Does location matter?

A quantitative study on impact of housing development location on carbon emissions in Johannesburg, South Africa.

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GREEN BUILDING COUNCIL SOUTH AFRICA
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Foreword

The urban housing funding gap in Africa continues to widen as the twin tides of population growth and rapid urbanisation outstrip the available capital allocated to meet this fundamental human need. The rapid proliferation of extreme weather and climate change events has brought the need to stop harmful climate practices to the fore.

We are faced with a unique opportunity to proverbially *"hit two birds with one stone"* by rolling out high-density urban core housing stock designed to generate significant and strategic climate outcomes.

This paper investigates the carbon emission outcomes of locating housing developments in the urban core versus the urban periphery. The costs and benefits of both approaches are assessed using globally benchmarked methodologies to develop a credible addition for stakeholders in the African urban housing development ecosystem.

The research outcomes and recommendations are not meant to be an end in themselves but to kickstart evidence-based, best practice discussions amongst urban housing development institutional investors, developers, sustainability practitioners, media and governments.

Divercity: CEO

GBCSA: CEO

Executive summary

Johannesburg will obtain megacity status – home to more than 10 million people – as soon as 2030. Housing is the single typology that will continually and abundantly be required in cities as they rapidly urbanise.

Across the globe, cities account for most of our carbon emissions and energy use. While cities cover 3% of the earth's land surface, they create more than 70% of all carbon emissions, mainly from buildings, energy and transport. They also consume 78% of the world's primary energy. Currently, 54% of all people live in cities – a percentage that is projected to rise to 68% by 2050. As the population grows, so does new construction, resulting in even higher energy consumption and carbon emissions. **Net Zero Carbon Cities: An Integrated Approach, Insight Report, World Economic Forum. January 2021.**

THE CHALLENGE

To lower carbon emissions from cities as they continue to grow. To this end, we investigated how the location of housing within urban areas relates to carbon emissions. We looked at the emissions not only from construction of developments (in the inner city compared with the urban periphery) but also at emissions related to lifestyle, over the time that this building would be inhabited.

The social, economic and spatial benefits of densification within urban landscapes are well known among city planners, urbanists and built environment professionals. Providing housing in locations that are connected to existing infrastructure such as healthcare, schools, jobs and parks serves to reinforce accessible and equitable cities and strives to break the destructive pattern of South Africa's apartheid infrastructure and planning.

But what is the actual cost to the environment of developing housing in connected urban landscapes when compared to providing housing in the urban periphery. The research group set out to do a full life cycle analysis with the addition of a lifestyle impact assessment to get a quantitative comparison on the carbon emissions associated with developing and occupying housing units in these two locations.

HOW WE DID THIS STUDY

The quantitative study set up comparative housing units in two opposing locations: the connected urban core and the car-orientated urban periphery. A full life cycle analysis was conducted on the construction and occupation of the units. This was overlaid with a lifestyle emissions study. The results give insight into the carbon emissions associated with developing and occupying housing in each location.

THE FINDINGS: WHATS INTERESTING?

The study findings show that where you live, work and play locks you into a carbon pattern. When this pattern is compounded by the amount of housing that will need to be provided and the typical building lifespan of 60 years, the cumulative impact on carbon emssions of location choice is significantly greater when developments contribute to car-orientated urban sprawl.

These findings are consistent with other international urban housing development location studies, such as the "20-minute neighbourhood" adopted in Paris and Melbourne where mixed use developments enable people of all means to live close to jobs, essential services and recreation. Street redesigns and infrastructure investments that prioritise mobility alternatives will disproportionately affect lower-income communities that tend to be transit-dependent.

The quantitative study findings show that urban housing developments in the urban core (near amenities and economic opportunity) versus the urban periphery led to a considerable cumulative reduction of 224MtCO2e in carbon emissions over the building lifecycle when multiplied by the housing backlog and conservatively estimated housing demand to 2050. **The reduction translates into a potential saving of 10 times the annual total emissions of Johannesburg in 2016, a monetary equivalent of R50 billion.**

- Urban core units were found to be typically 20% smaller than their peripheral counterparts. The smaller unit sizes allow for higher unit densification per land area occupied, lower service provision cost and potentially improved investment return profiles.
- 72% of the total building lifecycle emissions occurred during the building's operational phase and can be mitigated through proactive design and technology implementation.

Embodied carbon is big, but operational carbon is bigger in South Africa: Through the full life cycle analysis, the study highlights that the carbon associated with the actual construction of the units, embodied carbon (carbon associated with material choices) makes up the most significant portion, but when carbon related to operational energy use with in the units is overlaid, the relative proportion of embodied carbon is diminished to only 12-13%.

This highlights the importance of decarbonising the electricity grid and embracing renewable energy sources. However, due to the lifespan of buildings (assumed 60 years), the decisions we take now about material selection will have a long term impact, so it is important to raise this awareness among those responsible for the specification of materials.

HOW MUCH YOU TRAVEL MATTERS

Proximity of urban core building residents to essential amenities and economic opportunities significantly lowers the carbon emissions of a medium-income household below the emissions of a low-income household located in the urban periphery. Medium-income families are typically responsible for approximately three times the volume of emissions of lower-income families.

Spatial planning and associated transport network provision must encourage densification and access to economic opportunities and reduce reliance on private car travel and travel distances.

THE OPPORTUNITY

The following stakeholder groups influence critical spatial housing planning decisions necessary to realise the positive outcomes outlined above at scale:

- **Urban economists:** Advocate for holistic systems thinking, including externalised costs in urban development models (such as carbon emissions, air pollution, or lost time commuting) to assess total system cost implications when making housing infrastructure investment decisions.
- **Town planners:** Maximise low carbon spatial connectivity of new developments to improve equity and access to economic opportunities.
- **Public sector decision-makers:** Create the policy space to align development with climate goals through urban core housing incentives, regulations, and standards. The higher density of urban core housing development quickens housing provision goals to meet the demands of rapid urbanisation, inward migration and population growth.
- **Infrastructure investors and lenders:** Internalise the carbon emission performance of portfolios to ensure that they fully account for the total investment yield over its entire lifecycle.
- **Built environment professionals:** Develop and champion low carbon design, construction and operation of urban spaces and ensure whole life emissions are quantified and managed at all stages of design, construction, occupation and end of life.
- **Developers:** Maximise reductions in embodied, operational and end of life carbon emissions. The significant weighting of LCA emissions at the building operation stage presents low hanging fruit, potentially increasing the asset yield profile, meeting sustainable investor criteria and complying with growing environmental regulations.

THE TIME TO ACT IS NOW

This study confirms urban housing location in the urban core is an immediately feasible way of delivering large scale city-wide carbon emission reductions.

Collaboration is now required across all urban housing value chain stakeholders to actively incorporate the study findings in their daily decision-making to reduce the 80% of global carbon emissions in cities.

But what is the actual cost to the environment of developing housing in connected urban landscapes when compared to providing housing that is not well connected to amenities? The research group set out to answer this question with a full carbon life cycle analysis. This included a lifestyle impact assessment to get a quantitative comparison on the carbon emissions associated with developing and occupying housing located in different urban forms.

HOW WE DID THIS STUDY

The quantitative study set up comparative housing units in two opposing locations: a well-connected urban core and a the car-orientated urban periphery.

A full life cycle analysis was conducted on the construction and occupation of the units. This was overlaid with a lifestyle emissions study. The results give insight into the carbon emissions associated with developing and occupying housing in each location.

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Introduction

A quantitative study on impact of housing development location on carbon emissions in Johannesburg, South Africa .

CITIES ARE GROWING, AND LIE AT A CRITICAL NEXUS

By 2050, two thirds of the world's population are projected to live in urban areas. At the same time the physical extent, or footprint, of urban areas is growing at a faster rate than their populations. **The way in which cities develop in the future will have a significant impact on global efforts to mitigate and adapt to future climate change.** Cities (and the local governments that lead them), especially fast-growing ones in the developing world, lie at a critical nexus for driving climate action through planning strategies that foster more sustainable outcomes.

Urban planners and designers have long appreciated the negative impacts of sprawl on cities and their inhabitants. However, they have mainly focused on the qualitative impacts in relation to reduced mobility, inadequate services and poorer quality of life that are experienced in peripheral locations. In addition, environmentalists and ecologists have documented the vast losses that urbanization has accrued in terms of its negative impacts on ecological diversity and natural systems.

We must pay special attention to the broader impacts of urban planning decisions on carbon emissions, from the whole life cycle of the dwelling itself, to the consumption-related emissions of residents. The growing field of carbon calculation and assessment provides, a quantifiable pathway to reinforce our understanding of the impacts of sprawl in cities. Thus, this study employs the rigorous methodologies of carbon assessment applying them to both buildings and occupants in an attempt to develop a comprehensive picture of how we build and how we live in divergent locations of the city and how this ultimately affects our carbon footprints.

THE CONTEXT OF NATIONAL CLIMATE GOALS

The updated draft Nationally Determined Contribution under the Paris Agreement was launched for public comment in March 2021. It focuses on decarbonising the electricity sector in the 2020s, followed by a deeper transition away from fossil-based transport in the 2030s, whilst it envisaged the 2040s and beyond to be focused on hard to abate sectors.

LOCAL CLIMATE ACTION PLANS

In addition, Johannesburg has recently adopted a Climate Action Plan, with the aim of peaking emissions no later than 2030 and declining towards net zero by 2050. Stationary energy and transportation accounted for most city emissions in 2016. This highlights the importance of the future development of the built environment in achieving Johannesburg's climate goals.

WIDER DEVELOPMENT CONSIDERATIONS

Concurrently, the Department of Human Settlements recognises the need to improve housing provision as part of wider sustainable development objectives and their need to deliver to section 26 of the South African constitution. **Their vision for human settlements details that by 2030, a more functional and equitable property market is developed, with measurable progress in breaking apartheid spatial patterns and significant progress made in retrofitting existing settlements. By 2050, they envision that there will be visible results from an effectively coordinated planning system that transforms human settlements into equitable and efficient spaces, with proximity to places of work and social spaces and access to necessary infrastructure.**

JOHANNESBURG IS A PRIME EXAMPLE

Johannesburg has grown extensively in the past 30 years, more than tripling its physical footprint, and is expected to become a 'megacity' by 2030. The implications of this projected growth need careful consideration, to ensure that development decisions made now meet the needs of current and future generations of urban dwellers, whilst aligning to South Africa's and Johannesburg's' commitments under the Paris Agreement.

Johannesburg city centre

OUR RESEARCH BRIEF

- Quantitatively evaluate the whole lifecycle carbon emissions (embodied, operational and end of life carbon) associated with development within different locations in an urban area, and
- Explore and determine whether the carbon emission impacts of residential occupants are affected by the urban form within Johannesburg, focusing on the concept of 'lock in' to certain transport modes as a result of spatial configurations.

Our study context

There are 2 national policies we considered key to this study. These are the South Africa Nationally Determined Contribution (NDC) and the Department of Human settlements integrated planning policy.

At a local level the City of Johannesburg Climate action plan, and the Spatial Development framework 2040, were important in our understanding of the context. Key insights from these documents and other sources are explored below.

NATIONAL LEVEL, SOUTH AFRICA: A DEVELOPING ECONOMY WITH CLIMATE MITIGATION AMBITIONS

SOUTH AFRICAN NDCS

South Africa submitted an updated draft Nationally Determined Contribution (NDC) for public comment in March 2021. It raises South Africa's ambition in climate action by setting an absolute emissions cap of 510 Mt CO_2e, for 2025 and 440 Mt CO_2e by 2030, with aspirations for emissions to be closer to the lower cap of 398 Mt CO_2e in both years. This represents a reduction of the upper end of the target range of 17% in 2025 and 28% in 2030, compared to South Africa's first NDC. **South Africa recognises that meeting these targets requires the implementation of a range of policy measures as set out in the Integrated Resource Plan, the Green Transport Strategy, and the recently adopted carbon tax.**

South Africa recognises that their NDC needs to be implemented in the context of several development challenges, many of which have been exacerbated by Covid-19, and their current point of departure. SA's economy is almost a third more carbon intensive than the global average and much higher than other developing countries. Further, South Africa's total GHG emissions grew by 44% between 1990 and 2012, exceeding the global average of 13.6% growth.

South Africa has also built out its infrastructure provision significantly in these decades of emissions growth. Since 1994, South Africa has embarked on the largest public housing provision initiative in the developing world. Official government sources cite 4.3 million units as the 2018 figure for houses built through government initiatives including both fully subsidized units as well as units where access subsidies which enable medium income earners to access commercial loans were employed.
This significant number of new residential units were developed under various initiatives including the RDP (reconstruction and development program), BNG (building new ground) and the integrated human settlements policy. The integrated human settlements policies are the most recent and take a more holistic view on housing provision, placing greater emphasis on provision of shelter through settlement upgrading and the provision of basic services in addition to housing unit delivery.

The integrated human settlement policy also recognizes more strongly the role of the private sector in housing provision with many of its current mega-housing or catalytic housing projects being delivered as part of private developer partnerships, with government providing capital contributions to infrastructure as well as housing subsidies for qualifying recipients within larger and more diverse housing projects. In addition there has been a shift to providing rental housing in well located areas as opposed to the singular focus on single dwelling and individual stand developments which characterized the majority of housing delivered under the first decade on the RDP program.

Johannesburg skyline

Through the tension that is created between environmental stewardship and meeting ambitious development goals, the built environment emerges as a key sector, due to its ability to influence social and environmentally sustainable outcomes. **Residential living impacts more than just the construction sector. Urban form, and its constituent buildings have a large impact on the efficiency by which services can be delivered, total energy use, and infrastructure configurations which potentially 'lock in' high carbon behaviours.** Urban social sustainability is improved by well-designed and well-constructed urban forms. South Africa's department of human settlements recognises this. Their vision for human settlements is:

"By 2030, measurable progress shall have been made towards breaking apartheid spatial patterns, with significant progress towards retrofitting existing settlements offering the majority of South Africans access to adequate housing, affordable services in better living environments, within a more equitable and functional residential property market, and by 2050, visible results from effectively coordinated spatial planning systems shall have transformed human settlements in South Africa into equitable and efficient spaces with citizens living in close proximity to work and access to social facilities and necessary infrastructure."

LOCAL LEVEL, JOHANNESBURG: A GROWING CITY WITH AMBITIOUS CLIMATE ACTION GOALS

As part of the process of building up it's climate action plan, Johannesburg conducted a baseline assessment of the city's carbon footprint, through the methods and models informed by best practice under the C40 cities coalition.

The assessment measured emissions from direct combustion of fuels within the city boundaries and emissions from the consumption of grid supplied electricity, heating, and cooling.

The consumption of energy from residential buildings, and the manufacturing and construction sector both emerged as key components of the city's emissions profile, driven largely by the high emissions associated with South Africa's coal-based electricity generation. However, the transportation sector emerged as the single highest contributor to the cities carbon emissions at the time of the assessment, with on road transportation accounting for just under seven million metric tonnes of CO_2e. This was one third of all emissions measured within the study boundary.

This greenhouse gas baseline inventory, shown in figure 1, formed the evidence base for the city's climate action plan.

Recognizing the key roles of residential buildings and the transport sector, the climate action plan included specific provisions for goals related to green transport and optimised energy efficiency in buildings. Within a decade, the city envisions 70% of commuters will use public transport, walk, or cycle, and all new buildings will operate at net zero emissions. Targets for 2050 in these sectors are even more ambitious, with the city targeting 90% of commuters using public transport, walking, or cycling, and all buildings operating at net zero emissions.

RESIDENTIAL HOUSING PROVISION IN JOHANNESBURG, AND HOW THAT WILL NEED TO INCREASE IN THE FUTURE. INFORMED BY THE SPATIAL DEVELOPMENT PLAN 2040

Concurrently, Johannesburg's population and spatial footprint is growing. Between 2000 and 2016 the number of buildings within the city boundary increased by over 60% (GCRO, 2018), and the population increased from 3.2 million to over 4.4 million inhabitants between the two census years of 2001 and 2011 (Statistics South Africa). Whilst not all residential growth increased the urban footprint, there were significant increases in residential buildings on the urban periphery, constituting urban sprawl, driven by increases in estate and security village housing. (Ibid, 2018), see also Figure 1 and 2.

