Integrated Residential Household Energy Consumption and GHG Emissions Modelling at Metropolitan Scale

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Key messages and findings

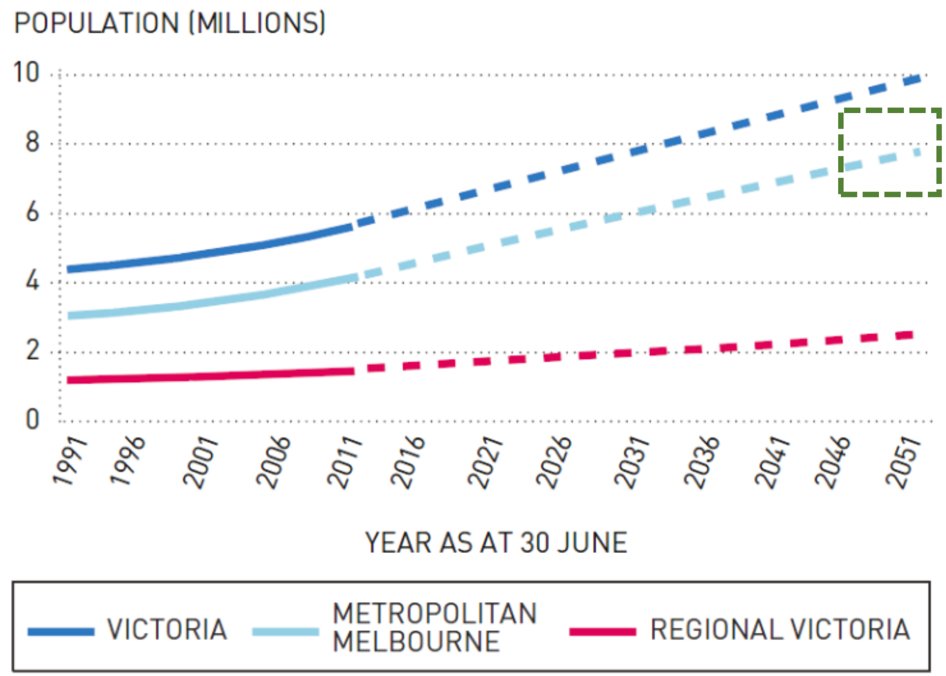
- The research have developed a methodology for integrating building energy and residential transport energy consumption and GHG emissions.
- The models were tested in different urban growth scenarios and the results analysed with the current and future urban planning regulations for Metropolitan Melbourne, showing that more disperse, car depended scenarios have a large impact on urban carbon emissions.
- The model can be a valuable help for decision makers on the impacts of urban form configurations for future urban settlements, looking for a reduction of GHG emissions and sustainability goals proposed by the metropolitan and federal authorities in Australia.
- Further research is needed regarding the building typologies changes over time, the impact of user behaviour and self allocation in residential transport, integration of the model with land use tools and current and future planning regulations and the impact of future transport technologies into the modelling.

Introduction

- **70%** world population living in cities in the next 30 years (UN-Habitat, 2014)
- Australia population will grow to **35 millions in 2050** (ABS, 2011)
- Melbourne Metropolitan area to have **7.7 million** inhabitants in 2050 (ABS, 2013)
- Australian Carbon Emissions per capita is rank **11th** in the world (UNEP, 2013)
- **89%** of electricity in Australia is produced by **non renewable sources**, mainly carbon and gas. (BREE, 2014)

FIGURE 2 – HISTORICAL AND PROJECTED POPULATION, 1991-2051

SOURCE: AUSTRALIAN BUREAU OF STATISTICS, 2013; DEPARTMENT OF TRANSPORT, PLANNING AND LOCAL INFRASTRUCTURE PRELIMINARY PROJECTIONS, 2014



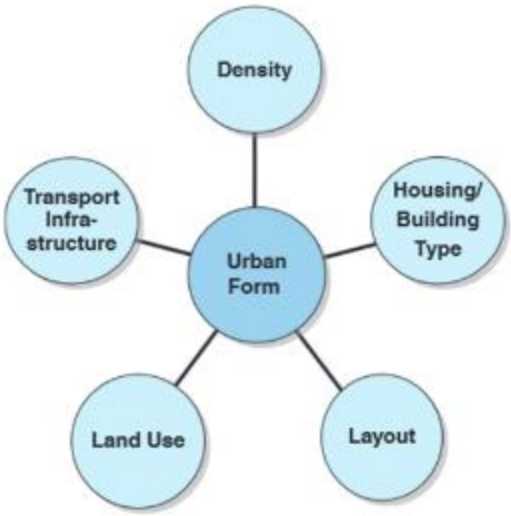
Questions

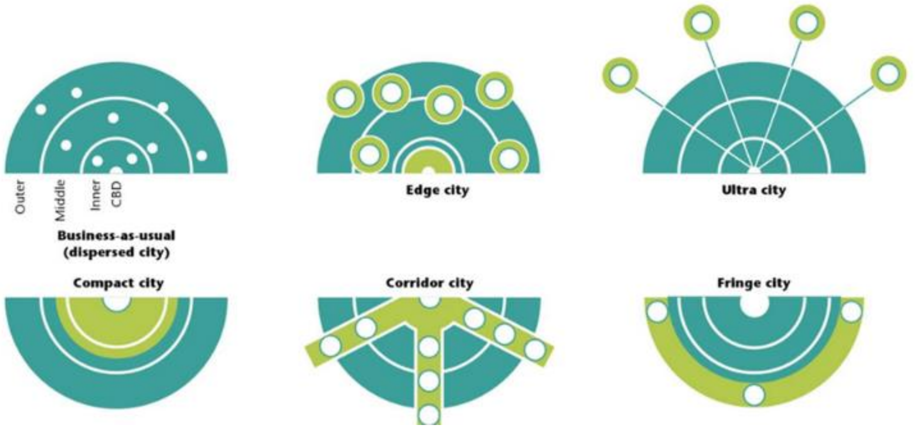
How can Australia cities reduce their ***energy and GHG emission footprints*** *while accommodating a growing population and maintaining their quality of life?*

What are the ***impacts of planning and design decisions that shape urban form and structure*** *on the energy and GHG emission footprints of our cities?*

Urban Form

- The structure and pattern of built form in cities (Jenks, 2007)
- To accommodate more people, continuing debate on compact vs. suburban development (Adams, 2009)
- At a macro level, the archetypical urban forms can range from Compact City, Edge City, Ultra City, Corridor City, Fringe City and BAU (Business as Usual) (Newton et al, 1997)
- But macro urban forms can also be a mix of these (Alford & Whiteman, 2009)





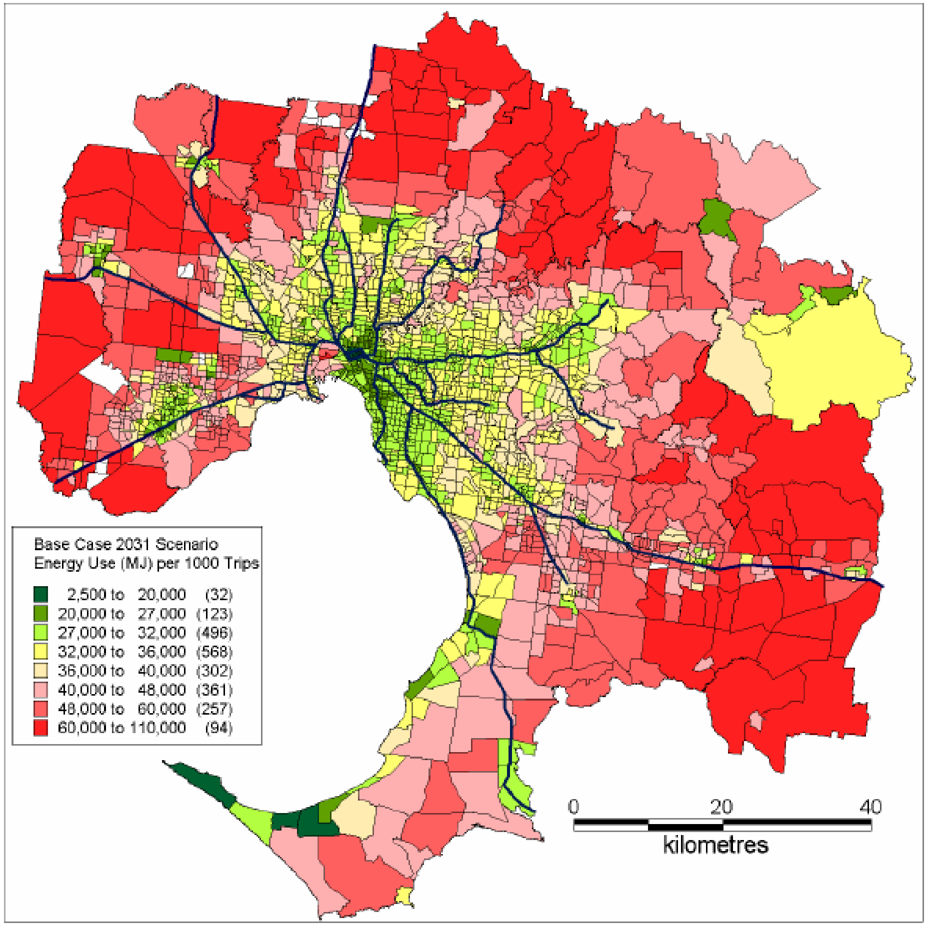
Urban Form and GHG emissions (1)

