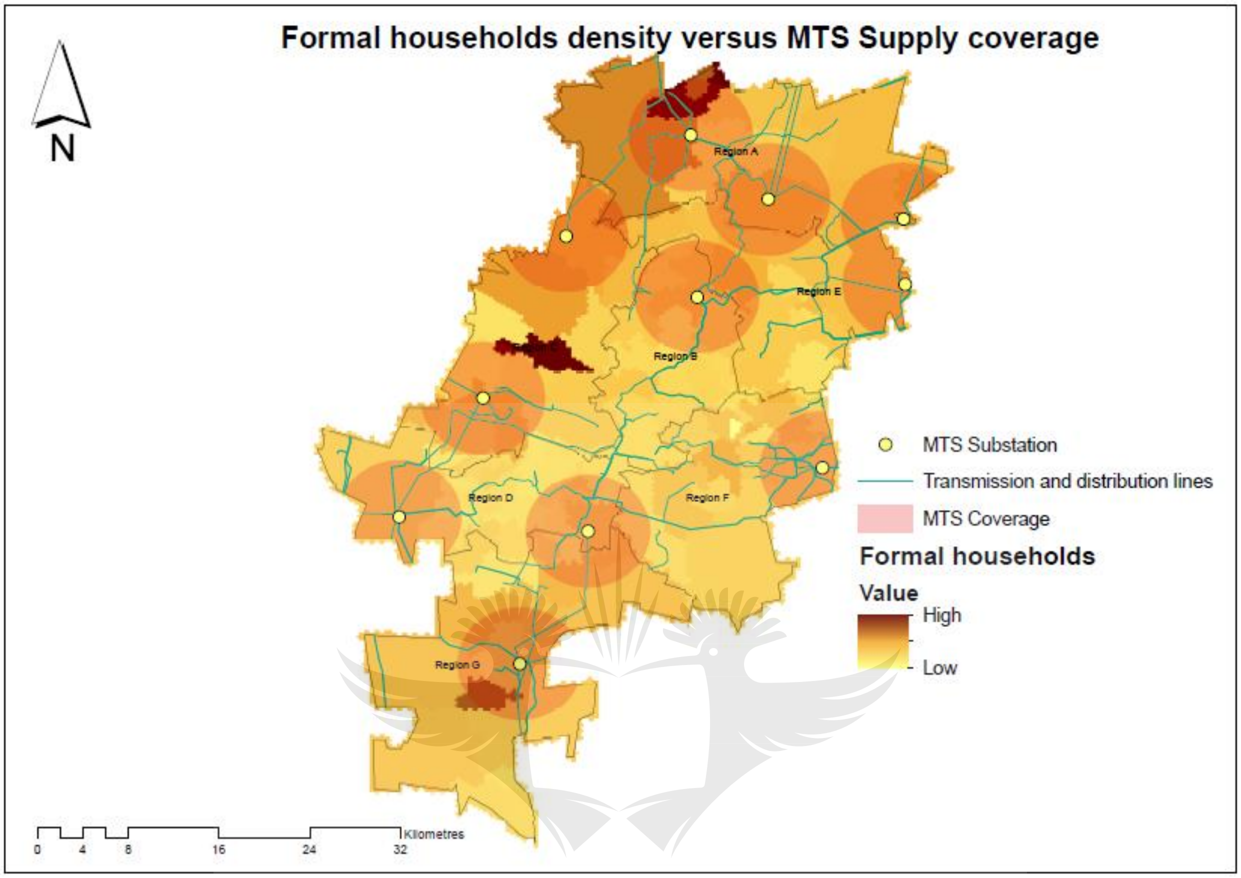
Figure 28: High-income group versus residential density



The delineation drawn from this indicates how the majority of residential density with high-income is experienced in Region A and E while other Regions within the south indicate developments attributable to a lack of high-income earners. The Southern aspect of the city is poor; increased coverage is experienced within the upper sections of the city where development is occurring with affordability seemingly being the driving factor.

The high-income dwellers, particularly in areas where sprawl is high and development is on the rise, i.e. Sandton, Midrand, and Fourways in Region A-C, are encompassed of formal housing with proper electrification where informal-settlements are overshadowed under statistical survey findings. This presents confusing results; however, the visualization below indicates how formalized housing in the north are best receiving better coverage as compared to other regions.

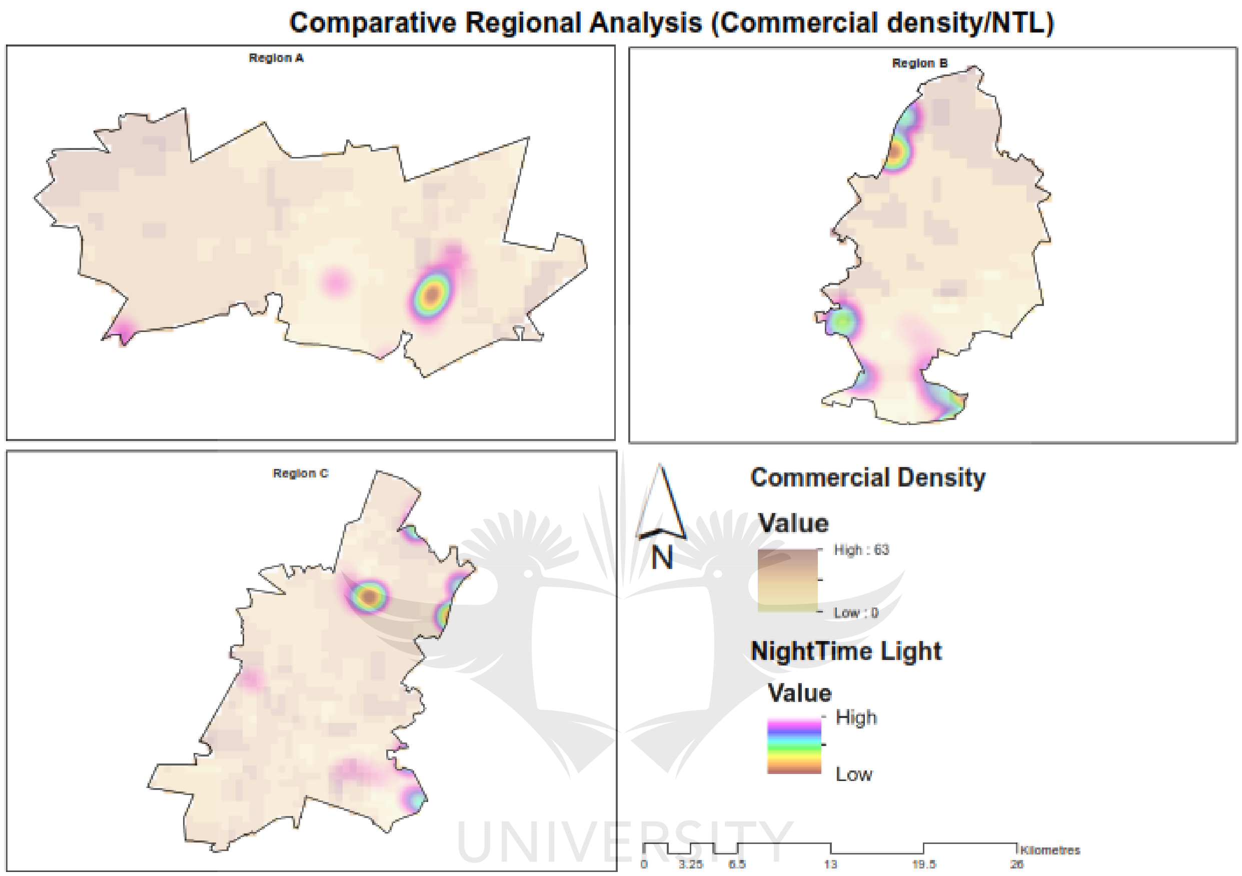
Figure 29: Supply coverage correlation with formal housing

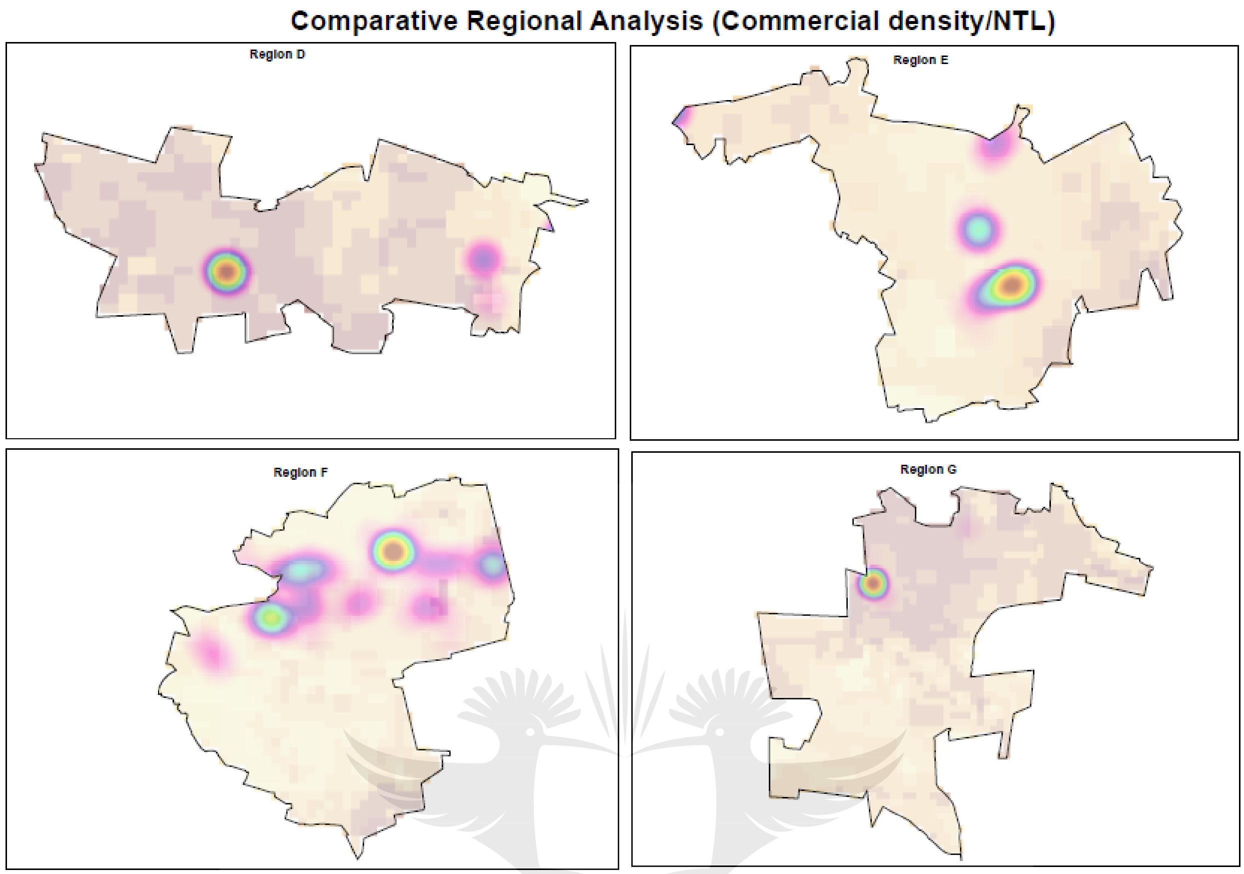


Commercial

The regional maps shown in Figure 30 show the regional commercial density location in relation to the energy distribution throughout CoJ regions. Each region mapped indicates the densified patterns across the spatial space in which the clusters occur and eventually overlap. According to the analysis, the density of commercial properties is mostly present and aligned along the industrial belt that cuts across Region C, B, to F as compared to Region G which experiences little commercial activity.

Figure 30: Regional Commercial density patterns in relation to NTL





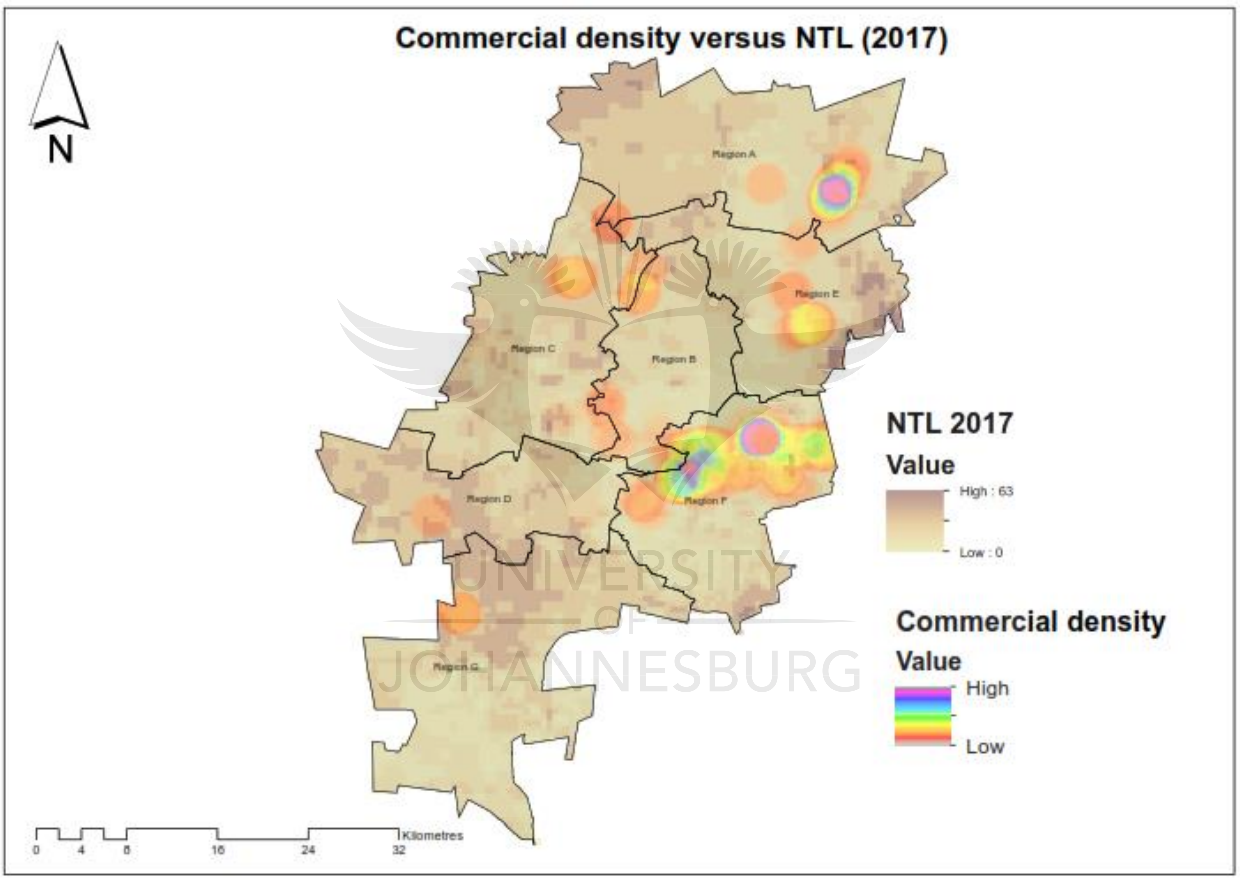
Discussion:

The majority of the commercial properties as observed above are highly concentrated within Region F, with Region B and C having a form of an overlapping pattern. Most of the properties are located along the main distribution lines unlike Region C, which has a strong presence of commercial activity however, not as intense as the urban center. Attributable to this could relate to the sparse localities in Region C serving as support systems for the past mining-boom.

The highest energy demand from commercial sites based on the NTL is experienced within Region F – which is composed of old residential buildings, offices in Braamfontein, department stores, hotels, etc. This high concentration of energy demand, particularly within the sphere of service and retail-orientated sector, spreads and expands out from Region F up until the north-western part of the city in Region C and D. This expansion represents the mining belt which is regularly energy intensive and reliant on commercial activities.

