

## **Article Title:** Climate conscious regional planning for fast-growing communities

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### **Abstract**

Climate-conscious development is a topic which has received widespread attention. One consequence of this is the prominence of greenhouse gas (GHG) emissions reduction targets set at various administrative levels (i.e. global, national, provincial and local governments). Despite the global interest, current models are incapable of integrating GHG emission reduction into the urban planning. This study presents lessons learned from a climate conscious growth study conducted for a fast-growing municipality in Okanagan, British Columbia, Canada, offering a model for local government target-setting generalizable across networks of communities, leading to significant cumulative GHG reductions at global scale. The study uses the results of engineering-based research to evaluate multiple planning scenarios developed to explore options for the subject municipality's future urban form and the associated GHG emissions for the target year 2040. Overall municipal GHG emissions for each scenario were simulated in the study considering the residential and transportation emissions projections. The findings indicated that the lowest emissions scenario was the ultra-compact growth model without area structure plan (ASP) allocations. Accordingly, it was concluded that a densified growth strategy with a higher share of multi-unit residential development is the technically best path forward in municipal growth planning to meet climate action targets. Negative public perception of increased densification in urban areas remains an obstacle to the technically best solution. Moreover, per capita basis could be a more feasible approach for GHG emissions target setting. This study's outcomes are expected to inform public sector institutions and decision makers in setting GHG targets and climate action planning.

***Keywords: Climate change, Regional Growth planning, Fast-growing municipalities***

# 1 Introduction

Climate change is one of the key challenges of the 21<sup>st</sup> century. In 2016, the United Nations Paris Agreement amongst 191 countries set ambitious new goals to combat climate change, including an agreement to implement measures to limit the global temperature increase to 1.5 °C above the pre-industrial levels [1]. In seeking measures to achieve this target, climate change mitigation plans are becoming increasingly prominent at national, regional and local government levels around the world.

Federal and provincial governments in Canada have worked actively over the last decade to reduce greenhouse gas (GHG) emissions. As part of its commitments under the Copenhagen Accord, the Government of Canada aims to reduce GHG emissions by 30% below the 2005 levels by 2030 [2]. In 2014, total GHG emissions in Canada were 732.6 Mt CO<sub>2</sub>eq<sup>1</sup>, a 2% decrease from the 2005 levels [3]. The province of British Columbia (BC) accounted for 8.6% of Canada's GHG emissions in 2014, putting the province among the top five provinces for GHG emissions in Canada [3]. BC too has legislated aggressive GHG reduction targets to address climate change. GHG emissions in the province are expected to be reduced by 33% from 2007 levels in 2020, and by 80% in 2050 [4]. In 2012, BC was able to reduce GHG emissions by 4.4% from 2007 levels [5]. However, more recent findings reveal that BC will miss achieving the aforementioned ambitious emissions reduction targets if current emissions trends continue [6]. More aggressive approaches are required if BC and Canada are to achieve their emissions reduction targets.

In response to emissions-induced climate change, an interest in transitioning into low carbon societies has emerged among urban planners and the construction industry [7]. Estimation of carbon footprint has become a critical aspect of urban planning [8]. According to Community Energy and Emissions Inventory (CEEI) of BC, GHG emissions at the municipal level are mainly attributable to transportation (~60%) and building sectors (~27%) [9]. Hence, regional growth planning strategies need to focus on reducing GHG emissions from the above sectors [10].

Strategic urban planning is a key tool for mitigating climate impacts and achieving wider sustainability goals [11][12][13][14][15]. Increased urban density is one strategy for achieving considerable GHG emissions reductions [10]. Energy and emissions planning is conducted in several Canadian municipalities to pursue sustainability goals [16] (e.g. City of Toronto [17], City of Kelowna [18], City of Nanaimo [19], City of Burlington [20], City of Nelson [21]). Since up to 80% of the Canadian GHG emissions are due to energy use [22], the largest portion of potential municipal emissions reductions may come from reducing energy-related emissions, as framed in a community energy plan.

Sustainable urban energy planning can influence a neighbourhood's energy demand and its effect on climate change [23]. Such a plan combines urban planning, living patterns, energy conservation, renewable energy use, transportation planning, and waste management activities at the local level, including and integrating assessment of the environmental, economic, and social impacts of such measures. Moreover, sustainable urban energy and emission planning can optimize intended energy resource and service allocation, capacity expansion planning, system cost, and system reliability with maximized energy security [24]. Energy efficiency improvement and conservation measures make up the major part of community energy planning efforts in Canada, with limited attention being given to long range energy planning [25].

Since citizens are key stakeholders of municipal-level decision-making, public acceptance is key to planning and successful implementation of climate conscious growth plans. Emissions reduction and the

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<sup>1</sup> Megatonnes of Carbon Dioxide equivalent

resulting environmental benefits contribute to the wellbeing of the society in the long run. However, the issue of costs and who bears them often acts as a barrier to adoption of sustainable practices. One key step to surmounting this barrier is active engagement of all stakeholders in community-level energy and emissions planning, together with efforts to ensure equitable distribution of benefits to stakeholders. Published literature has overlooked on inter-disciplinary methods that assist in regional energy and emission planning.

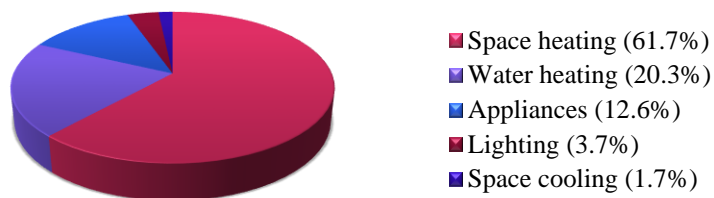
This paper presents lessons learned in a regional growth planning study performed for a fast-growing municipality in British Columbia, Canada, with implications for planning in similarly-situated Canadian and other local governments. Based on the findings, a comprehensive approach is proposed in developing a climate-conscious urban growth planning strategy for municipalities. Particular attention has been shed on uncertainty in urban planning, and the strategies for coping with such uncertainty. It is expected that the study will assist local governments in seeking to achieve climate action targets typically framed in terms of greenhouse gas reduction. The proposed method could be used as a multi-disciplinary road map for energy and emission planning for urban expansion.

## 2 Literature Review

The steady improvement of urban planning practices is supported by a growing body of knowledge integrating planning objectives with environmental performance objectives. Yigitcanlar and Teriman (2015), for example, proposed an integrated urban planning and development approach for achieving sustainability targets [26]. Lee and Lee (2014) have studied the impact of urban density on GHG emissions in the USA, demonstrating that doubling of regional population density could achieve GHG emissions reductions as much as 35% and 48% from household transportation and residential energy sectors respectively [10]. Caparros-Midwood et al. (2015) and Huang and Zhang (2014) have used an optimization-based approach for urban form planning under several sustainability objectives [27][28].