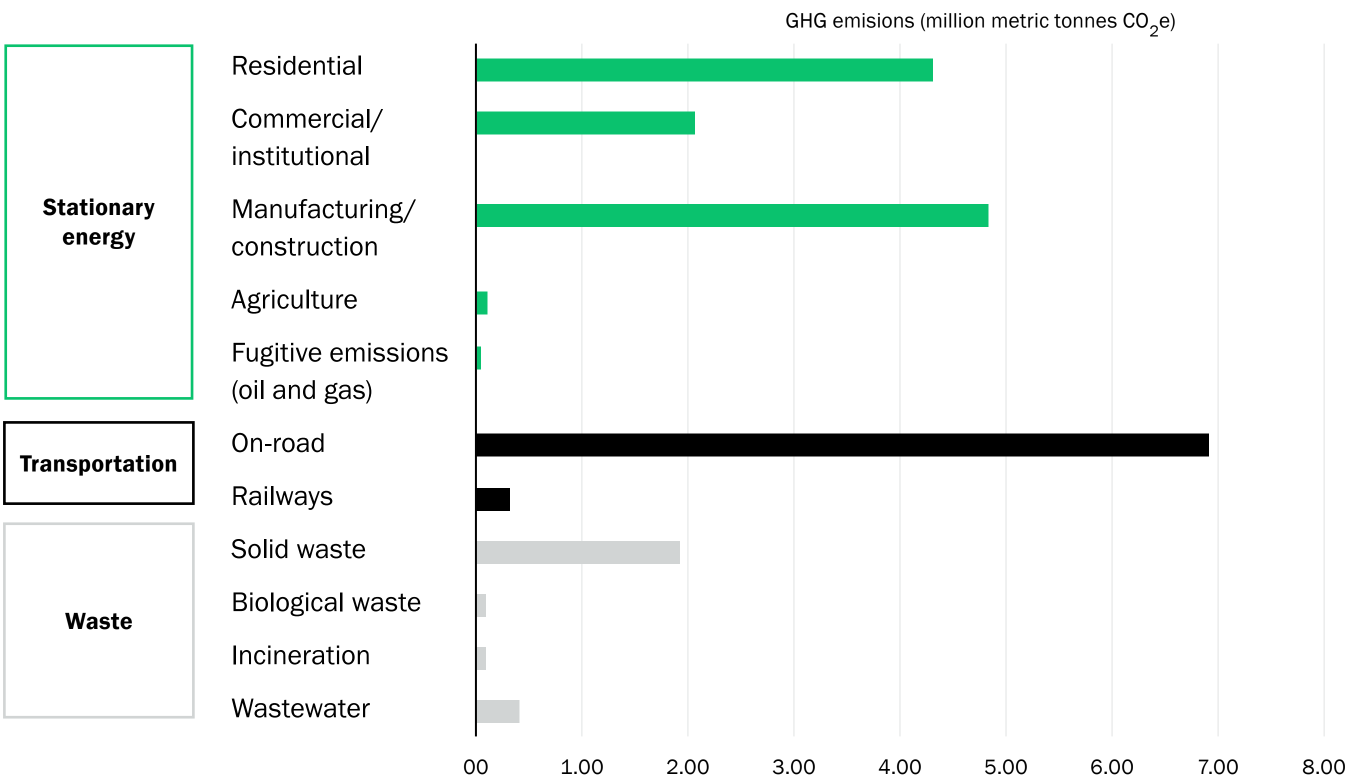


Figure 1 Johannesburg baseline GHG emissions inventory, 2016. (City of Johannesburg Climate Action Plan, 2021)

FUTURE HOUSING NEED

The pressure for increased housing provision in the city is very likely to continue in the future, with UN world urbanisation prospects projecting that the city will continue growing, albeit at a slower rate than observed in the past, and the city's consolidated infrastructure plan projecting a population of 7.6 million people by 2037. Projections to 2050 are less certain, but if we assume a constant rate of growth between 2040 and 2050 as that which is projected for 2035 to 2040 (1.34%) the population of Johannesburg could reach 8.6 million by 2050.

In addition, the city has set itself the goal to provide adequate housing for those living in currently unsuitable conditions through the continuation of the RDP. In the Gauteng region, this is estimated to be approximately 600,000 units (Msindo Psam, n.d). Translating this to Johannesburg on a population scaling basis, the backlog Johannesburg is likely over 200,000 units.

Therefore, just over 1.37 million dwellings will need to be constructed between now and 2050. This is assuming that the average people per dwelling stays constant at the level of the most recent census (2.8, Statistics South Africa), and Johannesburg's population grows by 3.3 million, from 5.4 million today to reach 8.7 million by 2050, and the ambition to address the backlog under the RDP program, by 2040 is realised. This would require just over a 10-fold increase in the yearly number of residential buildings built in Johannesburg compared to the average completed in the city over the past 10 years (Statistics South Africa, 2021)

It is within this context of growing housing need and increased climate action ambition that the city of Johannesburg implemented a new spatial development framework. R**ecognizing that the location and concentration of economic activity does not match where people live, and that housing delivery to date has arguably exacerbated historical patterns of spatial inequality, the spatial development framework seeks to address the interconnected issues of environmental pressures, urban sprawl, fragmentation, and spatial inequalities. It seeks to deliver this through a future vision of a compact, polycentric Johannesburg, with a strong urban core, efficient public transport, and dense, mixed-use sub centres, all situated within a protected urban environment. Through this vision, the SDF highlights the role that strategic spatial planning has on supporting climate action goals as well as wider sustainable development goals.**

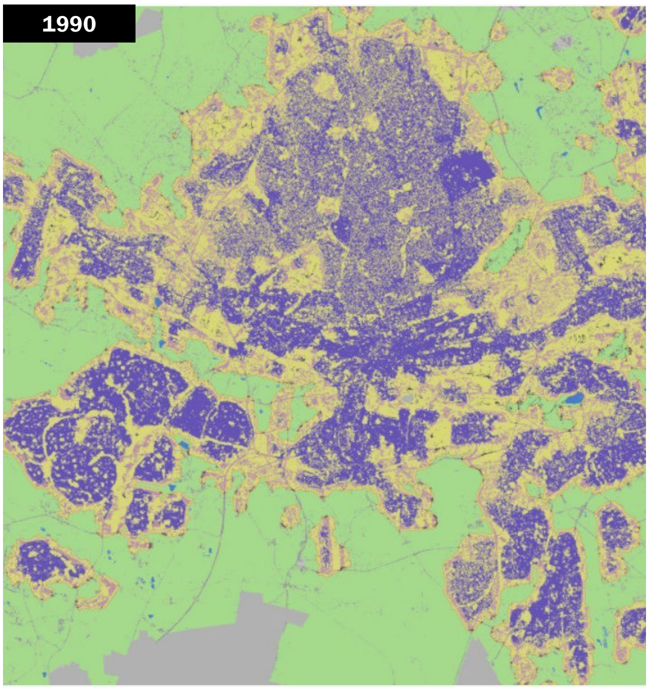


Figure 2 Johannesburg (wider metropolitan) urban footprint, 1990 (atlasofurbanexpansion.org)

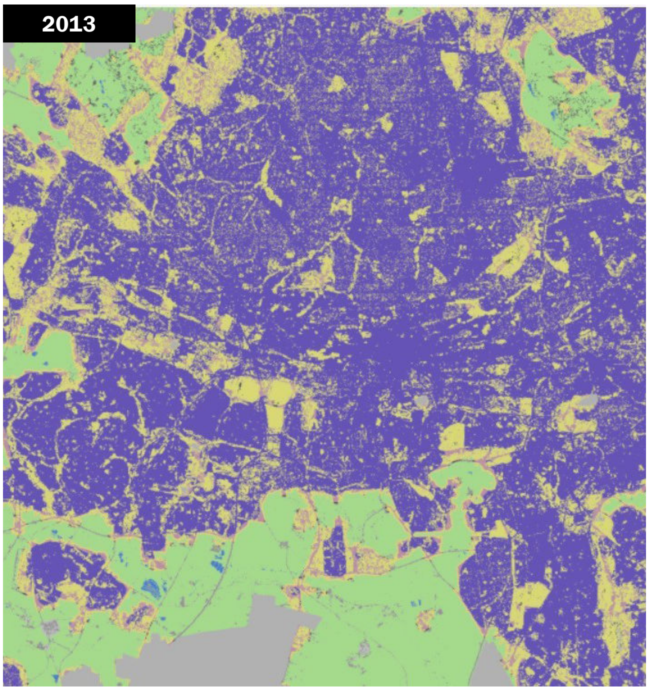


Figure3 Johannesburg (wider metropolitan) urban footprint, 2013 (atlasofurbanexpansion.org)

Our methodology

Research question, scope, analytical approach, primary assumptions, and exclusions

RESEARCH QUESTION

Does the urban form of Johannesburg affect the carbon emissions of residential occupants? An investigation of the impact of development location on carbon emissions for two different housing brackets.

THE SCOPE OF OUR WORK WAS TO:

- Quantitatively evaluate the whole lifecycle carbon emissions (embodied, operational and end of life carbon) associated with development within different locations in an urban area, and
- Explore and determine whether the carbon emission impacts of residential occupants are affected by the urban form within Johannesburg, focusing on the concept of 'lock in' to certain transport modes as a result of spatial configurations of where people live, work and spend leisure time.

ANALYTICAL APPROACH

The study is confined to the City of Johannesburg as the variability in city form and scale across South African cities is significant and defining urban core and periphery across locations would result in inconsistencies and hamper the comparison of typologies.

To fulfil the scope of our work from both components of the study, we used two analytical methods. We used an LCA method to quantify the whole lifecycle carbon emissions associated with a development. LCAs is a recognized and structured approach that is widely used globally to calculate the whole life-cycle impacts of a product taking into account all inputs and outputs related to carbon.

The emissions related to occupants were quantified through a Lifestyle assessment method using persona definition and drawing on available data sources to inform the relevant aspects of the occupant behaviour in terms of transport that would affect their carbon footprints.

The sum of these carbon impacts was then analysed and interpreted to draw out key learnings and define characteristics for building typologies across the two locations.

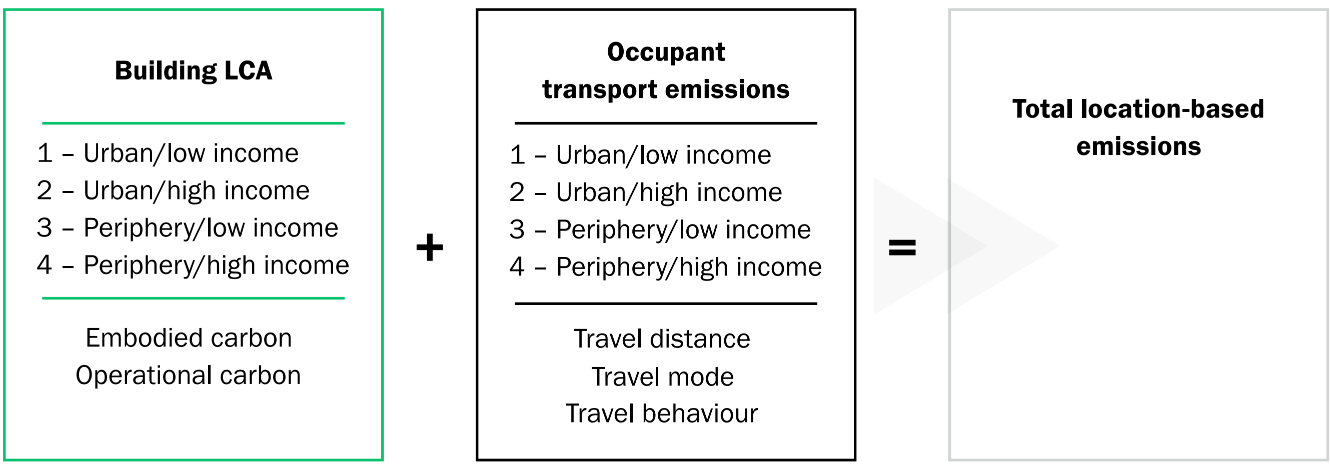
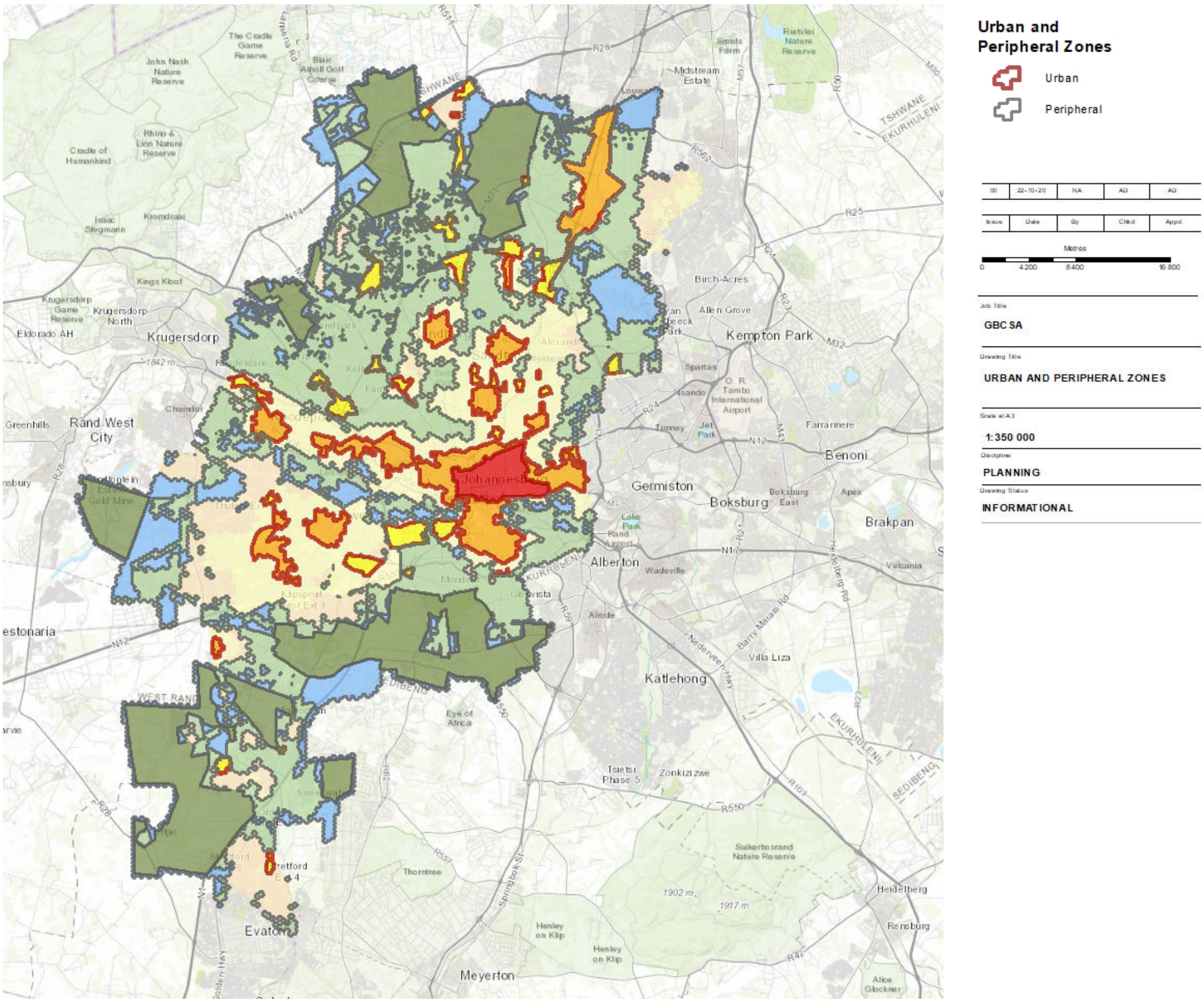


Figure 4 Assessment components



LOCATION DEFINITION

Location is the primary field for this study as it forms the basis through which carbon impacts across typologies is compared. The urban or higher density location is characterized by relative centrality, with better connectivity, increased access to the spatial economy and proximity to nodes of activity.

The focus of this study is the affordable housing sector as it is an area of the property market with a high potential impact on carbon emissions due to both its scale and forecast growth driven by an upsurge in demand.

The peripheral or lower density location is characterized by relative isolation and has poorer connectivity, lower accessibility to jobs and markets and reduced proximity to nodes of activity.

The spatial definition of urban and peripheral was derived through 2 key documents:

- **City of Johannesburg Metropolitan Spatial Development Framework (MSDF).**
- **City of Johannesburg Nodal Review policy data (NRP).**

The image above shows the two key zones defined by the MSDF, transformation zones in blue (urban) and consolidation zones in yellow(peripheral) as mentioned above which provided a starting point for the study.

The study further concentrated on the upper levels of the affordable sector as this is the area where private developers and authorities can have a degree of influence. Private developers are increasingly active in this area of the market and as other areas of traditional demand such as the high-income residential sector and commercial buildings experience development surplus impacted by Covid-19 pandemic and low economic growth, the affordable housing sector is likely to see an increase in private developer participation.

INCOME DEFINITION

Sources on income bands differ widely and for this study a number of sources were consulted including the Centre for Affordable Housing Finance (CAHF) residential property review, the Department of Human Settlements website as well as the SAPOA's (South African Property Owners Association) Inclusionary Housing Report 2018; thus defines lower income as under R12,500 and medium income as under R15,000.

Broadly these categories relate to housing prices under R600,000 per unit for low income and between R600,000 - R1,000,000 for medium income.

HOUSEHOLD SIZE DEFINITION

According to Statistics SA the average household size nationally 3.3 people per household (2019). Given that the prevalence of single people households in urban areas is greater this study has used an average household size of three people per dwelling. For the purposes of comparison, the housing unit profile was defined as two adults and one child for all unit types in both urban and peripheral locations. This assumption is used as the basis for the Occupant transport carbon footprint component of the study.

LCA PROCESS DEFINITION

Lifecycle Assessment (LCA) framework process

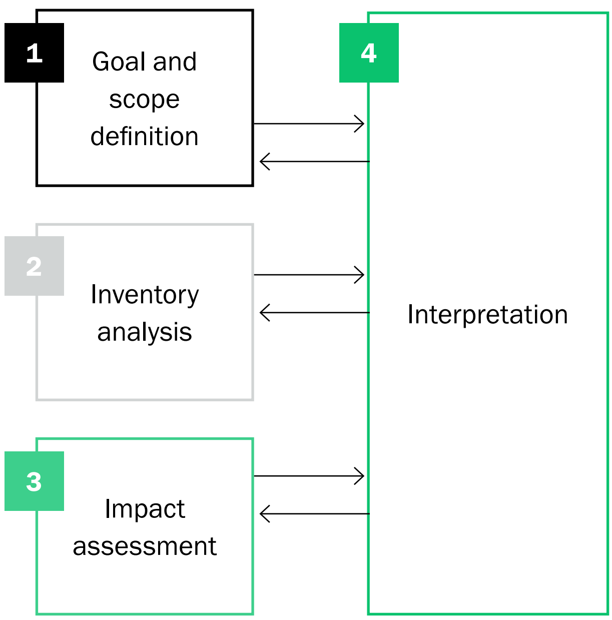


Figure 6 LCA framework (ISO 14044:2016)

The LCA process is defined by ISO14044:2016 on lifecycle assessment requirements and guidelines and ISO14040:2006 on lifecycle assessment principles & frameworks. The four main phases of the assessment are highlighted in figure 6, below. More detail on each phase is contained within the technical annex.

An LCA addresses the environmental and human health impacts throughout the life cycle of a product or process; from raw material extraction and processesing through to use, end of life treatment and final disposal (i.e. cradle-to-grave), according to ISO 14044.