Independent and distinct clusters of commercial energy demand from the center can be seen in Region A, D, and E. Region E, for instance, is prevalent of industrial estates, with clusters potentially forming in areas like Modderfintein and Wynberg where light manufacturing industrial activities occurs. These clusters can be spatially characterized to have buildings that relate to light factories, warehouses, and large bakeries. The overall synergy can be visually at a city level:

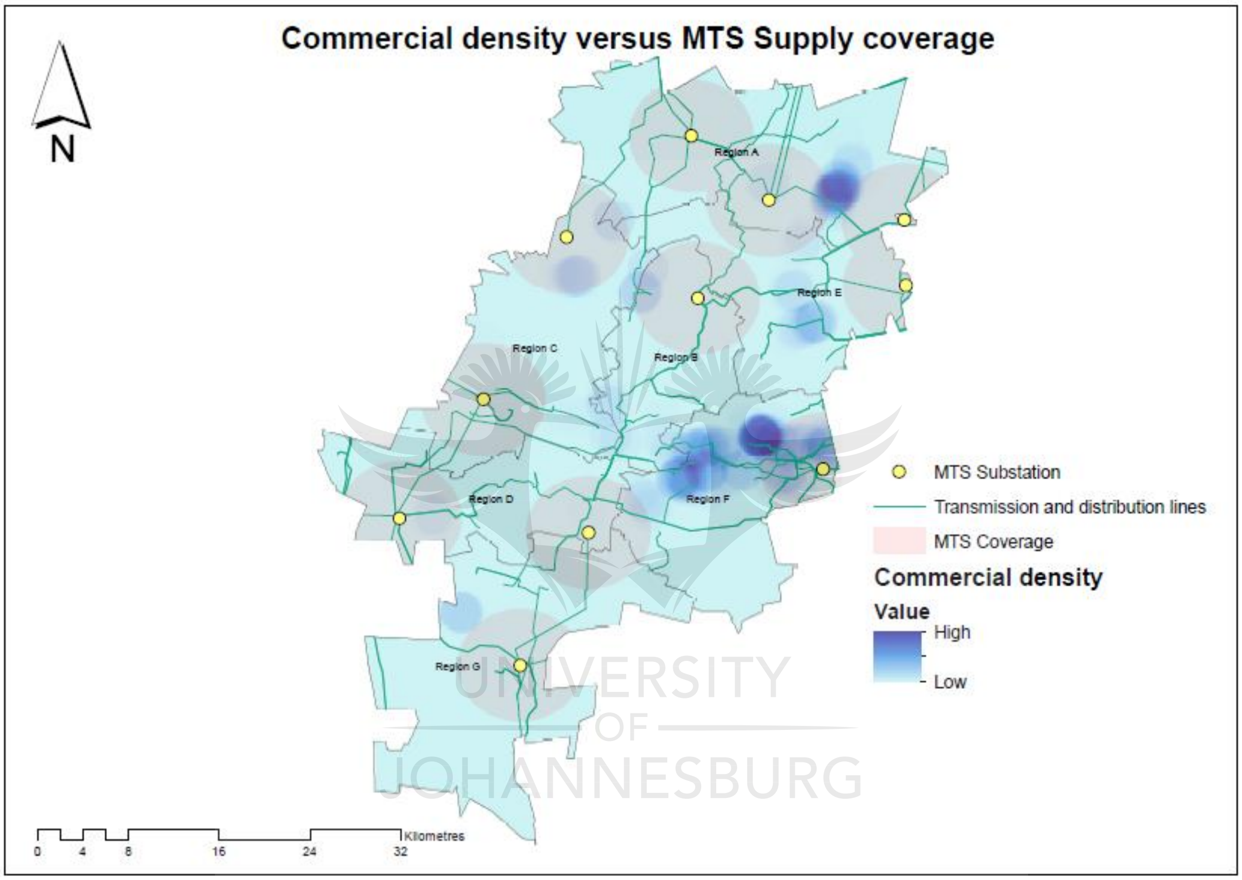
Figure 31: Commercial density versus NTL at a city level



Due to the nature of manufacturing and light commercial activities observed in Region E, the demand for energy seems to be average irrespective of being dislocated from the city center.

The map in Figure 32 below portrays the coverage of the MTS stations in relation the energy demand density by commercial properties throughout the city. Efficient coverage is prevalent in Region A, B, and E as compared to the poor coverage experienced in Region F where the demand is most likely to be experienced due to the high density.

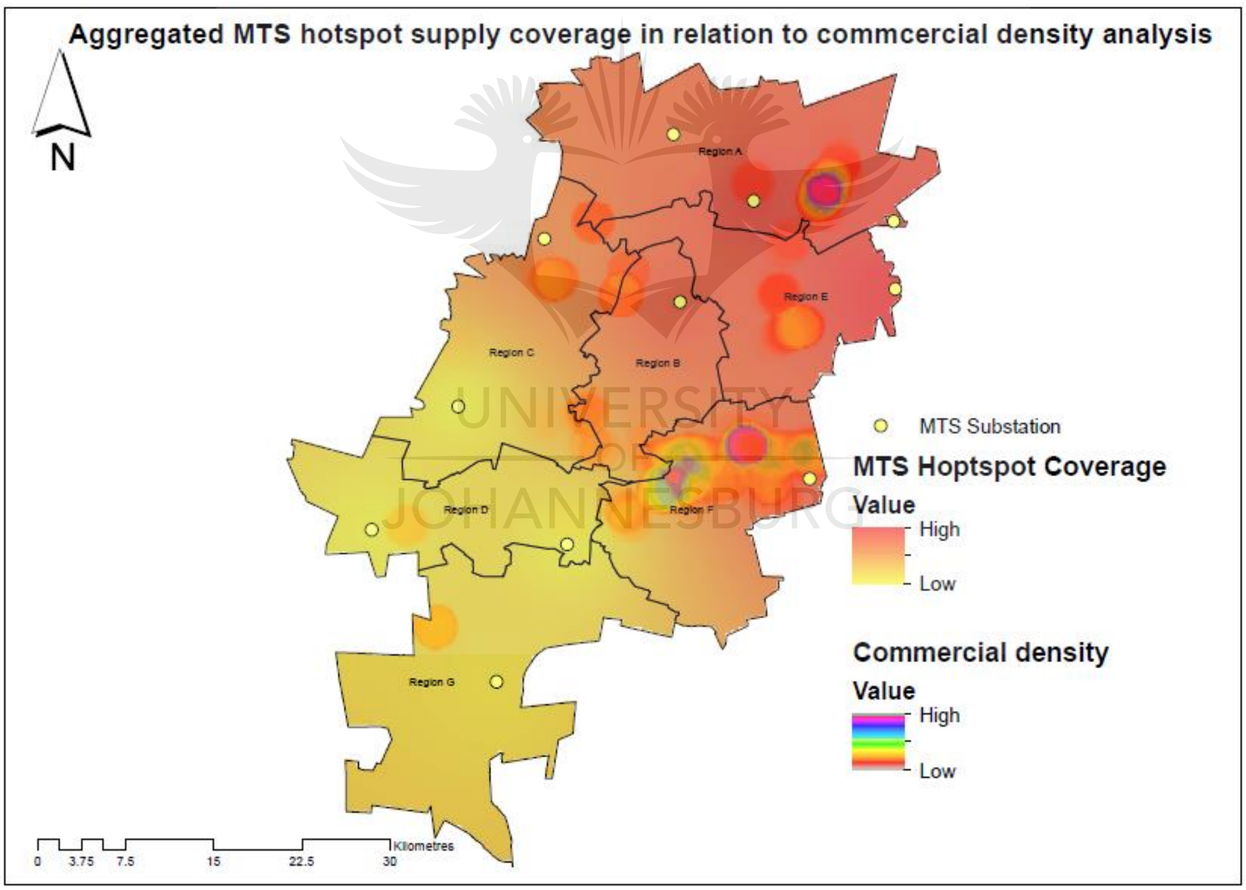
Figure 32: Supply Coverage by the MTS Stations in relation to commercial density



An increase in newer business (i.e. Midrand) and industrial nodes (i.e. Hans Strijdom Drive) in Region A, can explain the efficient coverage experienced when compared to Region F which is experiencing decline as businesses seek better ventures outside the city. Region E also has a high-density development occurring. This can be attributed to the informal settlements along Alexandra along with commercial nodes forming around Marlboro and Lindbro Park – which puts an increased need for additional infrastructure to improve the overall coverage.

Due to the centrality of Region F with its wide-spread roofing, visual coverage incapacitation can be attributed to the adoption of smart renewable resources. Various buildings around the city have taken advantage of the centrality and incorporated solar-roofing initiatives to maximize the sunlight as a resource for energy generation. The centrality also makes it possible for the local authority exercise inward energy investments and link existing peripheral stations (Region E, C, and B) to the inner city to provide support irrespective of the abandoned builds as a result of dead-mining activities. This coverage is better spatially mapped out below, indicating the efficiency of supply coverage with power availability.

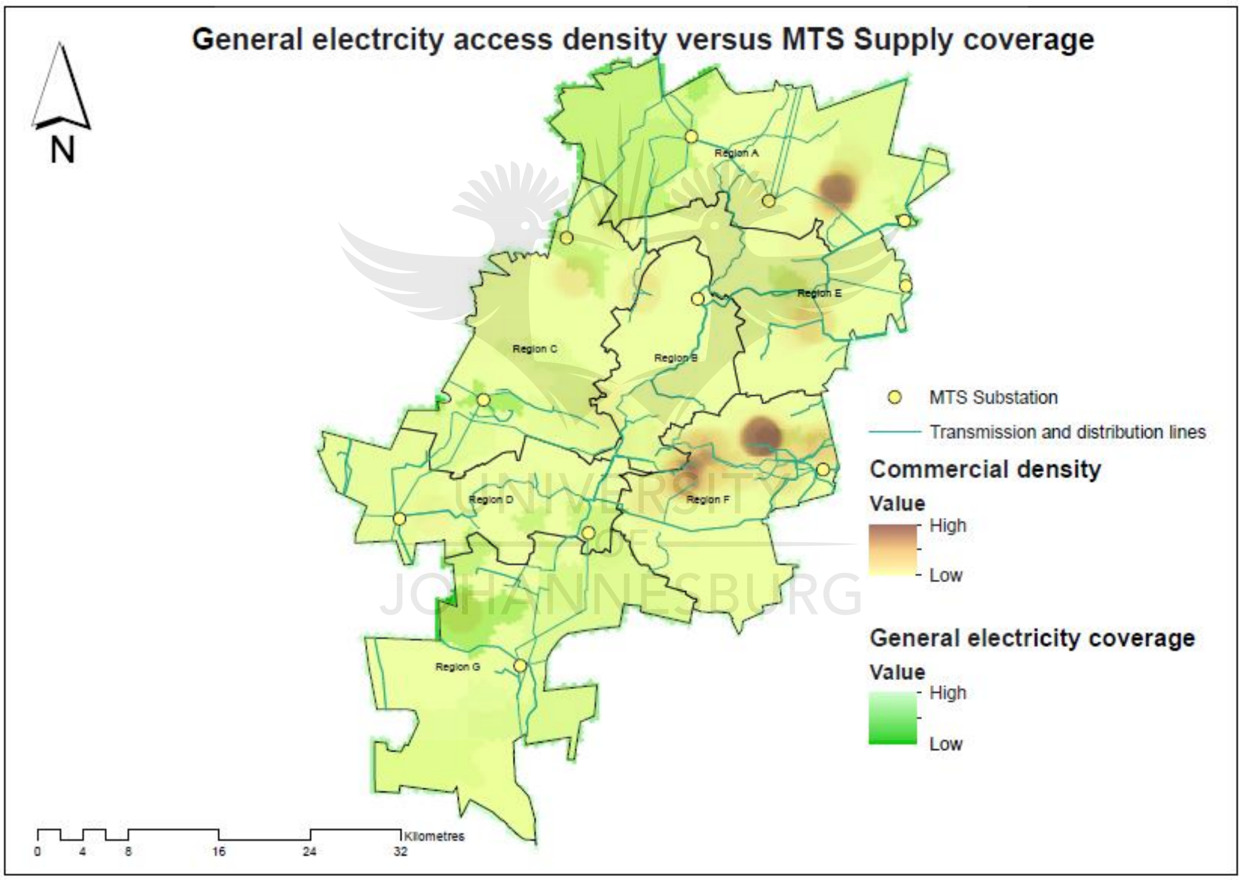
Figure 33: Supply Coverage by the MTS Stations in relation to hotspot analysis



The density of the demand experienced is an important indication of which areas are best capacitated and vice versa. With the above map, a delineation can be drawn that the majority of the areas experiencing the highest MTS heat density map are prevalent in the northern neighborhoods. The Regions (A and E) are experiencing high coverage and are often spatially spread out over a larger area with a strong presence of commercial estates and business parks occupying larger land tracts than other land uses proximal to the urban center of Region F.

The coverage incapacitation experienced along the mining belt may indicate a lack of energy-intensive activities due to finished mining projects. This can be shown below with the major densified commercial sites being under-capacitated in terms of power supply in the outskirts.

Figure 34: Access to electricity versus commercial density

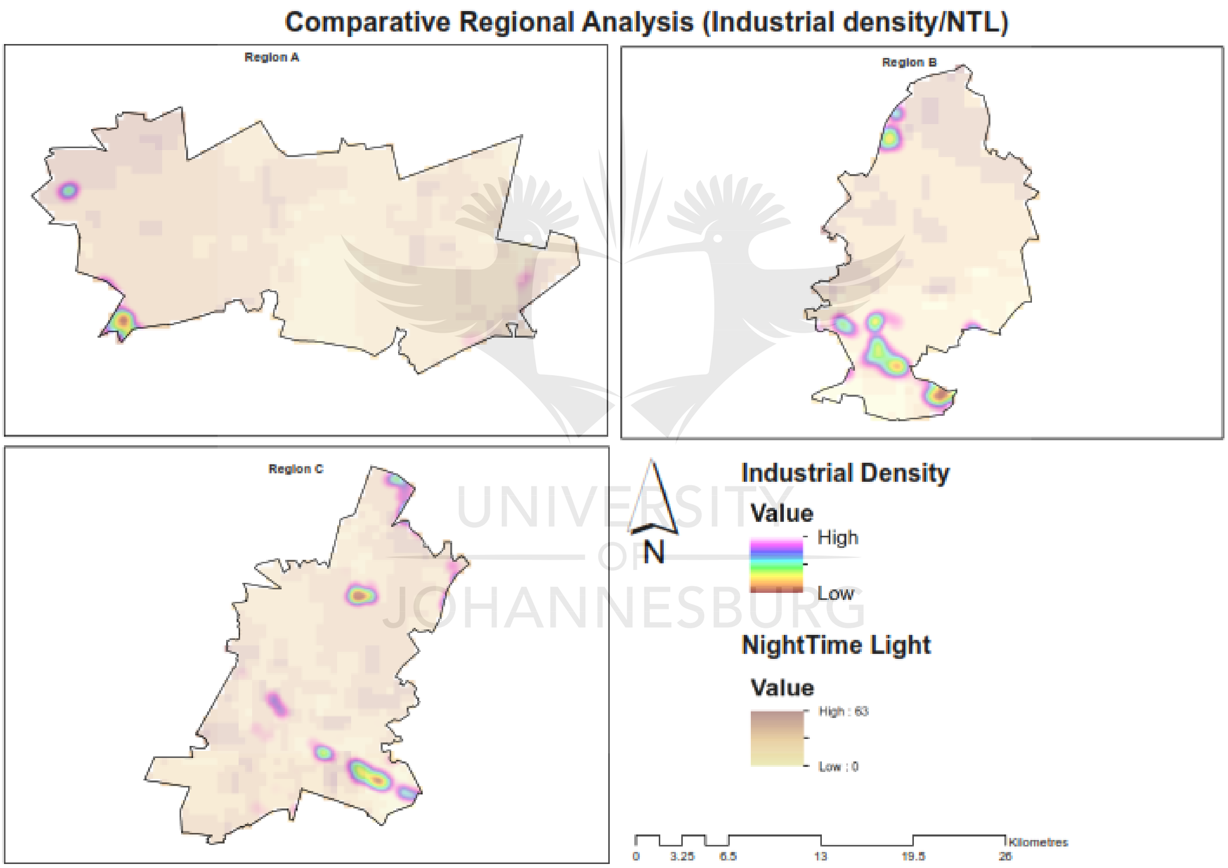


These peripheral sites are usually ideal for site and purpose transformation that deal with smart energy initiatives that seek to expand inward toward the center to other regions as infrastructure like rail, warehouses, electrification, communication etc. already exists and provides the potential for this initiative to take flight. This can ultimately draw in businesses to set up a form of a smart energy precinct that seeks to reduce energy costs and subsequently provide CoJ with a continuous framework to become a sustainable city.