### 2.1 Energy use in the residential sector

Five Canadian economic sectors constitute the national energy demand: residential, commercial and institutional, industrial, transportation, and agriculture. The residential sector accounts for 17% of Canada's secondary energy use, and 14% of the national GHG emissions [29]. The residential building subsector includes single family housing, row housing, multi-family housing and other housing types (such as mobile homes and cottages). A 15% increase in total GHG emissions is expected from the Canadian residential sector between 2012 and 2020 [30]. The main energy end uses of the Canadian residential sector are space heating, water heating, lighting, appliances, and space cooling [31]. Figure 1 depicts the percentage contributions of the end uses to the overall residential energy demand.



**Figure 1: End uses of residential energy in Canada**

Residential energy demand is met by primary<sup>2</sup> and secondary<sup>3</sup> energy sources. Figure 2 illustrates an overview of residential energy consumption, analyzed in terms of the energy sources, dwelling types, and

<sup>2</sup> Primary energy sources are used can be utilised in energy generation directly in the form they are harnessed from the nature, such as coal, oil, natural gas and wood, geothermal heat etc.

<sup>3</sup> A secondary energy sources is one generated from using a primary resource, such as electricity from coal or geothermal heat

end uses. This is derived from information published by Natural Resources Canada and the Government of Canada [31][32][33].

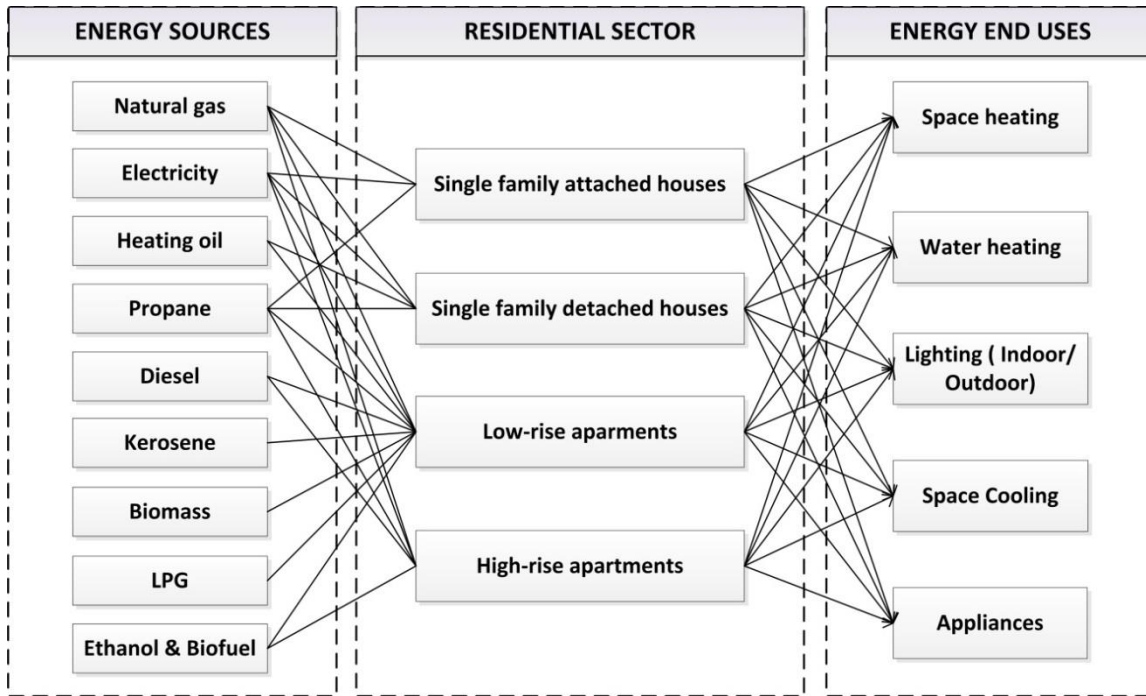


Figure 2: Overview of Residential Energy Consumption

Residential energy intensity varies by the type of dwelling [34]. To a lesser degree, the age of the residential buildings, the efficiency of the installed equipment and building design variations, and the energy use practices of the residents all contribute to variations in energy use between different households [35][23]. Among the residence types indicated in **Error! Reference source not found.**, single-family detached housing has the highest energy intensity per household. In addition, the residential floor space also varies by housing type. Table 1 details the energy intensity and floor area for each dwelling type in BC.

Table 1: Common types of dwelling in BC

<i>Dwelling type</i>	<b>Annual household energy consumption (GJ/household)</b>	<b>Mean floor area (sq. ft.)</b>
<i>Single-family attached houses</i>	76	1,988
<i>Single-family detached houses</i>	125	2,259
<i>Apartments (high &amp; low rise)</i>	46	1,094

## 2.2 Effect of urban density

Energy consumption and GHG emissions are strongly linked to population growth. Moreover, urban sprawl has been identified as a factor with considerable influence on GHG emissions and energy use (in the form of electricity and fuel)[36]. A study conducted in the Toronto Census Metropolitan Area (CMA) associated lower density suburbs with higher GHG emissions, mainly due to the use of private automobiles for commuting [35]. When considering the transportation and building components of the overall urban emissions, it has been noted that transportation emissions are significantly higher in low density development (LDD) in comparison to high density development (HDD)[36]. A case study analysis of the city of Toronto demonstrated that the annual GHG emissions contribution of transportation was 43% in

HDD and 61% in LDD [36]. Shifting from private transportation mechanisms to public transportation and other modes of mobility such as walking and cycling has been proven to have a positive impact on emissions reduction [37]. A high urban density is also associated with shorter commuter journeys [37].

In addition, as previously noted, single family households consume more energy per single housing unit when compared to multi-unit buildings, and low density development comprises a higher share of single family detached housing [36]. Another question arising in determining the best urban form is how the greatest use can be made of the available land [38]. Urban land area is becoming increasingly limited in many parts of the world, and housing has become a key issue in many metropolitan areas.

Proposals to decrease urban energy consumption and associated emissions often advocate increased densification and must secure public support for such densification. While densification is an important means to reducing energy use and improving community sustainability, many communities have socio-cultural reasons for resisting densification [39]. A study conducted in Australia, for example, showed that residents associate increased urban density with lack of aesthetic appeal, overcrowding, and congestion [40]. In addition, social status is often associated with particular housing types, with the higher urban densities being associated in public perception with renting and low-income households [40]. In order to develop a more sustainable municipal growth plan through HDD, it is necessary to also explore and manage the negative perceptions of such development. A participatory approach has been recommended in urban planning to integrate stakeholder values in urban planning process and increase its effectiveness [41].