Scenario	CO	VOC	NO_x	SO_2	PM_{10}	Link CO_2
Base Case 1991	2099.7	456.8	236.7	43.0	24.9	20616.6
Business-as-usual: urban growth in existing proportions at same locations	2569.9	531.1	279.5	44.3	28.2	26638.3
Compact: all new urban growth confined to the inner city	1376.6	366.6	289.3	42.1	24.7	15136.7
Edge: all new urban growth in edge cities	1751.7	409.0	230.1	43.3	27.6	20858.3
Corridor: growth confined to greenfield sites in outer metro corridors	1694.0	404.0	231.4	43.5	28.2	22499.8
Ultra: 70% of growth confined to regional centres within fast rail commuting distance	1767.7	412.4	237.1	43.7	28.5	22374.5
Fringe: growth confined to outer fringe.	1842.1	420.7	239.0	43.6	28.3	21119.0

From: Re-shaping Cities for a more sustainable future: Exploring the link between urban form, air quality, energy and GHG emissions (Newton et al. AHURI, 1997)

Urban Form and GHG emissions (3)

Figure 95 - Base Case 2031 Scenario – Energy Use and Trip Efficiency



Base Case 2031 Scenario Energy Use and Trip Efficiency

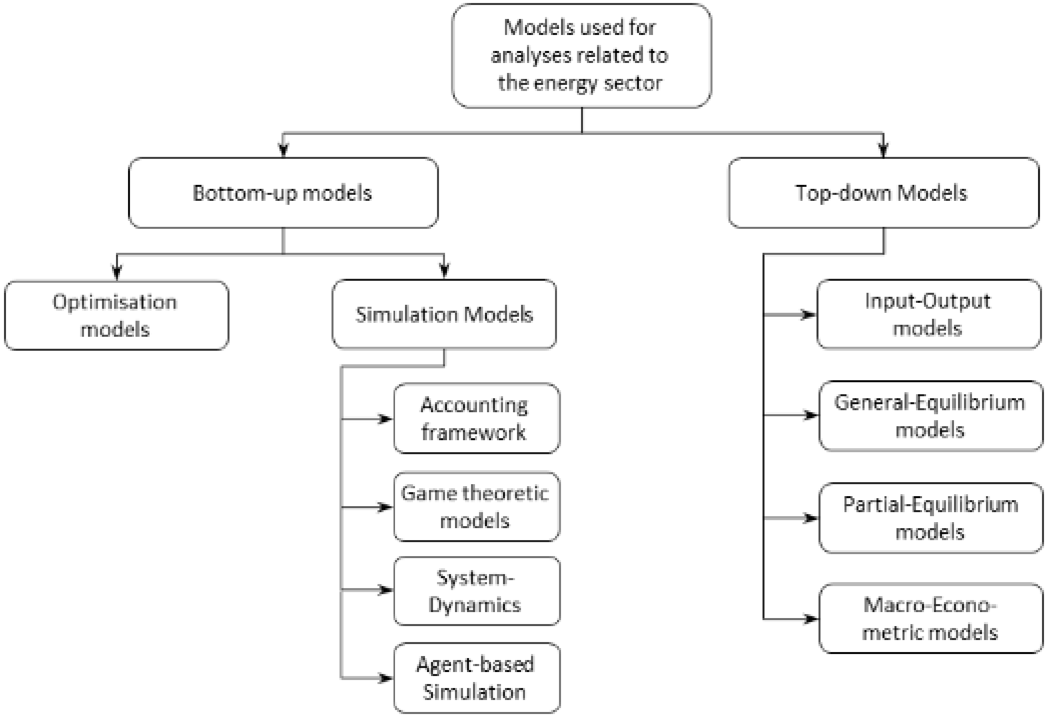
Urban Energy Systems

- The anthropogenic energy consumed by a city is mainly from buildings, transport, industry, construction, water pumping and waste (Kennedy, 2012)
- Buildings (Residential & Commercial) and Transport accounts for approx. 67 % of Energy Consumption in Cities (BREE, 2012)
- Therefore, the study will focus in those sectors of consumption

Ref: Bureau of Resources and Energy Economics (BREE)

Energy Modeling Methods

- **Top-down approaches**
  - Works at an aggregated level
  - Typically use to investigate inter-relationships between energy sector and the economy at large (national, regional)
  - Econometric and Technological
- **Bottom-up approaches**
  - Built up from data on a hierarchy of disaggregated components
  - Useful to estimate individual impact on energy use
  - Statistical and Building Physics.



F. Sensfuß. Assessment of the impact of renewable electricity generation on the German electricity sector - KIT

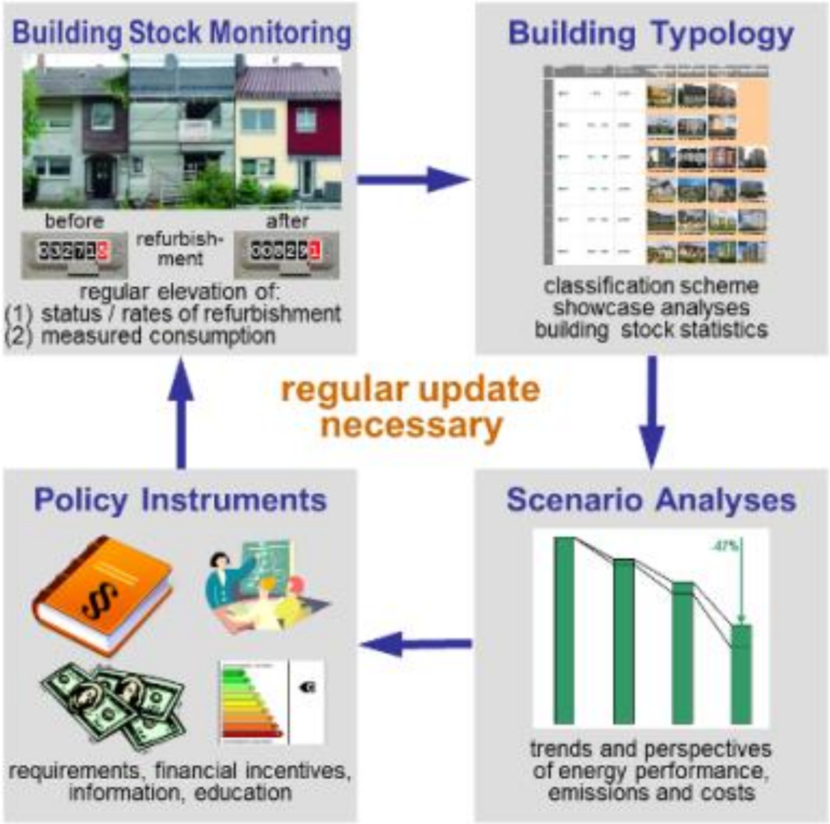
Bottom Up vs. Top Down Energy Modeling Benefits and Limitations (from Swan & Ugursal, 2009)

- **Top-down approaches Benefits and Limitations**
  - Focus on interaction between energy sector and economy at large
  - Avoid detailed technical descriptions
  - Able to model the impact of different social cost benefit energy and emissions broad policies and scenarios
  - Depends on past economy interactions to project future trends
  - Less suitable for examining technological-specific policies

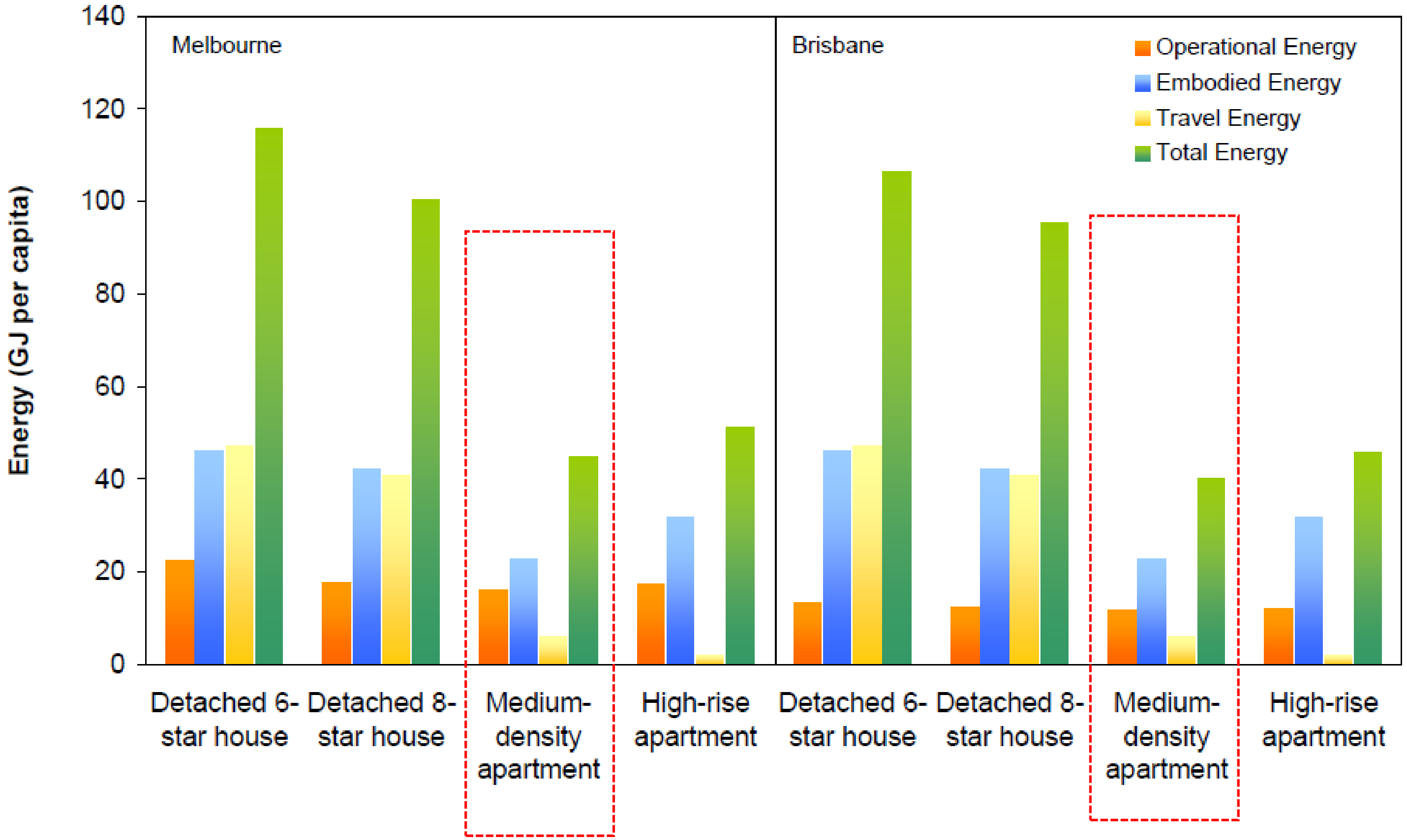
- **Bottom-up approaches Benefits and Limitations**
  - Describe current and prospective technologies in detail
  - Use physically measurable data
  - Enable policy to be more effectively targeted at consumption
  - Assess and quantify the impact of different combination of technologies on delivered energy
  - Requires large amount of technical data
  - Poorly describes market interactions