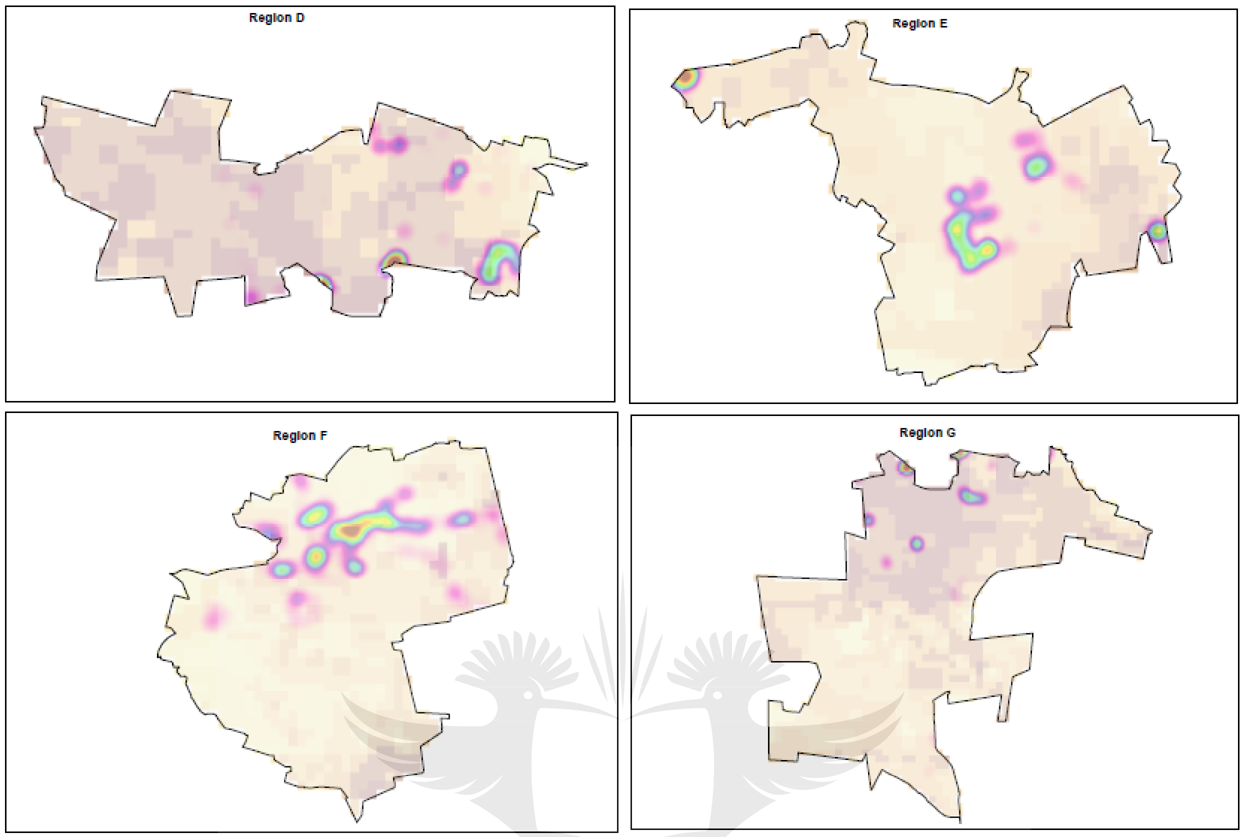
Industrial

There are +1000 known industrial building-based energy accounts along the mining belt that stretch across Region F to Region C and D. Figure 35 below shows the regional density map of the industrial sites in relation to the NTL power pattern throughout the city – with Region A and G having the least industrial activity.

Figure 35: Regional industrial density patterns in relation to NTL



Comparative Regional Analysis (Industrial density/NTL)



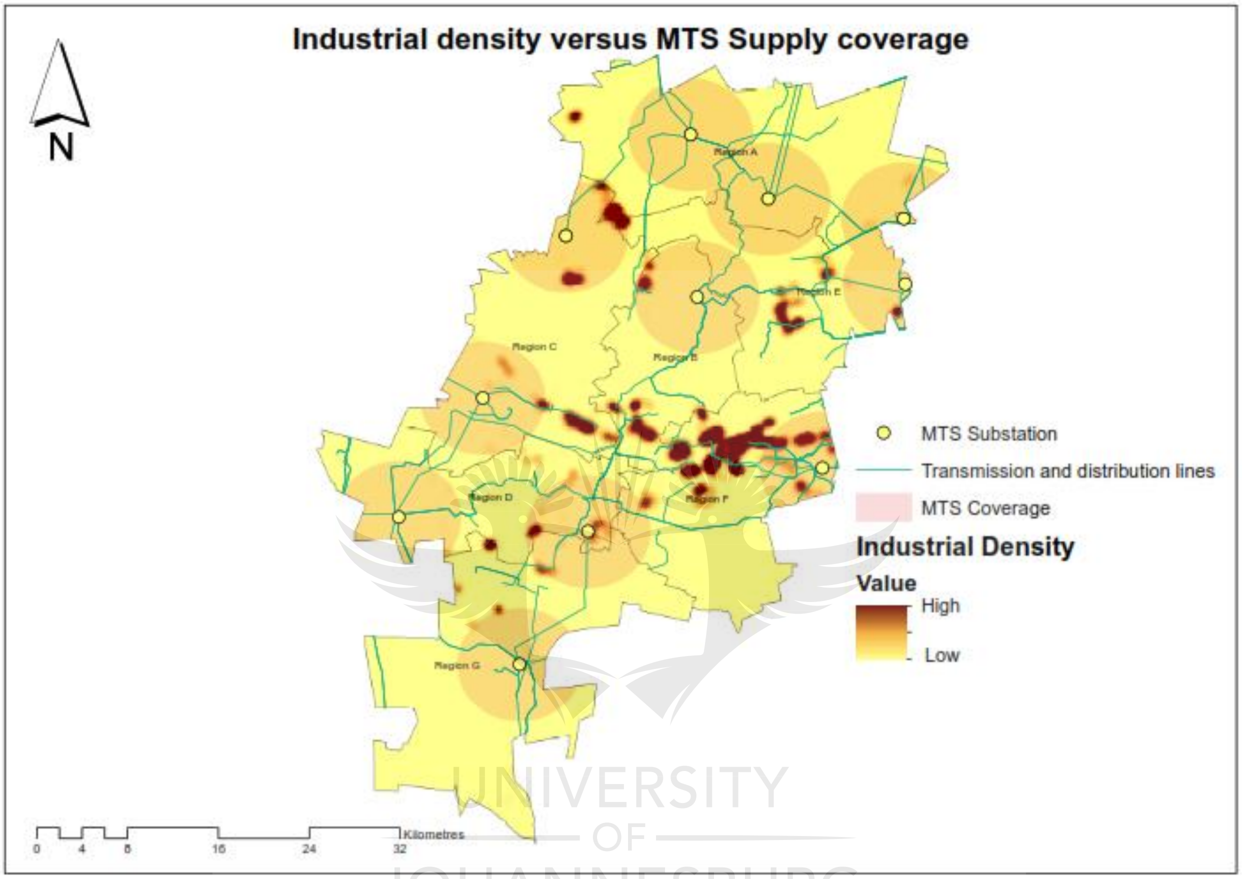
Discussion:

The main cluster of industrial activity is within Region F with Region B and C portraying an overlapping relationship of industrial activity. Region D and A indicate fewer industrial activities as the regions are mostly agricultural-based. Besides that, Region E performs better than G - as more infrastructural capacity is required in that area.

Although a high density of industrial activity is experienced in Region F, there have been various projects undertaken to address the demand. One of them involves deindustrialization and retrofixing the industrial sites to residential buildings i.e. Maboneng.

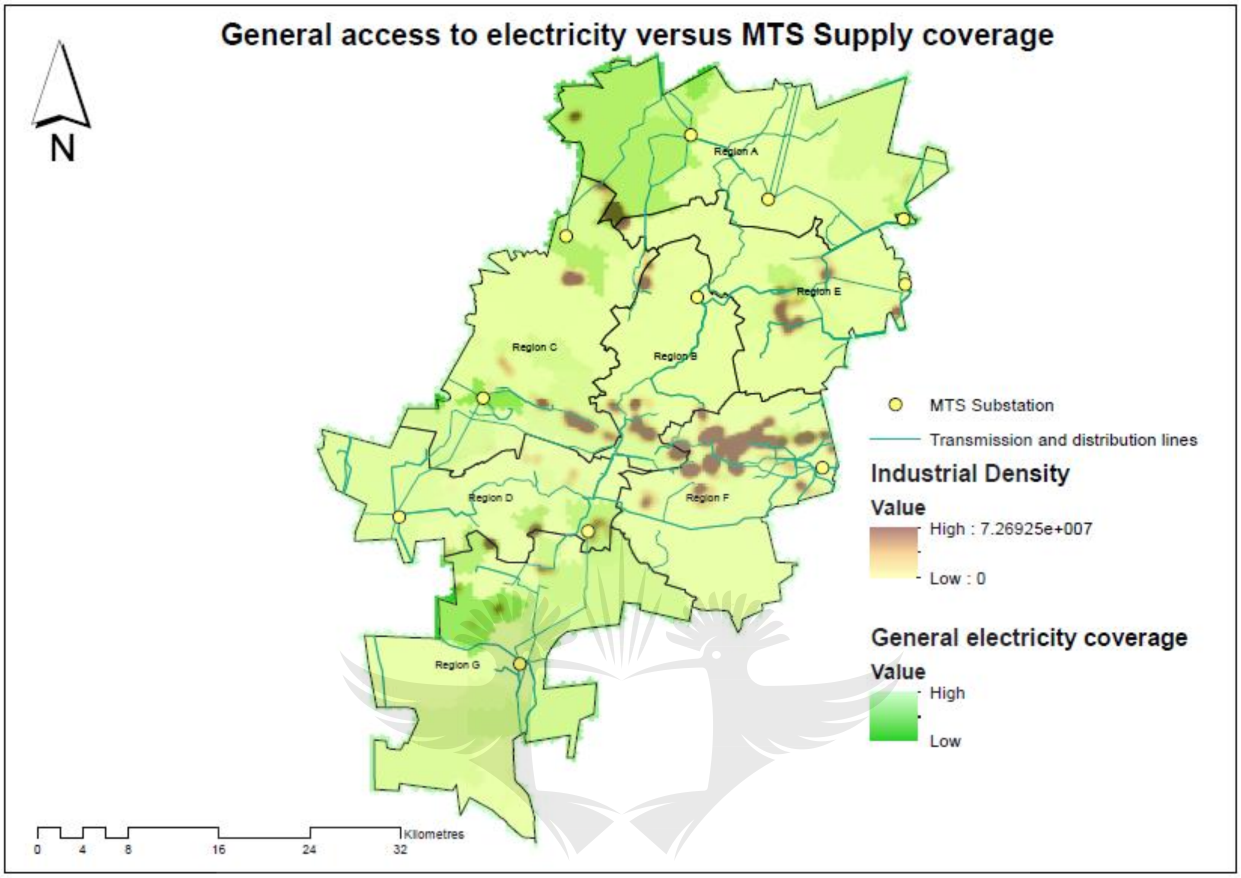
Furthermore, the map below indicates which densified industrial areas are within the power coverage. Region F still portrays power coverage incapacitation as compared to Region C which performs best in relation to other Regions when taking density in consideration. The mining belt still faces heavy under-capacitation as a result of inner-city deindustrialization and lack of intensive mining activities.

Figure 36: Supply Coverage by the MTS Stations in relation to industrial density



The smaller areas within CoJ with the highest industrial energy demand transition between Region C and E – which present these regions as desired destinations where industrial development. This can be broken down into wards indicating access to electricity by the industrial sites.

Figure 37: Access to electricity versus industrial density



Region F indicates a high-density pattern of industrial nodes where a synergy of warehouse, manufacturing, and flex buildings (i.e. office space, light manufacturing, and research and development) are located together.

As shown in the image above, better coverage is within the city periphery along the belt, however, there is little presence of industrial sites in the outskirts, particularly in Region G as compared to the inner center. Based on the generated map, Region C is most likely the preferably destination for industrial development as the Region is well lit – however, faces little connectivity in terms of electrical transmission lines which call for light industrial developments in the Region.

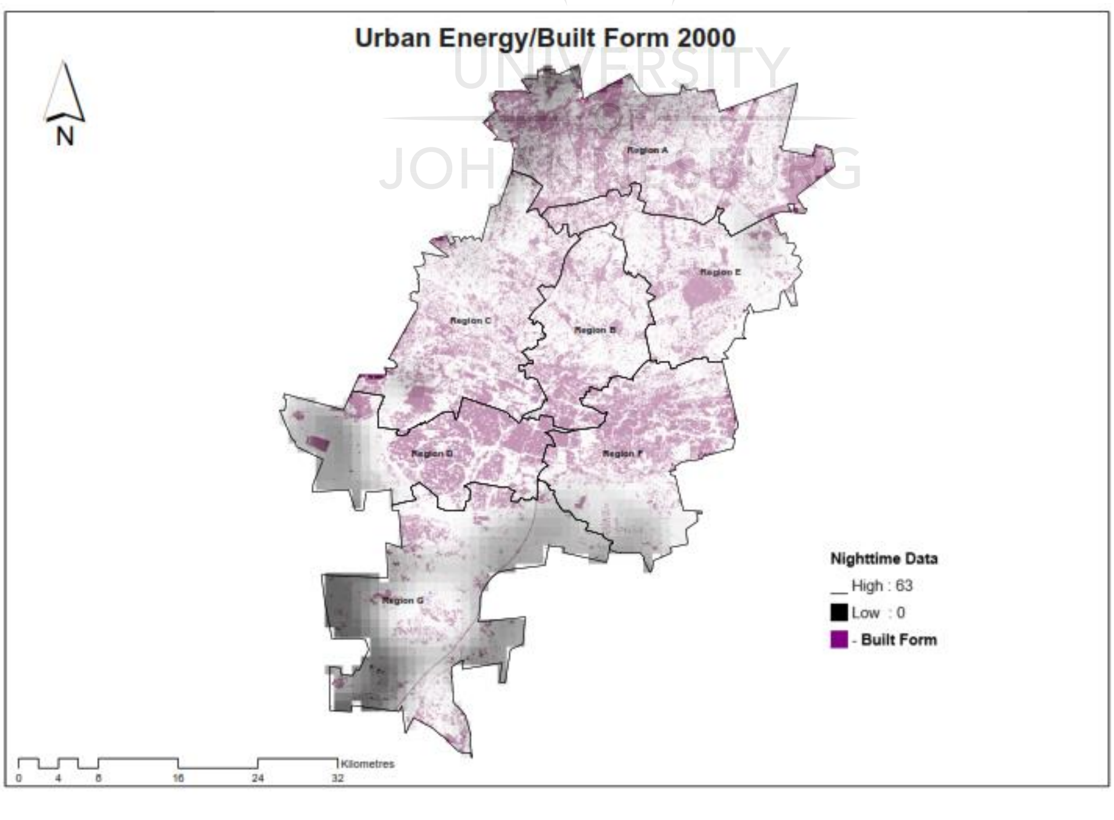
4.3. Energy spatio-temporal analysis (2000-2017)

Spatial energy distribution

With the spatial visualization to follow, the built form has only been considered while other land uses such as vegetation, barren land, and water bodies were excluded because of the minimal relationship they share with power due to the nature of the research. With that in line, the year 2000 was pivotal as the city was declared a metropolitan with the population souring at 2.7 million (State of African Cities, 2014) and the subsequent conjoining of townships such as Soweto being part of the city.

The high population at the time indicates how the demand for energy was and also unpacks the dynamics of spatial energy transformation of excluded areas given the past apartheid era. Major developments such as the establishment of universities, medical facilities, and office districts resulted in further residential agglomeration within and outside the city. An image of the year 2000 in relation to the NTL data presents an interesting visualization.

Figure 38: Urban energy versus growth year 2000

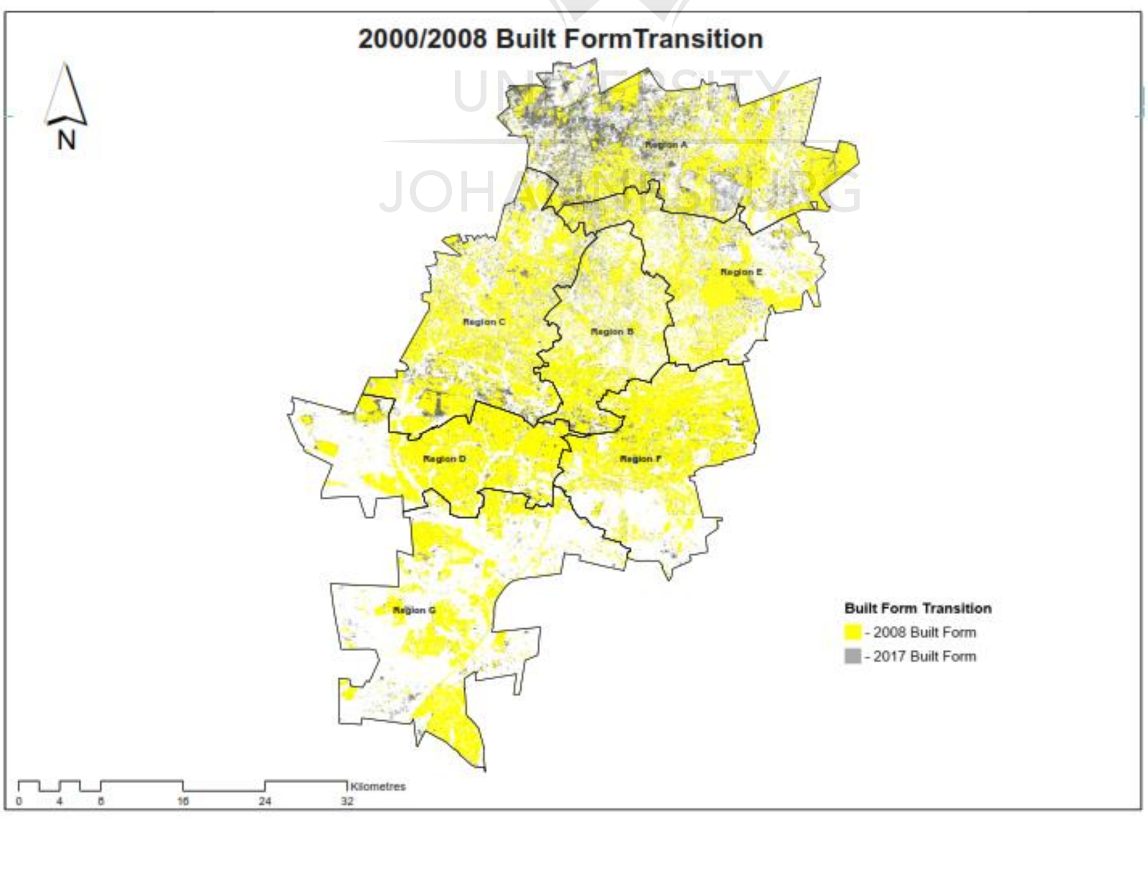


The majority of urban growth was central and spread out in the northern regions as compared to the southern ones where Region G performed the least in terms of power presence. This primarily indicates the level of the economic activity that was undertaken in the region. For instance, Region D-F are characterized by intense commercial and industrial activities that met the demand from mining activities, hence the spatial energy distribution for the regions is moderately-spread and sufficient.