### **2.3 Emissions forecasting and scenario-based planning**

Scenario-based planning approaches have been considered in many studies, especially with regards to energy use and emissions. Scenario analysis can be an asset in investigating uncertain future impacts, while considering a complex problem under multiple aspects [42]. A review of the literature in this area shows that the majority of the published studies are focused on energy use and GHG emissions. Morales and Sauer (2001) have studied methods to reduce GHGs in Ecuador residential sector. The authors found that energy conservation programs, deployment of energy efficient technologies and enhanced use of renewable energy sources reduce GHG emissions [43]. Similar conclusions were reached by Kadian et al. (2007) who studied energy related emissions sources in households of Delhi, India. The results showed that fuel substitution is a viable option for air emissions reduction [44].

Energy use planning and forecasting approaches can be used in supporting physical interventions and improvement strategies in the building sector. Techniques such as statistical models, engineering methods, artificial intelligence, energy simulation programmes, and hybrid approaches have been used in energy forecasting [45]. While engineering methods are used at the building level to forecast energy performance through thermodynamics and physical principles, artificial intelligence methods (such as artificial neural networks) can be used for prediction at different scales from buildings to urban areas [45]. Simulation models are useful in estimating the effects of hypothetical planning scenarios, especially in identifying the future impact of present decisions [41]. Geographic information system (GIS) based simulation models are also being used in urban scale forecasting [45]. The Long-range Energy Alternatives Planning System (LEAP) software has been used by many researchers previously for community energy planning [46][47][48]. Emissions forecasting by spatial location and population density is used in environmental impact related studies [49].

Sustainable urban energy planning can influence a neighbourhood's energy demand and its effect on climate change [23]. Moreover, sustainable urban energy and emissions planning can optimize intended energy resource and service allocation, capacity expansion planning, system cost, and system reliability with maximized energy security [24]. Community energy planning in Canada tends to focus on energy efficiency improvements and conservation, with comparatively limited attention to long range energy and

emissions planning [50]. Further work is needed to develop tools to support community decision makers in making emissions reduction a daily reality through sustainable urban growth planning.

## **2.4 Uncertainty in urban planning**

Several forms of uncertainty may be identified and distinguished in planning and associated engineering problems. Data uncertainty is the most commonly found form, arising incompleteness or vagueness in the available information [51]. Further uncertainty may arise even in the context of adequate information, as human manipulation of information in light of explicit and implicit preferences may express or induce imprecision giving rise to uncertainty [51]. In scenario-based analysis, the projected scenarios themselves are uncertain in light of their hypothetical nature exploring possibilities as well as probabilities. This is compounded by the uncertainties in the information used in developing scenarios. Uncertainties in scenario planning are also associated with ambiguity carried in assessments of external environmental variables, and the fact that only a limited set of decision options are considered, thus ignoring some possible alternatives [41]. In addition, the defined scenarios may be subject to uncertainties due to changes in the environmental variables, especially over time [52]. It may be difficult to evaluate multiple scenarios due to the epistemic and stochastic (aleatory) uncertainties present in the studied system [53][54]. In contrast to epistemic uncertainties caused by gaps in knowledge, aleatory uncertainties are due to the system variability and therefore cannot be known with precision [53]. Uncertainties in information also affect models [52]. The model design does not always consider an exhaustive list of parameters which may affect the outcome. Hence, the planning models are limited by their own lack of robustness.

The dynamic and complex environment associated with urban planning leads to a high level of uncertainty readily analyzed in terms of the multiple forms of uncertainty surveyed above [55]. One main source of uncertainty is the operational need to rely on assumptions when addressing planning problems, driven by limited data availability subsequently introducing uncertainty into prediction of the future effects of various decisions and choices [41]. In this context, planning problems in urban contexts may be usefully approached as optimization problems under multiple and often conflicting objectives and constraints. The processes, factors, and their interactions in such contexts need to be considered by the decision makers in handling such a problem. The information about interactions between different factors and processes are also uncertain [56]. Urban planning problems also rely on the interests and preferences of stakeholders, especially decision makers. Scenario and model uncertainties are an unavoidable component in scenario based urban planning [41]. Growth scenario selection is highly influenced by planners' choices and expert opinion, and growth projections are subject to the limitations in available data.

A wide range of techniques are used to reduce and manage uncertainty in the context of urban planning. Epistemic uncertainty is often addressed by collection of additional data. Aleatory uncertainty may be addressed by better sampling to improve knowledge of variability. [53]. Probabilistic modelling such as Monte Carlo simulation is often used to address data uncertainty [53]. Monte Carlo simulation generates a range of possible outcomes from specified probabilities, informing quantitative analysis and decision-making. This method was first used in the Manhattan Project which developed the atom bomb in World War II, and has since been used to model many physical and conceptual systems [57]. The use of fuzzy logic-based membership functions is beneficial in accounting for human preferences, as well as vague, imprecise or qualitative data [53][58][59]. A fuzzy-based approach has been used in previous studies to deal with uncertainties in urban planning under a complex environment [55]. Sidi et al. (2008) used a fuzzy optimization approach using evolutionary algorithms to develop a decision support system for real-time regulation of urban transport traffic [58]. Probabilistic risk assessment is conducted to investigate the possible consequences in an uncertain future, with tools such as Bayesian networks [60]. Effective identification of forms of uncertainty in urban planning, together with selection of effective uncertainty-reduction and management techniques will refine urban planning processes, contributing to improved decision-making.

### 3 Methodology

This study investigated the effects of various urban density growth scenarios on the GHG reduction targets of a municipality in British Columbia, Canada. The municipality consists of ten sectors based on geographic location, and the growth plan is associated with these sectors. The goal of the municipal authorities is to identify the most ideal growth strategy in distributing the expected population growth into these sectors. An overview of the methodology is illustrated in Figure 3. The study used the results of engineering-based research to evaluate five planning scenarios for the city's future urban form and forecast associated GHG emissions for target year 2040 at a projected population of approximately 180,382. These scenarios were then compared with the existing situation in the municipality, under the assumption that the business-as-usual-scenario will continue in the future. Public preference survey of city's residents and interviews of land use experts was used to identify public acceptability and preferences regarding future growth strategy. Detailed information about scenario planning and emission forecasting is discussed in following section.