IEE Project Episcope TABULA

- The overall strategic objective of the EPISCOPE project was to make the energy refurbishment processes in the European housing sector transparent and effective.
- Starting point was the TABULA concept of residential building typologies which was continued and expanded.
- A main outcome is a concerted set of energy performance indicators which shall enable key actors and stakeholders on different levels to ensure a high quality of energy refurbishments

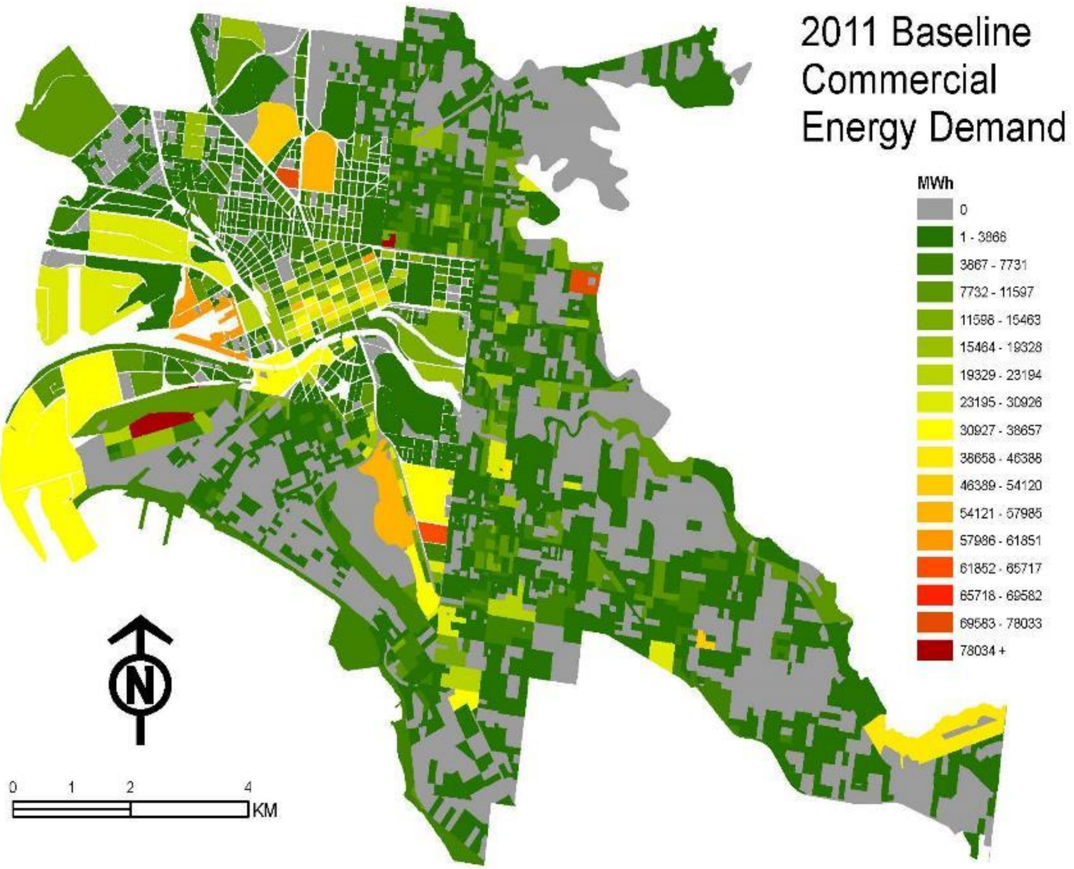


Hybrid Building Energy Typology Assessment



Annual per capita energy consumption for Melbourne and Brisbane, by housing type (Crawford & Fuller, 2012)

CSIRO Bottom Up Building Typology Approach

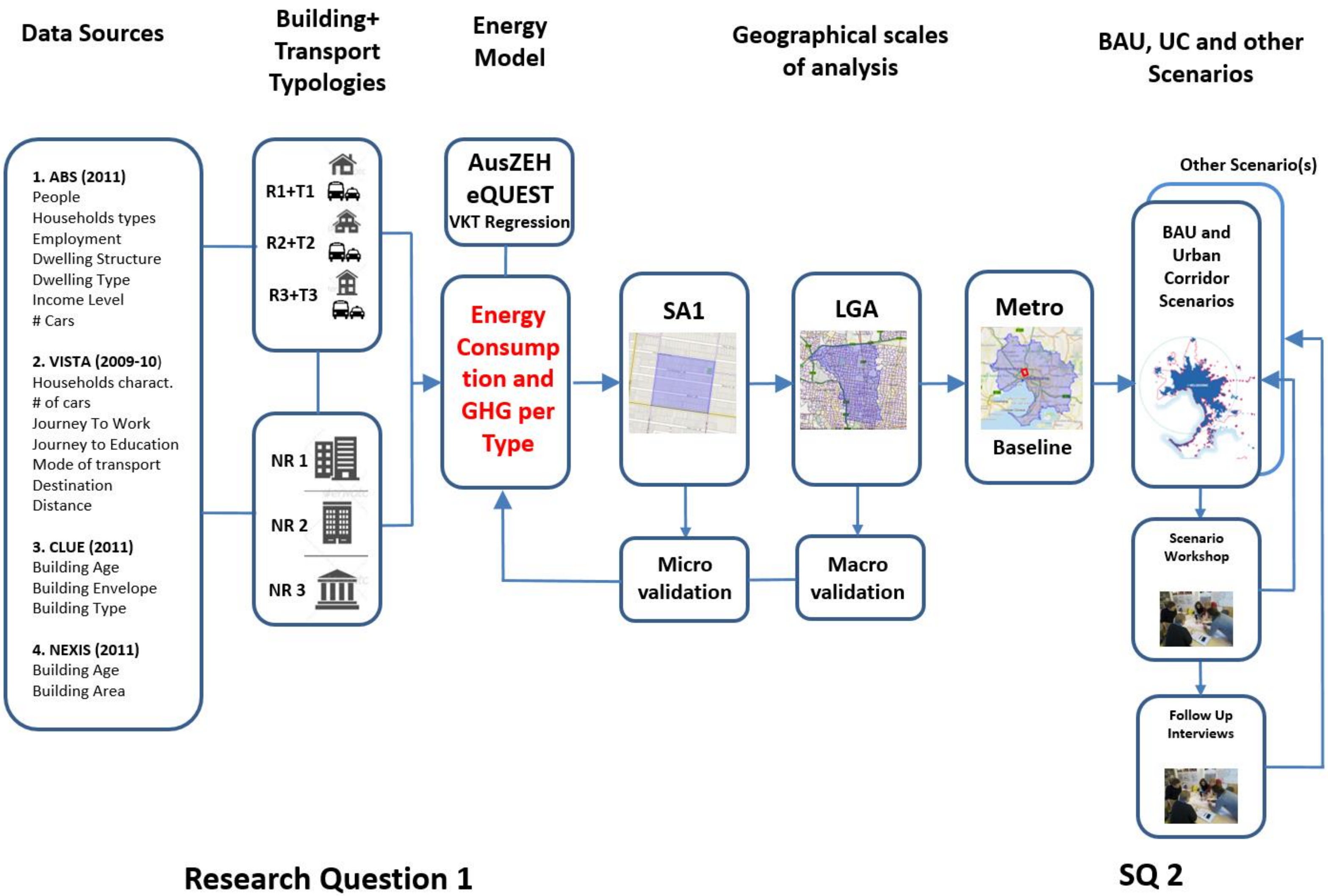


- Modeling of operational energy of residential and commercial buildings in Inner Melbourne at parcel level
- 288 Residential buildings typologies and 90 commercial building types
- Exploration of future scenarios with change of energy mix and retrofitting percentages.
- It doesn’t include transport energy or GHG emissions

Research Challenge

- Need an integrated (building + transport) metropolitan energy consumption assessment that can account for their spatial distribution and changes over time, and be able to scale up from small levels of analysis (SA1) to Metropolitan;
- Need a more diverse building typology modelling approach to be able to assess the impact of new policies and technology adoption in energy consumption in a wide range of building typologies; and
- Need an intermediate bottom up approach that doesn't require extensive and time-consuming simulation runs to assess different scenarios, but a quicker and more practical approach to inform the relative merits (based on energy and GHG info) of alternative development plans, designs and policy options at different urban scales.