Region G, when compared to other regions, can be subjected to the concept of energy poverty. However, factors such as the Region, along region A – particularly portions of it, being agricultural harbors can account as to why little activity is observed. Besides that, the overall analysis for the year 2000 indicates that the built up was predominantly central – indicating a relationship of independence from peripheral localities.

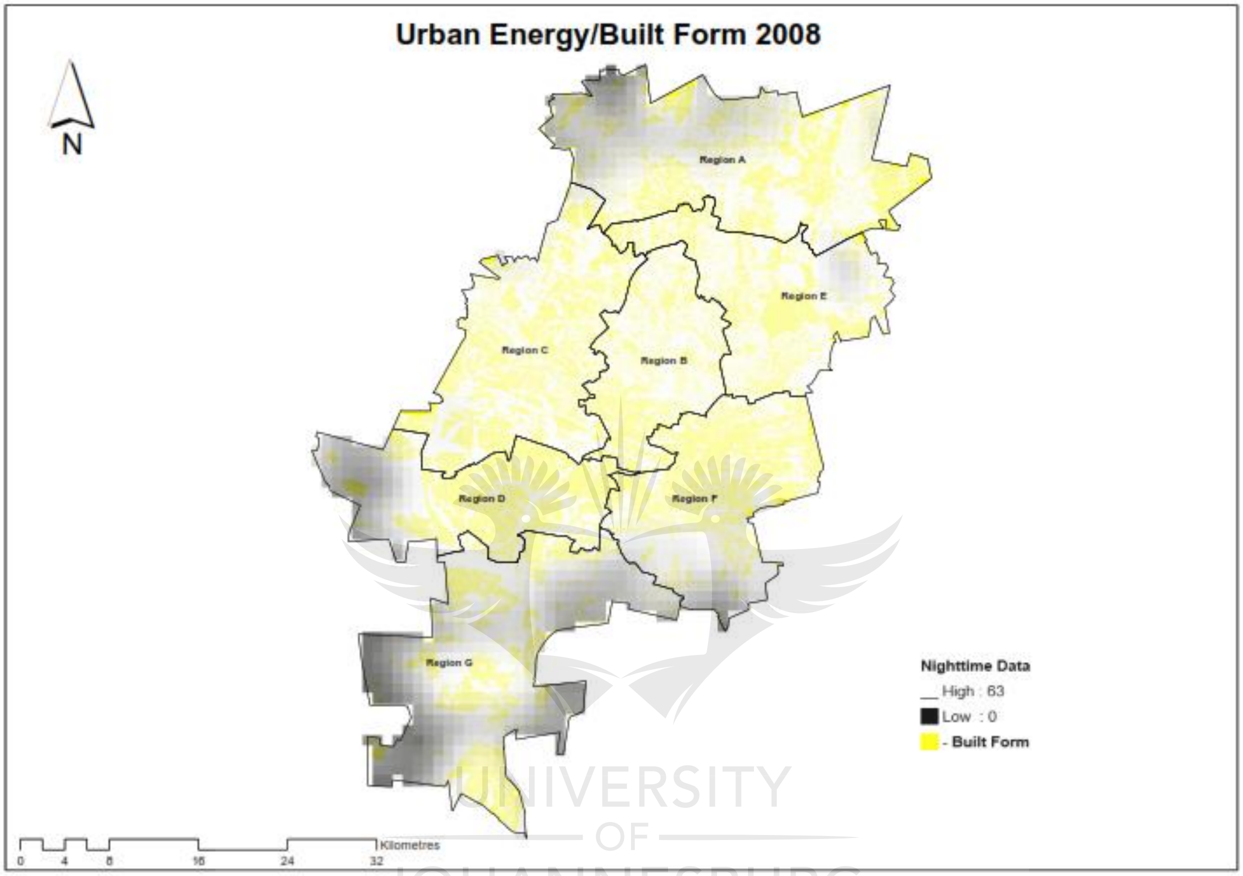
As can be seen on Figure 39, the transition period 2000/2008 experienced major growth. Urban developments continued to be central with noticeable developments occurring in past performing regions like G.

Figure 39: Urban growth transition 2000/2008



This growth had great implications for the overall spatial distribution for the year 2008 as shown below:

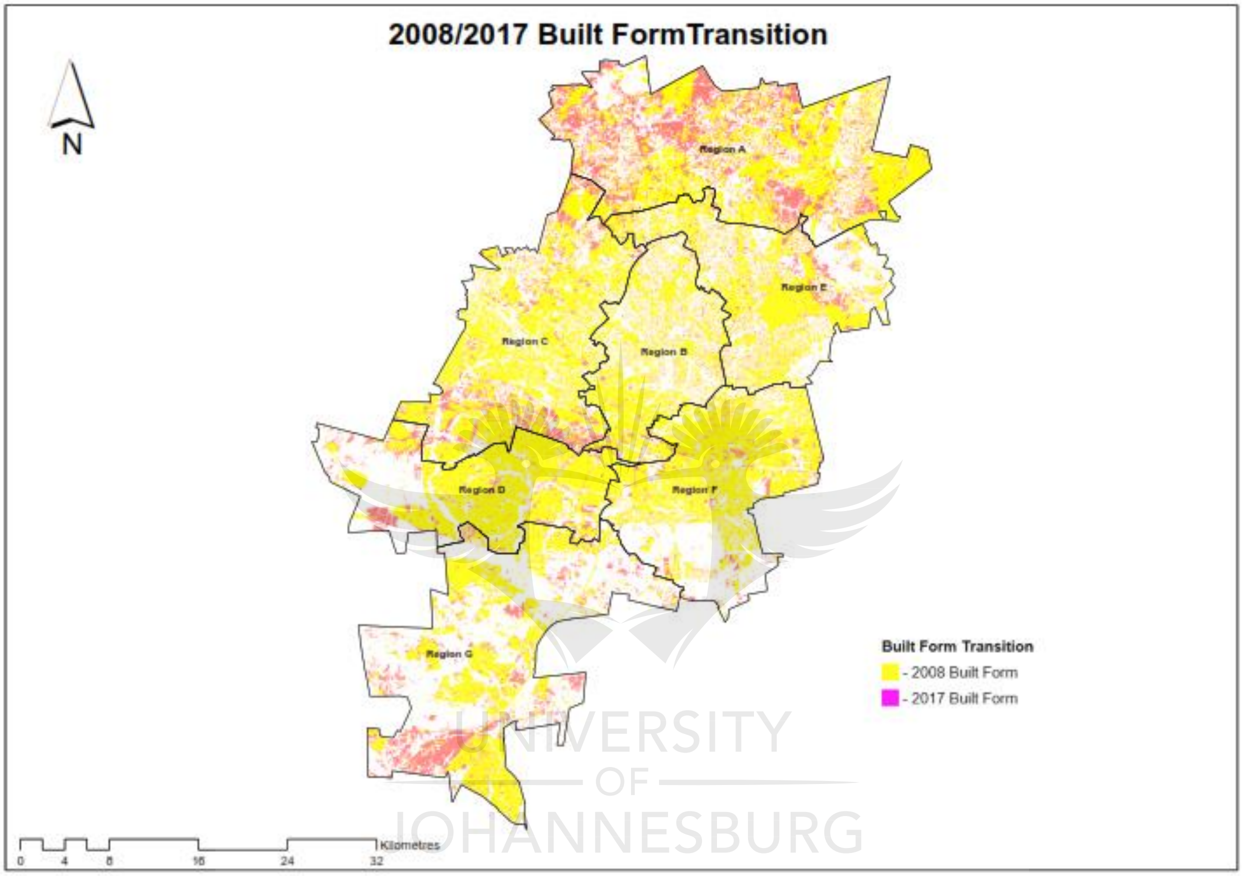
Figure 40: Urban energy versus growth 2008



The analysis indicates that development intensity has increased in Region G. Region D still particularly experiences some lag while Region C also indicates improvements during the 8-year period. Although growth took place and centrally intensified, much of the areas i.e. G and C still experience poor illumination. Region E performed best in terms of growth and access to power. Portion of Region A and G, irrespective of the growth, still experience a sense of energy poverty.

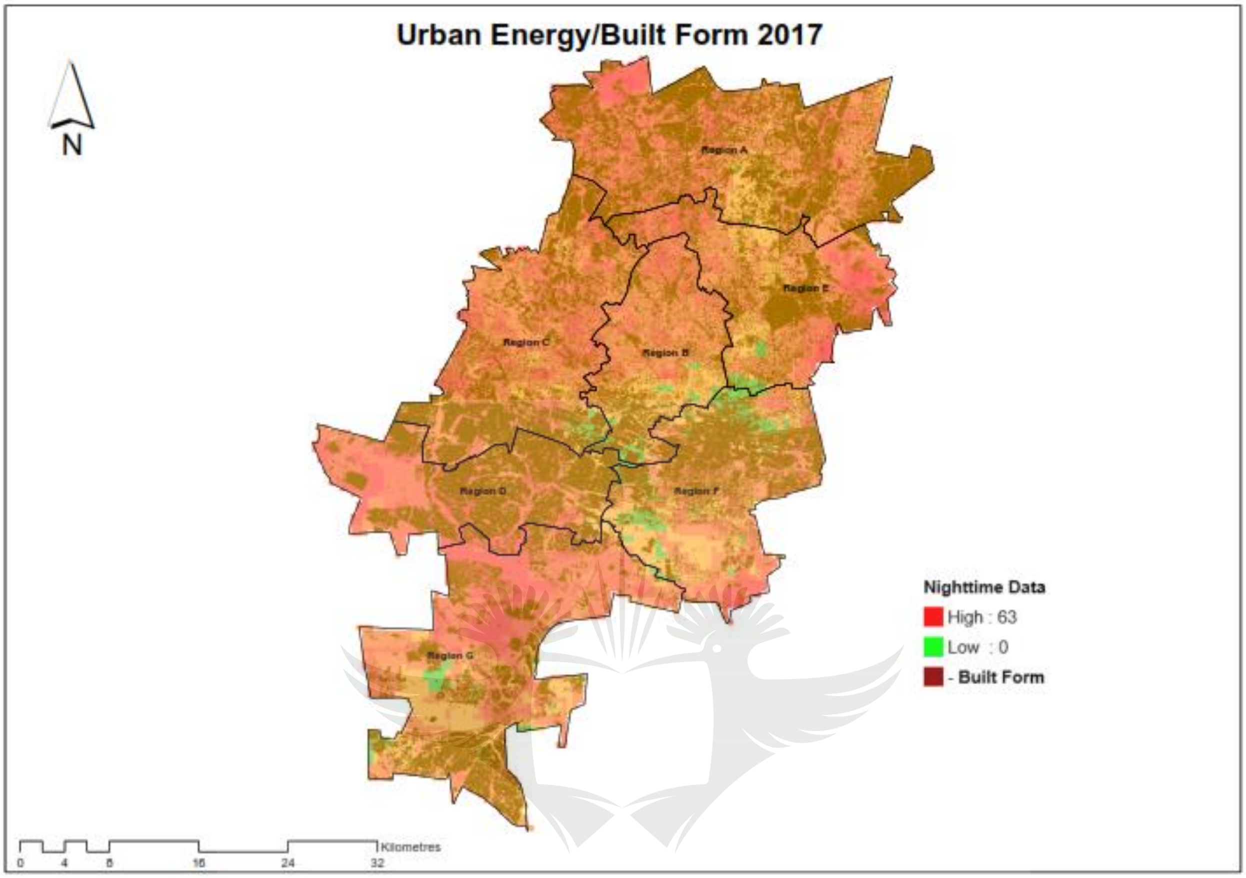
With this in line, the assumption of growth being associated with energy access can be rendered inconsistent. The population, by the year 2010, almost doubled (4.7 million) according to the Statistics By Place for Johannesburg (2010). This growth, resulting in increased households, fostered a booming housing market as more developments occurred in the northern side of the city from 2008-2017. More in-fill developments within the central regions reduced costs related to electrical infrastructure as compared to expansions – however, the upper regions experienced higher growth as shown below:

Figure 41: Urban growth transition 2008/2017



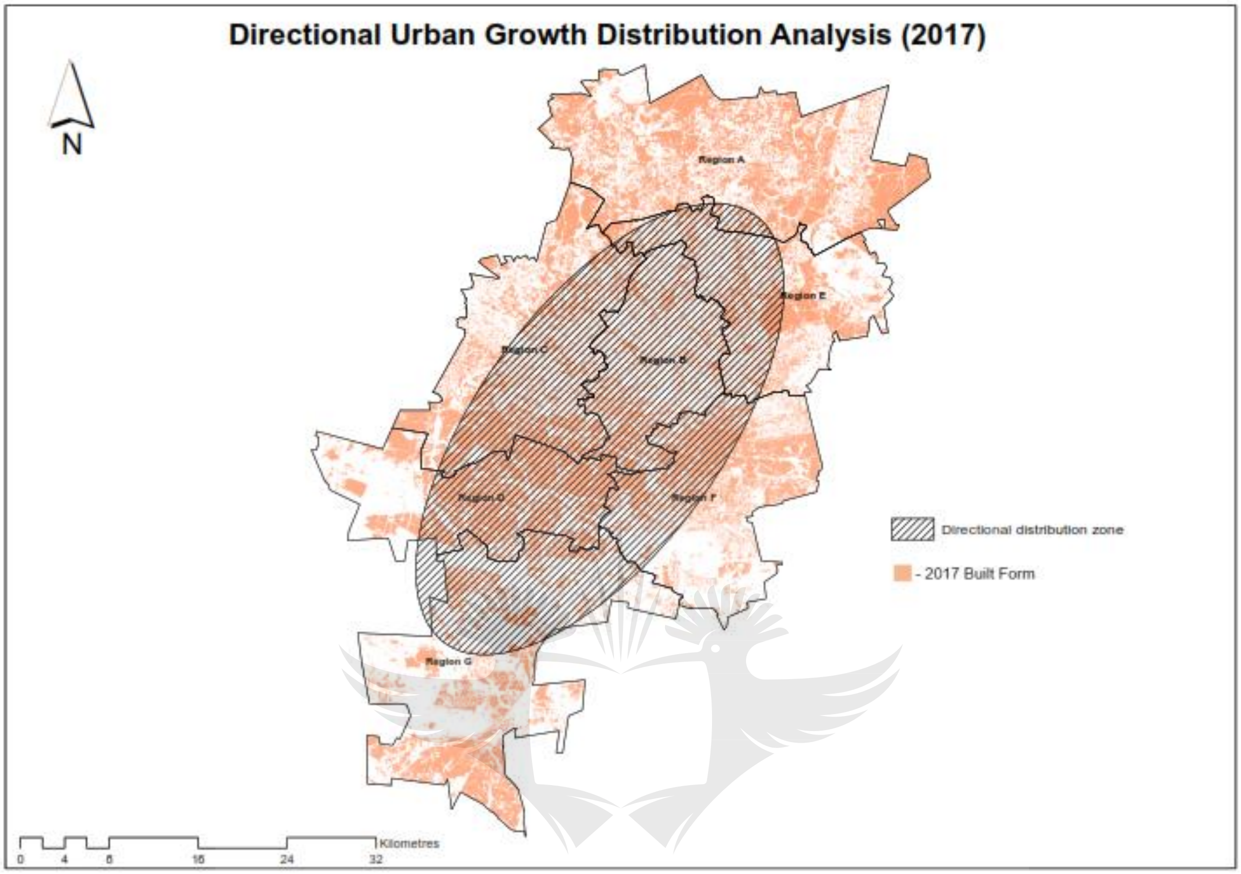
This growth predominantly occurred in Region A as the preferred destination compared to lower regions where a form of decline is being experienced. Region D continued to experience steady growth while region G is finally undergoing spatial transformation. Factors relative to this could relate to the region receiving infrastructural investment projects that look into the electrical sector as the locale is disconnected from the central regions with little influential economic affluence that can stimulate the desired growth. With this in mind, power supply has significantly increased in the area along in Region A as show below:

Figure 42: Urban energy versus growth 2017



Having experienced a drastic growth, the 2017 NTL data presents an interesting visual case. The central growth's energy intensity has decreased while the outskirts have increased. This is a complete opposite compared to the other years. The majority of the city space appears to be well-lit with the spatial energy particularly being well-spread and balanced. Growth as shown throughout the years will continue to intensify within the core and expand north. This trend can be expressed by the distributional direction analysis based on the Standard Deviational Ellipse:

Figure 43: Distributional urban growth analysis based



The outcome can be both ways. A ripple effect central to Region D, B, and F losing energy supply or the densified areas have been subject to the principles of sustainable development as per Sustainable Development Goal-11 where the excess green and yellow color portrays a mix of built-up and greening/open spaces like urban parks and trees.