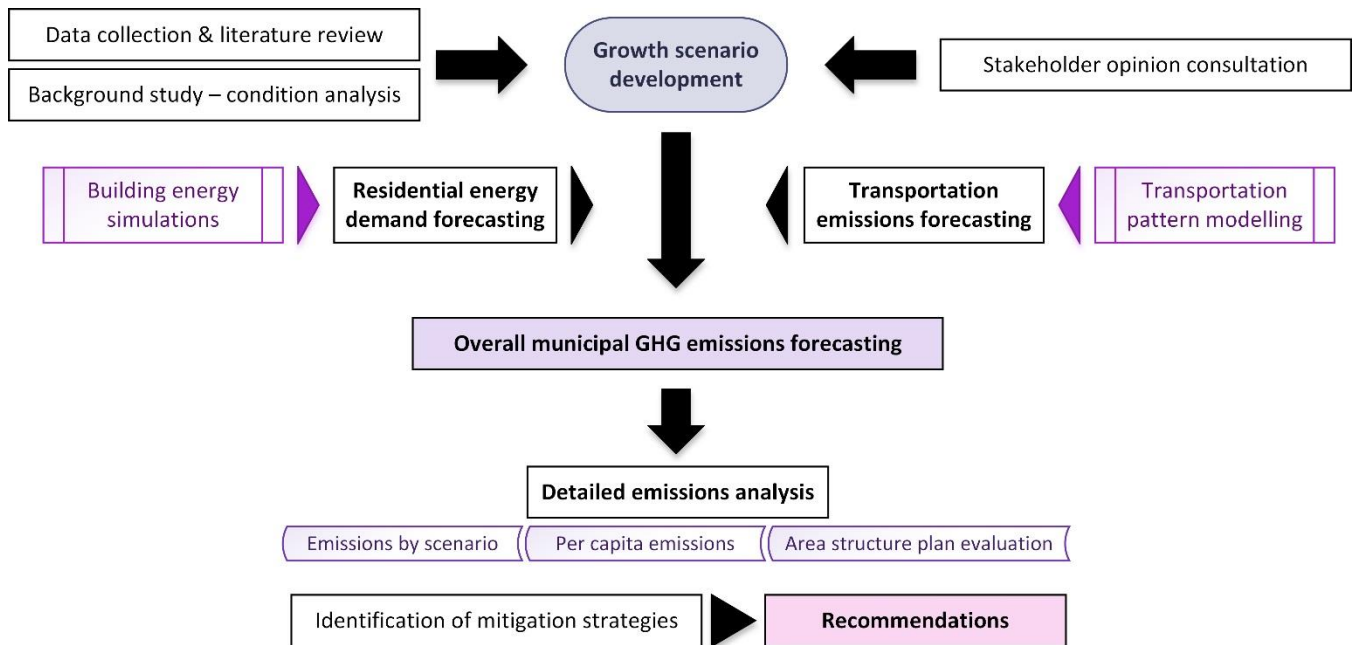


Figure 3: Overview of the methodology

#### 3.1 Scenario development

Five planning scenarios were identified for the municipality in addition to the unchanged business-as-usual case, based on discussions and consultation with the city planners as described below. A set percentage population allocation is specified for each geographic location under each scenario, based on the development priorities and housing targets. Figure 4 depicts the population distributions allocated to the 10 geographic sectors under each of the proposed growth scenarios for the municipality. The population distribution and dwelling split under each scenario has been determined based on the requirements and population growth projects of the municipality.

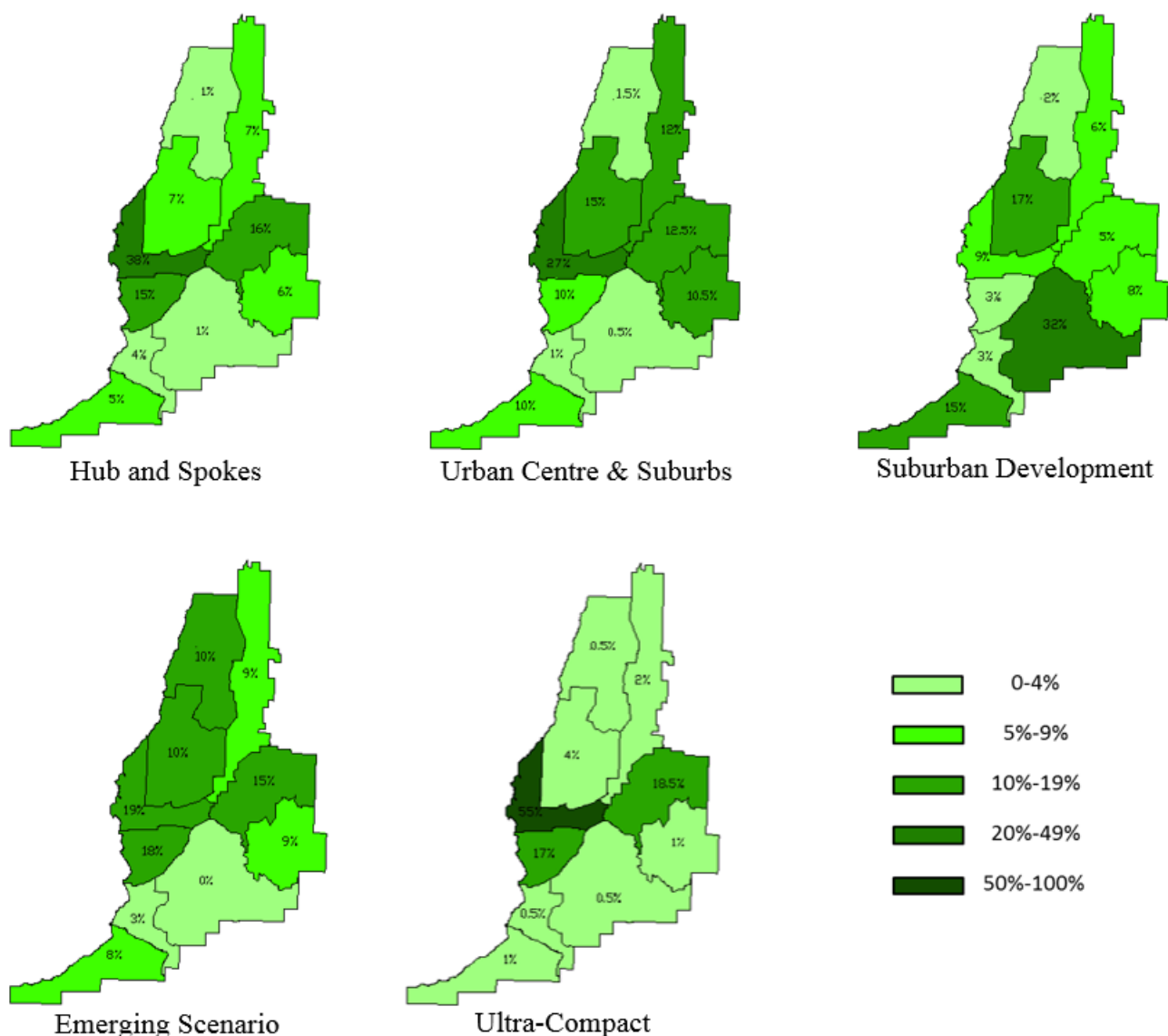
1. Business-as-Usual (BAU): Current sector-wise population density and the split between dwelling types will continue until 2040.