A life-cycle carbon assessment narrows the focuses of the study to more narrowly on the contribution to environmental impacts associated with climate change, in terms of CO_2 equivalents quantified as volume of greenhouse gas emissions (GHGs) in terms of CO_2 equivalents, refered to within this document as "carbon emissions". Within the LCA for carbon there are a number of componentsCarbon LCA's follow four part methodology (figure 6.) and are segmented by project stage (figure 7), that are summarised in figure 6, and defined below.

EMBODIED CARBON

Embodied carbon is the total carbon emissions generated to produce a built asset. Including the emissions caused by the extraction, manufacture/processing, transportation and assembly of every product and element in an asset (A1-A5). For the purposes of our study this also includes the maintenance, replacement (B1-B5), deconstruction, disposal and end-of-life aspects (C1-C4) of the materials and systems which make up the asset.

OPERATIONAL CARBON

Operational carbon relates to the total carbon emissions generated during the usage of a built asset. These emissions arise from energy consuming activities including heating, cooling, ventilation and lighting of a building in addition to electrical appliance useage within a building (B6). It also includes operational water consumption (B7).

WHOLE LIFE CARBON

Embodied carbon

Product stage	**A1**	Raw material Supply	
	A2	Transport	
	A3	Manufacturing	Cradle to gate
Construction stage	**A4**	Transport	
	A5	Construction installation process	
In-use stage	**B1**	Use	
	B2	Maintenance	Cradle to practical completion
	B3	Repair	
	B4	Replacement	
	B5	Refurbishment	
End of life stage	**C1**	De-construction Demolition	
	C2	Transport	
	C3	Waste processing	
	C4	Disposal	Cradle to grave

Operational carbon

In-use stage	**B6**	Operational Energy Use
	B7	Operational Water Use

CIRCULAR ECONOMY

Beyond building life cycle	
Benefits & Loads	
Reuse, Recovery, Recycling	Cradle to cradle

Figure 7 The EN 15978 system boundaries, demonstrating the stages constituting a whole life carbon assessment (source: LETI Embodied Carbon Primer)

BUILDING LIFETIME AND COMPONENT DEFINITION

For the purposes of this study a 60-year lifespan was adopted. This was informed through stakeholder engagement with key actors in the built environment sector including the City of Johannesburg spatial planning department and research institutions such as the South African Cities Network and the Gauteng City Region Observatory.

The object of assessment is a single housing unit including structural elements, materials used in footings and foundations, structural wall assembly, structural floors and ceilings (not including finishes), and roof assemblies.

	LCA Stage	Element	Value	Source
		Expected Lifetime of Buildings	60 years	
A1 - A3	Product	Building materials	As detailed in building typologies section below	GBCSA, Divercity and developer data.
A4	Transport	Transport to site	Local (100 km) , regional (200 km) and imported mate- rials (from China and Australia) considered	Weighted distance based on type of materials and local/ regional/imported assumption
A5	Construction	Transport to wavste management	Average distance 70km	Empirical observation of waste management sites in Johannesburg
A5	Construction	Energy consumption	Electricity 25 kWh/m^2 + Diesel 3.5 l/m^2	OneClick LCA typical assumption.
A5	Construction	Water consumption	180 litres/m^2	Arup project experience.
A5	Construction	Waste produced	Volume: 80 kg waste /m^2 GFA	South Africa: State of Waste Report
B6	Use	Operational energy	Peripheral Low income: 217 kWh/ month - Middle income: 363 kWh/ month; Urban Low income 175 kWh/ month - Middle income: 290 kWh/ month	Metered data (Divercity) and SANS 2019
B7	Use	Operational water	242 l/household unit/ day	Metered data (Divercity)
B1 - B5	Use	Replacement / Maintenance	Roof: 2 replacements of waterproofing membrane and layers above it	Informed by engagement with buildings engineers and international standard range
C1	Deconstruction	Energy consumption + Waste produced	Energy and water: same as A5 stage	Assumed equal to A5
C2	Transport	Transport to waste management	Average distance 70 km	Mapped Johannesburg's Waste Management sites
C3 - C4	Waste	Waste management	100% building materials treated as waste; Standard waste management procedures per waste type	Engagement with GreenCape South Africa.

Figure 8 Inventory of elements, and their related project stage, included in the LCA.

LCA EXCLUSIONS

The decision to focus on new buildings is due to the significant impact of new building within the construction industry in comparison to the refurbishment and renovation of existing ones.

Finishes and interior fit outs have not been included in the LCA. This is due to the variability of selecting and sourcing such items. Additionally the study focuses on the unit only and therefore any services such as HVAC, lifts etc are excluded. Common areas in walk up or high rise buildings such as corridors and stairways are also excluded.

LIFE CYCLE INVENTORY

The LCA inventory we constructed for this study is summarised in the table below. Further detail relating to materials and processes, quantities, and selected datasets are included within the technical annex.

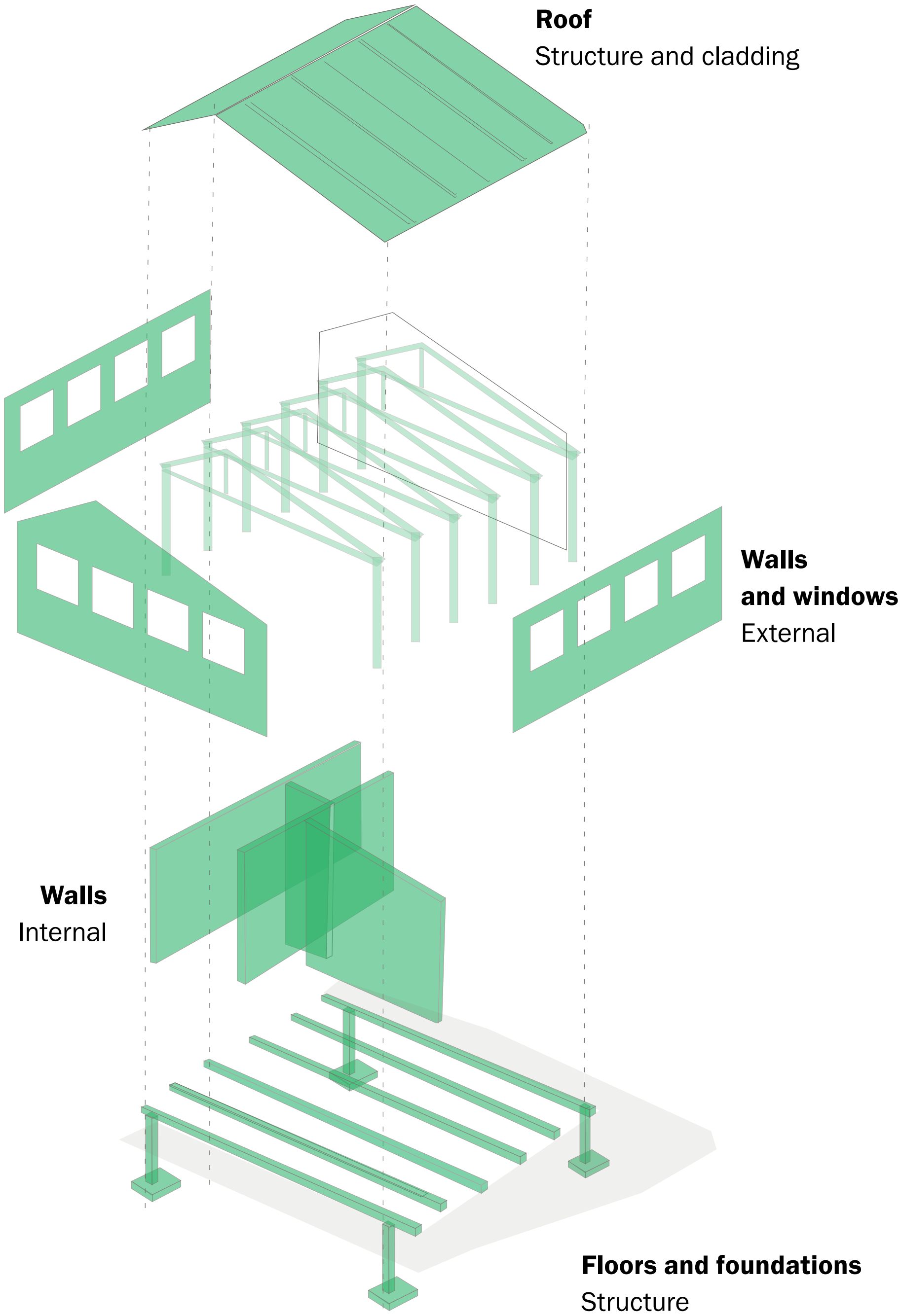


Figure 9 Building elements included within the LCA

METHODOLOGY FOR ESTIMATING TRANSPORT-RELATED EMISSIONS OF OCCUPANTS

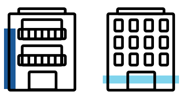
Our estimation of transport-related emissions relates to the emissions associated with occupants' transport activities in each of our building "types". These were expected to vary significantly depending on income and location.

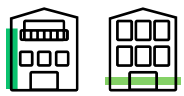
SPATIAL MAPPING AND PERSONA DEVELOPMENT

We adopted a persona approach, developing a persona for each of the family types under consideration. These personas establish an average transport pattern for each family type, with a focus on distances to work, school and leisure facilities, in addition to likely mode of transport.

For both urban and peripheral nodes a number of actual spatial maps were developed to inform each household's ability to access schools, places of work, leisure and healthcare facilities. These maps are presented in figures 11 and 12.

Building LCA	+	Occupant transport emissions	=	Total location-based emissions
1 – Urban/low income 2 – Urban/high income 3 – Periphery/low income 4 – Periphery/high income		1 – Urban/low income 2 – Urban/high income 3 – Periphery/low income 4 – Periphery/high income		
Embodied carbon Operational carbon		Travel distance Travel mode Travel behaviour		





	URBAN CORE	PERIPHERY
	Ability to access within 1km radius (10 min walking distance)	
Primary shopping	Convenience stores, supermarket, market, retail stores	Limited primary shopping: one Supermarket, Convenience retail
Recreation	Play parks, Open spaces, Gym, Library	One Play park, one larger Open space
Primary education	Primary school, College, Museums, Cultural	Primary school, High school, no Cultural facilities, one Church
Mobility	Access to Train, Bus and Taxi routes	Access to Taxi routes

Figure 10 Assumed to services for each typology

Figure 11 Typical spatial map for Urban typologies

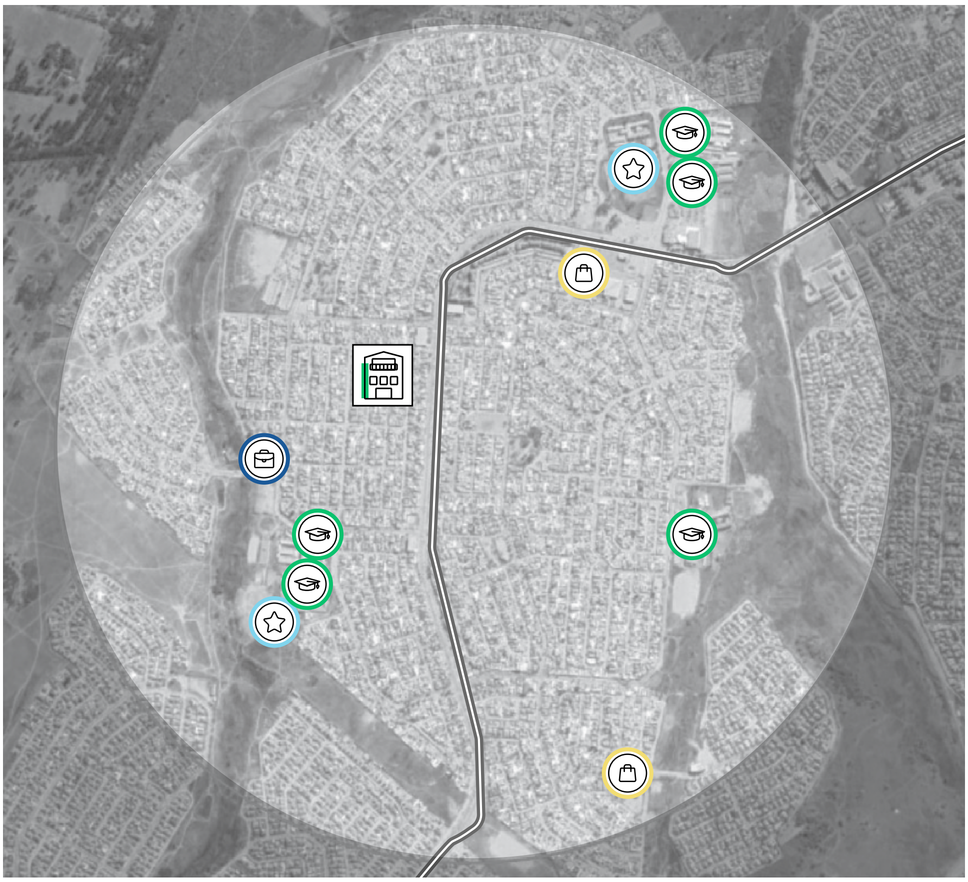


Figure 12 Typical spatial map for Periphery typologies

MEET THE KHUMALOS

Urban
Low income

"We love living in the inner city. It really is the heart of Johannesburg. Even though I work in Midrand I can access transport services through only a short walk and I feel confident that my family is safe as they walk home from school and work as the streets are always busy."
Norman K.

Jackie Khumalo
33 years old | Pre-School teacher

Norman Khumalo
36 years old | Shopfitter

Jo Khumalo
7 years old | Primary School learner and skater

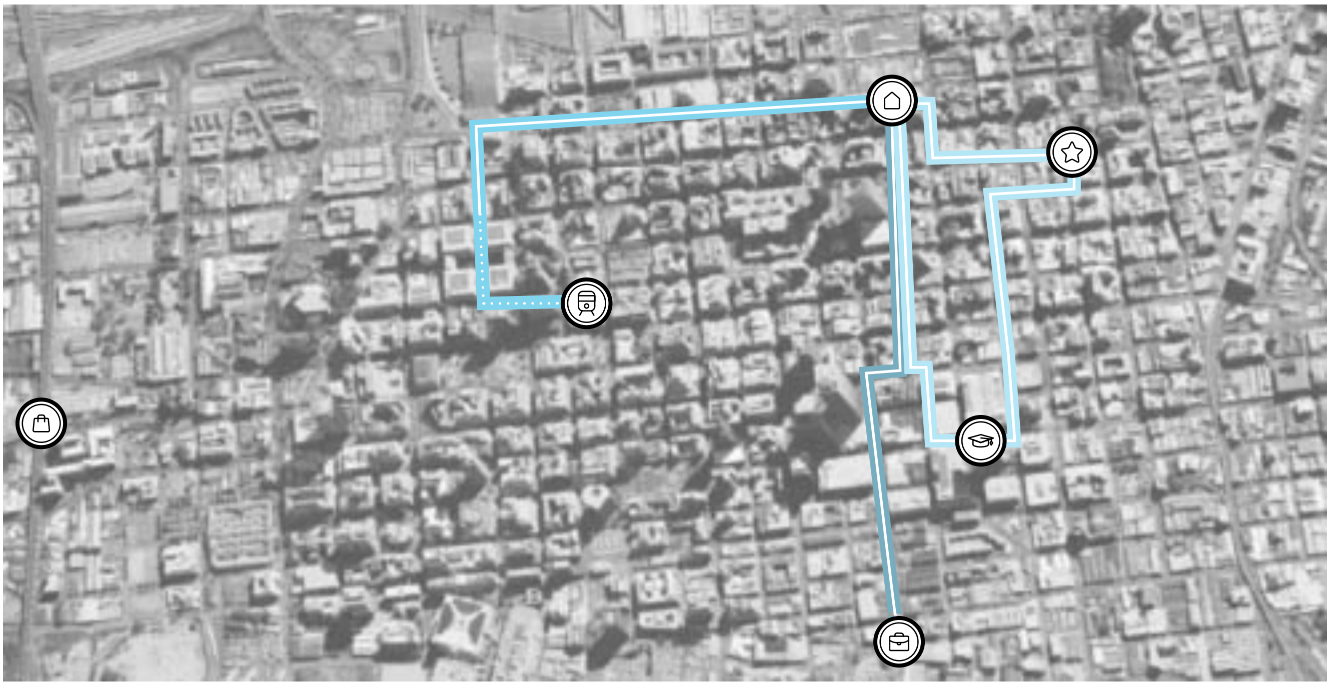
Jackie is 33, Norman is 36 and little Jo is 7. Jackie and Norman both hail from KZN and met through a friend 8 years ago. They had their first date at the Joubert Park gardens and have been city dwellers ever since.They have lived in Koch Street in the city centre for the last six years.

Jackie works as a teacher in a preschool in the city. She walks to work in the summer and takes a short ride on the BRT system in the winter. She drops Jo off at Eagle primary school on her way to work. Jo enjoys school. Now that he is older, he sometimes walks home with a group of friends. They often stop at the End street park on their way home. A new skating ramp was added to the park last year and Jo is getting a lot better at skating. He dreams of going pro and will enter the inner city junior champs next year.

Norman is a carpenter. He works for a shopfitting company in Midrand as a joiner. Once a month the Khumalos take the taxi from Park station to visit Norman's sister in Mamelodi.

The family shops every Saturday at Newtown Junction. This is Jo's favourite day as his mom always gets him an ice cream after the 20 minute walk.

Jackie's commute
Norman's commute
Jo's commute



MEET THE NTULI'S

Urban
Medium income

> *"We still want to go out and enjoy city life. Being close to the buzz of the city gives us a chance to enjoy ourselves on family friendly outings and activities and helps me build the network I need to grow my young business."*
> *Jeff N.*

Beth Ntuli
26 years old | City Information Officer

Jeff Ntuli
25 years old | Entrepreneur

Thando Ntuli
18 months | Creche/ECD centre

Elizabeth is 26 and Jeff is 25. They are a young couple and recenty adopted a child. They both studied at the University of Johannesburg and lived in Braamfontein as students. They love the lifesyle that the inner city offers and still wanted to have access to the cultural activities and social life that they enjoyed as students.