The adoption of sustainable energy principles like the utilization of solar can also be accountable for the reduction in energy visualization in which power-intensive commercial and industrial sites have gone off the grid and thus adopted to cleaner energy sources given their already-contributing carbon emissions from manufacturing and processing activities.

Overall, urban growth can be seen to be taking a trend towards the north of the city while southern regions experience a form of a slow development with gradual access to power.

The central regions, due to their pulling factors, have resulted in increased densities and higher populace and are thus adopting smart energy initiatives to ease off the pressures related to electrical purchases and extensions. Region A will further rapidly develop and may experience growth at a rate twice of Region G due to the regional characteristics and preferences to socioeconomic opportunities like power supply and decent connectivity.

4.7. Modelled future growth development

4.7.1. Generated urban growth map for the suitability model using CA-Markov

The research first employed the IDRISI software to project and generate how the city's growth would be like 30 years from the year 2017. This process was pivotal as growth is not static and as such, the suitability would best make sense with the future growth being taken under consideration. This avoids the process of utilizing the current growth to assume the site/parcels for growth would be existential in the future.

With the initiation of the Markov procedure, the transition probabilities matrix and transition areas matrix were generated using the classified land use land cover image for the year 2008 as the earlier timeframe and 2017 as the later stage. The transition areas matrix, according to Khawaldah (2016) "*expresses the total area (in cells) expected to change in the next period while transition probabilities matrix shows the likelihood of a pixel from one class changing to another class or within same class in the coming period*".

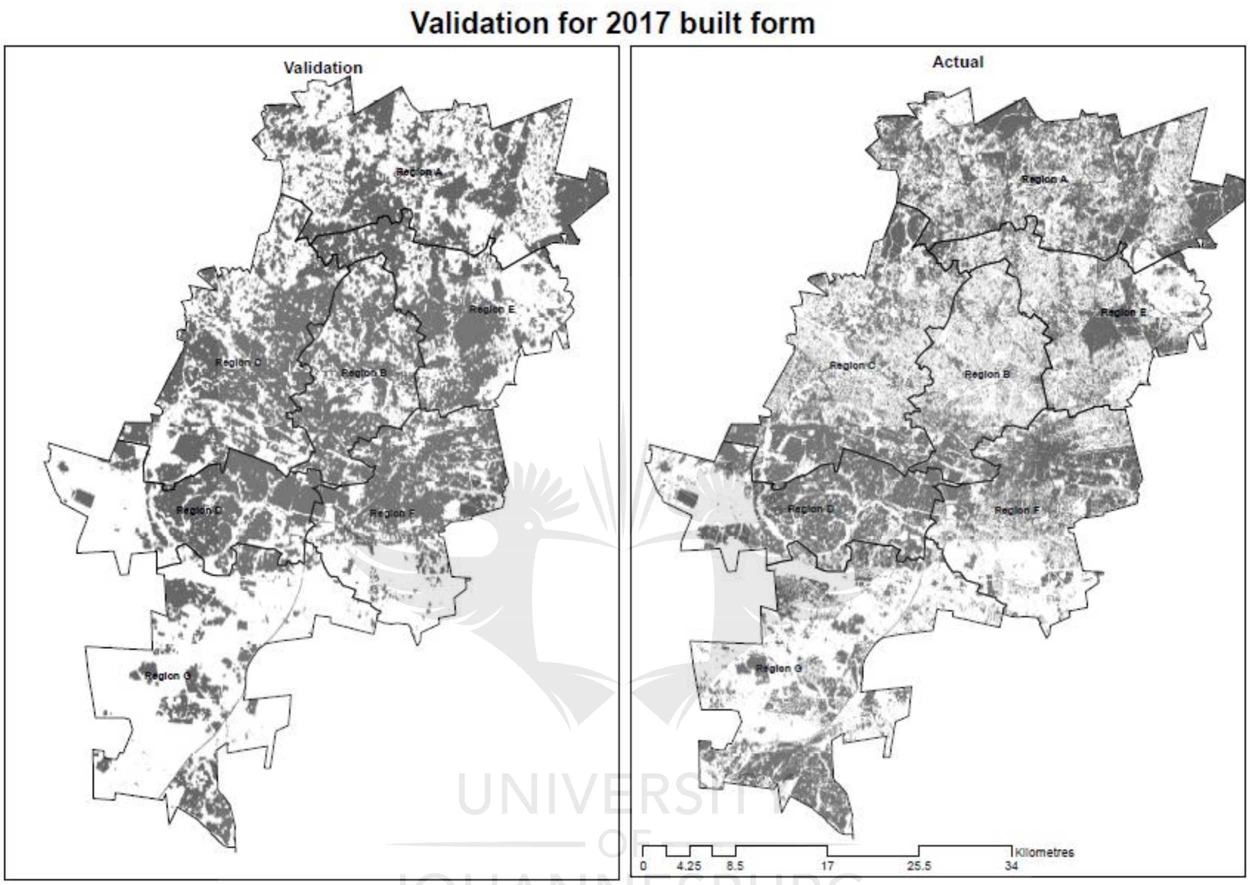
Validation

The simulation legitimacy of the Cellular Automata Markov (CA-Markov) tool underwent evaluation through the application of base resolution statistical methods to quantify the agreement and disagreement between two land use scenes. The quantification of agreement and disagreement figures between the two maps were measured with regards to locality and quantity of cells in each land use class through Kappa statistics.

The validation process is important as it provides an overall accuracy assessment of the CA-Markov model in predicting future growth. This procedure involved using the actual classified scene of (2017) and that of the projected (2017) produced from another CA Markov analysis which involved the scenes for year 2000 and 2008 to project the year

2017. Figure 39 portrays the scenes of the City of Johannesburg, where the actual scene was referenced with the projected growth to obtain the Kappa statistics.

Figure 44: Simulated scene (2017) versus the actual growth (2017)



The scenes generated from the validate tool shows the produced kappa coefficient values for the validation process under Table 5. The generated Kstandard for the validation procedure was 0.6634 - moreover, this standard figure is fairly high and therefore gives satisfactory simulation results for a good prediction.

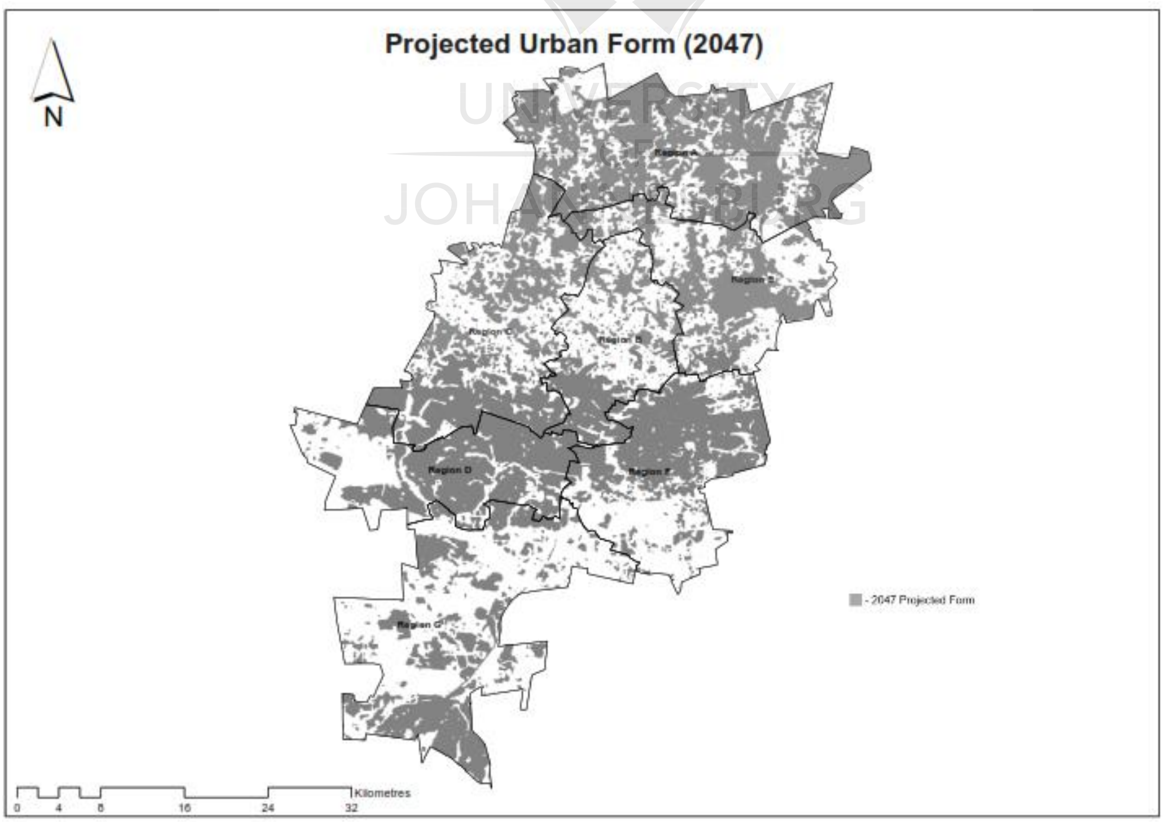
Table 5: Validation summary for projected scene

Item	Indices
Agreement Chance	0.1160
Agreement Quantity	0.1797

Agreement Strata	0.3898
Agreement Grid-cell	0.0367
Disagree Grid-cell	0.0238
Disagree Strata	0.0076
Disagree Quantity	0.1744
K-no	0.7949
K-location	0.5466
K-location Strata	0.6976
K-standard	0.6634

Based on these figures, the projected map to be used as a basis of analysis under growth suitability in ArcMap, is shown below:

Figure 45: Projected 2047 urban growth for CoJ

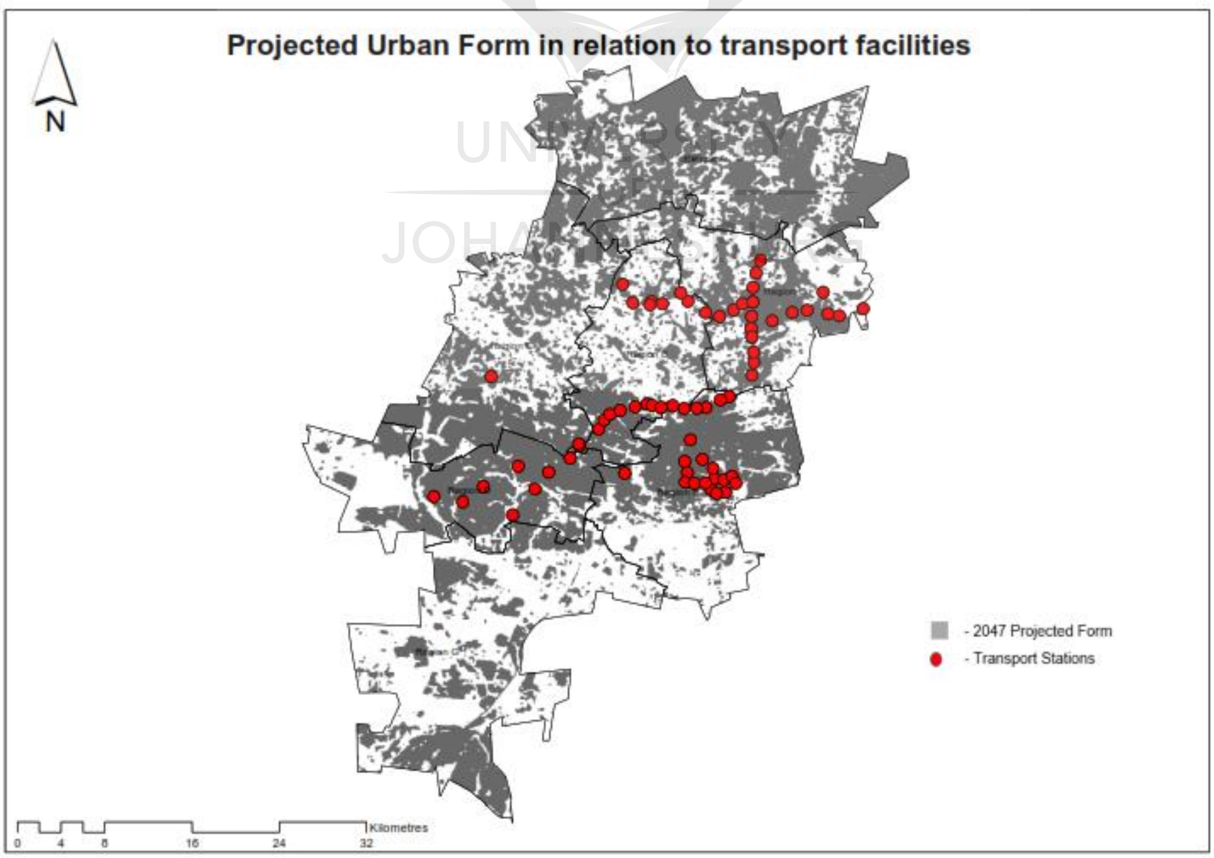


As shown in the scene, the majority of the growth is expected to be towards the upper regions while central ones indicate an aspect of increased density. The lower regions still lag behind due to being disconnected from the city center, particularly region G. This disconnect can be attributed to various elements such as the lack of infrastructural expansion capacity, budget, and industry attraction that could lead to more activity in the region.

Suitability analysis

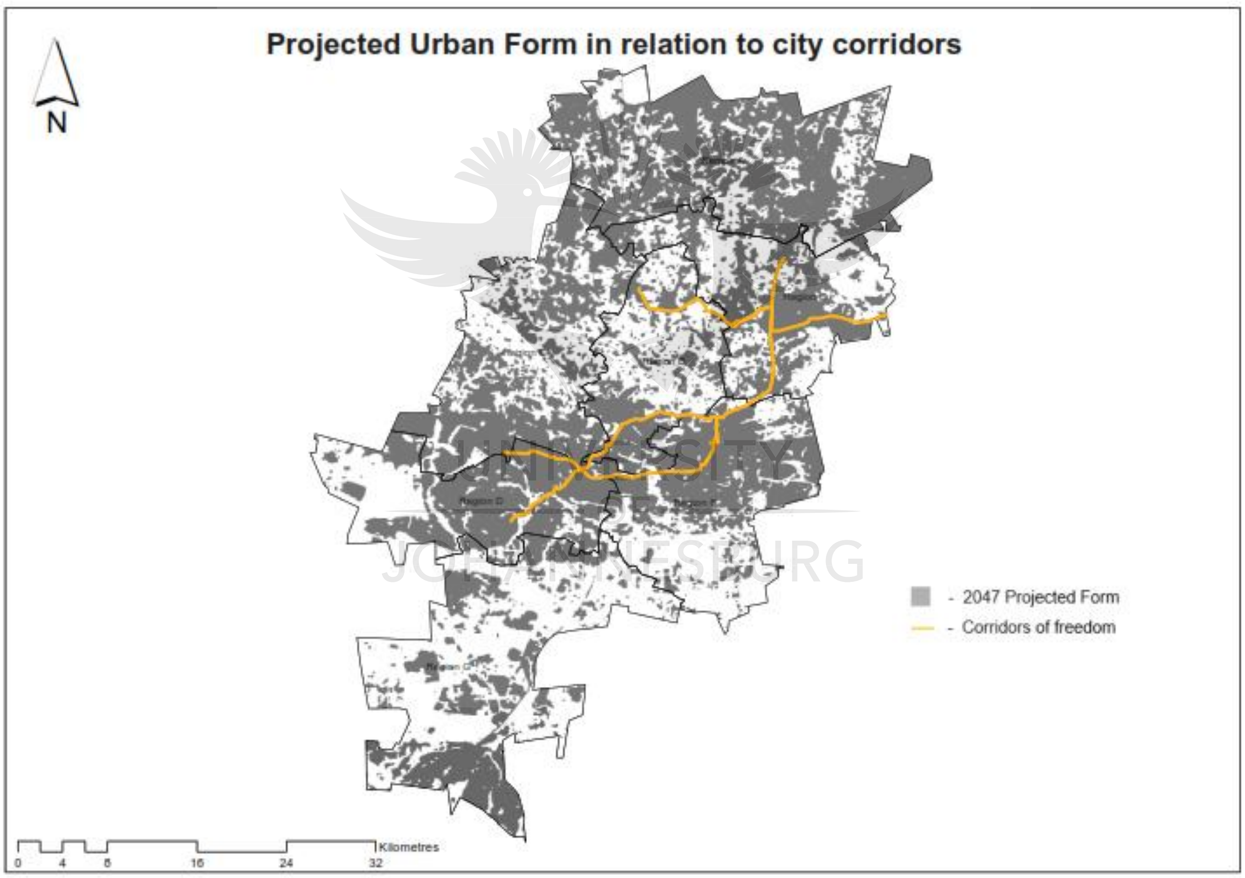
The study consists of the following parameters: projected urban growth, power utilities, main roads, conserved and protected areas, population density, economic nodes, corridors, transport infrastructure, substations, and residential density. The proximity to transport facilities (i.e. transport stations) encourages densification as growth is likely to foster around those nodes where private and public enterprises merge – insinuating a level of convenience in commuting from one locale to the next as shown below:

Figure 46: Growth in relation to the transport facilities



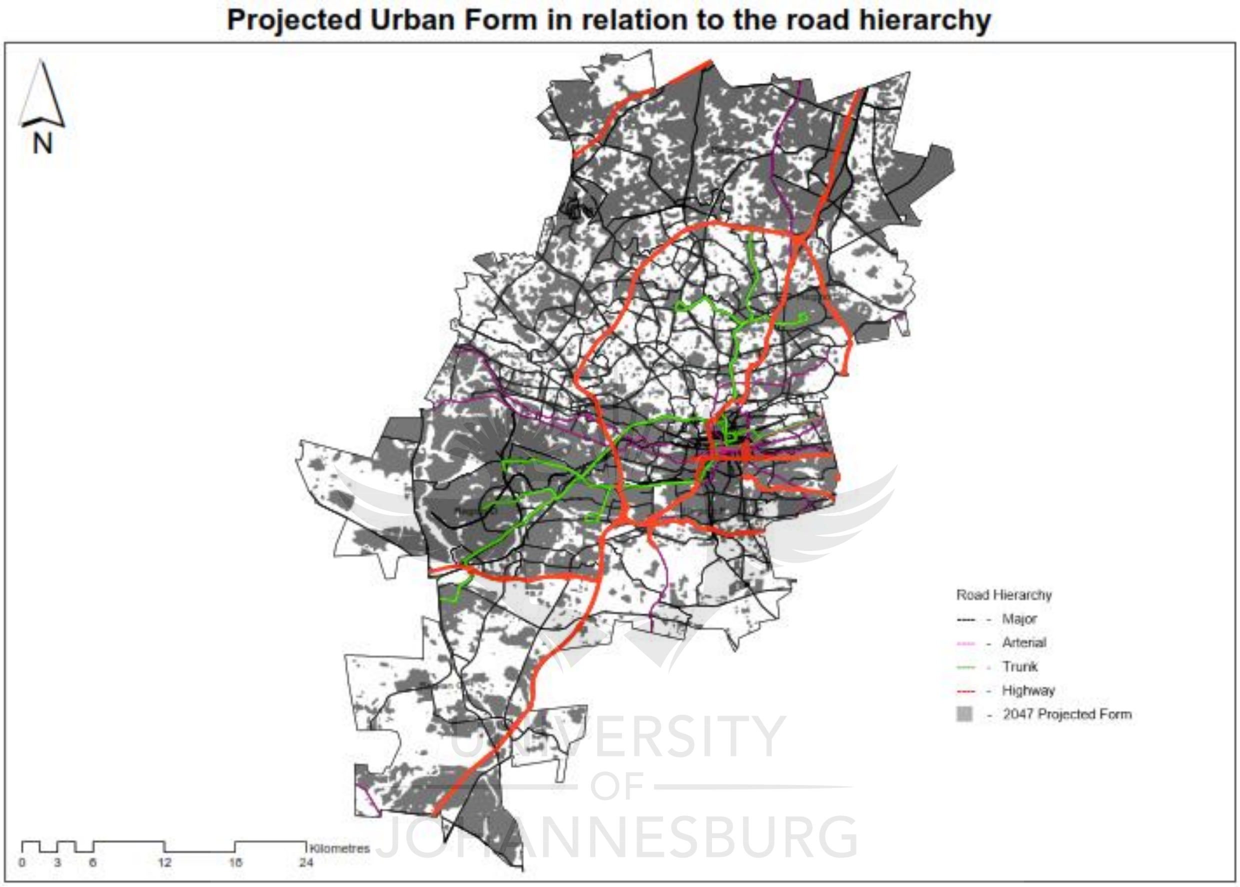
With public and private enterprises stemming in strategic points through the city, particularly along Region E, F, to D; the development of corridors of freedom will be pivotal in fostering additional developments. The projected growth is likely to be transport-driven – with corridors serving as vessels that connect the underprivileged sections of the city to other parts of it. Further expansion is anticipated in the northern regions to address the sprawling developments and reduce private vehicular use. The current set-up is still extensive within the central regions and is likely to stimulate future growth across the present corridors as shown below:

Figure 47: Growth in relation to the corridors of freedom



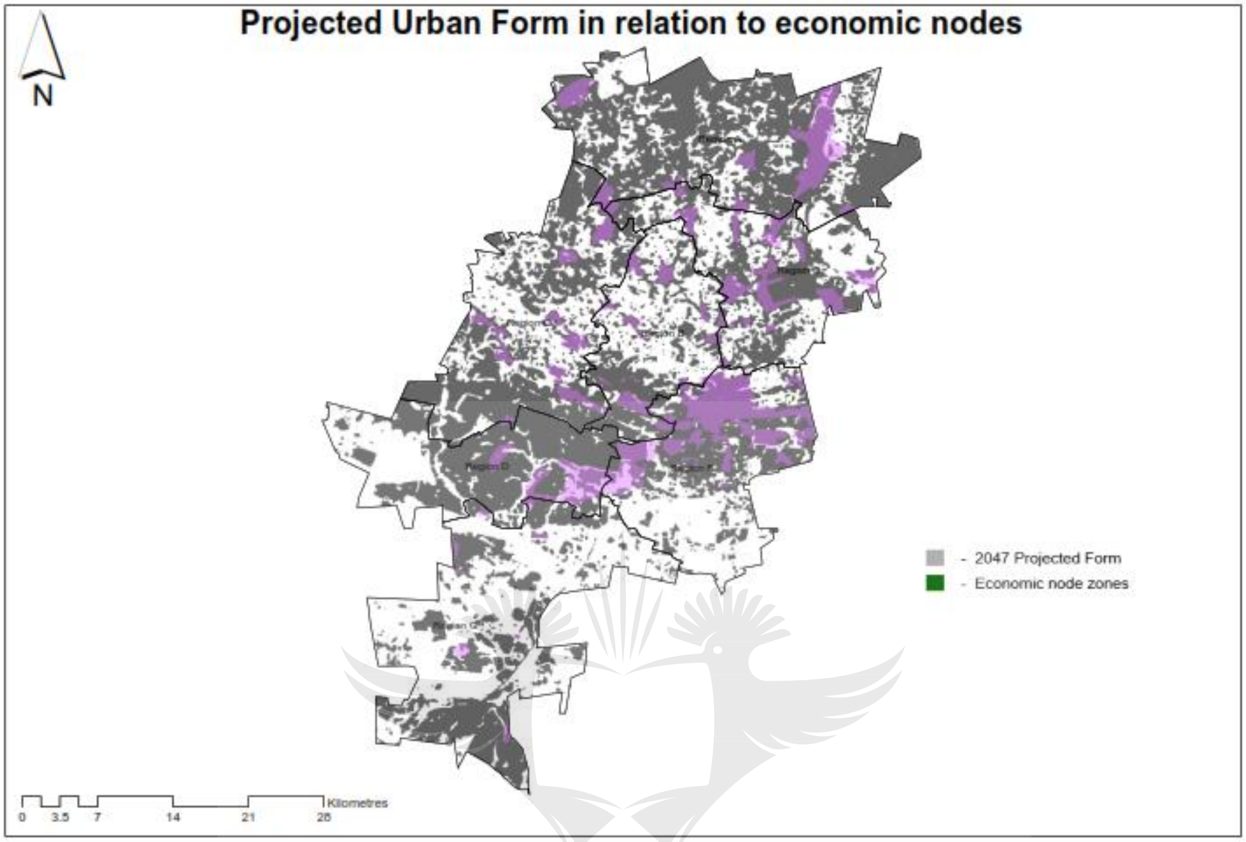
Similarly, transportation routes serve as nerves throughout the city – being responsible for the flow of goods and services i.e. Figure 48. Proximity to roads is critical in the study as connectivity provides the flow in and out of developments with efficiency being stipulated through proper linkages. With this in line, future growth is best satisfactory when proximity to existing road networks is viable. With the current road network, much of the concentration is central and peripheral regions portray behavior of sprawling developments. Future expansion, given the densified developments in the upper regions will call for more road networks to allow viable flow and growth stability.

Figure 48: Growth in relation to the transportation routes



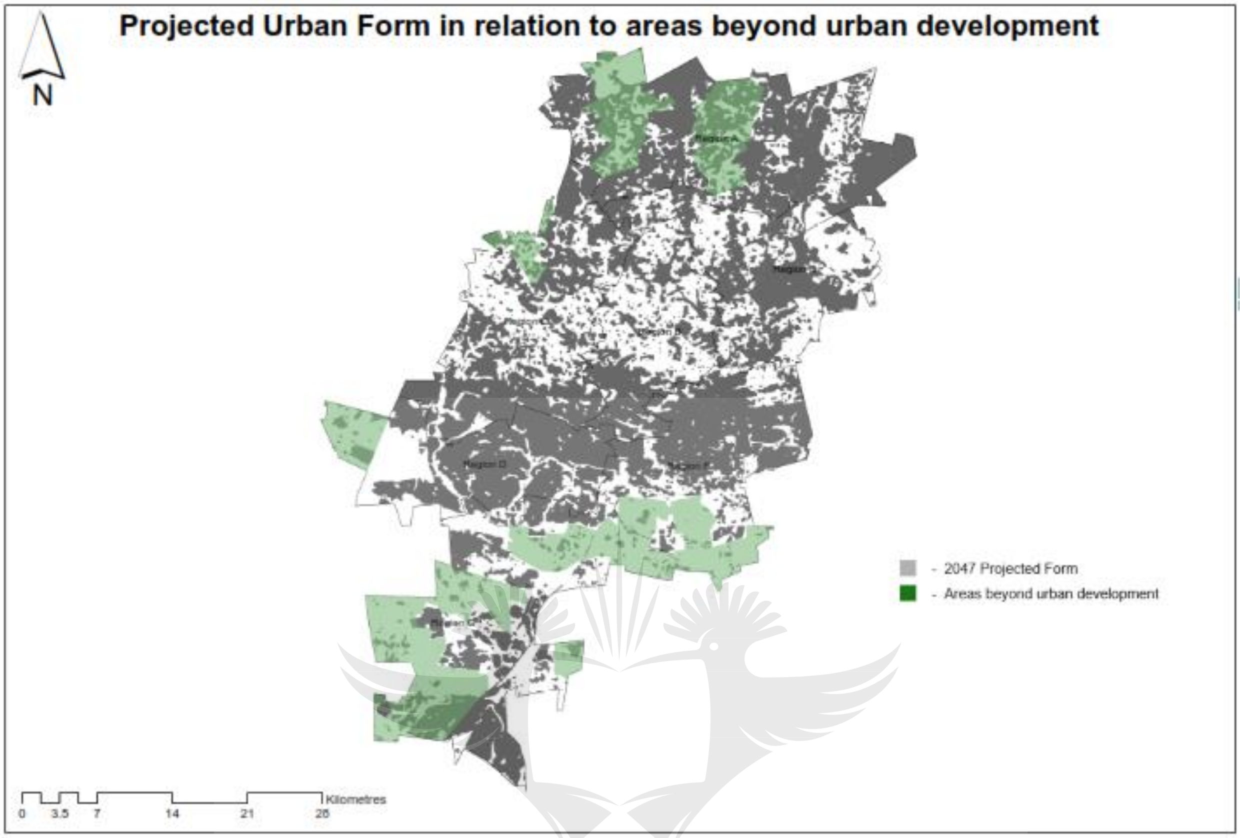
In the study, preference of suitability was also given to areas that are nearby economic nodes as growth is likely to centralize around areas earmarked for socioeconomic opportunities. The city's SDF 2040 identifies opportunities of economic nodes – with most of them being central and expanding to the north. Region G and D are still underperforming; and with the projected growth, less activity is still being experienced within those regions.

Figure 49: Growth in relation to the economic nodes



This proves to be an issue in the future as it might set the environment for continued and worsened perpetuation in income brackets when comparing the low, middle, and high-income earners. Perhaps accounting for the little economic and development activity experienced in the mentioned regions is the map below:

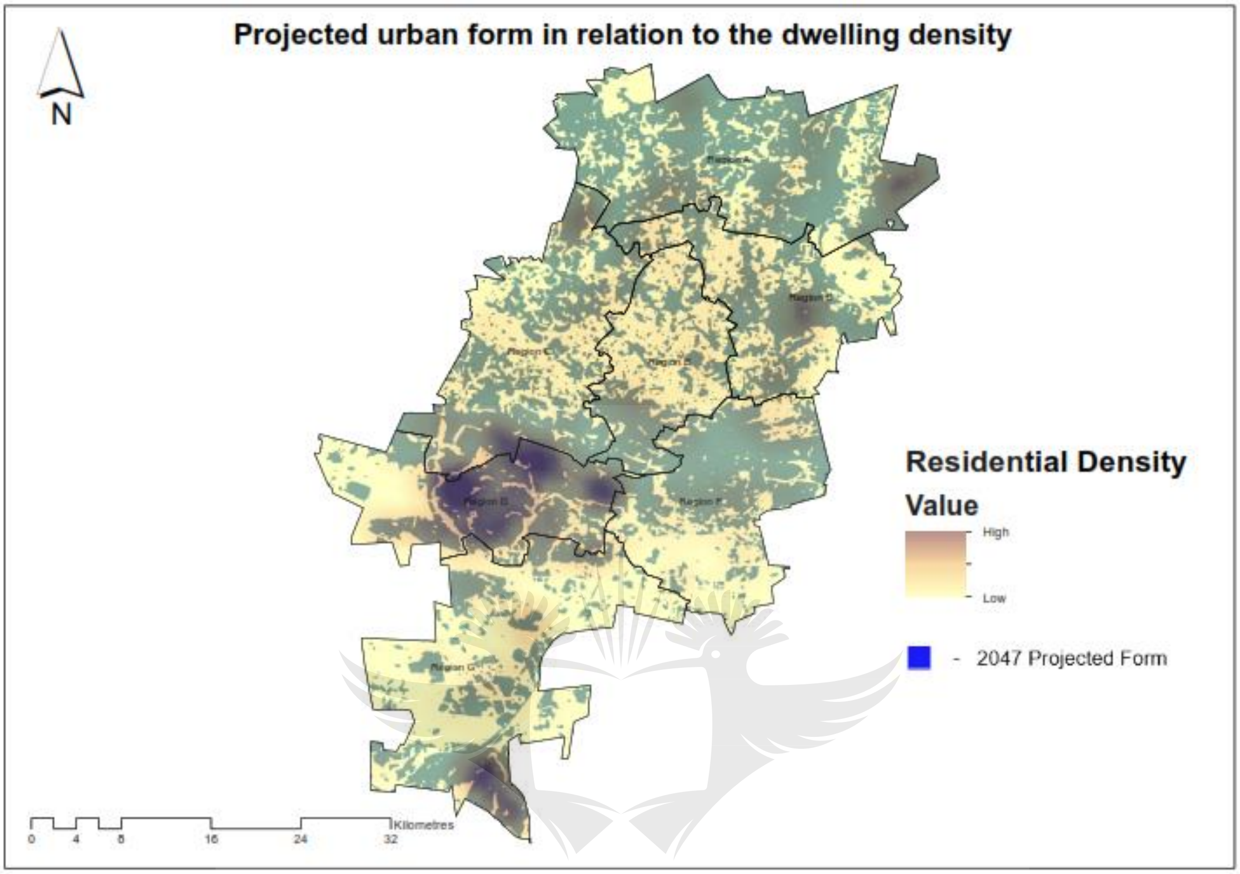
Figure 50: Growth in relation to past areas beyond urban development



The majority of Region G and the lower section of Region F have been identified as sites/areas beyond urban development. Attributable factors could relate to Region's G lack of capacity in attracting local investors for local economic development or the fact that the region is mainly disconnected from the central, and often influential regions.