2. Ultra-Compact: This scenario aims for dense development in the core of the city with low travel to services. The new developments would primarily consist of high-rise apartments.
3. Hub and Spokes: This scenario aims for medium density developments in village centres with low travel to services. The new developments would primarily consist of low-rise apartments.
4. Urban Centre and Suburbs: This scenario aims for medium density developments in village centres with high travel to services. The new developments would primarily consist of low-rise apartments.
5. Suburban Development: This scenario aims for low density developments in suburbs with high travel to services. The new developments would primarily consist of single family houses.
6. Emerging Scenario: The findings of the public perception research regarding dwelling type and expert opinion of growth areas were used to determine population distribution. Information was collected through a survey and interview-based approach targeting stakeholders in the real estate industry and residents<sup>4</sup>.

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<sup>4</sup> The residents of single family detached homes were targeted in the opinion survey as they were assumed to be the group most averse to increased densification.



**Figure 4: Sectoral population distribution under proposed growth scenarios**

The analysis included evaluation of the difference between population allocations to different geographic sectors with and without the Area Structure Plans (ASP)<sup>5</sup>. The municipality grants approval for proposed future developments according to its specified ASP. This allocation has the effect of limiting the amount of projected population that could be distributed to different geographic sectors, based on the existing densities in each sector. As part of the analysis, comparisons were made between energy and emissions projections for the population distribution “with” ASP (considering the approved allocations of population) and “without ASP” (ignoring the approved allocations of population). It was hypothesized that removing the housing allocation quotas permitted under ASP could have a positive impact on GHG emissions. The possibility of further distributing a higher population to the denser geographic sectors was presumed to result in a more compact development model, thus reducing emissions. Table 2 and Table 3 detail the dwelling split under the above proposed growth strategies.

<sup>5</sup> An Area Structure Plan is a designated boundary within an Official Community Plan that proposes development potential, of which technical studies will evaluate the feasibility of future land uses, density, and general location of transportation and utility networks.

**Table 2: Dwelling split under different growth plans - without ASP**

<i>Dwelling types</i>	<i>Scenarios - Without ASP</i>					
	<b>BAU</b>	<b>Ultra-Compact</b>	<b>Hub &amp; Spokes</b>	<b>Urban Centre and Suburbs</b>	<b>Suburban Development</b>	<b>Emerging Scenario</b>
<i>Single family Detached houses</i>	46%	41%	44%	45%	50%	46%
<i>Single family attached houses</i>	21%	20%	20%	21%	22%	18%
<i>Low rise apartments</i>	29%	32%	30%	29%	25%	28%
<i>High rise apartments</i>	4%	7%	6%	5%	3%	8%

**Table 3: Dwelling split under different growth plans - with ASP**

<i>Dwelling types</i>	<i>Scenarios - With ASP</i>					
	<b>BAU</b>	<b>Ultra-Compact</b>	<b>Hub &amp; Spokes</b>	<b>Urban Centre and Suburbs</b>	<b>Suburban Development</b>	<b>Emerging Scenario</b>
<i>Single family Detached houses</i>	46%	36%	40%	42%	51%	47%
<i>Single family attached houses</i>	21%	16%	17%	18%	20%	21%
<i>Low rise apartments</i>	29%	38%	35%	33%	26%	27%
<i>High rise apartments</i>	4%	11%	8%	6%	3%	5%

### 3.2 Emissions projection

Simulations were performed to forecast GHG emissions from transportation and residences for a ‘business-as-usual case,’ the engineering-based density scenarios, and the emerging scenario. Autodesk® Green Building Studio was used to develop residential dwelling models and to perform energy analysis, in order to estimate energy intensity for each dwelling type. In order to account for the uncertainty of energy intensity, a range of values were calculated for each type of residential unit. Monte Carlo simulation was conducted to identify the probable energy intensity for the dwellings, assuming a triangular distribution for the intensity values. In order to obtain maximum, minimum and most likely energy intensity values, the following three scenarios were calculated for the four dwelling types considered:

- **Most energy efficient scenario (Minimum energy use):** Up-to-date energy efficiency approaches were incorporated for the dwelling units complying with Energy Star® rating. Energy efficient appliances and behavioural practices were assumed in this scenario.
- **Most likely scenario (Moderate energy use):** This scenario considered the current practice for housing construction in British Columbia (complying with the BC building code 9.36). In addition, current behavioural patterns and equipment efficiencies were considered.
- **Energy inefficient scenario (Maximum energy use):** This scenario considered conventional construction practices for dwelling units with limited attention to the energy efficiency. Energy inefficient behaviours and appliances were assumed for this scenario.

Building energy simulations were conducted under the assumptions of each energy use scenario to determine the maximum, most likely, and minimum values. Based on these values, the 80%-probable energy intensity listed in Table 4 for various housing types were estimated through Monte Carlo simulation.

**Table 4: 80%-probable energy intensity value From Monte Carlo Simulation**

<i>Dwelling type</i>	<b>Energy intensity (GJ/m<sup>2</sup>)</b>
<i>Single family detached house</i>	0.91
<i>Single family attached house</i>	0.75
<i>Low rise apartment building</i>	0.99
<i>High rise apartment building</i>	0.89

From December 2014, the BC building code incorporated new energy efficiency requirements for houses and small buildings. As future residential constructions should comply with the energy requirements of BC building code [61], a uniform distribution of energy intensity was assumed for all future homes within a single dwelling type. LEAP software was used in developing the community energy model. LEAP software calculates the energy demand and GHG emissions based on the total activity level and energy intensity for each sector. The energy demand for each sector calculated for each secondary demand category is uniquely identified with predefined fuels. Hence, LEAP also calculates the total final energy demand from each fuel for all technology branches. Energy intensities for the “category with aggregate energy intensity” branch type, and fuel shares and efficiencies for each technology branch are used to calculate the overall useful energy intensity for the aggregate energy intensity branch and the activity shares for each technology. This approach has been widely used in community energy planning [46][47][48]. Residential energy use was assessed based on the information published by Natural Resources Canada, Statistics Canada, and other governmental bodies reporting Canadian energy end uses, residential energy intensity, and energy use patterns for urban communities. Total global warming potential (GWP) from the residential sector was calculated by simulating energy demand for the period. The following equation was used to calculate the GWP from each fuel source.

$$\text{energy consumption} \times \text{emissions factor} \times \text{global warming potential} = \text{Total GWP CO}_2\text{eq}$$