Research Methodology



Building Typologies description

Building Typologies Classification Attributes (Seo and Foliente)

Residential Buildings:

1. Dwelling Structure: 4 (high rise, detached, semi-detached, low rise)
2. Dwelling Age: 4 (pre 1991, 1992-2006, 2007-2011, Post 2011)
3. Occupancy Type 4 (couple with no child, couple with children, single parent family, other)
4. Operation hours: 3 (half day, all day, evening)
5. Electricity/gas ratio: (70%-30%)

Non Residential Buildings:

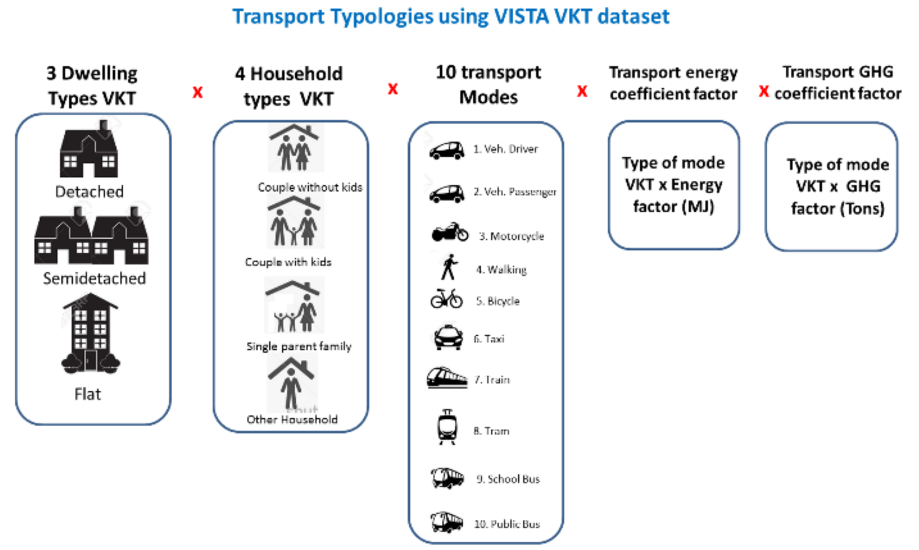
1. Building Structure: 3 (LR, MR, and HR)
2. Building Age: 3 (pre 1980, post 1980, less than 5 years)
3. Business Type: 10 (Commercial accommodation, community use, educational/research, entertainment/recreation, hospital/clinic, office, retail, storage, wholesale, workshop/studio)

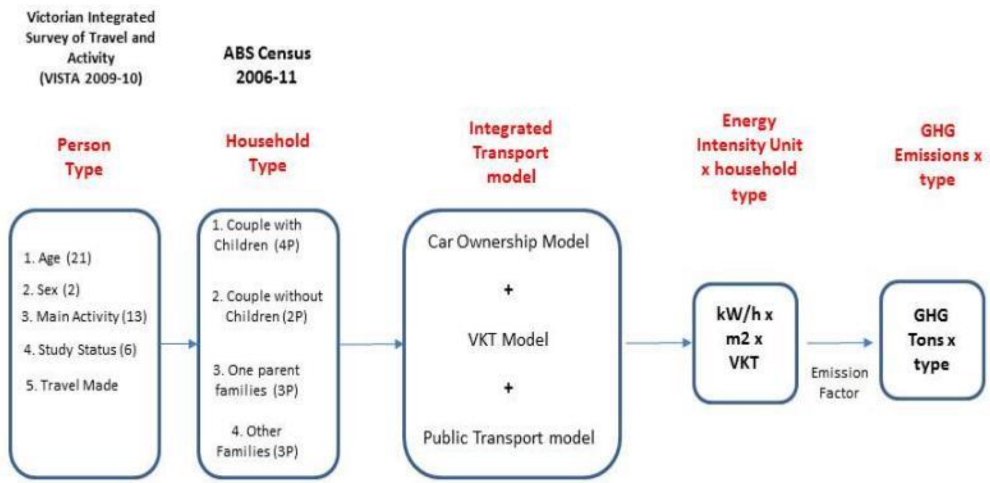
Residential transport model

- The Integrated Transport Model is composed of 3 sub models to estimate the residential VKT (Vehicle Kilometre Travelled) per Household per Mode:

1. Car Ownership Model
2. Car VKT Model
3. Public Transport Model

- The model use linear and nonlinear statistical regression modelling to estimate the predicted values for the scenarios residential transport projections (based on Rickwood, and Corpuz).





Household as modeling integrating element

Household Energy Integration – Building & Transport

	DEMAND													SUPPLY				CONSUMPTION			
BUILDING					LOAD					HOUSEHOLD (ABS)				ENERGY SYSTEM				GROSS ENERGY		UNIT INTENSITY x annum	
BUILIDING TYPOLOGIES	Climate zone	Age	Construction Type	Building Envelope	HVAC	LIGHT	WaHe	APPS	EQUIP.	S	D	F	P	GAS	ELECT	SOLAR	WIND	ENERGY kW/h	GHG m3	ENERGY kW/h/m2	GHG m3/m2
RESIDENTIAL																					
Res. Buidling Typology 1																					
Res. Building typology 2																					
COMMERCIAL																					
Comm.Building Typology 1																					
Comm.Building Typology 2																					

TRANSPORT TYPOLOGIES						SUPPLY TRANSPORT				CONSUMPTION			
						MODE		SOURCE		GROSS ENERGY		UNIT INTENSITY x annum	
						PUBLIC	PRIVATE	FUEL	OTHER	ENERGY kW/h	GHG m3	ENERGY kW/h/m2	GHG m3/m2
		S	D	F	P								
	MOBILITY ACTIVITY TYPES												
	MOBILITY ACTIVITY SUBTYPES												

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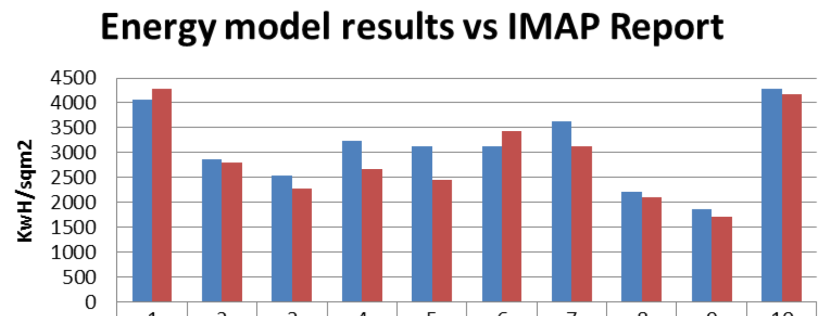
Assumptions and Limitations

- **Building Energy Consumption**
  - Residential (R) and Non-Residential (NR) buildings' operational energy only
  - Not including embodied energy of buildings and technology systems
- **Transport Energy**
  - Household related transport energy consumption only
  - Not including the embodied energy of transport (neither public nor private) and commercial-related transport consumptions (freight and others)
  - The database used for residential transport model is a survey, therefore aggregation and extrapolation needed might create some noise in the results.
  - Externalities such as congestion, speed and age of vehicle stock are not considered yet in this model.

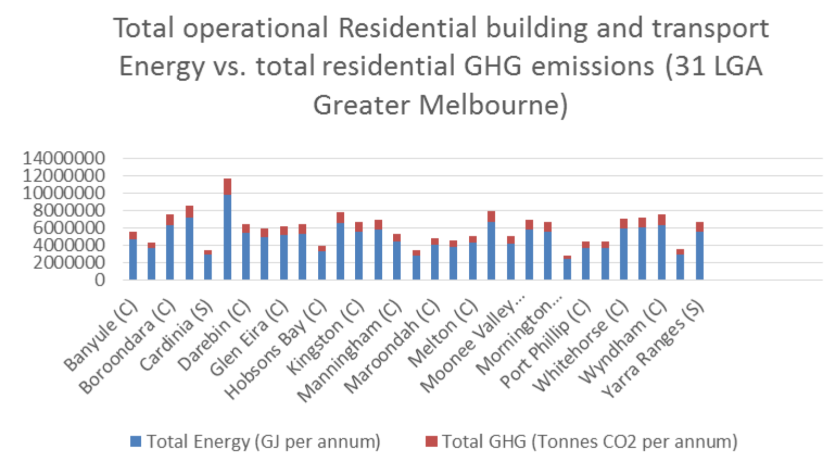
Validation Building Model Results

For comparison, a random set of 10 SA1 from the simulated energy consumption were selected and its overall result per annum was divided in the number of dwellings reported in the ABS 2011 Census.