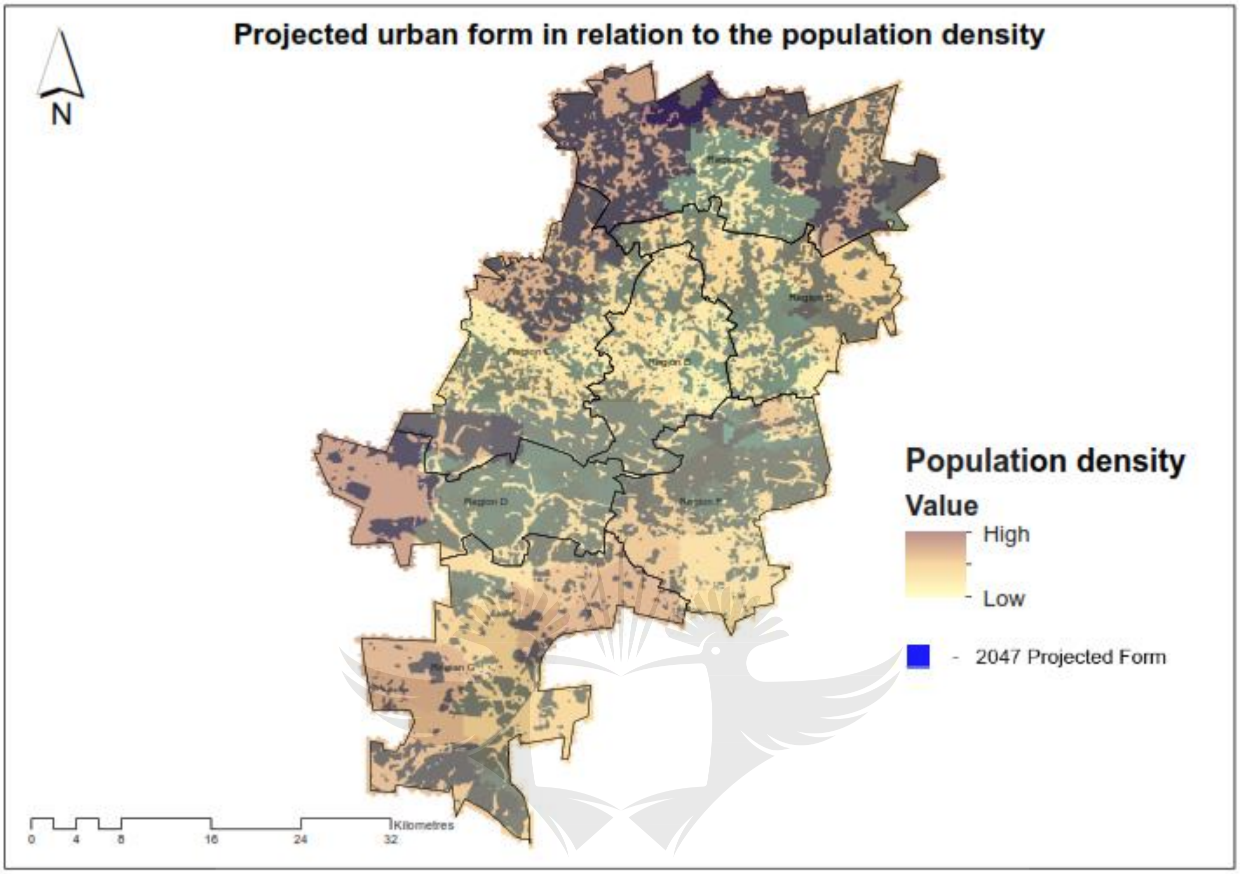
Much of the low-income populations will be subject to the same conditions that existed before given that Region G, based on the past residential density, will still not have its needs met. The development is likely to change, however, not much. Region D, having the past highest density, indicates that the figure will eventually increase in size and form.

Figure 51: Growth in relation to past residential density



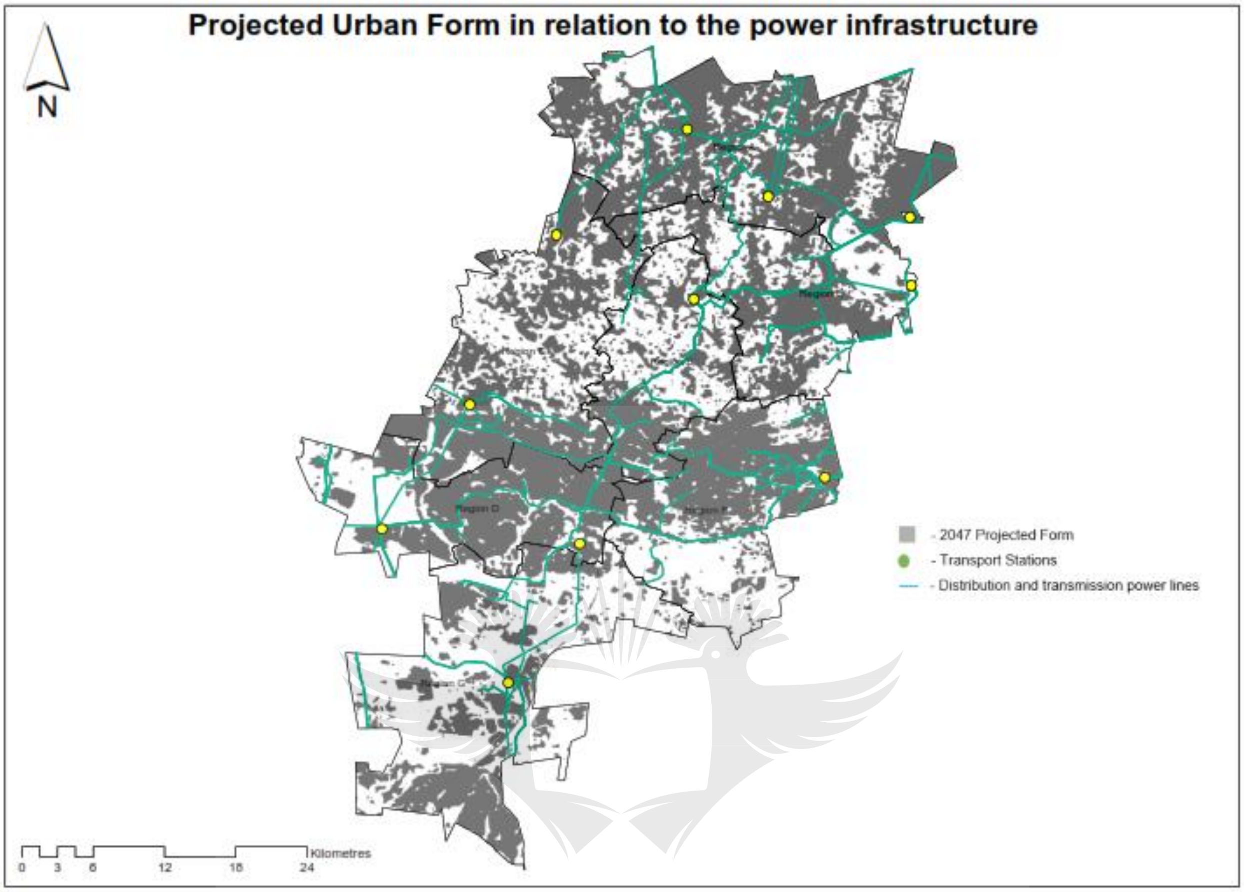
This is important to take under consideration as an element as residential and population density are influential factors behind urbanization and remain drivers of development through the city. With reference to the population density, areas with higher population will result in increased demand for power, however, as shown in the analysis below, even areas with low density can equally be having the same demand.

Figure 52: Growth in relation to past population density



The vast majority of the past population density was located on the peripheral sections i.e. primarily townships of the city – and the model indicates increased growth in those areas. With this, strategic interventions revolving around how the power infrastructure will respond to the demand and supply dynamics will need to be comprehensive. The future growth in relation to the existing power infrastructure is indicated below:

Figure 53: Growth in relation to the power infrastructure

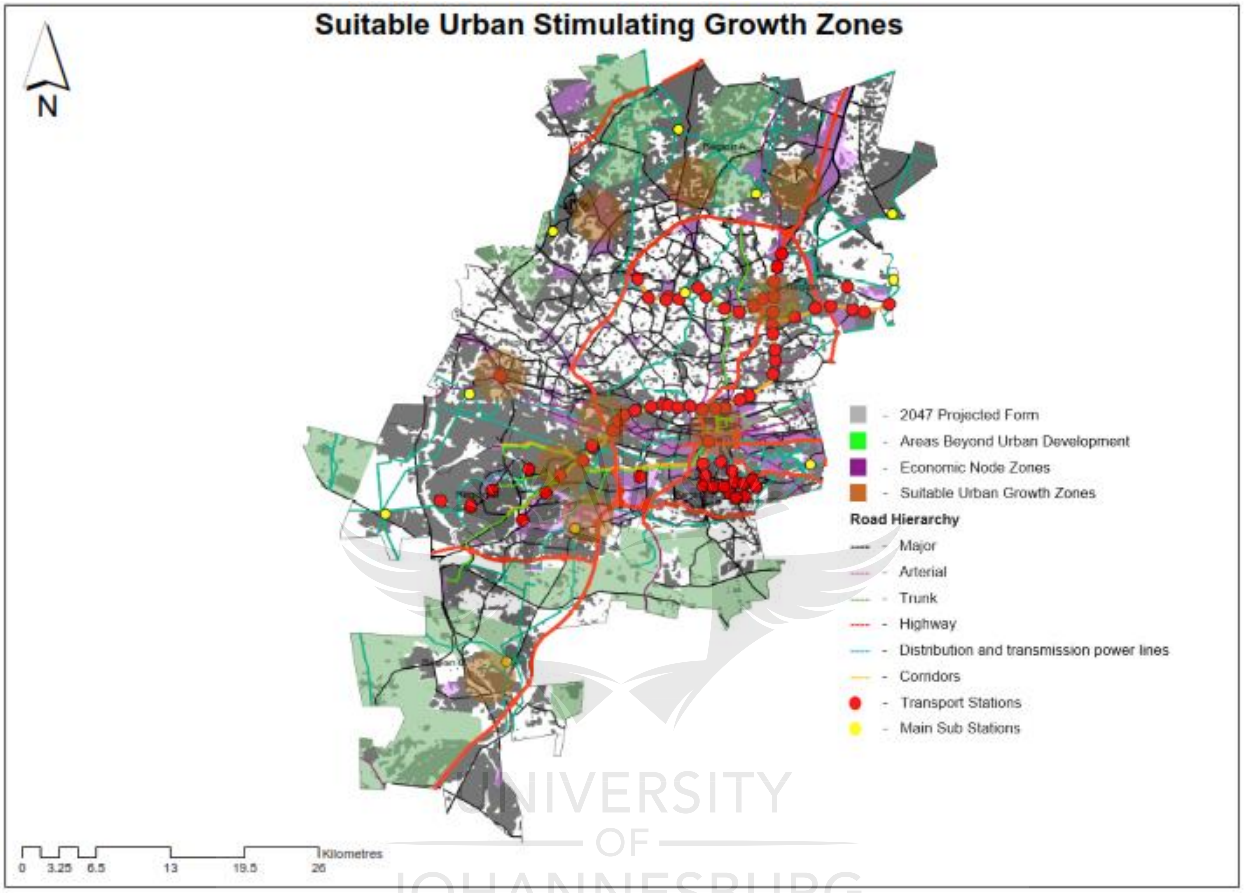


Cognizance should be given as to how the power utility serves as the main element considered as the significant factor driving urban growth in this study. Further, the electrical infrastructure such as the distribution and transmission lines along with the available data on the main substations was key in foretelling where the desired urban growth might suffice.

As visible above, most of the infrastructure is predominantly central – spanning from the west to the east and the upper north of the city. Such availability is likely to cater for the growth further upwards as compared to much of the southern regions.

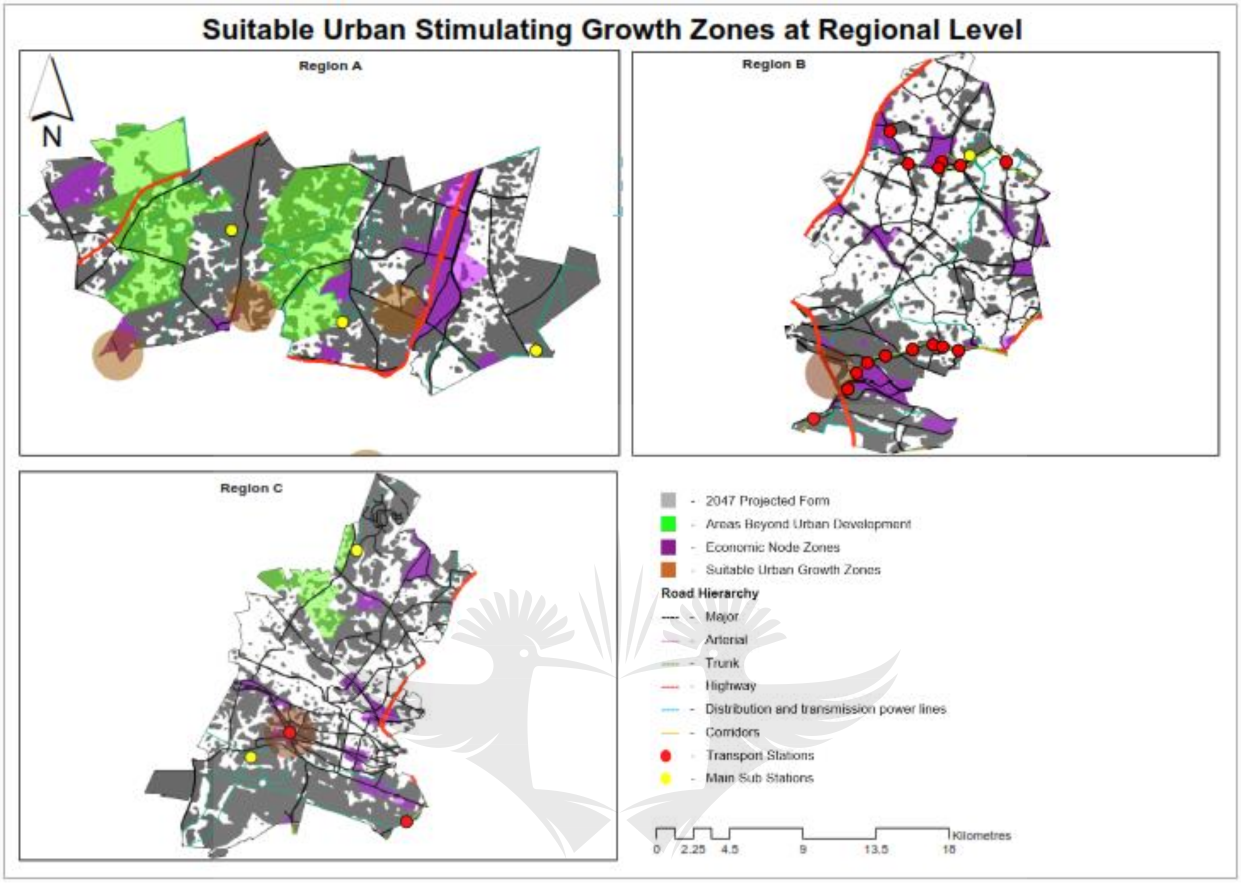
With all the given elements discussed above in relation to the projected growth, this subsection indicates the final/potential points from which the desired growth will stimulate from when various elements are interlinked. The brown nodes in Figure 54 provide illustrations of zones that are regarded as highly suitable and best capacitated with electrical infrastructure from where additional future urban growth will stem from.