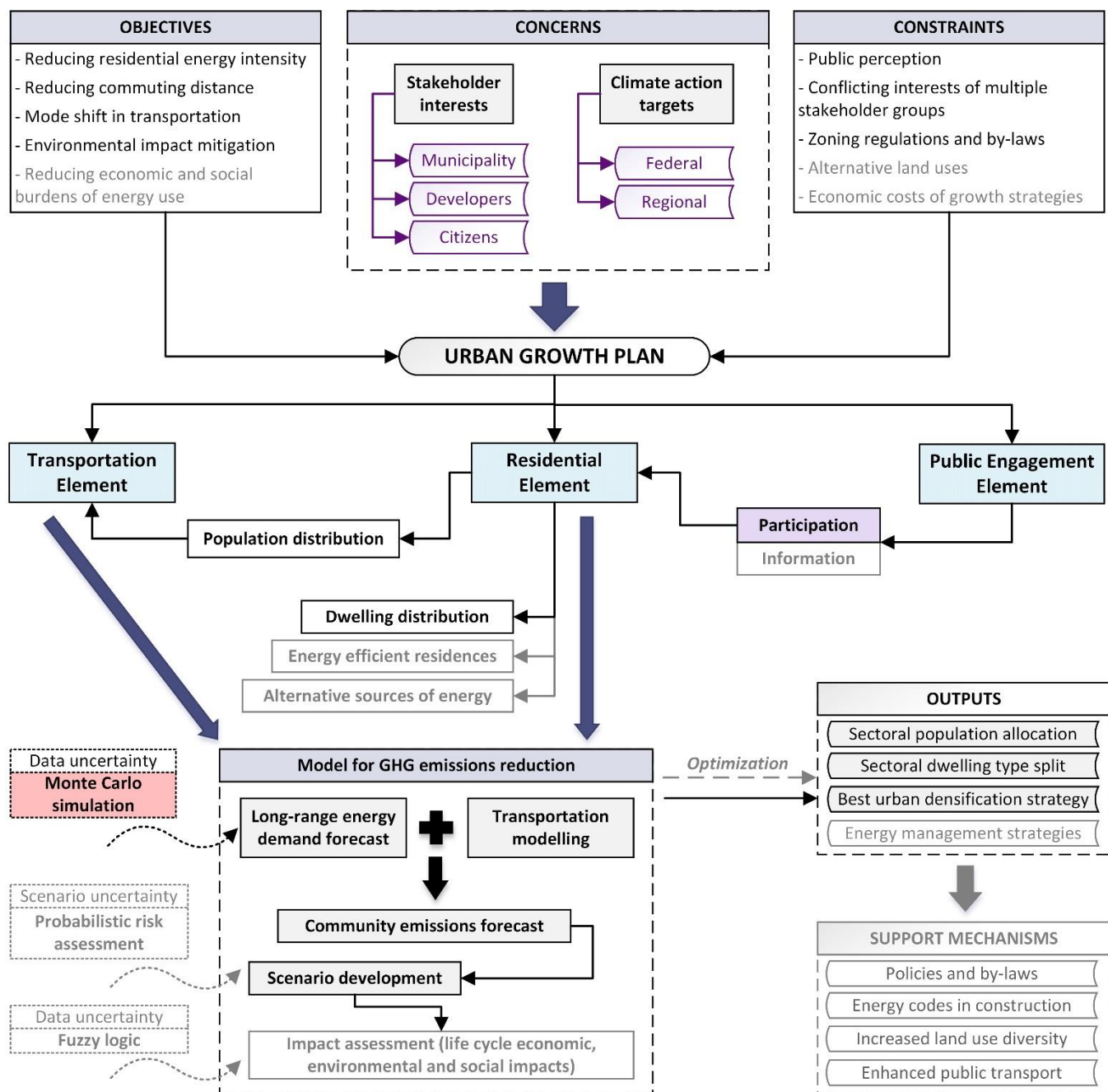
Transportation-related GHG emissions were assessed directly in relation to the vehicle kilometres travelled (VKT). The transportation emissions reduction was attributed to the reduction of total trip length, and the mode shift (i.e. passengers switching from single occupancy vehicles to high occupancy vehicles or non-motorized transportation). The TRIP-Based Urban Transportation Emissions (TRIBUTE) model developed by Rahman and Idris (2016) for municipalities was used in the assessment for the transportation sector [62]. TRIBUTE assesses the potential shares of alternative modes of transportation, with variations in personal, land use, and modal factors. Average VKT values are used in tandem with the projected share of travel under each mode and the respective emissions factors to estimate the total GHG emissions from the transportation sector [62]. This approach was repeated for all the projected scenarios in assessing the transportation emissions under each set of conditions.

Each scenario is presented with the projected per capita GHG emissions in tCO<sub>2</sub>eq<sup>6</sup> resulting from residential housing and passenger transportation. The 2007 emissions level in the municipality was taken as the baseline for comparison, as the emissions reduction targets for BC are set for this base year.

The study and its findings were used in developing an overview for municipal-level urban growth planning strategy, with the goal of supporting climate action targets. Figure 5 details the planning approach thus defined. The objectives and constraints acting on the urban planning problem need to be identified in formulating a growth model for a municipality. The growth plan should be capable of satisfying stakeholder interests and climate action targets set at the federal, provincial and other levels of government. An urban growth plan comprising of residential, transportation, and public engagement elements can be supported through an optimized model for emissions reduction, based on long-range energy and transportation and land use planning. In order to identify the true costs and impacts under environmental, economic, and social aspects, it is necessary to take a life cycle perspective in assessing the opportunities and future outcomes [63]. A given municipality can further use mechanisms such as policies and by-laws, energy codes, financial incentives, and enhanced public transportation to support chosen growth strategies, while gaining public acceptance through public engagement employing a participatory governance approach supported by transparent provision of information to residents and other stakeholders.

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<sup>6</sup> Tonnes of Carbon Dioxide equivalent



**4 Figure 5: Overview of urban growth planning approach for municipalities**

This section presents simulation results and GHG emissions forecasts for potential growth strategies. The 2007 level of GHG emissions shown in Table 5 was used as a baseline for comparison. Values in Table 5 were obtained from Community Energy and Emissions Inventory (CEEI) of BC [64].