The results of the residential building average per dwelling of the selected SA1s was 20.003 kWh per annum, showing a difference of 8.5%, and generally a deviation of less than 10% is considered good for studies of this kind (IMAP, 2014).

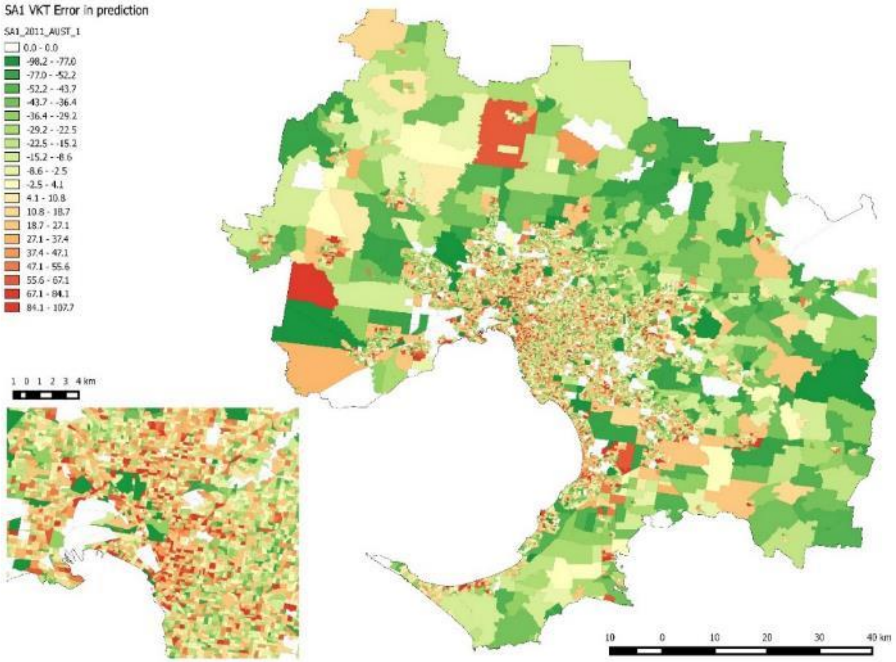


	1	2	3	4	5	6	7	8	9	10
IMAP	4068	2864	2533	3,234	3128	3130	3623	2222	1,875	4,274
Python	4278	2793	2288	2681	2462	3425	3120	2101	1721	4177



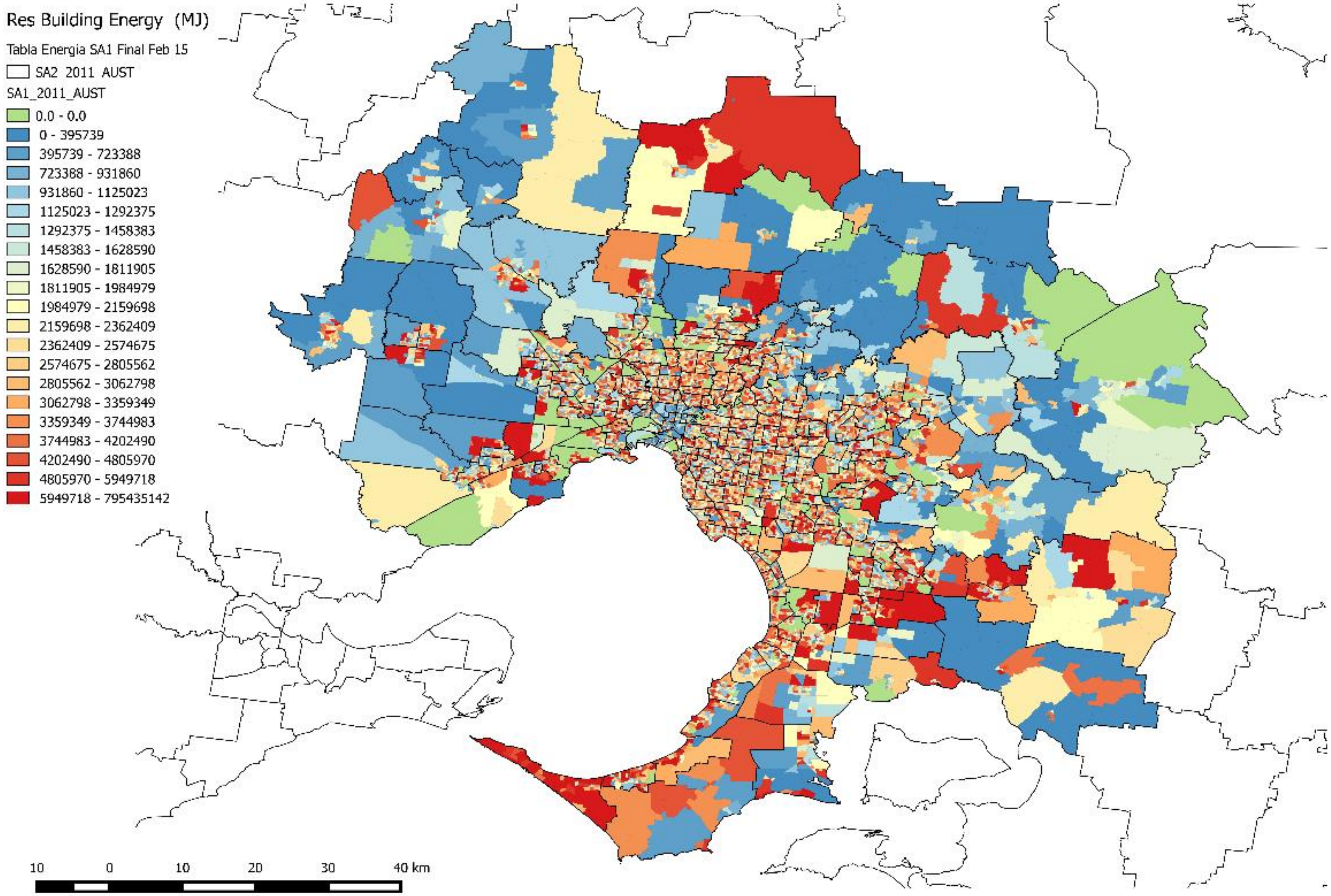
Validation Transport Model Results

- Difference in prediction between observed VKT and predicted VKT mapped in GIS.
- The observed VKT were obtain by averaging the travel distances per mode at SA 1 level and ABS Census information.
- Plotting the differences allows to identified areas were the model is not performing well.

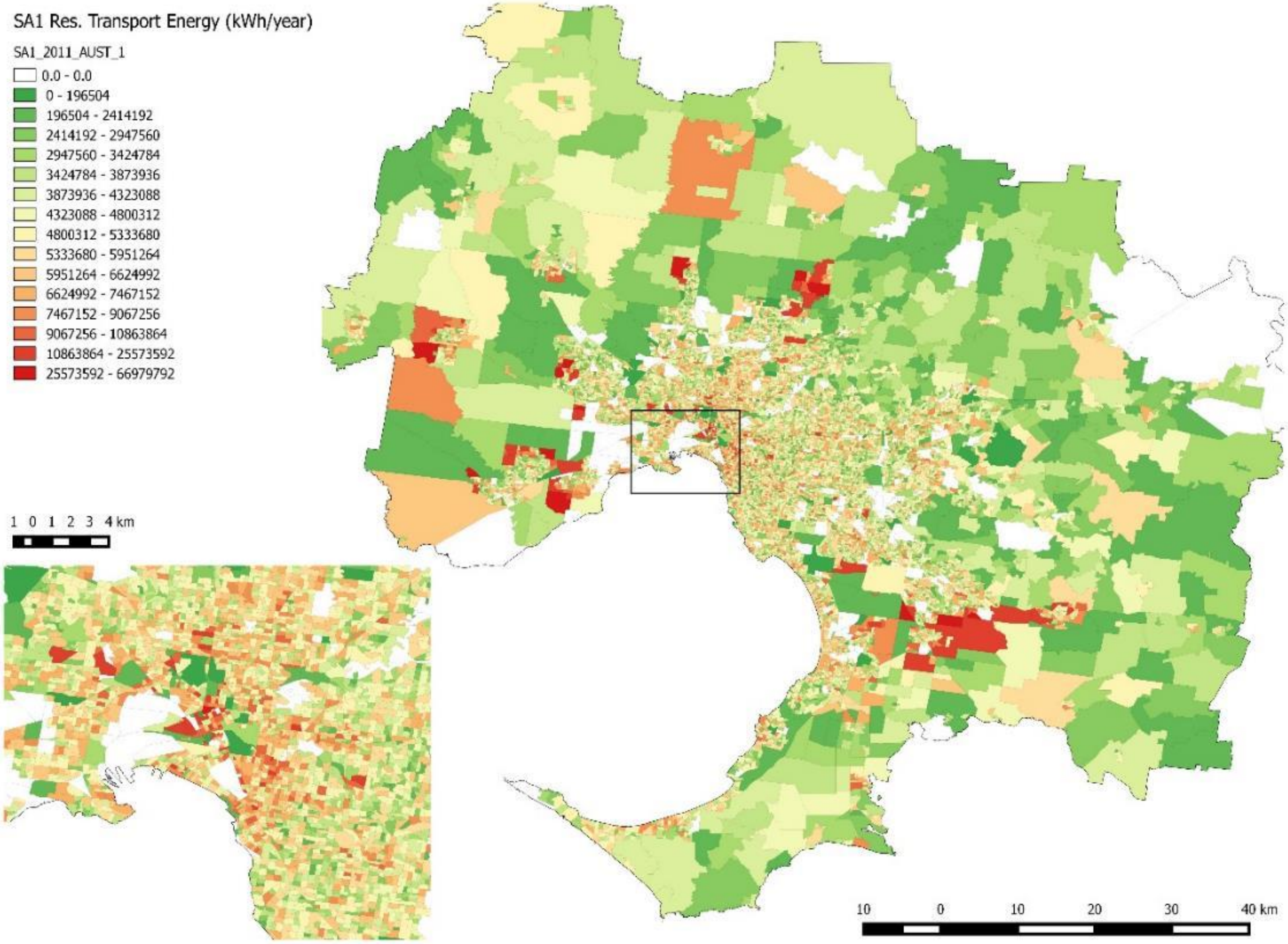


Prediction error = (Predicted VKT_{pc} – Actual VKT_{pc}) / (Actual VKT_{pc}) * 100%