Elizabeth is currently employed as an information officer by the City of Johannesburg. She walks to work or takes the BRT to Joubert Street.

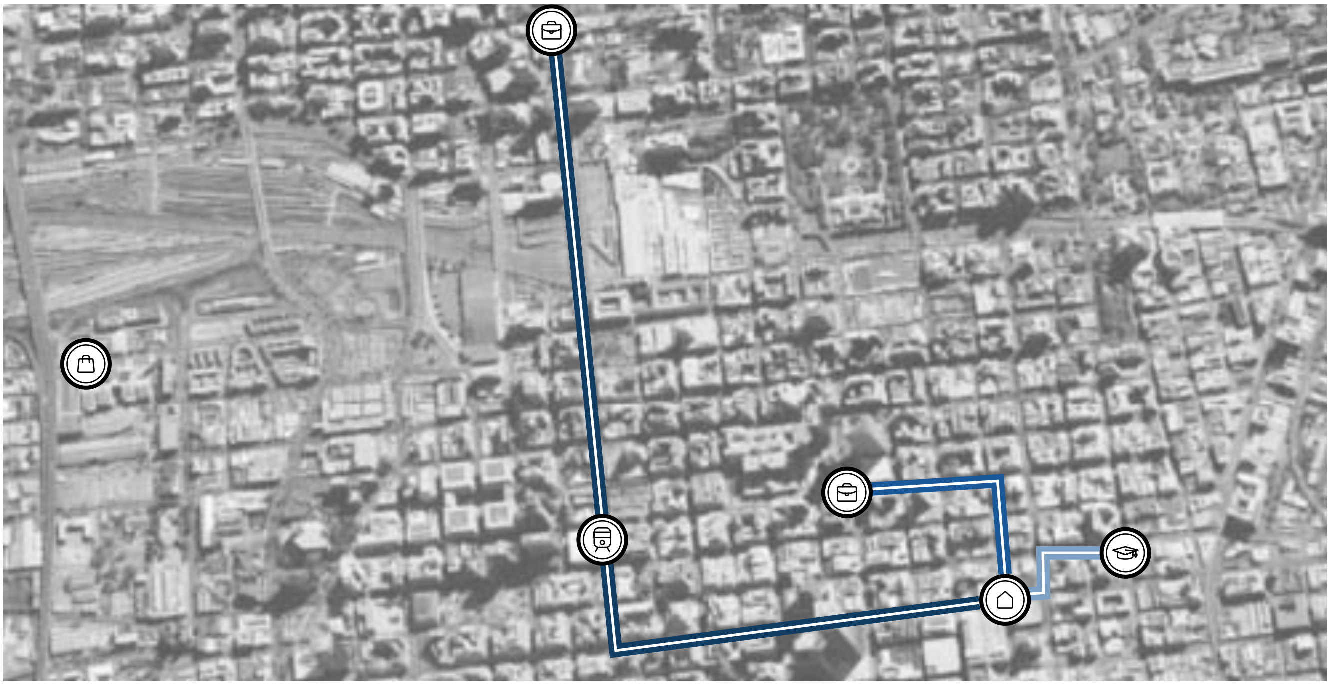
Jeff is an entrepreneur and building a communications business. Being in the inner city, he is able to access his target client base and can also access shared office space that is affordable. Thando, the baby is watched by a neighbour who runs a creche just 5 minutes away from the family apartment.

The young parents love knowing that their child is close by and Jeff picks Thando up early, on days he is working from home.

The city also runs an early childhood development centre a block away from the apartment where Jeff takes Thando for weekly activities.

Once a month they drive to Rosebank for a day out and every month they take the Guatrain to Pretoria to visit Beth's mom who cant get enough of her grandchild.

Beth's commute   Jeff's commute   Thando's commute



"Living closer to work could save us so much money which I could use to further my dream of a career in fashion."
Elna S.

MEET THE SONGA'S

Periphery
Low income

Elna Songa
26 years old | Receptionist

John Songa
28 years old | Clerk

Busi Songa
2 years old | Creche

John is 28 and Elna is 26, they are parents to Busi who is 2. John works as a clerk in the inner city and Elna has recently started an internship as a receptionist at a media company but dreams of a career in fashion. She has had put that dream on hold and took the reception job because it was closer to her home.

She previously worked in Randburg in a boutique, but once she had a child she couldn't afford the commute costs. The daily journey took an hour and a half just one way and she needed to take two buses, one into the inner city and then a second to Randburg.

John takes the taxi to the inner city. If he is late he missed the direct route and has to take two taxis which cost him more money. It takes him an hour to get to work.

Elna drops Busi off at creche so she also has to take 2 taxis, one for the school trip and the other in the opposite direction to her workplace.

Getting to work and school costs the family around 25% of their income.

Elna's commute
John's commute
Busi's commute

MEET THE NKOSI'S

> *"I can't remember the last time we had breakfast together . If I dont leave before 6am to beat the traffic I'm stuck on the road for ever!"*
> *Primrose N.*

Periphery
Medium income

Primrose Nkosi
44 years old | Book-keeper

Ben Nkosi
48 years old | Unemployed

Jenni Nkosi
14 years old | High School learner

Ben and Primrose have lived in the West all their lives. They met in high school and bought an apartment in a complex at Floracliffe close to their parents.

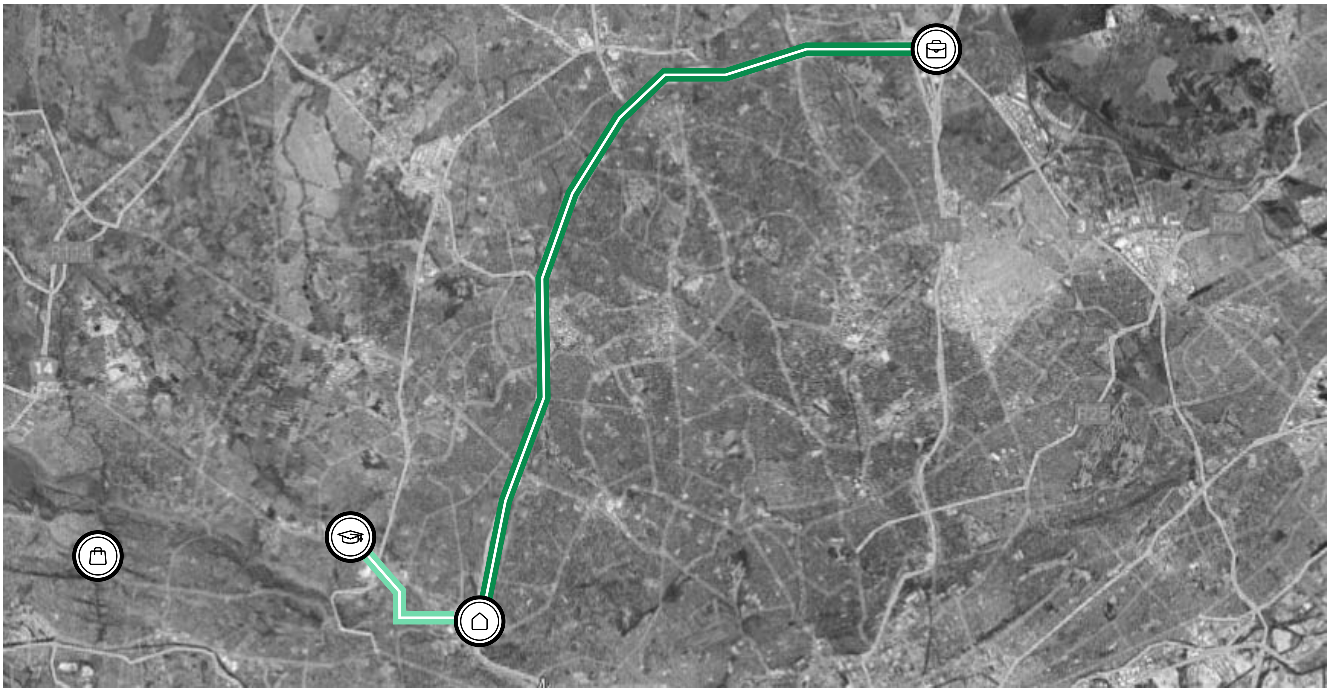
Ben was retrenched in 2018 and has given up looking for work. There are so few jobs in the West and travelling for interviews was stretching their already strained budget. He does odd jobs as a welder from home. Primrose works as a book-keeper for a construction company in Midrand.

Every day she drives almost 30km to work, along the Ontdekkers corridor and through the northwestern suburbs on her way to the Midrand Business Park.Her daugher Jenni goes to school in Constantia Kloof. Ben drops and picks her up.

Although the route to work should take 30 mins Primrose is almost always caught up in traffic and can sometimes spend an hour and a half on a single journey to work, especially if she leaves during rush hour. To avoid the inevitable delays she now leaves for work by 5:45 am.This means she hardly ever gets to see her daugher in the mornings and misses out on family time by having to go to bed early too.

Jenni worries about her relationship with her family and the toll that this lifestyle takes on all of them. On the weekends they drive to Westgate mall about 10km away as the shops in the area are small and expensive.

Primrose's commute   Ben's commute   Jenni's commute



The table below summarises the key assumptions for the LCA and travel behaviour averages used in the study and the reader is directed to the technical annex for the rationale behind these choices.

		THE KHUMALOS Urban Low income	THE NTULI'S Urban Medium income
Buildings	Size	35m²	65m²
	Rooms	2 rooms, 1 bathroom	
	Location characteristics	– City core/urban node – Good access to services, amenities and public transport	– City core/urban node – Good access to services, amenities and public transport
	Construction elements	– Structure including foundations, vertical structure, floor slabs – Roof – External walls and windows – Internal walls	– Structure including foundations, vertical structure, floor slabs – Roof – External walls and windows – Internal walls
	Building lifetime	60 years	
	Income level	<12,500 RAND	<15,000 RAND
Occupants	Occupants	3 people	
	Travel characteristics	– By foot access to play, recreation & shopping – Public transport for larger shopping trips & recreation activities – Access mall and large urban park once per month – Visit relatives once per month	– By foot access to play, recreation & shopping – Public transport for larger shopping trips & recreation activities – Access mall once per week – Access large recreation facilities twice per month
Transport – average per person trip	Work	8.6km	
	Education	1.75km	
	Mall	5km	
	Large park/ Recreation facility	5km	
	Hospital	5km	
	Social visits	20km	
	Aggregated per day	23.22km	24.82km

<table>
<tr><th></th><th></th><th>THE SONGA'S
Periphery
Low income</th><th>THE NKOSI'S
Periphery
Medium income</th></tr>
<tr><td rowspan="6">Buildings</td><td>Size</td><td>45m²</td><td>75m²</td></tr>
<tr><td>Rooms</td><td>2 rooms, 1 bathroom</td><td>2 rooms, 2 bathrooms</td></tr>
<tr><td>Location characteristics</td><td>– Peripheral zone
– Limited access to services, amenities and public transport</td><td>– Peripheral zone
– Limited access to services, amenities and public transport</td></tr>
<tr><td>Construction elements</td><td>– Structure including foundations, vertical structure, floor slabs
– Roof
– External walls and windows
– Internal walls</td><td>– Structure including foundations, vertical structure, floor slabs
– Roof
– External walls and windows
– Internal walls</td></tr>
<tr><td>Building lifetime</td><td colspan="2">60 years</td></tr>
<tr><td>Income level</td><td><12,500 RAND</td><td><15,000 RAND</td></tr>
<tr><td rowspan="2">Occupants</td><td>Occupants</td><td colspan="2">3 people</td></tr>
<tr><td>Travel characteristics</td><td>– By foot access to play, recreation & shopping (limited options)
– Public transport for larger shopping trips & recreation activities
– Access mall once per week
– Access large urban park once per month
– Access public hospital twice per month
– Visit relatives by minibus once per month</td><td>– Private car used for larger shopping trips & recreation activities
– Access mall twice per week
– Access social services twice per month
– Visit relatives twice a month</td></tr>
<tr><td rowspan="7">Transport – average per person trip</td><td>Work</td><td colspan="2">24.7km</td></tr>
<tr><td>Education</td><td colspan="2">3.6km</td></tr>
<tr><td>Mall</td><td colspan="2">20km</td></tr>
<tr><td>Large park/ Recreation facility</td><td colspan="2">10km</td></tr>
<tr><td>Hospital</td><td colspan="2">10km</td></tr>
<tr><td>Social visits</td><td colspan="2">40km</td></tr>
<tr><td>Aggregated per day</td><td>83.21km</td><td>86.43km</td></tr>
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Results

LCA + carbon lifestyle results

Building LCA	+	Occupant transport emissions	=	Total location-based emissions

The results of our study are presented within this section, and are laid out as follows:

- Building LCA results - A comparison of embodied and operational emissions by building typology across the 60 year design life
- Occupant travel results - A comparison of occupant travel-related emissions by location and income across 60 years
- Total emissions - Comparison of embodied, operational and occupant-travel emissions by location and income across 60 years
- Emissions split - Emissions profile (%) of each typology and persona across 60 years

BUILDING LCA RESULTS

FROM AN EMBODIED CARBON PERSPECTIVE (A1-A5, B1-B5, C1-C4)

Our results indicate that both urban-based building types perform better on average than those on the periphery. **Due to minor differences in material selection across locations we can infer that the difference in these impacts is mainly due to unit size with urban units being on average 20% smaller than their peripheral counterparts. The higher urban densities thus contribute to lower emissions.**

OPERATIONAL EMISSIONS (B6-B7)

Account for the highest share of LCA emissions across all building types, with approximately 72% of the total over a 60-year design life. This is significant and points to a large opportunity to reduce operational emissions through integration of renewable energy generation technologies and grid decarbonization generally; this will be explored further in our sensitivity analysis.

OCCUPANT TRAVEL RESULTS

- Despite households in both periphery building typologies travelling similar distances each day, there is a large variance between the two; medium income families are responsible for approximately three times the volume of emissions of lower income families over a 60-year time period.
- **This is driven almost entirely by choice of transport mode, with medium income families predominantly utilising private cars to satisfy their transport needs, whilst the lower income periphery group use taxis for the majority of their travel needs.**
- A similar variance exists between both urban core households, with the difference being driven by lower income households making use of local rail systems and taxis for the majority of their transport needs.
- **The differences in travel behaviour across the income and location variables are expected due to the lack of effective public transportation systems and/or unequal distribution of services.** Use of public transport in South Africa is mainly by need rather than by choice, due to a lack of service quality, reliability and provision. T**he provision of safe, well managed and reliable transport systems is a key opportunity to leverage 'by choice' commuters. In addition, the expansion of transport services to multi-modal systems including non-motorized infrastructure across the city can influence travel behaviour positively by increasing the share of public transport and non-motorized movement overall.**
- A reduced reliance on private car transport within the urban core setting highlights a key benefit of public transport systems and greatly reduced distances to local amenities relative to occupants within the periphery settings.

A comparison of embodied and operational emissions by building typology across the 60 year design life

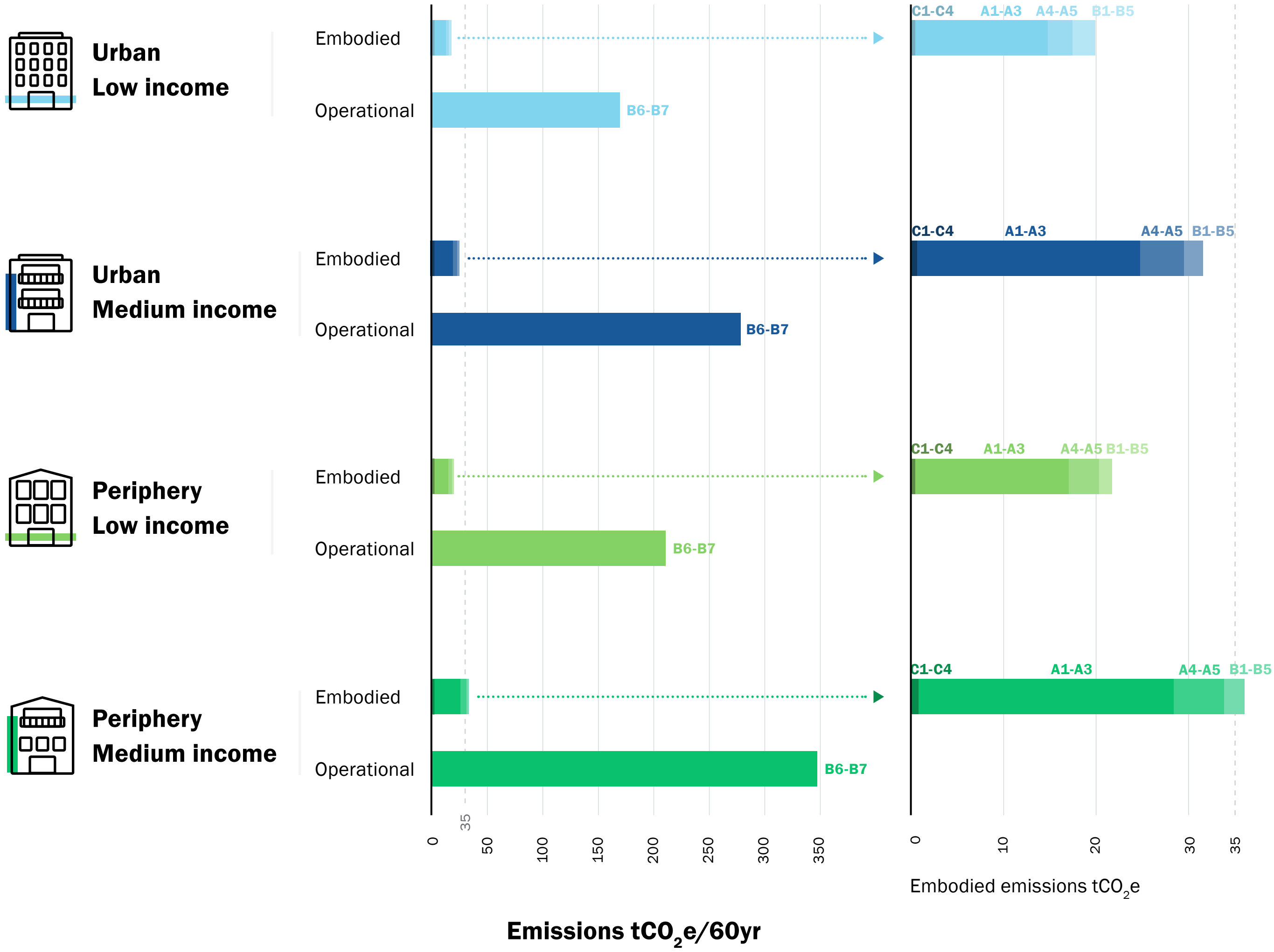


Figure 13 Embodied and Operational emissions by building typology - 60 years. See p.15 for A1-C4 definitions.