**Table 5: GHG Emissions in 2007 (Baseline)**

<i>Sector</i>	<b>GHG Emissions (tonnes of CO<sub>2</sub> eq)</b>
<i>Residential sector</i>	140,958
<i>Transportation sector</i>	374,334
<i>Total GHG emissions</i>	515,292

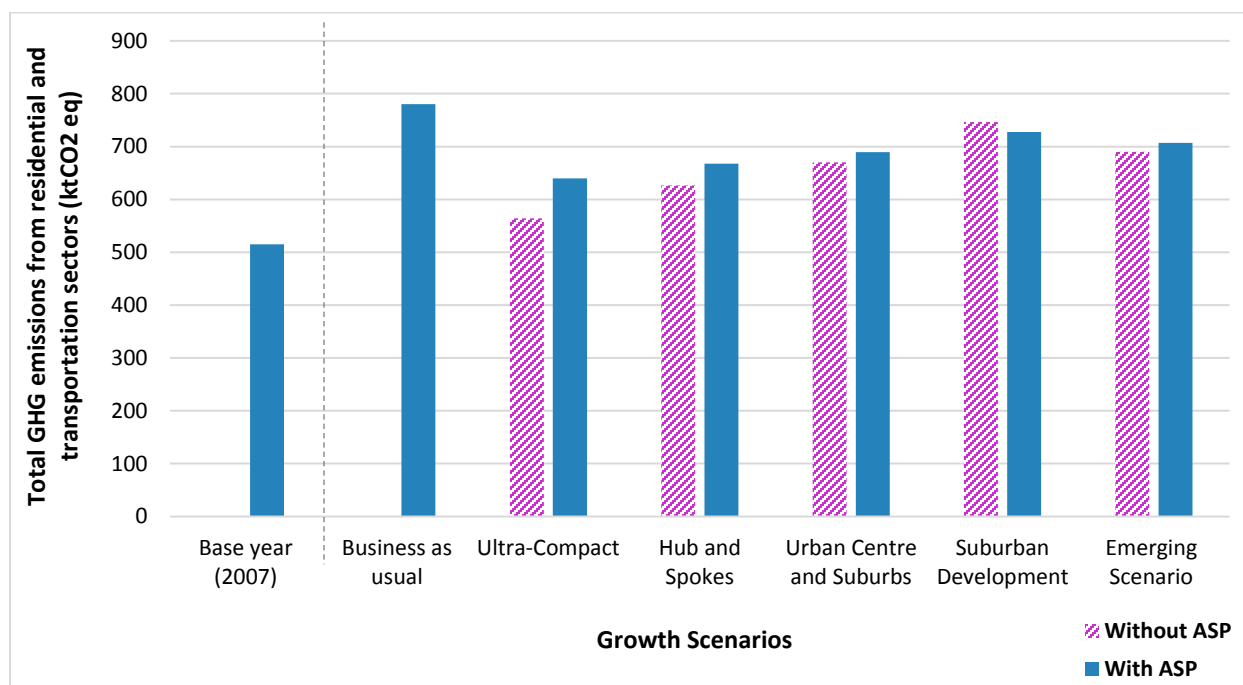
The business-as-usual scenario developed in this study assumes no change in the patterns of population density and dwelling type split in 2040. As such, all travel components such as vehicle kilometres travelled, modal share, density indicators, diversity indicators, and design indicators are assumed to be the same as in 2007. The only change considered is the total population. This scenario demonstrates what will happen with regards to GHG emissions in 2040 if the municipality makes no action plans with regards to densification and urban growth. By comparing alternatives with this base scenario, it is possible to specify the positive effects of various growth strategy options for emissions reduction. The forecast GHG emissions for projected development scenarios in the year 2040 are presented in Table 6. The emissions from the transportation and residential sectors were aggregated in projecting the total future emissions.

**Table 6: GHG Emissions Forecasts for 2040**

Forecast emissions	GHG emissions from transportation sector (ktCO <sub>2</sub> eq)		GHG emissions from residential sector (ktCO <sub>2</sub> eq)		Total GHG emissions (ktCO <sub>2</sub> eq)	
	Without ASP	With ASP	Without ASP	With ASP	Without ASP	With ASP
<i>Business-as-usual</i>	-	590,550	-	189,600	-	780,150
<i>Ultra-Compact</i>	403,547	461,094	160,300	178,591	563,847	639,685
<i>Hub and Spokes</i>	455,911	483,517	170,500	183,796	626,411	667,313
<i>Urban Centre and Suburbs</i>	491,437	501,290	178,400	188,147	669,837	689,437
<i>Suburban Development</i>	546,879	527,835	199,400	199,682	746,279	727,517
<i>Emerging Scenario</i>	503,087	514,321	186,800	192,735	689,887	707,056

#### 4.1 Overall impact on GHG emissions

Figure 6 compares GHG emissions forecasts for 2040 under different growth strategies, with and without the application of ASP. All other scenarios show a lesser increase in GHG emissions under the projection when compared to the business-as-usual (BAU) case. This indicates that implementing growth strategies in the municipality has a positive effect in terms of emissions.



**Figure 6: Total GHG emissions forecast for 2040 under different growth scenarios**

Figure 7 compares overall GHG emissions forecasts for growth scenarios on percentage increase basis compared to the base level in 2007. It can be noted that the business-as-usual (BAU) scenario presents the highest potential increase in emissions, at a 51% elevation above the base level in 33 years.