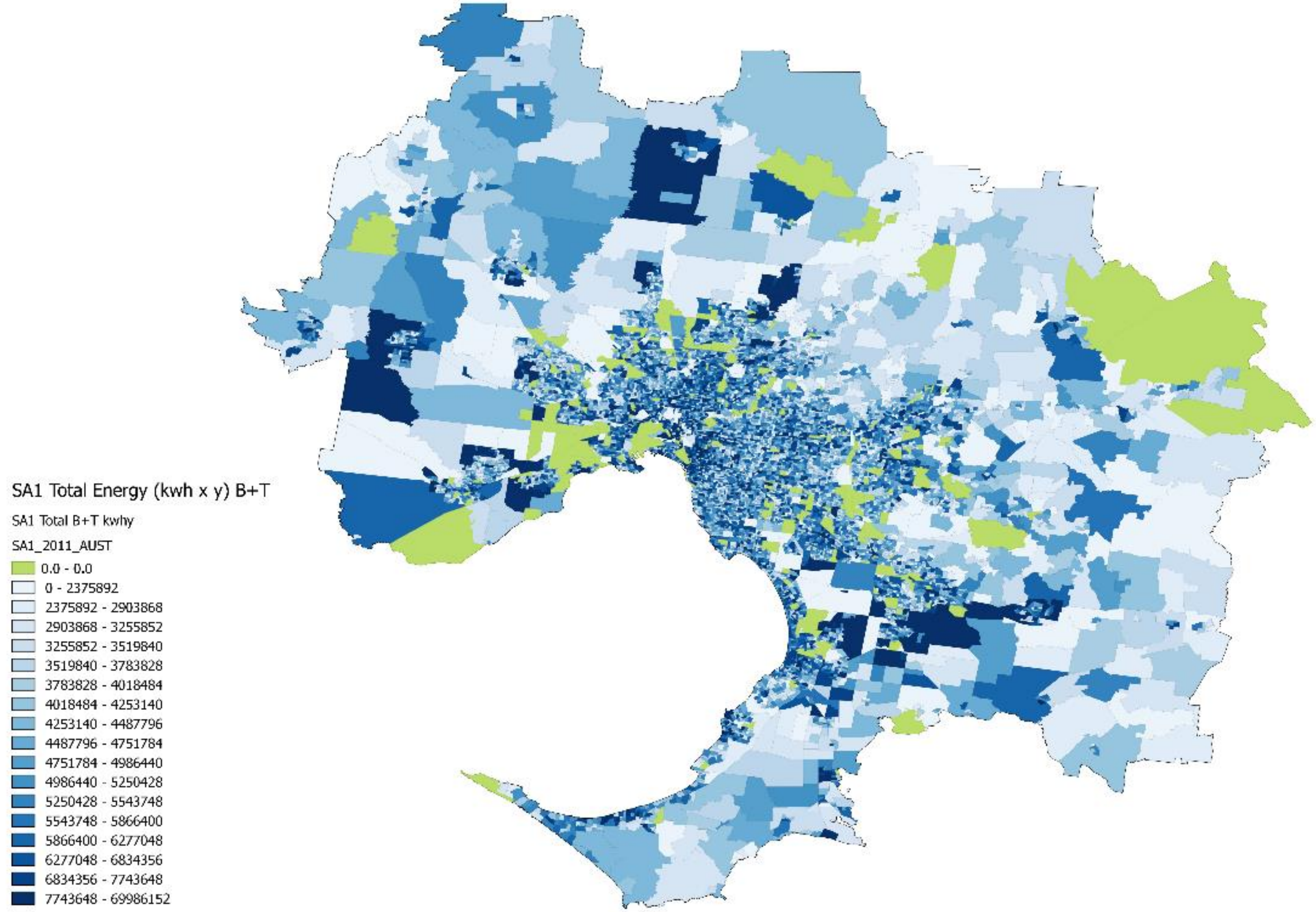
Baseline Residential Building Energy 2011



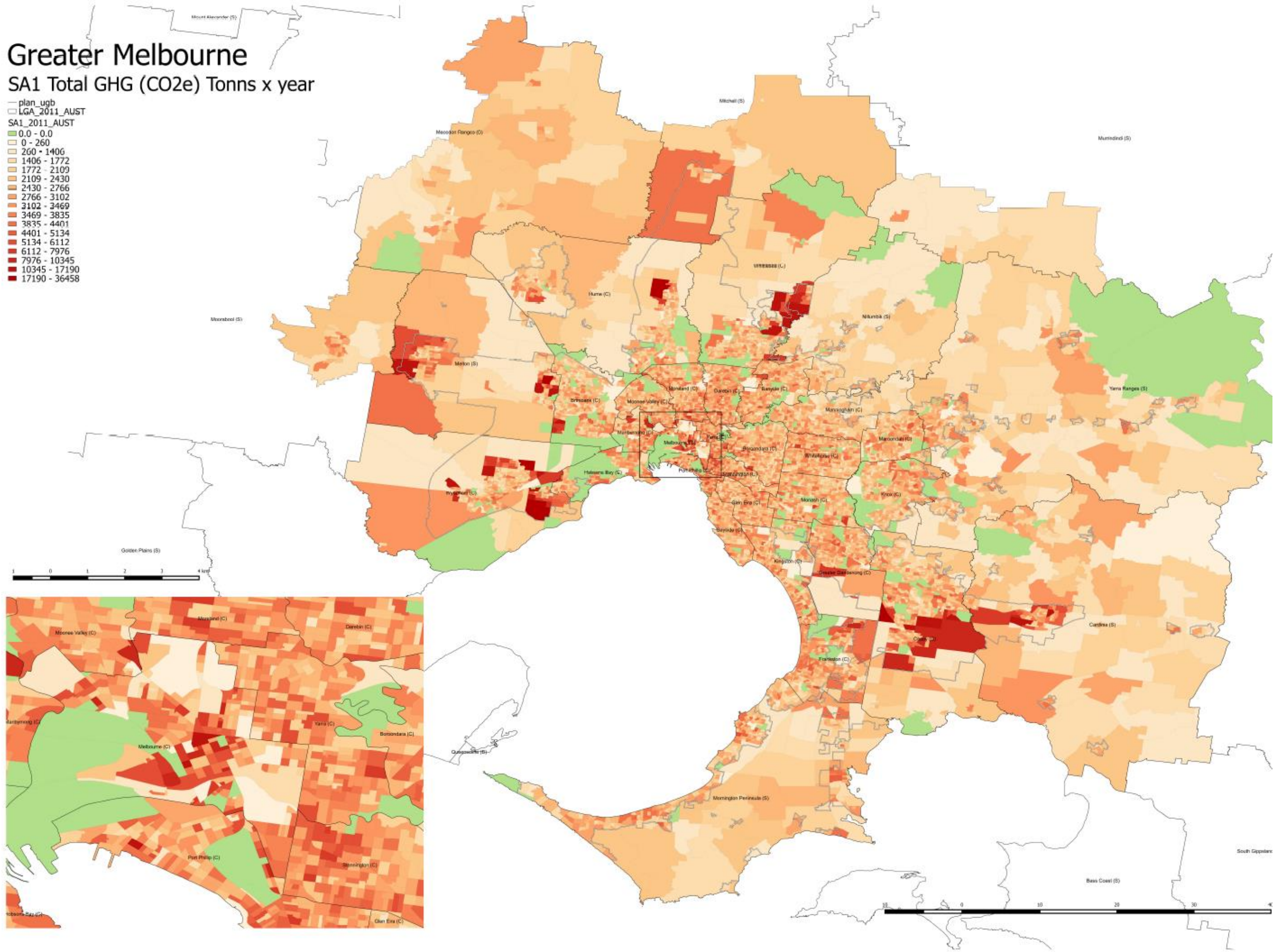
Baseline Residential Transport Energy 2011