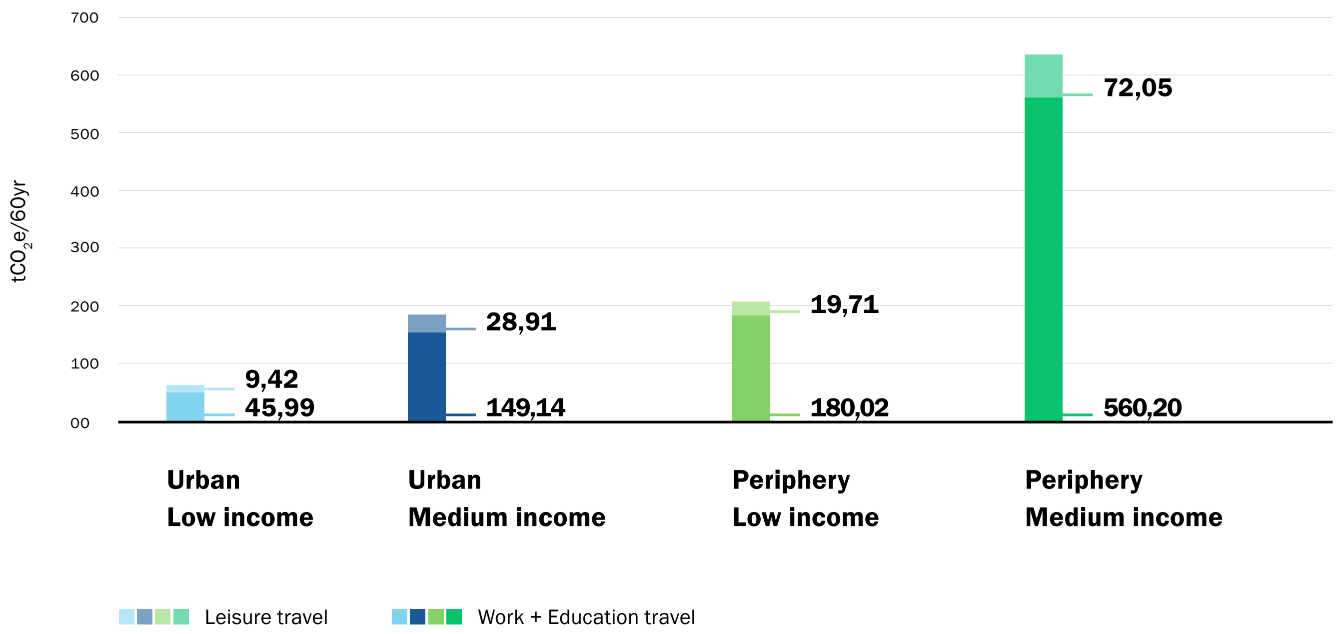


Figure 14 Occupant travel-related emissions by location and income - 60 years

TOTAL EMISSIONS

- **Combining our LCA results with our Occupant travel results provides us with an insight of total emissions per building location and income group over a 60-year time period.**
- The first thing to note is the relative proportion of emissions associated with occupant travel between urban and periphery locations; between 24% and 39% in the urban core versus 49% to 65% in the periphery. Although higher income groups have higher travel related emissions within the same location, **comparing equivalent income groups between locations shows that location does have a large impact. Furthermore, the importance of location is highlighted by the observation that the transport emissions associated with a medium income family in the urban core, is less that the transport emissions associated with a low income family located in the periphery.**
- Not surprisingly, given the variance in occupant travel emissions impact across our four typologies, there is also a large variance in terms of operational emissions between urban core and periphery groups; **with operational emissions making up approximately 31-45% of total emissions within the periphery, and a much higher 53-66% within the urban core.**
- The share of **embodied emissions** is broadly constant across all four groups, making up an average of 7% of emissions.
- This chart highlights the need to not only consider emissions associated with the construction and energy consumption of a property during the planning phase, but to also consider spill over effects, due to increased travel distances in periphery settings, and occupant preferences for private modes of transport in higher income groups. **The potential to "lock-in" broader consumption related emissions is significant and should be managed at policy, investment and development levels to ensure emissions are minimised as far as practicable.**

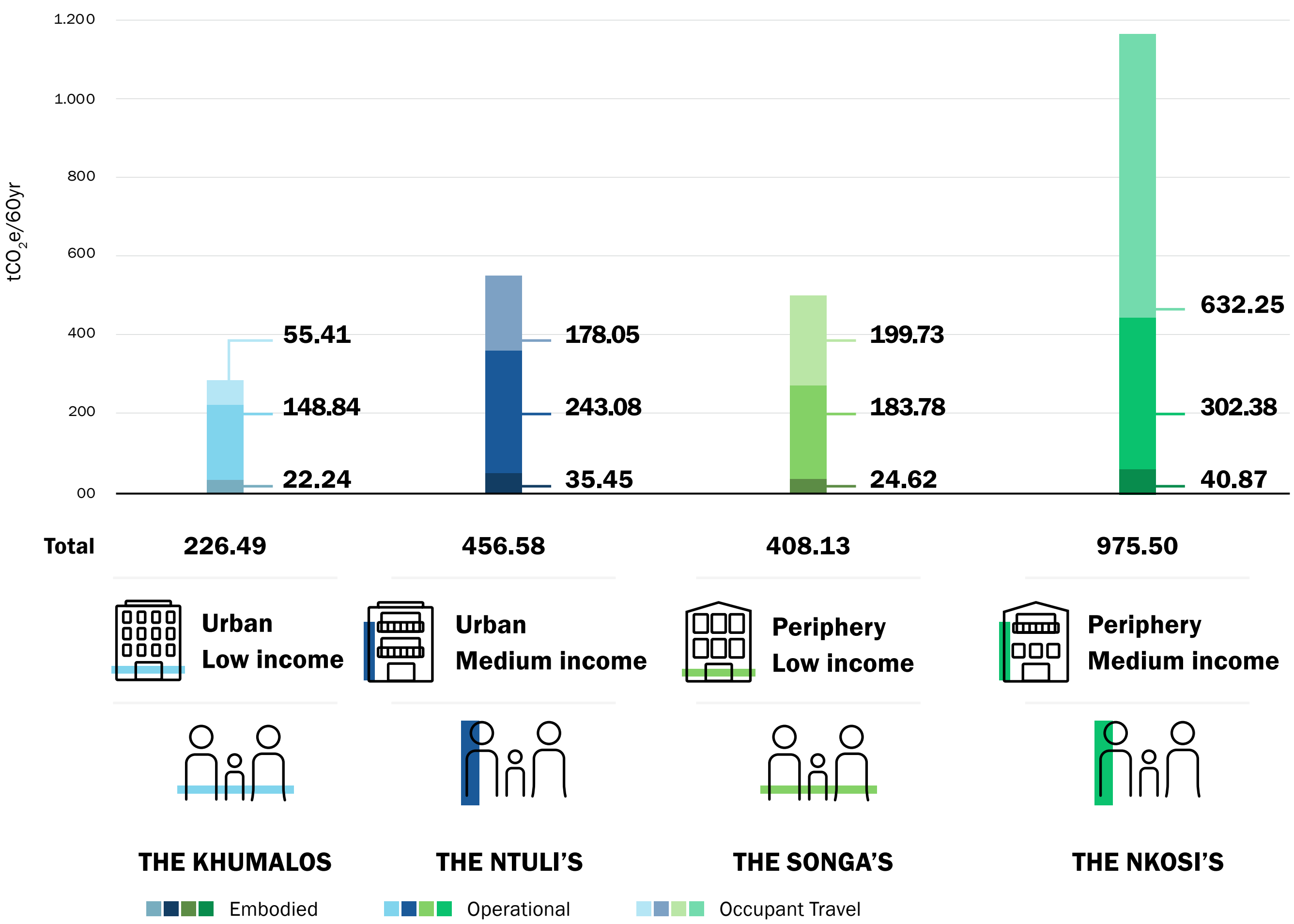


Figure 15 Total emissions (Embodied, Operational and Occupant travel) by building type and occupant income - 60 years

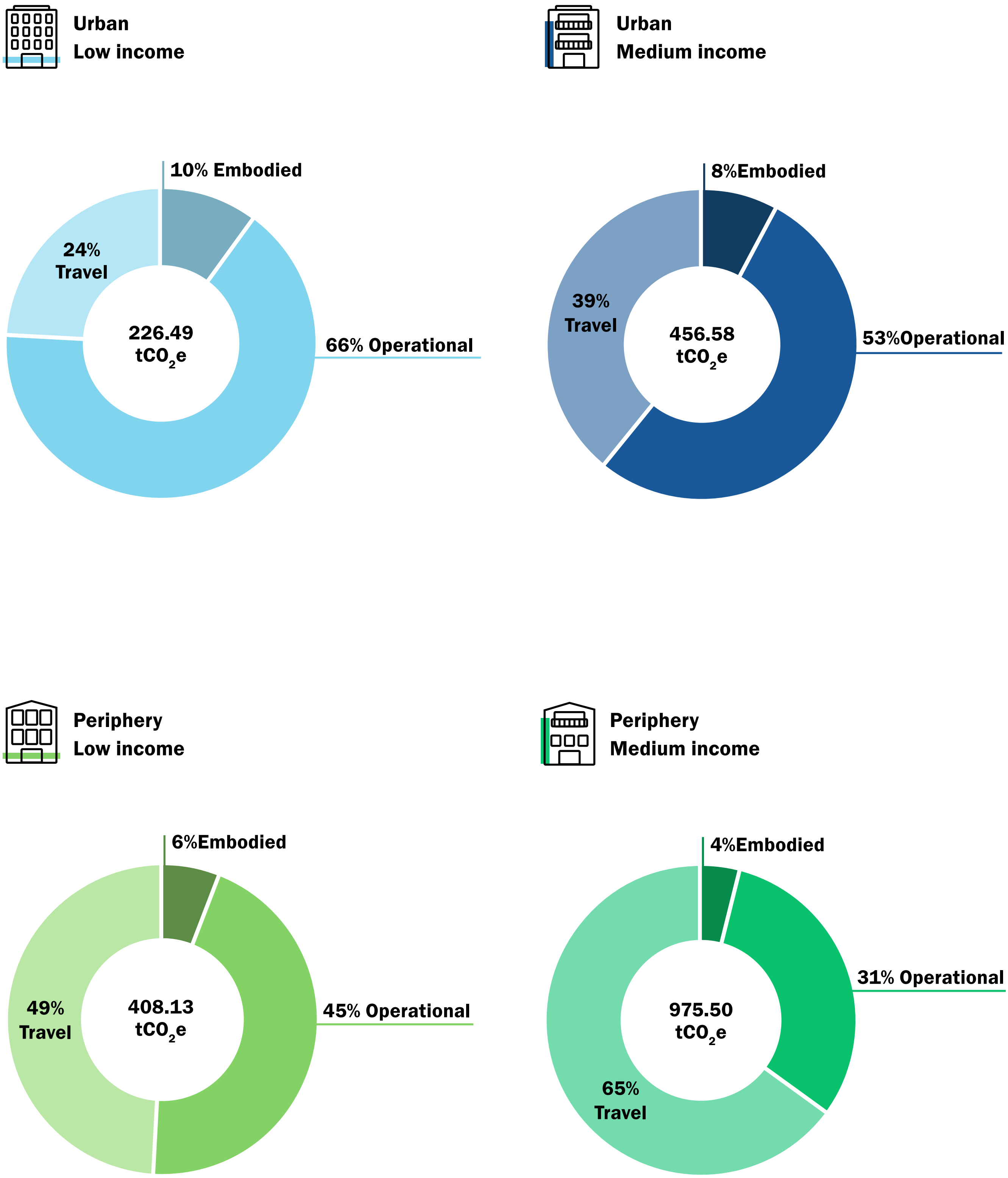


Figure 16 Percentage emissions split by location and occupant travel

SENSITIVITY ANALYSIS

Given the large share of operational emissions across our focus groups, we undertook a sensitivity analysis to understand the likely impacts of designing developments with integrated solar generation.

Our assessment considered the impact on our building LCA (aggregated embodied and operational emissions over 60 years) of 80% energy consumed being solar, rather than the current grid mix in Johannesburg.

The results are highlights in Figure 17. Savings are fairly uniform across the four building types, with a 61-63% saving across the four building types.

There is a large and significant opportunity to drive emissions reductions through scaling up of investment in renewable generation technologies for supply of new buildings and retrofit of existing buildings within the city. With savings of up to a third on offer, commercial models and design adaptations warrant consideration.

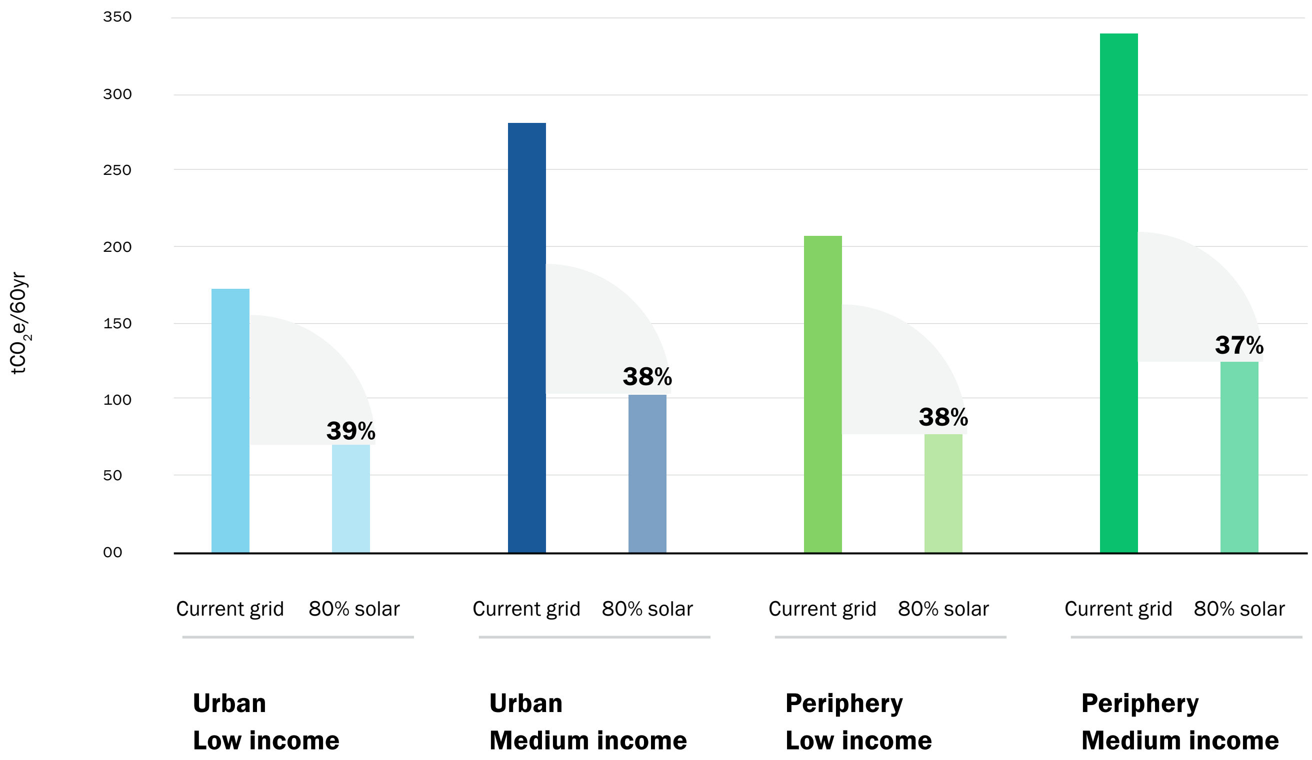


Figure 17 Sensitivity analysis - impact of 80% solar energy on building LCA (embodied and operational) emissions

Impact

So, what does this mean for the provision of housing and how does it align with the local and national climate goals? Building in the urban periphery vs. the urban core

Meeting the requirements for housing due to population increase and clearing the backlog requires that:

- up to 56,000 dwellings be built per year in the city, which would require a massive investment programme, and
- a 10-fold increase in the number or yearly completed dwellings in the city.

To quantify the future impact of building these homes in the periphery as opposed to building in the core, we scaled up our results and translated these onto housing need for Johannesburg.

The graph below presents the two opposite ends of the spectrum of stylised emissions pathways, the top line shows the cumulative emissions associated with building on the periphery, whilst the bottom line shows the cumulative emissions associated with building in the urban core. Emissions factors for embodied, operational and transport emissions are an average for low- and middle-income groupings.

These two scenarios provide an upper and lower bound for future emissions of Johannesburg from building construction, operation, and occupant travel to 2050, holding all variables constant.

The figure also shows how the annual gap in emissions increases over time, driving an exponential increase in the cumulative emissions gap between the two stylised development pathways.