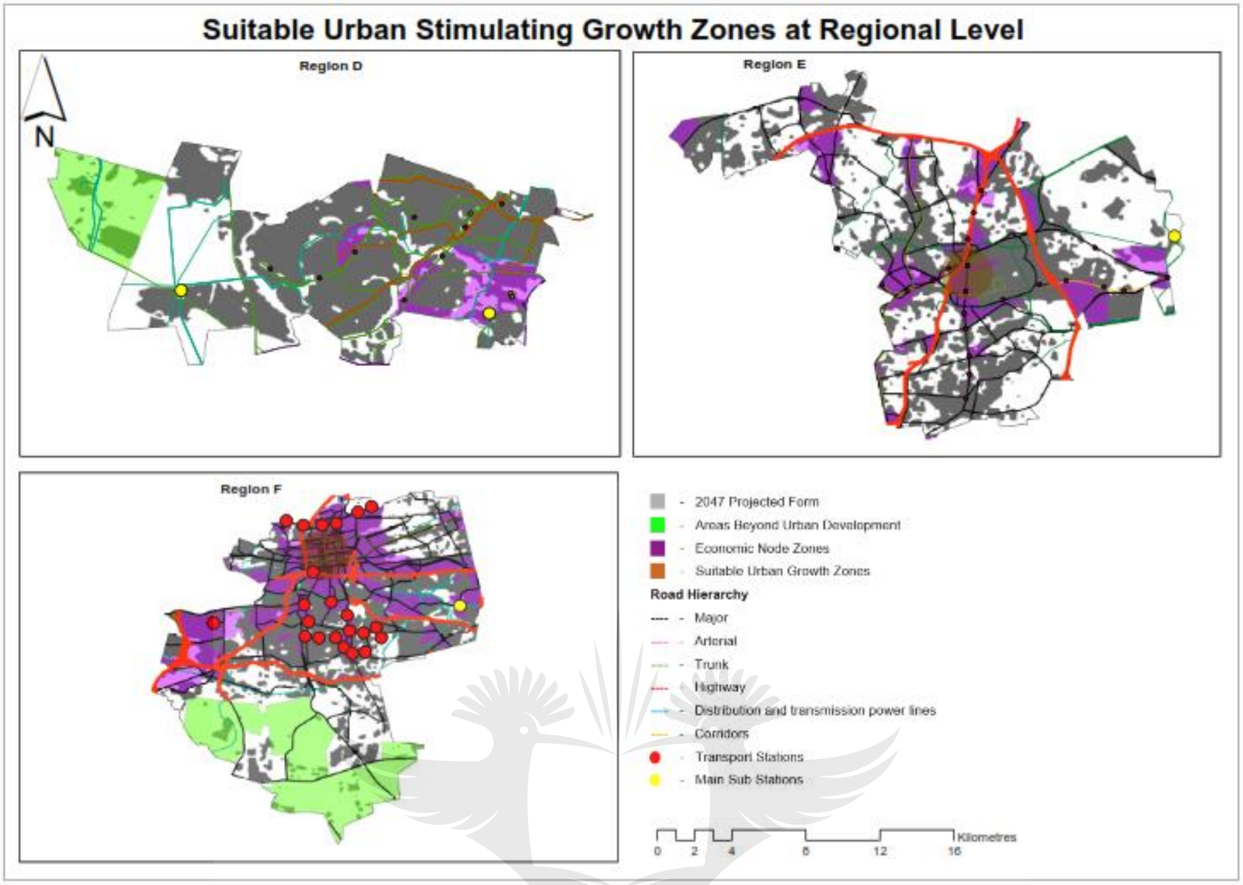
Figure 54: Suitable growth assessment in relation to factors



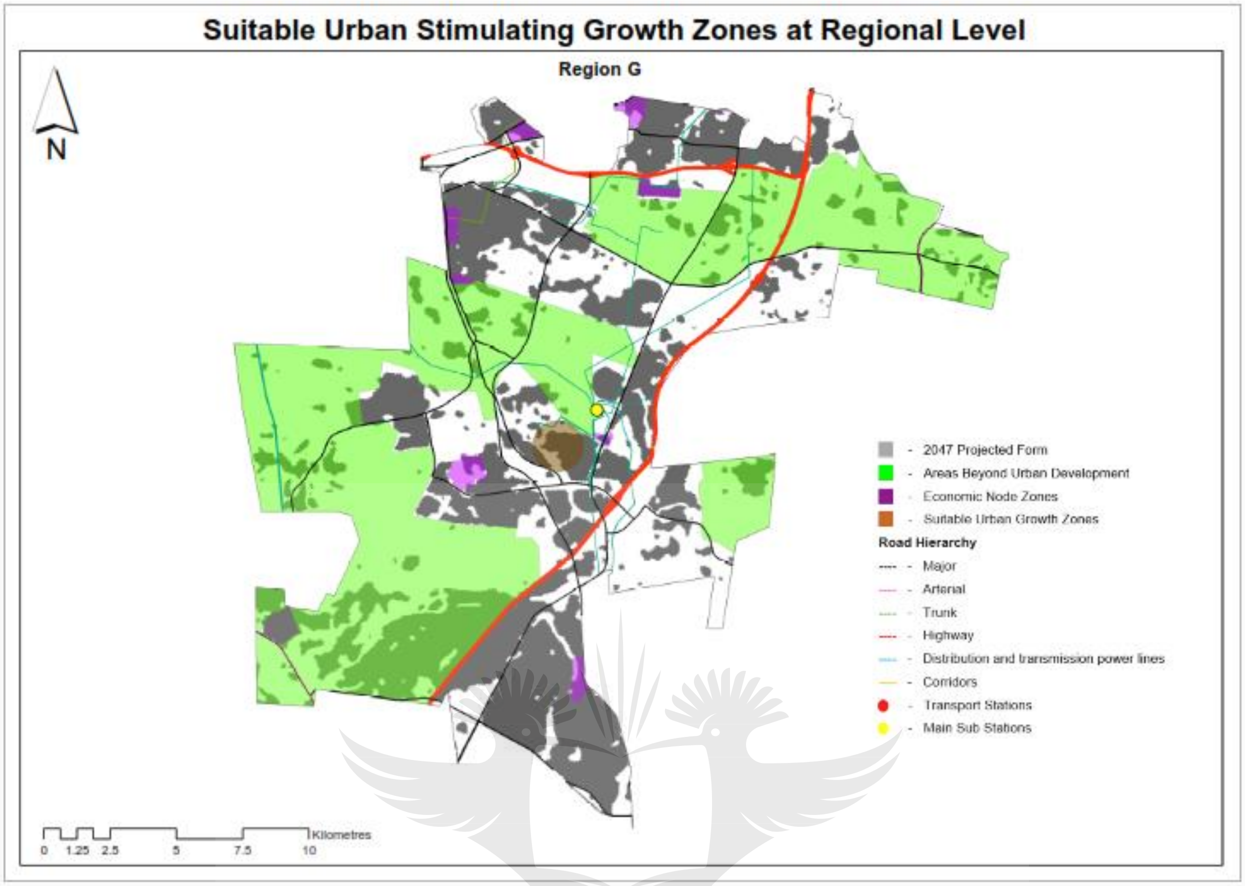
The rationale indicates that the projected growth reflects the principles of the desired growth of the City i.e. polycentric vision city development (SDF, 2018:19). The suitability thus indicates a shift to a well-organized and holistic urban logic of polycentricity with a strong focus on power infrastructure capacity that is well-supported by strategic economic nodes and increased residential densities within the inner city to emphasize in-fill initiatives. Further details can be observed at a regional level:

Figure: Suitable growth assessment at a regional level





Suitable Urban Stimulating Growth Zones at Regional Level
Region D
Region E
Region F
N
2047 Projected Form
Areas Beyond Urban Development
Economic Node Zones
Suitable Urban Growth Zones
Road Hierarchy
Major
Arterial
Trunk
Highway
Distribution and transmission power lines
Corridors
Transport Stations
Main Sub Stations
0
2
4
8
12
16
Kilometres



The suitable zones from where growth will be most stimulated are areas that are well surrounded by transportation routes and substations of various intensities connected by a heavy presence of transmission and distribution lines that may provide an environment for additional energy stations to cater for increased development.

The desirability of suitable growth in the northern regions is also indicated by a trend of growing interest from developers as most development establishment applications are headed that way as per the SDF (2018:64). This is contrary to lower Regions such as G and some southern parts of F where there is a lack of socioeconomic opportunities, and most importantly, energy to power up any potential development that might occur.

This serves as an issue for the city as development is headed one way and may cater for issues such as increased migrations within the city center along with the northern regions. This means more demand on the power infrastructure in the future and as such, it is of importance that the lower regions are capacitated with power to attract developments as the energy poverty in the future will be prevalent.

4.7.2. Summary chapter of the findings of the discussion

This sub-chapter synoptically presents the major findings found within the preceding section. The findings are in point form and are as follows:

Reviewing smart power utility infrastructure development at a city level

- CoJ is comparatively advancing its efforts in the persuasion of smart energy applications. It is ranked 35th in relation to other African countries (i.e. Cairo: 37th; Lagos: 40) as per the ratings by the Ericsson Networked Society City Index (2016).
- The setback within the majority of the energy Acts revolves around the lack of emphasis regarding the typology of energy sources that require the most attention and need for further scholarly research and development.
- There is a lack of energy by-laws at a city level.
- There exists a lack of institutional support to catalyze development of sectorial plans interlinked with the energy sector at a local level.
- Legislation covers broad issues – particularly attributable to being set at a national level – intrinsically neglecting local conditions.
- The White paper on Renewable Energy is by far, the most comprehensive legislation that touches upon the aspects of smart energy utilities.
- Challenges pertaining to how municipalities should implement smart energy initiatives are unclear. To an extent, the municipal roles in the implantation of energy efficient utilities are not specific due to the lack of specialized coordination between the tiers of government.
- Complex issues relative to the energy Acts boil down to the neglect in the procurement abilities of the municipalities pertaining to the acquisition of smart utility technology.
- City Power had set a target of installing 12 000 Smart Grids for 2017/2018 financial year (City Power Annual Report, 2018). Of this target, 6226 meters were installed – indicating a poor average progress of 51.88% for the year.

- Significant efforts can be observed throughout the city regarding the adoption an installation of smart energy utilities.

Assessment of the relationship between energy and land use and form

- The less-dense an urban setting is, the higher the demand of energy needed for heating.
- The decreased energy output in Region F can be as a result of dilapidated buildings that have been exposed to a lack of renovations that seek to adhere to established building energy standards.
- Low-density settlements such as Waterfall City are usually characterized by renewable energy sources (Solar) as compared to large-scale (coal) urban centers.
- Middle, frequently low-income households are prone to allocating lesser fiscal investments for food and other necessities in relation to the money allocated for purchasing power to process the food and other interrelated household aspects.
- The utilization of power highly depends on the average price and availability of different urban energy systems i.e. electricity.
- Higher levels of electricity consumption are most likely to occur in urban areas where commercial energy, household income, power accessibility and associated infrastructure positively correlate with each other.
- Lower density areas harness greater potential for renewable energy systems to thrive as compared to high-density urban centers.
- Commercial sites have been noted to have higher power consumption when compared to the residential land-use.
- The highest average residential density relationship to urban spatial energy is experienced in Region D.

- The most common residential energy demands are experienced in Region B and F, with some of the areas like Region A averaging a slight demand with influence from the adjacent regions.
- Densely populated informal settlements on the south experience massive energy poverty.
- Region A serves as the only locale with the most residents that are without income however, receiving a fair amount of coverage.
- The majority of the those employed in the city are within the north while the opposite can be observed in Region G while Region D faces the least employment. The relationship established is that the higher the employment rate, the better the access and coverage of power attained.
- The highest energy demand from commercial sites based on the NTL is experienced within Region F – which is composed of old residential buildings, offices in Braamfontein, department stores, hotels, etc.
- Region C is most likely the preferably destination for industrial development as the Region is well lit – however, faces little connectivity in terms of electrical transmission lines which call for light industrial developments in the Region.

Energy spatio-temporal analysis (2000-2017)

- The majority of urban growth from the year 2000 was central and spread out in the northern regions as compared to the southern ones where Region G performed the worst in terms of power presence.
- Low-density settlements where per capita energy consumption and production is high has significantly increased at a rate equal to sprawling developments. This phenomenon portrays low-dense urban forms as major contributors to the utilization of energy.
- Agricultural harbors with Region G and E account for why little growth activity is observed throughout the years.

- Growth predominantly occurred in Region A as the preferred destination compared to lower regions where a form of decline is being experienced.
- The central growth's energy intensity has decreased while the northern outskirts have increased significantly over time.
- The adoption of sustainable energy principles like the utilization of solar can be accountable for the reduction in energy visualization. This implies that power-intensive commercial and industrial sites have gone off the grid and thus adopted cleaner energy sources given their already-contributing carbon emissions from manufacturing and processing activities.
- Urban growth is taking a trend towards the north of the city while southern regions experience a form of a slow development with gradual access to power.
- Region A portrays potential to further develop rapidly and experience growth at a rate twice of Region G due to the regional characteristics and preferences to socioeconomic opportunities like power supply and decent connectivity.

Modelled future growth development

- A critical factor to fuse within spatial energy models involves power utilities as agents of flow of various resources within and between cities.
- The majority of the anticipated future growth is expected to be towards the upper regions while central ones indicate an aspect of increased density.
- Central regions, along with the increased density, is accompanied by an increase in vegetation density.
- The projected growth is likely to be transport-driven – with corridors serving as vessels that connect the underprivileged sections of the city to other parts of it.
- Future growth is best satisfactory when proximity to the existing road networks is viable.

- Preference of suitability is also given to areas that are nearby economic nodes as growth is likely to centralize around areas earmarked for socioeconomic opportunities. Those areas are predominantly in Region E, F, and A.
- The rationale indicates that the projected growth reflects the principles of the desired growth of the City i.e. polycentric vision city development.
- The suitable growth points are also well surrounded by transportation routes and substations of various intensities connected by a heavy presence of transmission and distribution lines that may provide an environment for additional energy stations to cater for increased development.
- The desirability of suitable growth in the northern regions is also indicated by a trend of growing interest from developers as most development establishment applications are headed that way as per the SDF.
- Regions such as G and some southern parts of F experience minimal growth desirability as the majority of land within those regions are earmarked as locales beyond urban development. As such, the majority of growth intensifies centrally and expands further to the north.

Chapter 5

5.1. Conclusions and recommendations

Introduction

This section provides an overview and summary of the dissertation and is then followed by recommendations. In doing so, a review of the main methodology adopted will be discussed along with their implication for the study. The findings will be outlined and discussed and thereafter followed by the suggested recommendations.

Main summary

This dissertation aimed at understanding the spatial dynamics within the city by looking at the efforts of the local authority in investing in smart energy initiatives both from a legislative and practical perspective. An extension of this study related at understanding the synergy between land use, form, and spatial energy and subsequently sought to derive a spatio-temporal energy analysis to substantiate the above goal. The last section, which was the main goal of this paper, presented an urban growth projection for the year 2047 to see how the city might develop if growth is taken into consideration with the existing electrical infrastructure.

In accomplishing the above, a brief review of legislative literature, scholarly articles, and observational analysis was undertaken to understand the relationship between land use, form, and spatial energy as well as the smart energy initiatives within the city. The spatio-temporal analysis was undertaken through nighttime light data along the classified growth of the city for the year 2000, 2008, and 2017. With regards to the suitability analysis, a projected future growth was first done using IDRISI - subsequently the future growth was then subject to a criterion within ArcMap to have the output of the desired sites with best access to energy facilities.

The output results of this research can be categorized according to the objectives:

Reviewing smart utility infrastructure development at a city level:

In reviewing the smart utility efforts within the city, the findings indicate that the city is performing well, however, other regions (Region A and F) are doing much better than others (Region G). The level of the initiatives cut across different sectors such as security and surveillance, traffic, housing, transportation, and lighting in general. Apart from a wide sectorial application of smart energy, the legislative coverage was observed to be broad and lacked locational attributes as the city does not have any by-laws specific to smart energy application and development. Most of the legislation is national and does not provide much information pertaining to smart and renewable energy.

Determining the relationship between urban land use, form, and energy:

In assessing the relationship between land use, form, and energy – the residential sector proved to have one of the highest demands and density as compared to the other land uses (Commercial and Industrial) under study. Better power coverage is experienced in the northern regions where the majority of new cities and suburbs are forming. The industrial and commercial sector were primarily located along the mining belt with more demand being experienced in Region F. This demand indicated a poor relationship between the two with power as the coverage being poor and pointed out to the Region being under-capacitated.

Assessing the city's past-current urban growth in relation to energy:

The assessment of the city's urban growth in relation to the spatial energy indicated interesting visualizations for the years under consideration. Urban development along the years indicated a strong growth trend towards the northern parts of the city, particularly in region A as compared to Region G – which is experiencing the lowest growth in the past 17 years. The upper regions portray efficient coverage that is well-balanced along the years. The central regions indicate a moderate supply and coverage of power as compared to the eastern and southern sections of the city.

Extrapolating an urban development suitability model based on the power utility for CoJ 30 years from the year 2017:

The suitability analysis conducted for the city was based on the projected growth layer of 2047 along with other facilities fundamental to growth. Development was mostly experienced in the northern regions as the upper region's level of development is advanced considering the criterion applied. In other sections, the household income affordability index also indicated that the majority of the middle-high income earners are located in the north. This could be attributed to most of the developments being able to cover costs associated with township establishments. Furthermore, Region G showed the least suitability due to low coverage being experienced. This detachment slows down the region's potential to expand.

5.2. Recommendations

Recommendations proposed will also be categorically discussed according to the objectives as shown below:

Smart utility infrastructure development:

- Additional investments need to be made in the ever-busy transportation sector i.e. more solar-powered traffic lights in the inner city;
- City by-laws on renewable energy sources' development and application need to be enacted to regulate the market and foster smart energy initiatives; and
- The initiative of electric vehicles would require significant infrastructure and would most likely take place in peripheral regions where sites to advance them are readily available for development.

Urban land use, form, and energy:

- Densified settlements utilize a vast amount of energy to address daily needs. To address this, a mixture of energy sources can prove to be beneficial more especially to regions that cannot afford electrical infrastructure expansions;
- Settlements located outside the central regions are often incapacitated and lack efficient coverage. The recommended action would relate to the encouragement of infill development applications as expansion and maintenance is costly; and
- Future expansions should postulate upon smart energy management systems such as smart grids, electricity cogeneration, and application of renewable energy sources for small-scale urban land uses like single-dwelling residential units.

Future growth in relation to power infrastructure

- The forecasted growth in the upper regions will require innovative ways of dealing with the energy demand. As such, the synergy of renewable energy into the existing grid will be crucial;
- Central regions require additional capacitation. This calls for more initiatives such as the installation of solar geysers and roofing to address the misbalanced power supply;
- Southern regions should be subjected to increased local economic development initiatives to foster investor attraction and growth; and
- Investment in electrical infrastructure in lagging areas should be key – with the municipality being empowered to foster integrated energy plans with adequate funding.

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