Residential Energy Baseline
Buildings + Transport 2011



Residential GHG Baseline Buildings + Transport 2011

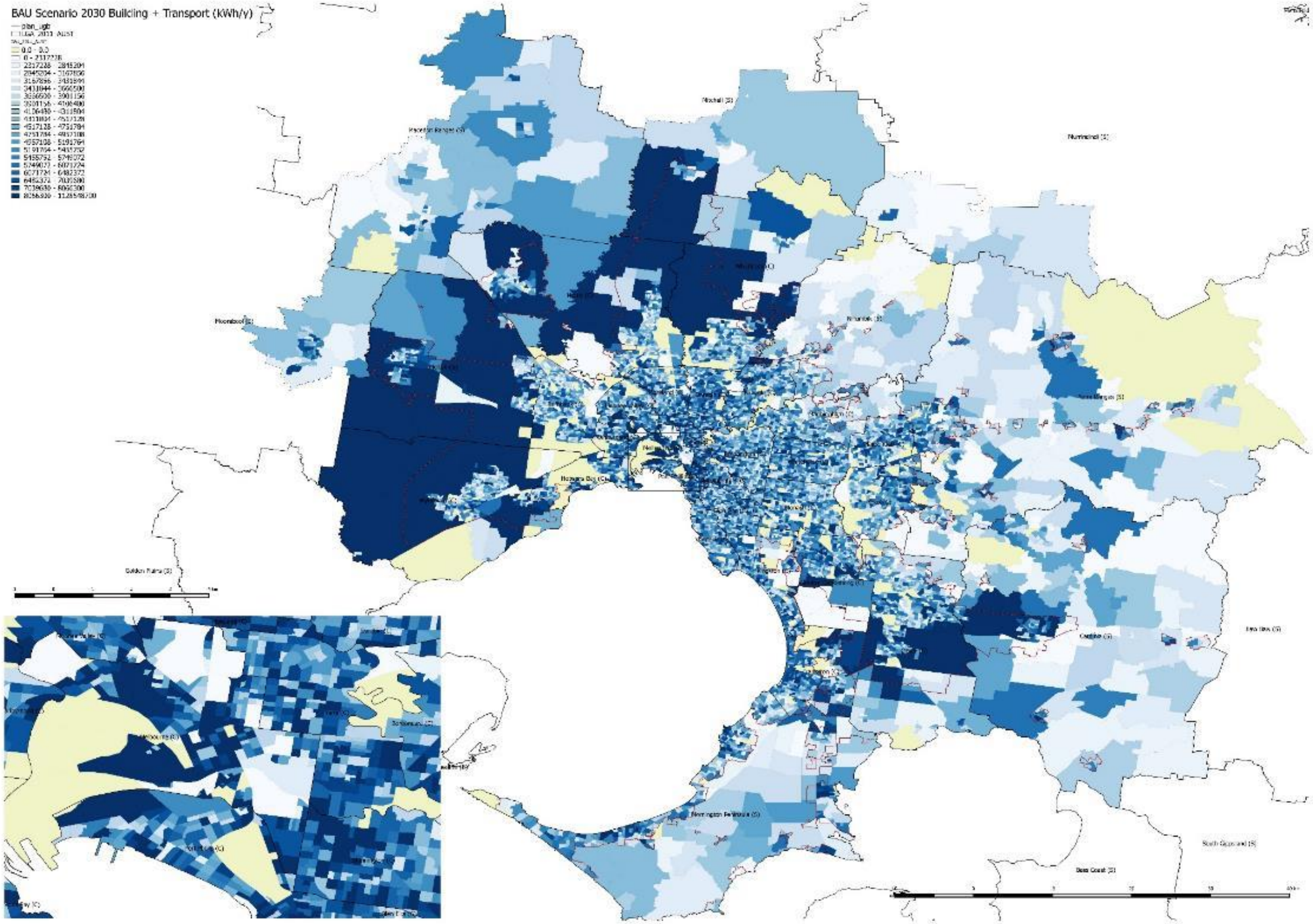


Scenario 1: Business As Usual parameters:

Sources:

Population:	Victoria in Future (2015-2041) VELP Population and Household Projections (ABS, 2015)
Employment:	The Current and Future State of Victoria: a spatial perspective (SGS, 2015) Plan Melbourne 2050 Refresh (Employment Clusters)
Infrastructure:	The current and future State of Victoria: A macro perspective (Deloitte Access Economics, 2016) Public Transport Victoria Network Development Plan The current and future State of Victoria: A spatial perspective (SGS Economics and Planning, 2016) Plan Melbourne 2017-2050
Spatial:	Plan Melbourne 2050 Refresh (2017) ABS Building Approvals per LGA , 2015-2106 Victorian Planning Agency PSP information Land Use Budget info
Energy supply:	Mapping Australia Photovoltaic installations (Australia PV Institute) Delivering Sustainable Urban Mobility (ACOLA) Australia Energy Projections to 2050 (BREE) Victoria Renewable Energy Roadmap (DEDJTR)

Scenario 1: Business as Usual 1



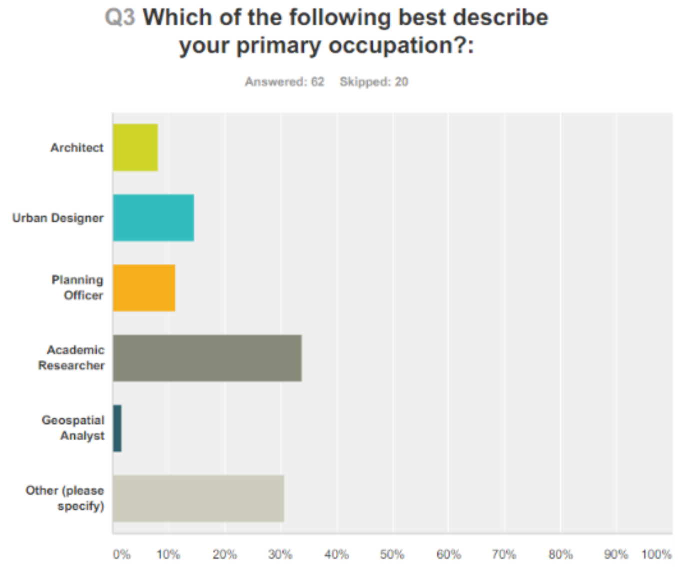
Preparation of alternative scenarios: Urban Growth Online survey results

- The survey collected information about the drivers of change affecting urban growth in Metropolitan Melbourne

- Selected participants gave their opinions about the plausibility of different urban growth scenarios for Metropolitan Melbourne.

The Online Survey was sent to 165 participants from four general stakeholder groups:

1. Urban and Transport Planners (public)
2. Urban Developers (private companies)
3. Local Authorities (council, metropolitan)
4. Professional Experts (Academia)

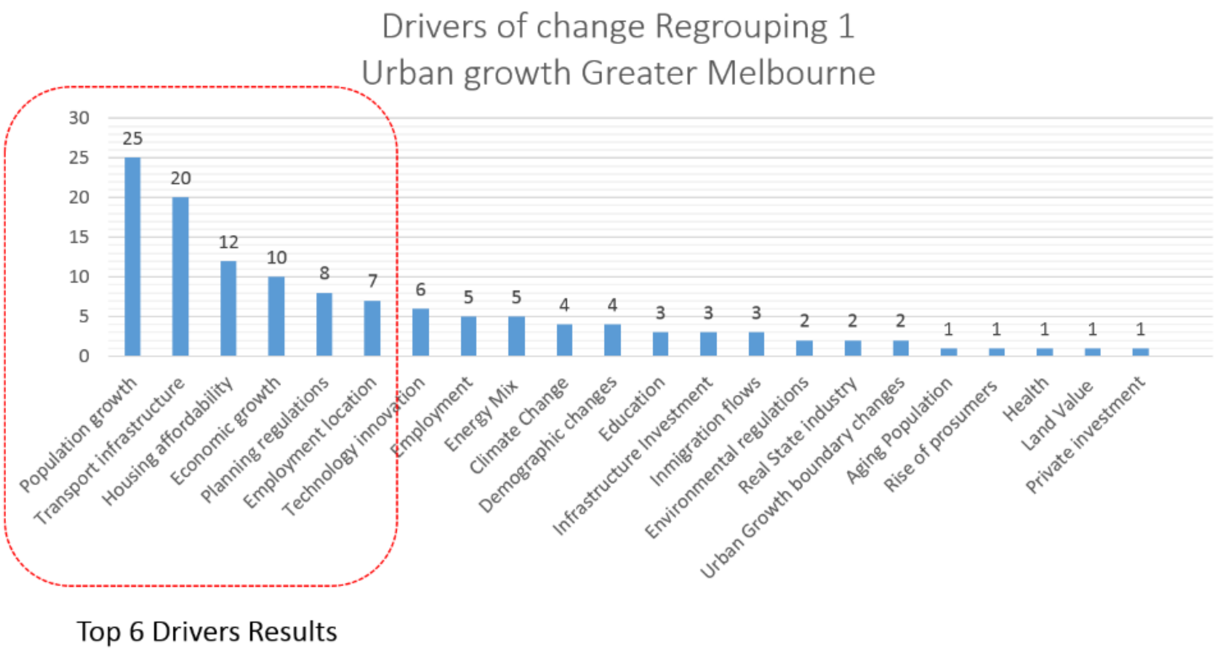


Answer Choices	Responses	
Architect	8.06%	5
Urban Designer	14.52%	9
Planning Officer	11.29%	7
Academic Researcher	33.87%	21
Geospatial Analyst	1.61%	1
Other (please specify)	30.65%	19
Total		62