This insight highlights the importance of decisions taken now and their potential to compound emissions impact, either positively or negatively. **Situating a development on the periphery risks locking in modes of high carbon travel. The opportunity for significant emissions reductions at the national scale is achievable through a co-ordinated, multi-stakeholder approach focused upon lower carbon housing and transport systems.**

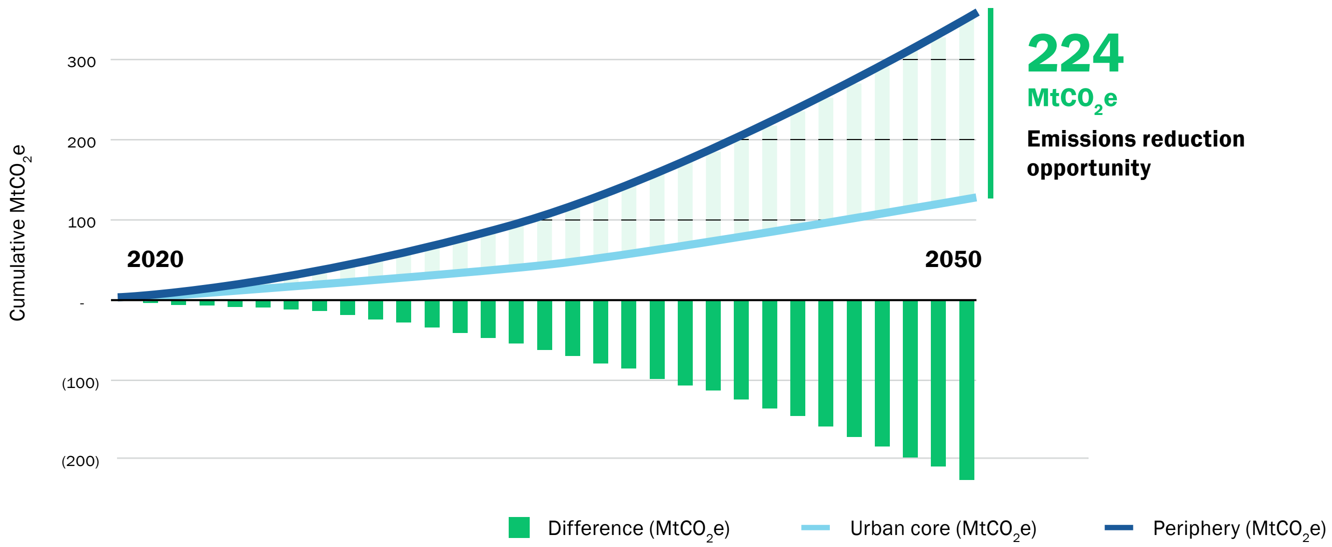
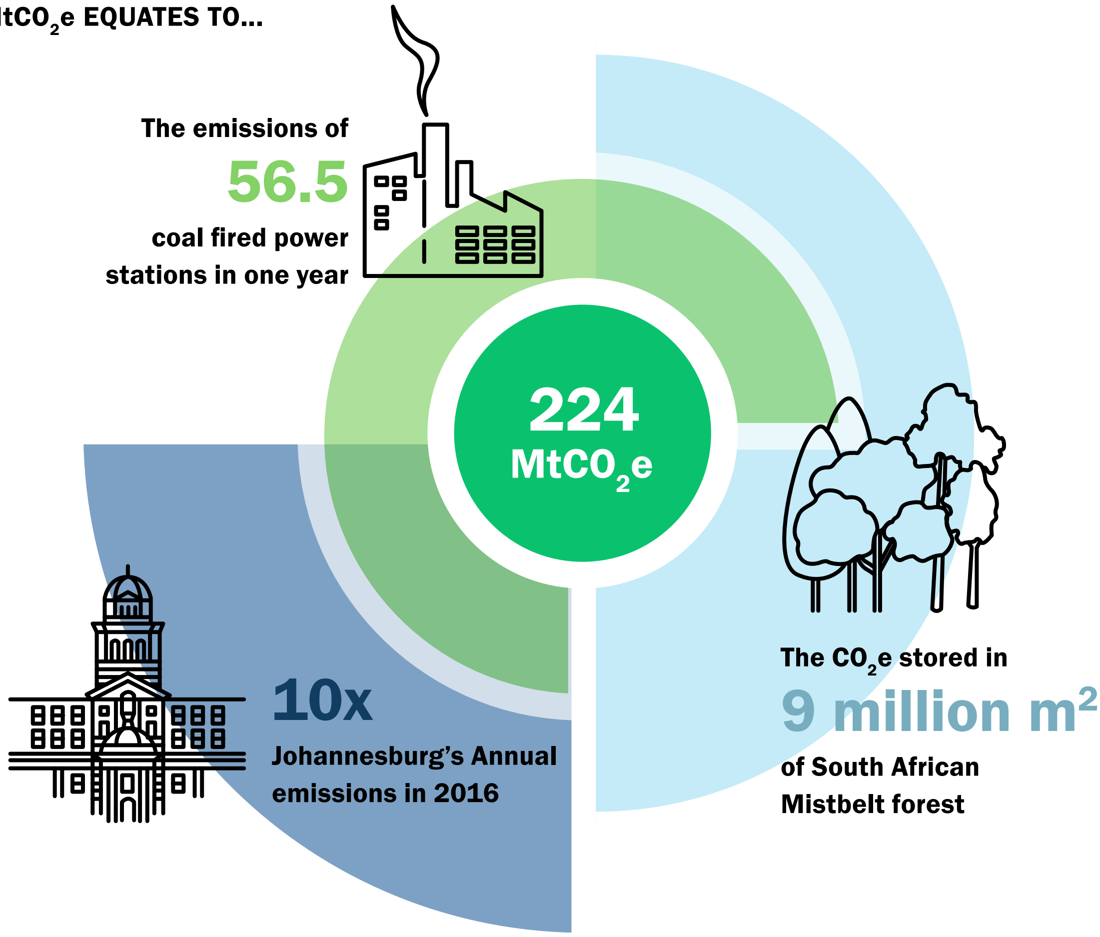


Figure 18 Opportunity to cut emissions through spatial planning in Johannesburg - two stylised examples.

By 2050, the cumulative emissions gap between these two scenarios (development in the urban periphery vs the urban core) is 224$MtCO_2e$, almost 10 times the annual total emissions of Johannesburg in 2016 (21 $MtCO_2e$).

224 $MtCO_2e$ EQUATES TO...



WHAT IS THE CARBON COST OF NOT CLOSING THE GAP?

South Africa established a carbon tax in 2019, levied on businesses and companies emitting a large amount of carbon dioxide emissions. Article five of the Carbon Tax Act No 15 of 2019[6], establishes the base rate of the carbon tax at 120 Rand/tCO_2e. It will increase year on year from 2022 at the rate of consumer price inflation (CPI)

Several allowances are made in the design of the tax, the combination of which have the potential to set the resulting tax rate at 6 Rand/tCO_2e[7].

To project the future value of South Africa's Carbon tax, we assume the middle value between 6 and 120 as our starting point (63 Rand/tCO_2e), and project an increase of 4.5% per year, which is in line with the Treasuries target of 3 to 6% CPI.

The figure below shows how the cumulative emissions gap presented above, would translate into South African Rand, based on our projection of the value of the South African Carbon Tax.

The figure shows that by 2050, the emissions gap translates into over 50 Billion Rand, with a rapid increase projected between 2035 and 2050. Whilst developers and the transport sector are not currently subject to the South African carbon tax, this figure serves to demonstrate the significant future externality cost. This could become a key informant in decisions of where to spatially locate development.

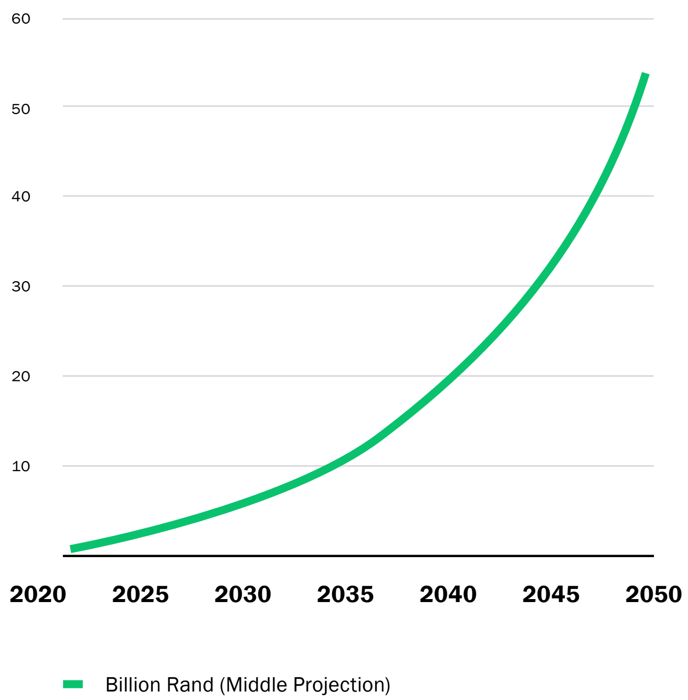


Figure 19 Monetized emissions gap (cumulative) based on application of SA Carbon tax projections

IMPACT – FURTHER SCOPE

Urban form has an impact on a number of other key performance indicators as well as carbon emissions. Whilst we have presented a quantified GHG emissions impact, a number of other variables will be impacted by decisions to develop in the periphery rather than the core. These are summarized in the table below.

These impact categories warrant further research to further inform an approach to spatial planning which is optimised to minimise emissions associated with whole city systems which can be scaled up nationally.

IMPACT	URBAN CORE	PERIPHERY
Service vehicles	Will need to travel shorter distances on average **Lower increase** than periphery	Will need to travel greater distances on average **Greater increase** than urban core
Physical infrastructure	Significant physical infrastructure will likely already be in place, necessitating less infrastructure development than in the periphery.	Physical infrastructure will need to be installed and routed from the nearest node, will likely require significantly more than in urban core. A greater increase in emissions relative to Urban core.
Carbon sequestration	Development in urban core will spare a greater area of land in the periphery which can sequester more carbon.	Development in periphery will degrade carbon sinks and the lands ability to sequester carbon.
Urban heat island (UHI) effect	Will likely have a greater impact on the UHI effect than in the periphery, increasing carbon emissions associated with cooling.	Will have an impact, but likely lower than Urban core

Insights and recommendations

Our study has highlighted a set of impacts associated with different spatial planning decisions in Johannesburg. Our findings have applicability to a broader range of cities across South Africa.

The impacts of different decisions can be effectively managed in various ways by stakeholder groups involved across all upstream and downstream processes; from policy makers to occupants.

OVERARCHING INSIGHTS

- Developing and densifying in urban centres and avoiding further sprawl presents the opportunity to avoid 224MtCO2e by 2050. This represents the scale of opportunity open to a broad range of stakeholders, involved in the planning and delivery of our built environment, for radical collaboration to drive our collective ambitions on climate mitigation.
- Operational energy and transport-related emissions require urgent attention; decarbonisation of the national electricity grid and increased investment in public transport, focused on optimising user experience, are critical accelerators of the transformation required.
- This highlights the need for policy makers and developers to empower residents to live lower carbon lifestyles. This can be enabled through increased provision of renewable energy and the provision of safe, reliable and affordable public transport.
- Whilst embodied carbon makes up a small percentage (4-10%) of the total emissions profile, it is still an important aspect to actively manage; as other industries and activities decarbonize over the coming years, embodied carbon associated with housing provision will make up an increasing share.
- When it comes to the embodied and operational emissions associated with residential dwellings, we have found it is better to develop in urban environments that are connected to reliable, safe and affordable public transport routes as these offer residents a diversity of economic and social activities. The greater the urban sprawl, the less reliable and beneficial public transport becomes.
- Ease of access to services and opportunities are key drivers of transport demand, our findings point to the need for practice of spatial inclusivity and integrated design in urban planning and design, which will enable significant reductions in transport-related emissions.

A set of insights and recommendations for each stakeholder group has been summarized below. In short, a collaborative, focused approach is needed across the property and transport sectors to achieve the necessary emissions reductions at scale. Further, spatial planning must consider the spill over effects associated with building occupants travel-related emissions.

FOR PUBLIC SECTOR DECISIONMAKERS AND LOCAL GOVERNMENT

Those responsible for the development and implementation of local housing and transport policy have an important role to play in setting the aspiration for emissions reduction and creating the policy space through which the emissions profile of South Africa can be transformed.

- Make every effort to break apartheid planning by encouraging, facilitating, and incentivising development along public transport routes and hubs that are close to a range of economic opportunity.
- Incentivise development toward urban nodes of opportunity.
- Structure incentives to ensure development costs reflect total emissions impact and minimise risk of transport emissions lock-in.
- Invest in a good, safe, reliable, and accessible public transport network, prioritizing trains and trams, then busses and taxis. Regulate private car use, with greater penalties for single passenger car travel.
- Develop and implement standards to minimise urban sprawl and reduce travel distances.
- Develop policy aimed at significantly increasing on-site renewable energy generation and storage across residential developments.
- Adopt stringent fuel efficiency requirements to ensure transport emissions are significantly reduced in-line with South Africa's NDC .
- Invest in improving the safety, quality, coverage, and reliability of public transport options to drive modal shift from private car use, particularly in periphery locations .

FOR DEVELOPERS

Organisations tasked with acquisition and development of land for residential dwellings have a role to play in ensuring their decisions factor in whole life consequences regarding the LCA emissions profile of their designs, whilst being mindful of travel-related spill over effects.

- Operate on fabric first hierarchy to reduce energy demand within new buildings.
- Maximise use of renewable technologies within developments to reduce operational emissions.
- Work with material producers to identify and integrate lower carbon materials into designs where possible (e.g. Material substitution, increasing recycled content, end of life planning).
- Develop commercial models which capture broader location-related benefits on regional/national emissions from development close to economic opportunities that supports spatial inclusivity.
- Lobby for better incentives for developing close to existing economic opportunities, such as the inner city or Louis Botha corridor. Opportunities should also include access to parks, schools, and places of recreation.
- Incentivise and reward efficient tenant behaviors, for example by charging by metered energy consumption.

FOR BUILT ENVIRONMENT PROFESSIONALS

Professionals engaged within the built environment have a critical role to play in the development and championing of lower impact design, construction and operation of our city spaces.

- Advocate for lower carbon options
- Ensure whole life emissions are adequately quantified and managed across the design, construction and operational lifecycles, in close collaboration with both upstream and downstream stakeholders
- Provide training to colleagues to ensure they understand the emissions context in which they are operating and they feel confident identifying and making decisions relating to minimisation of emissions across the systems in which they are operating
- Take responsibility for verification and assurance of data to promote consistency and ensure high standards are adhered to
- Ensure any best practice is recorded and shared widely, to accelerate adoption of best practice across built environment professionals.
- Commit to measure and verify carbon emissions reductions through established green building certification tools.

FOR TOWN PLANNERS

Town planners have a critical role to play in influencing location and transport-related choices of downstream stakeholders. Operating at the nexus between transport and housing systems, they are well placed to deliver transformation and help drive down overall emissions.

- Spatial connectivity is key. There is urgent need to address city form and direct the location of new housing developments to well-located urban nodes. Our analysis also calls for action around lower emission public transit provision to connect the large proportions of existing housing in poorly connected and serviced peripheral areas.

FOR INFRASTRUCTURE INVESTORS AND LENDERS

Increasingly, investor value and returns will be a function of emissions performance. By working to internalise emissions performance of their portfolios, investors and lenders can play a vital role in accelerating change.

- Adopt a whole value approach which covers the asset lifecycle
- Make emissions performance a key investment decision metric to ensure emissions performance is rapidly improved over time
- Utilise shadow carbon pricing, aligned with national policy to minimise potential transition risks
- Collaborate across the value chain to drive innovation

FOR URBAN ECONOMISTS

Urban economists have a key role to play in ensuring a broader range of co-benefits are achieved, whilst minimising disadvantages.

- Advocate for systems thinking through including externalised costs in urban development models, such as carbon emissions, air pollution, or lost time commuting.
- Measure the opportunity cost of developing in areas disconnected from economic opportunity.
- Measure the economic costs of the loss of biodiversity (provision of ecosystem services) associated with continued development in the periphery.

“Running the same system harder or faster will not change the pattern as long as the structure is not revised.”

Dennis Meadows

Call to action

The time to act is now!

With each passing year, our window of opportunity will decrease. Early and large-scale collaboration is needed across all value chain stakeholders to put us on a path to significantly lower carbon outcomes within the sector, our nation, and Africa more broadly.

GHG emissions in South Africa are increasing significantly and are projected to continue increasing over the coming decades. Our study has focused on the impact of spatial planning decisions on regional emissions within the city of Johannesburg. Our findings have relevance to the national South African scale.

Over the coming years we must work collaboratively across the built environment value chain to deliver transformation and achieve the following outcomes:

1. **A significant increase in renewable energy generation capacity associated with residential developments.**

2. **An increased modal share for public transport, particularly amongst more affluent populations.**

3. **Increased housing density and urban complexity to ensure easy access to local amenities and greatly reduce travel distances.**

We have highlighted a 224MtCO_2e emission reduction opportunity to 2050, we must adapt our approach to spatial planning and transport network provision significantly if we are to maximise emissions reductions and contribute meaningfully to our NDC aspirations and the meeting of Global Paris Agreement goals.

Technical Annexure

This annexure provides additional information and background on the study parameters, assumptions and selected inputs.

Purpose

This technical annexure provides additional information on the LCA methodology and process and defines the modules or components that are considered in the development of an LCA building model.

It also provides additional information on assumptions and sources consulted to define some of the key study parameters.

These parameters include :

- The rationale for selection of the affordable market segment
- The definition of location
- The definition of Income levels
- The definition of Household Size

The primary assumptions were informed through desktop research and synthesis of existing data
and information sources, stakeholder engagement and referencing workshops, and input from discipline specialists within the project team; whose contributions were based on their subject matter experience and context knowledge.