Preparation of alternative scenarios: Urban Growth Online survey results

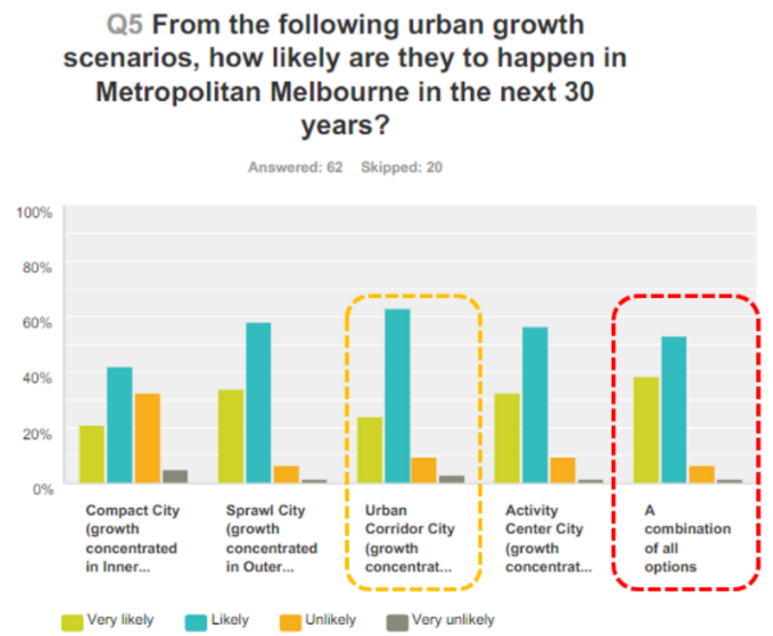
- The survey asked for at least 3 main drivers of urban change in Metropolitan Melbourne organized in order of importance

- The top answer for each driver were regrouped to obtain general trends of drivers to consider in the creation of the urban growth scenarios for Metropolitan Melbourne.



Top 6 Drivers Results

Preparation of alternative scenarios: Urban Growth Online survey results

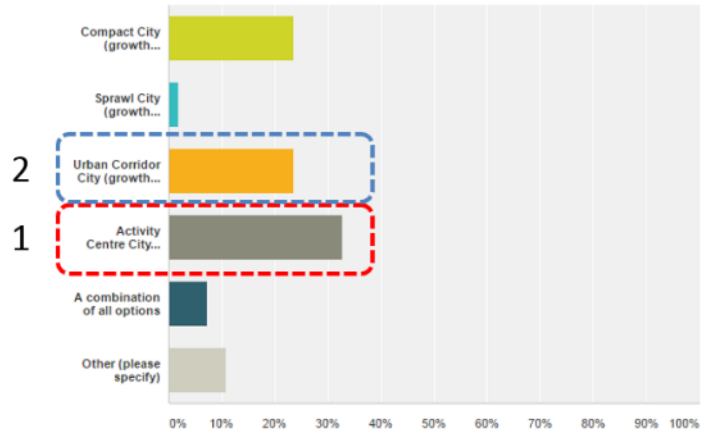


	Very likely (1)	Likely (2)	Unlikely (3)	Very unlikely (4)	Total
Compact City (growth concentrated in Inner Melbourne Area)	20.97% 13	41.94% 26	32.26% 20	4.84% 3	62
Sprawl City (growth concentrated in Outer Melbourne Area)	33.87% 21	58.06% 36	6.45% 4	1.61% 1	62
Urban Corridor City (growth concentrated along main transport corridors)	24.19% 15	62.90% 39	9.68% 6	3.23% 2	62
Activity Center City (growth concentrated around activity centers and Employment clusters)	32.26% 20	56.45% 35	9.68% 6	1.61% 1	62
A combination of all options	38.71% 24	53.23% 33	6.45% 4	1.61% 1	62

Preparation of alternative scenarios: Urban Growth Online survey results

From the following urban growth scenarios, what scenario in your opinion could perform better in terms of reduction of operational energy (1) consumption in buildings and residential transport?(1) Operational energy: Amount of renewable or non-renewable energy required to maintain the building functions and occupant activities and to operate different transport vehicles.

Answered: 55 Skipped: 20



Answer Choices	Responses	
Compact City (growth concentrated in Inner Melbourne Area)	23.64%	13
Sprawl City (growth concentrated in Outer Melbourne Area)	1.82%	1
Urban Corridor City (growth concentrated along main transport corridors)	23.64%	13
Activity Centre City (growth concentrated around activity centers and Employment Clusters)	32.73%	18
A combination of all options	7.27%	4
Other (please specify) Responses	10.91%	6
Total		55

Urban Growth Scenario Workshop

- In this Workshop the participants analysed the energy performance results of the Business As Usual (BAU) and Urban Corridor scenario.

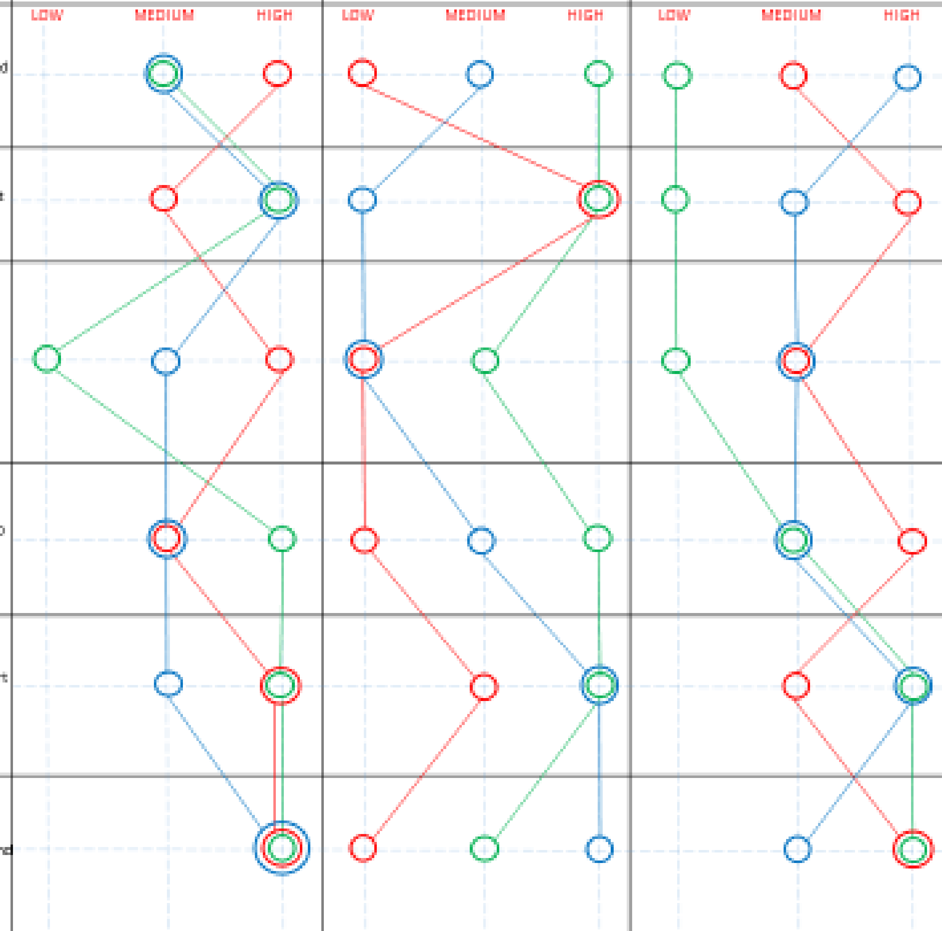
- Selected stakeholders gave their opinions on the proposed methodology, and propose changes or adjustments to the urban growth parameters to be used in the next scenarios.

The workshop had participants from four general stakeholder groups: (16 participants)

1. Urban and Transport Planners (public)
2. Urban Developers (private companies)
3. Local Authorities (council, metropolitan)
4. Professional Experts (Academia)

Urban Growth Scenarios Drivers Matrix

All tables Scenarios settings 1				
Drivers of Change	**BAU 2050 SETTINGS**	**Scenario 1**	**Scenario 2**	**Scenario 3**
1. Population Growth Demographic Changes Immigration Flows Aging Population	Population and demographic change as reported in VIF 2016 and ABS			
2. Transport Infrastructure Investment Transport Accessibility	Follow Plan Melbourne Metropolitan Transport Plan			
3. Economic Growth Housing affordability Employment location Industry diversification Education Real State Industry	Plan Melbourne Employment and Education Clusters			
4. Planning regulations Environmental Regulations Urban growth boundary change	Continue current planning regulations and keep current urban growth boundary			
5. Technology innovation Vehicular fleet change Building Technology change	Changes in vehicular fleet according to Transport department projections – Buildings current 6 star rating standard			
6. Energy Mix Climate Change Rise of the prosumers	Current Energy Supply program shifting to gas and solar generation			



Conclusions and further work

- The research have developed a methodology for integrating building energy and residential transport energy consumption and GHG emissions, using the household type as integrating element.
- The model were tested in different co-generated urban growth scenarios to explore the impact different urban growth configurations in the operational energy and GHG emissions, and it could be applied in other contexts, depending on availability of data and changes in buildings typologies.
- The model can be a valuable help for decision makers on the impacts of urban form configurations for future urban settlements, looking for a reduction of GHG emissions and sustainability goals proposed by the metropolitan and federal authorities in Australia.
- Further research is needed regarding the building typologies changes over time, the impact of user behaviour and self-allocation in residential transport , integration of the model with land use current and future planning regulations and the impact of future transport technologies into the modelling.
- The methodology can be developed into an urban energy mapping web based tool that allows stakeholders for an easy and real time exploration of scenarios parameters changes.