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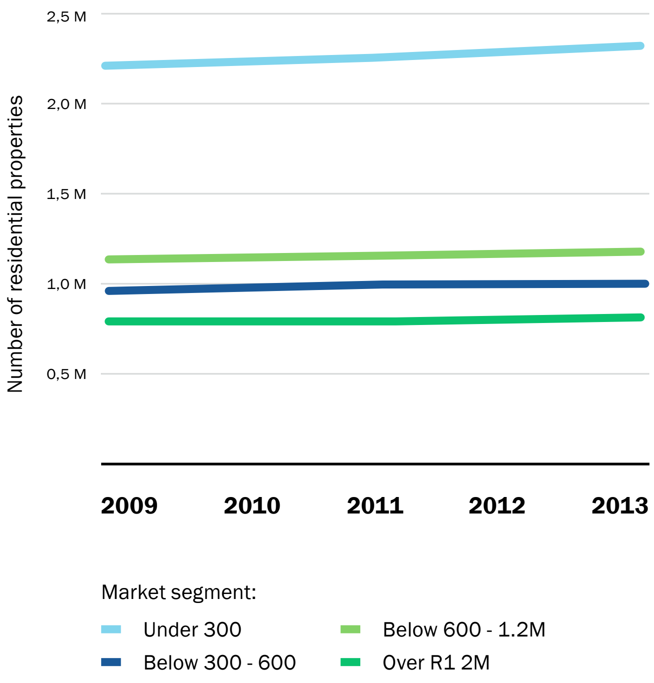
Assumptions

WHY FOCUS ON THE AFFORDABLE HOUSING MARKET SEGMENT?

The majority of the residential property market – 63% in 2013 – includes homes valued at less than R600 000. This number has grown by 5% since 2009, compared to 3% growth in the higher value segment market.

Total Residential Propeties Nationally, by market segment 2009 -2013



Total Residential Propeties Nationally, by market segment 2009 -2013

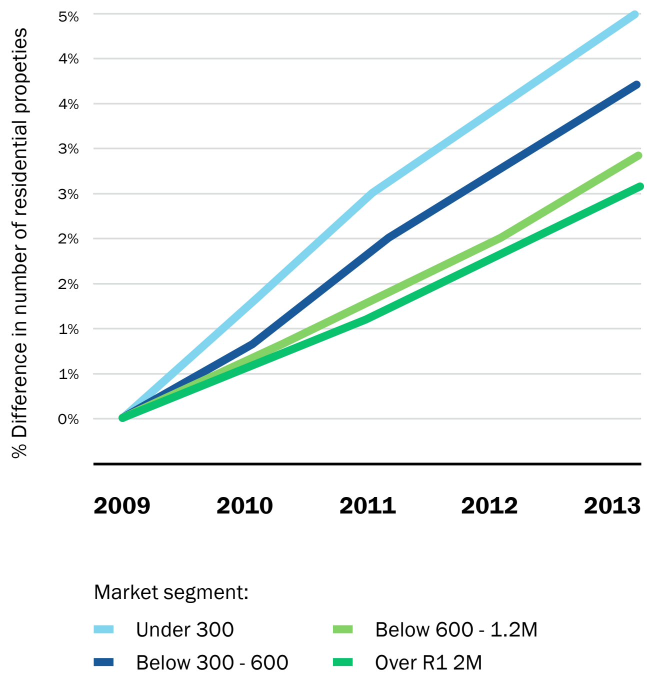


Figure 1 Growth and rate of growth across residential sectors. Centre for Affordable Housing Finance

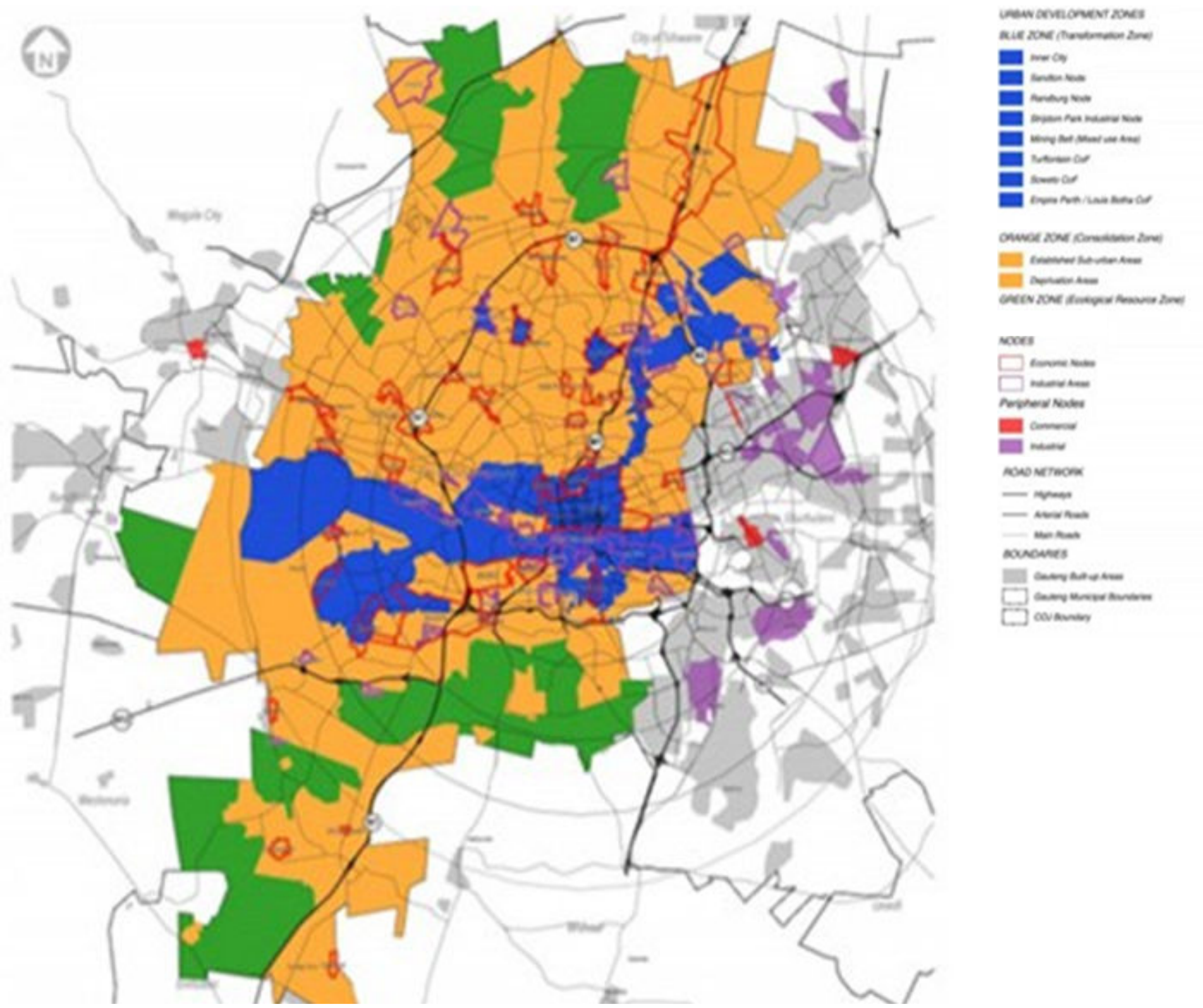


Figure 2 MSDF Urban Development Zones

LOCATION DEFINITION

Location is the primary field for this study as it forms the basis through which carbon impacts across typologies is compared. The urban or higher density location is characterized by relative centrality, with better connectivity, increased access to the spatial economy and proximity to nodes of activity.

The peripheral or lower density location is characterized by relative isolation and has poorer connectivity, lower accessibility to job markets and reduced proximity to nodes of activity.

The spatial definition of urban and peripheral was derived through 2 key documents:

- The City of Johannesburg Metropolitan Spatial Development Framework 2040 (MSDF)
- The City of Johannesburg Nodal Review Policy

JOHANNESBURG METROPOLITAN SPATIAL DEVELOPMENT FRAMEWORK (MSDF)

The MSDF provided the following definitions relevant to the study.

- Urban areas may be defined as per the SDF definition for inner-city core and inner-city node areas as well as the transformation zone which relates to public transport provision.
- Peripheral areas may be areas outside of the urban areas but within the extent of the metropolitan city boundary – i.e.. Consolidation zone.
- Figure 2 shows the two key zones defined by the MSDF, transformation zones in blue (urban) and consolidation zones in yellow (peripheral). This provided a starting point for location definition for the study.

THE CITY OF JOHANNESBURG NODAL REVIEW POLICY

The nodal review identifies a variety of nodes that are then ranked by intensity of commercial and residential activity. There are seven broad nodes and zones defined, which are:

More Intense Activity

- Inner City Node
- Metropolitan Nodes
- Regional Nodes
- General Urban Zone
- Local Economic Development (LED) Zone

Less Intense Activity

- Suburban Zone
- Peri-urban Zone
- Beyond the Urban Development Boundary

For the purposes of this study the highest intensity nodes, namely inner-city and metropolitan are considered as the ‘urban’ definition. The three lowest intensity nodes including sub-urban, peri-urban and beyond the urban development boundary are considered as the ‘peripheral’ definition.

INCOME DEFINITION

This study focuses on the affordable housing sector as it is an area of the property market with a high potential impact on carbon emissions due to both its scale and projected growth driven by demand. The study further concentrated on the upper levels of the affordable sector as this is the area where private developers and authorities can have a higher degree of influence.

The lowest levels of the affordable market which are fully subsidised housing units; are highly controlled by government. Access to subsidies is limited at present to mostly state housing providers, NGO’s and only a small number of private housing developers. There is also a low level of innovation within this sector and limited building typologies. Therefore this lowest segment of the affordable market was not part of the study.

Sources on income bands differ widely and for this study a number of sources were consulted, including the CAHF residential property review, the Department of Human Settlements website as well as the SAPOA’s (South African Property Owners Association) Inclusionary Housing Report 2018; This study thus defines lower income as under 12,500 Rand/month and medium income as under 15,000 Rand/month.

Broadly these categories relate to housing prices under 600,000 per unit for low income and between 600 and 1,000,000 for medium income.

NUMBER OF OCCUPANTS PER HOUSEHOLD

The average household size nationally 3.3 people per household (Statistics South Africa 2019). Given that the prevalence of single people households in urban areas is greater this study has used an average household size of 3 people per dwelling. For the purposes of comparison the housing unit profile was defined as 2 adults and 1 child for all unit types in both urban and peripheral locations.

BUILDING LIFESPAN

For the purposes of this study a 60 year lifespan was adopted. 60 years is the typically accepted global standard for the life of a building. This was also contextually validated through stakeholder engagement with key actors in the built environment sector including the City of Johannesburg spatial planning department and research institutions such as the South African Cities Network and the Gauteng City Region Observatory.

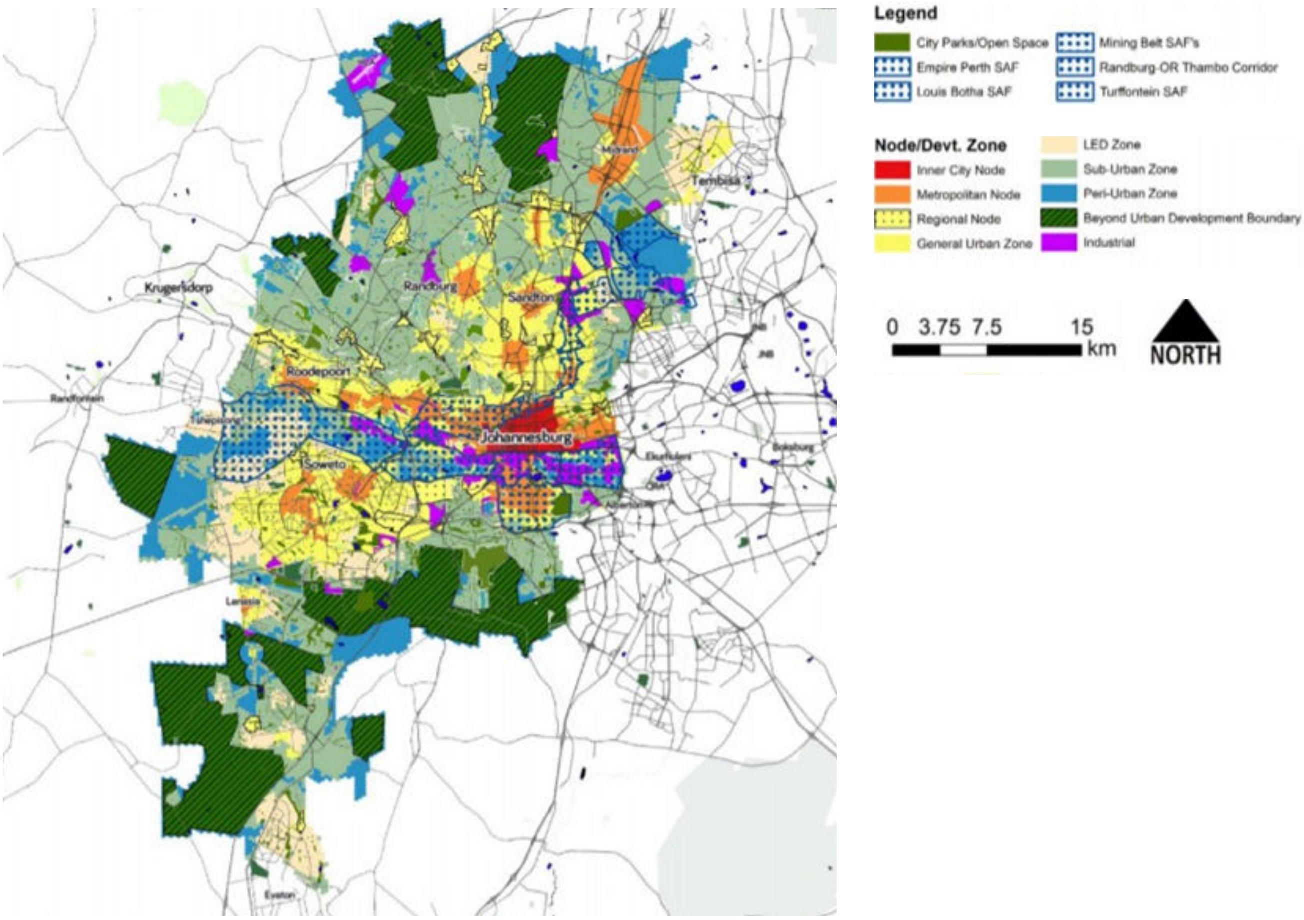


Figure 3 City of Johannesburg Nodal Review Policy - Showing categorisations of the built environment

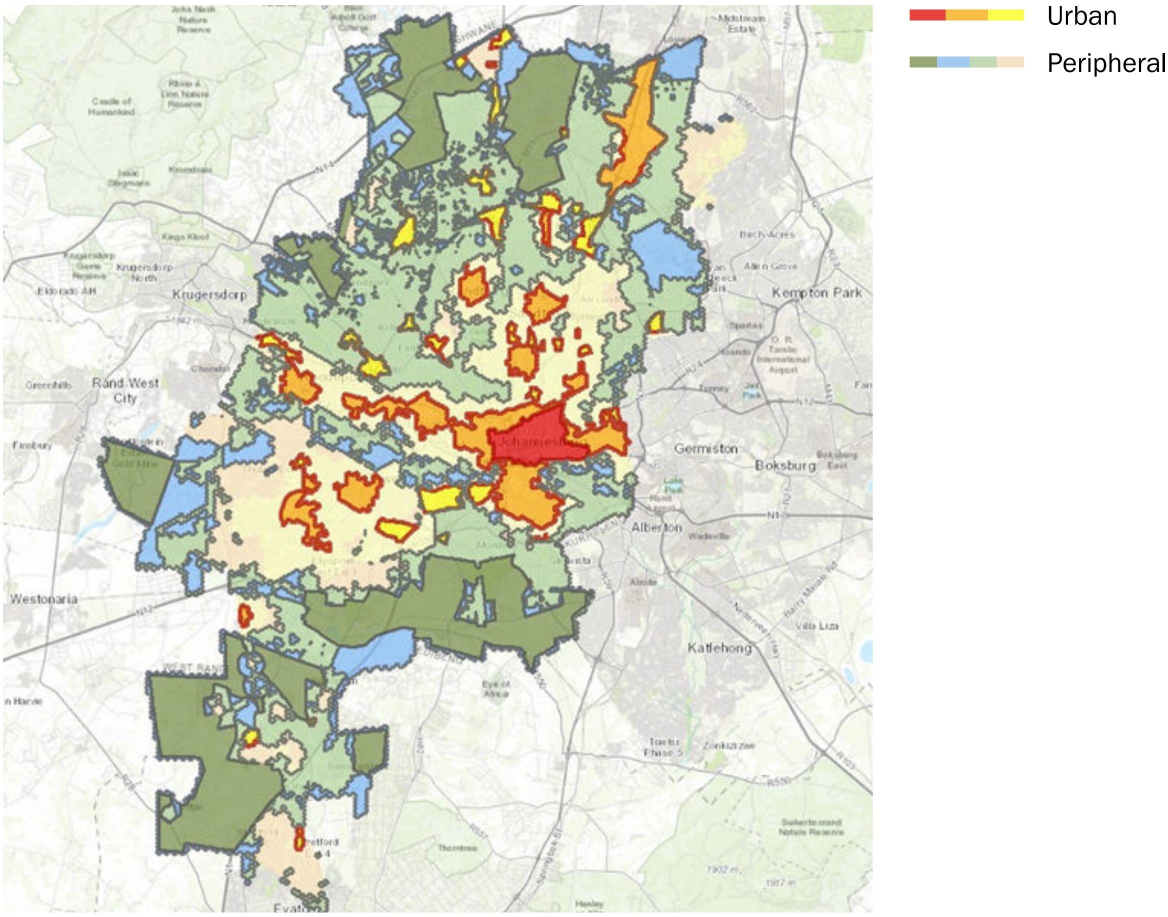


Figure 4 Urban and periphery boundary study definition

Life cycle analysis

WHAT IS A LIFE CYCLE ASSESSMENT

A life cycle assessment (LCA) is used to systematically record and analyze the impact on the environment throughout the entire life cycle of a product or service. This involves an end-to-end analysis of the product or service. The analysis considers all raw materials, transports, production processes, usage and disposal of the analyzed element. A carbon footprint of an analyzed element such as a building is a special application of the LCA methodology that specifically focuses on greenhouse gas emissions.

To acquire an overall understanding of a built project's total carbon impact, it is necessary to assess both the anticipated operational and embodied emissions over the whole life of the asset.

Considering operational as well as embodied carbon emissions together over a project's expected life cycle constitutes the whole life approach.

LCA is a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy, and the associated environmental impacts directly attributable to a building, infrastructure, product or material throughout its life-cycle (ISO 14040: 2006)."

BUILDING MATERIALS

The below table indicate typical values of embodied carbon for building materials used in the study.

The building elements included in the unit level LCA were the:

- Roof:
- Structure and cladding
- Walls: external and internal
- Floor structure
- Foundations

The following items were specifically excluded from the LCA:

- Fixtures & Fittings
- Floor Cladding
- External Site works, including common areas such as lifts, stairwells, and parking areas.

Therefore the LCA focuses on the individual unit rather than the whole building.

Material	Embodied Carbon
Rammed Earth	48 $kgCO_2e/m^3$
Softwood Timber	110 $kgCO_2e/m^3$
Laminated Timber	219 $kgCO_2e/m^3$
Stone	237 $kgCO_2e/m^3$
Clay Brick	345 $kgCO_2e/m^3$
Concrete	635 $kgCO_2e/m^3$
Glass	3600 $kgCO_2e/m^3$
Steel Section	12090 $kgCO_2e/m^3$
Aluminium	18009 $kgCO_2e/m^3$

LCA ANALYSIS SYSTEM BOUNDARY

Modules A1 to A5

The system boundary of the analysis accounts for cradle- to-grave environmental impacts associated with all the life-cycle stages for the building structure and enclosure as defined in EN 15978 and ISO 21930, sections A-1 through A-5, B-1 through B-7, and C-1 through C-4.

The assessment includes all building-related construction products, processes and services, used over the life cycle of the building.

The boundary for modules A1 to A3 covers the 'cradle to gate' processes for the materials and services used in the construction. The data sets used to represent each material or assembly were obtained from Ecoinvent 3.6.

The boundary for module A4 includes transport of materials and products from the factory gate to the building site, and transport of construction equipment to and from the site.

As the products manufacturers, and therefore the manufacturing locations, are not defined, an assumption has been made for transport. Based on the local market for construction products in Johannesburg area, three transport distances have been established:

- 100 km for local materials,
- 200 km for regional materials,
- Specific scenarios for the imported materials.

Module A5 energy, water usage and waste estimated is based on average values for construction processes:

- Electricity: 25 kWh per m^2 construction
- Diesel: 3,5 l per m^2 construction
- Water: 180 litres per m^2 construction
- Waste processing and disposal: considering construction and demolition waste rates for South Africa.

Modules B1 to B5

The products and materials specified for structure and envelope have low maintenance requirements. The only anticipated operations required are: Roof replacement (B4): It is assumed two replacements of the roof during the 60-year service life.

Modules B6 to B7

The operational energy use (B6), and water use (B7), as defined in EN 15978 and ISO 21930, has been estimated based on SANS 2019.

Modules C1 to C4

The boundary for modules C1 to C4 includes:

- Deconstruction (C1), including on site deconstruction processes. The energy and water usage estimated for these processes are based on average values for construction processes:
- Electricity: 25 kWh per m^2 deconstruction
- Diesel: 3,5 l per m^2 deconstruction
- Water: 180 litres 0,63 m^3 per m^2 deconstruction
- Transport (C2), considering an average of 70 km transport to waste management facilities.
- Waste processing and disposal (C3 – C4), considering the current best practices for construction waste management in the local market.

	LCA Stage	Element	Value	Source
		Expected Lifetime of Buildings	60 years	
A1 - A3	Product	Building materials	As detailed in building typologies section below	GBCSA, Divercity and developer data.
A4	Transport	Transport to site	Local (100 km) , regional (200 km) and imported mate- rials (from China and Australia) considered	Weighted distance based on type of materials and local/regional/imported assumption
A5	Construction	Transport to wavste management	Average distance 70km	Empirical observation of waste management sites in Johannesburg
A5	Construction	Energy consumption	Electricity 25 kWh/m^2 + Diesel 3.5 l/m^2	OneClick LCA typical assumption.
A5	Construction	Water consumption	180 litres/m^2	Arup project experience.
A5	Construction	Waste produced	Volume: 80 kg waste /m^2 GFA	South Africa: State of Waste Report
B6	Use	Operational energy	Peripheral Low income: 217 kWh/month - Middle income: 363 kWh/month; Urban Low income 175 kWh/month - Middle income: 290 kWh/month	Metered data (Divercity) and SANS 2019
B7	Use	Operational water	242 l/household unit/ day	Metered data (Divercity)
B1 - B5	Use	Replacement / Maintenance	Roof: 2 replacements of waterproofing membrane and layers above it	Informed by engagement with buildings engineers and international standard range
C1	Deconstruction	Energy consumption + Waste produced	Energy and water: same as A5 stage	Assumed equal to A5
C2	Transport	Transport to waste management	Average distance 70 km	Mapped Johannesburg's Waste Management sites
C3 - C4	Waste	Waste management	100% building materials treated as waste; Standard waste management procedures per waste type	Engagement with GreenCape South Africa.

Urban
Low income

Typology is within the city core or within an urban node, in an area with good access to services, amenities and public transport. The typical building has been considered as an 8 storeys building with apartments and 1- and 2-bedrooms units. The unit under analysis is a 2-bedroom unit for all the typologies to make them comparable.

Size
35 m^2 - 2 rooms – 1 bathroom

Roof
- Protection: cement mortar
- Bitumen waterproofing membrane
- 80mm thick Isoboard (extruded polystyrene) (3.33 m^2K/W)

Internal walls (110 Brickwork)
- Single leaf wall: 90mm clay bricks
- Plastered: cement/mortar - 10 mm plaster (each face)
- Brickforce, brick ties

External walls (230 Brickwork)
- Double leaf wall: 110 x 2 Clay bricks
- Plastered: cement/mortar - 10 mm plaster (one face)
- Brickforce, brick ties
- 1 window per room (3 total), 1 m^2 each
- 5 mm toughened glass (windows)
- Window frames (aluminium)

Floor slabs
- In-situ concrete reinforced slab - 300 mm thick
- 33 kg/m^2 steel

Urban
Medium income

Typology is located in the city core or urban node, in an area with good access to services, amenities and public transport. The typical building has been considered as a 4 storeys building with 1- and 2-bedrooms units. The unit under analysis is a 2-bedroom unit for all the typologies to make them comparable.

Size
65 m^2 - 2 rooms – 1 bathroom

Roof
- Roof tiles – cement tiles 20 mm
- 135mm thick Aerolite (glass wool) (3.38 m^2K/W)
- Pine timber roof, typical truss roof arrangement
- Plasterboard ceiling (12.5 mm board)

Internal walls (110 Brickwork)
- Single leaf wall: 90mm clay bricks
- Plastered: cement/mortar - 10 mm plaster (each face)
- Brickforce, brick ties

External walls (230 Brickwork)
- Double leaf wall: 110 x 2 Clay bricks
- Plastered: cement/mortar - 10 mm plaster (one face)
- Brickforce, brick ties
- 3 windows, 1 m^2 each bedroom and 2 m^2 living room
- 5 mm toughened glass (windows)
- Window frames (aluminium)

Floor slabs
- In-situ concrete reinforced slab - 300 mm thick
- 33 kg/m^2 steel

Periphery
Low income

This typology is located in a peripheral zone, in an area with limited access to services, amenities and public transport. The typical building has been considered as a 4 storeys building with 1- and 2-bedrooms units. The unit under analysis is a 2-bedroom unit for all the typologies, to make them comparable.

Size

45 m^2 - 2 rooms – 1 bathroom

Roof

- Roof tiles – cement tiles 20 mm
- 135mm thick Aerolite (glass wool) (3.38 m^2K/W)
- Pine timber roof, typical truss roof arrangement
- Plasterboard ceiling (12.5 mm board)

Internal walls (110 Brickwork)

- Single leaf wall: 90mm clay bricks
- Plastered: cement/mortar - 10 mm plaster (each face)
- Brickforce, brick ties

External walls (230 Brickwork)

- Double leaf wall: 110 x 2 Clay bricks
- Plastered: cement/mortar - 10 mm plaster (one face)
- Brickforce, brick ties
- 3 windows, 1 m^2 each bedroom and 2 m^2 living room
- 5 mm toughened glass (windows)
- Window frames (aluminium)

Floor slabs

- In-situ concrete reinforced slab - 300 mm thick
- 33 kg/m^2 steel

Periphery
Medium income

This typology is in a peripheral zone, in an area with limited access to services, amenities and public transport. The typical building has been considered as a 4 storeys building with 1- and 2-bedrooms units. The unit under analysis is a 2-bedroom unit for all the typologies to make them comparable.

Size

75 m^2 - 2 rooms – 2 bathrooms

Roof

- Roof tiles – cement tiles 20 mm
- 135mm thick Aerolite (glass wool) (3.38 m^2K/W)
- Pine timber roof, typical truss roof arrangement
- Plasterboard ceiling (12.5 mm board)

Internal walls (110 Brickwork)

- Single leaf wall: 90mm clay bricks
- Plastered: cement/mortar - 10 mm plaster (each face)
- Brickforce, brick ties

External walls (230 Brickwork)

- Double leaf wall: 110 x 2 Clay bricks
- Plastered: cement/mortar - 10 mm plaster (one face)
- Brickforce, brick ties
- 3 windows, 1 m^2 each bedroom and 2 m^2 living room
- 5 mm toughened glass (windows)
- Window frames (aluminium)

Floor slabs

- In-situ concrete reinforced slab - 300 mm thick
- 33 kg/m^2 steel

TRANSPORT MODEL ASSUMPTIONS

The transport assumptions were based on observations of local amenities and attractions and average distances calculated on aerial maps.

Urban – Low income

- Has the ability to access play and recreation and shopping opportunities by walking.
- For larger shopping trips or recreational activities, they take public transport to a mall or large urban park.
- They go to the mall once a month and larger urban park once a month.
- Once a month they travel to the public hospital.
- They visit relatives in neighboring towns once a month.

Urban – Medium Income

- Has the ability to access play and recreation and shopping opportunities by walking.
- For larger shopping trips or recreational activities, they take private car to a mall or large urban park.
- They go to the mall once a week and to large recreation facilities twice a month.

Urban households average distances

- Average distance to mall: 5km
- Average distance to large park/recreation facility:5km
- Average distance to hospital: 5km
- Average distance social visits- 20km

Peripheral household – Low income

- Has the ability to access a limited number of recreation and shopping opportunities by walking.
- For larger shopping trips or recreational activities, they take public transport to a mall or large urban park.
- They go to the mall once a week and larger urban park once a month
- Twice a month they travel to the public hospital. They access social services twice a month – post office, library, clinic etc. by Mini Bus taxi.
- They visit relatives in neighboring towns once a month by Mini Bus taxi

Peripheral household – Medium Income

- For larger shopping trips or recreational activities, they take private car to a mall or large urban park.
- They go to the mall twice a week and to larger recreation facilities twice a month.
- They access social services twice a month.
- They visit relatives twice a month

Peripheral households – Average distances

- Average distance to mall: 20km
- Average distance to large park/recreation facility: 10km
- Average distance to hospital: 10km
- Average distance social visits- 40km

COMMUTER Work trip summary

			Work (per person per trip)						
			Total Distance	RAIL	BUS	MINI-BUS	PRIVATE CAR	TOTAL motorized Km	NMT
Peripheral	Ontdekkers/ Inner City	Low income	22.4km			22,4		22,4	
		Medium Income	22.4km				22,4	22,4	
	Ontdekkers/ Midrand	Low income	25km			25		25	
		Medium Income	25km				25	25	
	Diepsloot/ Randburg	Low income	27,7km		7,7	20		27,7	
		Medium Income	27,7km				27,7	27,7	
	Diepsloot/Sandton	Low income	23,7km			23,7		23,7	
		Medium Income	23,7km				23,7	23,7	
Urban	Inner City/ Inner City	Low income	1.5km						1,5
		Medium Income	1.5km						1,5
	Inner City/ Midrand	Low income	20km	16		4		20	
		Medium Income	20km				20	20	
	Randburg/ Randburg	Low income	2km					0	2
		Medium Income	2km					0	2
	Randburg/Sandton	Low income	10.9km			10,9		10,9	
		Medium Income	10.9km		6		5	10,9	

COMMUTER Education trip summary

			Education (per person per trip)						
			Total Distance	RAIL	BUS	MINI-BUS	PRIVATE CAR	TOTAL motorized Km	NMT
Peripheral	Ontdekkers	Low income	4,2			4,2		4,2	
		Medium Income	4,2				4,2	4,2	
	Diepsloot	Low income	3			2		2	1
		Medium Income	3				3	3	
Urban	Inner City	Low income	1,5						1,5
		Medium Income	1,5						1,5
	Randburg	Low income	2			1		1	1
		Medium Income	2			1	1	1	1

DISCRETIONARY Trip summary

			Discretionary (per household per week)						
			Total Distance	RAIL	BUS	MINI-BUS	PRIVATE CAR	TOTAL motorized Km	NMT
Peripheral	Ontdekkers	Low income	75km			65		65	10
		Medium Income	90km				85	85	5
	Diepsloot	Low income	60km		10	40		50	10
		Medium Income	75km			20	45	65	10
Urban	Inner City	Low income	35km		20			20	15
		Medium Income	50km				25	25	25
	Randburg	Low income	30km		20		5	25	5
		Medium Income	55km		15		25	40	15

AGGREGATED TRIPS

	Main mode (total km/household) - per day				
Zone	**Train**	**Bus**	**Minibus- taxi**	**Private car**	**Total km**
Peripheral Low	0,00	8,41	104,80	0,00	**113,21**
Peripheral Medium	0,00	0,00	1,43	115,29	**116,71**
Urban Low	16,00	2,86	15,90	0,36	**35,11**
Urban Medium	0,00	6,97	1,00	29,57	**37,54**

AGGREGATED TRIPS kgco²/household/day

	Main mode (total kg CO2/household) - per day				
Zone	**Train**	**Bus**	**Minibus- taxi**	**Private car**	**Total kgCO2e**
Peripheral Low	0,00	0,92	11,48	0,00	**12,41**
Peripheral Medium	0,00	0,00	0,16	38,95	**39,10**
Urban Low	1,20	0,31	1,74	0,12	**3,38**
Urban Medium	0,00	0,76	0,11	9,99	**10,86**

Stakeholder engagement

The technical assumptions and observed parameters for the study were supported by stakeholder engagement. Engagement also assisted in identifying sources used as reference in the study which included data sets, published sources and publicly available studies.

Sessions with key stakeholders provided the project team with further technical guidance, input and access to additional data sources, particularly informing the assumptions

At this engagement the primary assumptions were presented and tested with stakeholders.
They provided input into validating key fields such as the definition of urban and peripheral within the context of the study, as well as the building life-span. In addition they suggested sources to support transport and operational energy assumptions.
The list of attendees is recorded below.

Client Representatives

- Jo Anderson | Green Building Council of South Africa
- Carel Kleynhawns | Divercity Urban Property fund
- Georgina Smit | Green Building Council of South Africa

External Key Stakehodlers

- Stefan Van Niekerk | City of Johannesburg
- Muhammed Sayed | Development Bank of Southern Africa
- Christina Culwick | Gauteng City Region Observatory
- Mzukisi Gwata | City of Johannesburg
- Geoffrey Bickford | South African Cities Network

Arup Team:

- Celia Puertas | LCA Specialist
- Damien Canning | LCA Specialist
- Yusuf Raja | Environmental Practitioner
- Tessa Brunette | Sustainability Specialist
- Mohamed Kajee | Transport Engineer and Planner
- Aamena Desai | Urban Designer
- Zayd Vawda | Electrical Engineer

Additional sources reviewed

In addition to the data sets and information provided by the client and sourced by Arup, and the input of stakeholders; a number of documents and sources including policy documents, studies by others and media sources were reviewed and provided background information to the study. These are listed below per theme:

CONSTRUCTION

- **Author:** BUSINESS WIRE
  Article title: South Africa Construction Market 2021-2025: Key Trends and Opportunities Post COVID-19 ResearchAndMarkets.com
  Website: Businesswire.com

- **Article title:** Deconstructing-south-africas-construction-industry-performance
  Website: mg.co.za | engineeringnews.co.za
  [Accessed 4 August 2021].

- **Author:** Research Markets
  Article title: South African Construction Industry, 2015-2019 & 2020-2024 - Growth Prospects by Market, Project Type and Construction Activity
  Website: globenewswire.com

EMISSIONS

- **Article Title:** South Africa saw-a-rise-in carbon-emissions in 2019
  Available at: qz.com | climatelinks.org

- **Author:** World Green Buildng Council
  Title: Bringing Embodied Carbon Upfront 2020
  Website: www.worldgbc.org

HOUSING

- **Document:** The South African Housing Market Overview 2015
  Website: housingfinanceafrica.org

- **Document:** PUBLICLY-AVAILABLE-ADMINISTRATIVE-DATA-ON-SUBSIDISED-HOUSING-FINAL-30-SEPT-2019-CG.
  Available at: cch.co.za | housingfinanceafrica. org | cch.co.za [Accessed 4 August 2021]

- **Available at:** statssa.gov.za | ooba.co.za
  [Accessed 4 August 2021].

- **Document:** Towards-the-development-of-a-national-white-paper-on-human-settlements-
  Available at: westerncape.gov.za

- **Document:** Housing delivery South Africa.pdf
  Available at: dhs.gov.za | fullercenter.org

TRANSPORT

- **Document:** Published 2019, University of Johannesburg, Household travel survey for the City of Johannesburg, 2018, Published by Community Agency for Social Enquiry (South Africa)
  Available at: ujcontent.uj.ac.za [Accessed 4 August 2020].

- **Article title:** The state of public transport in South Africa
  Website: saferspaces.org.za

- **Article title:** Commuting costs the poor dearly -The Mail & Guardian
  Website: mg.co.za

- **Author:** Phakamani Mvelashe
  Article title: Our readers share how much they spend on public transport monthly – it can cost up to R1500 to get to work for some | Drum
  Website: news24.com

URBANISATION

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