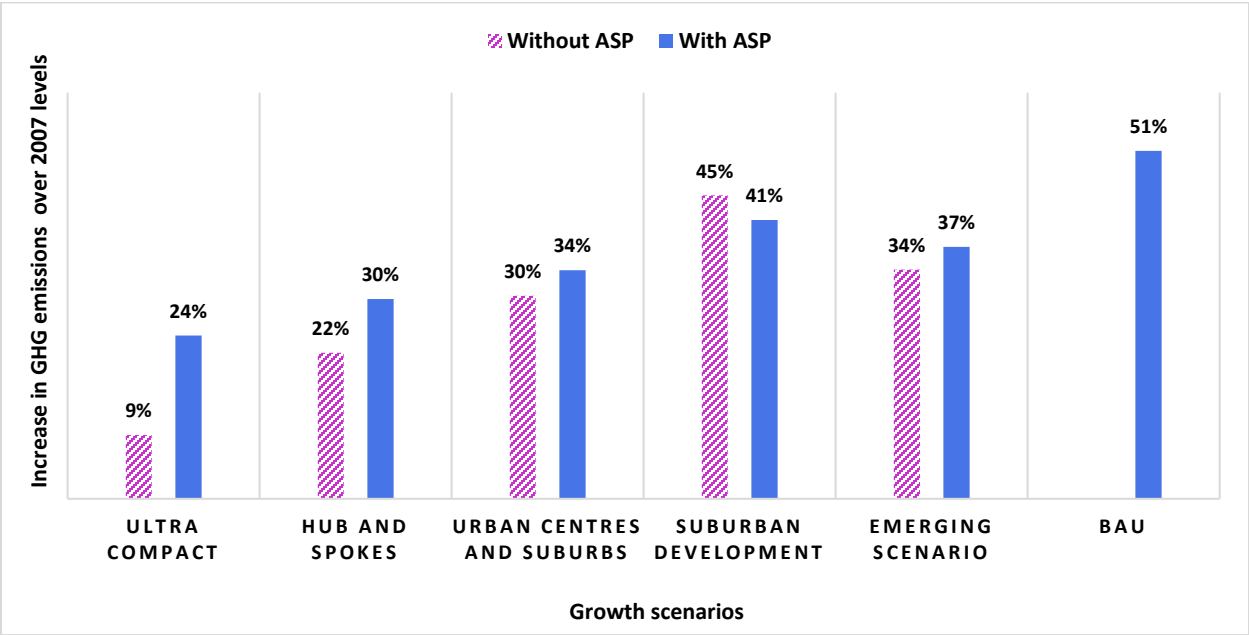
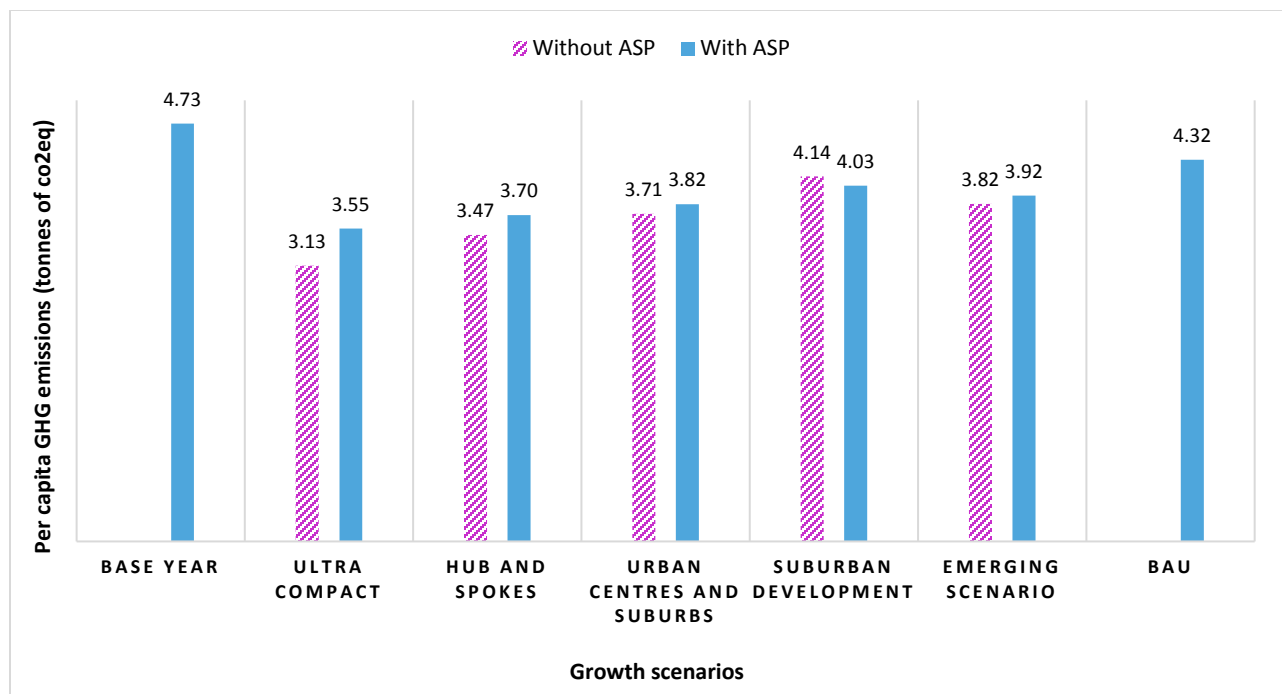


Figure 7: Projected increase in GHG emissions from the base level under different growth scenarios

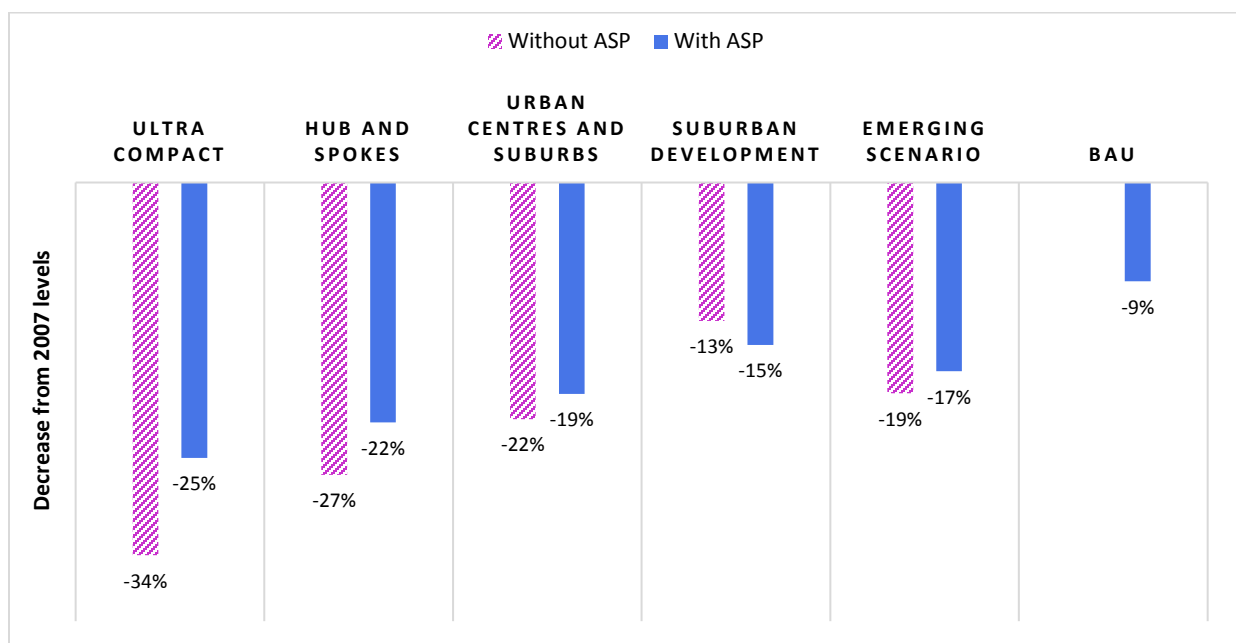
4.2 Impact on per-capita GHG emissions

**Error! Reference source not found.** Figure 8 further elaborates the emissions projection through a per-capita approach. While the overall emissions increase as depicted in Figure 9 from 2007 to 2040, the per-capita emissions actually decrease within the same period. When considering the growth strategies, per-capita emissions follow the trends set out in the overall emissions projections, with the highest per-capita emissions in the BAU case, and the lowest under the ultra-compact scenario. However, it can be seen that in many growth scenarios, the per-capita emissions do not have significant variations with and without ASP.



**Figure 8: Per-capita GHG emissions projected for 2040 under different growth scenarios**

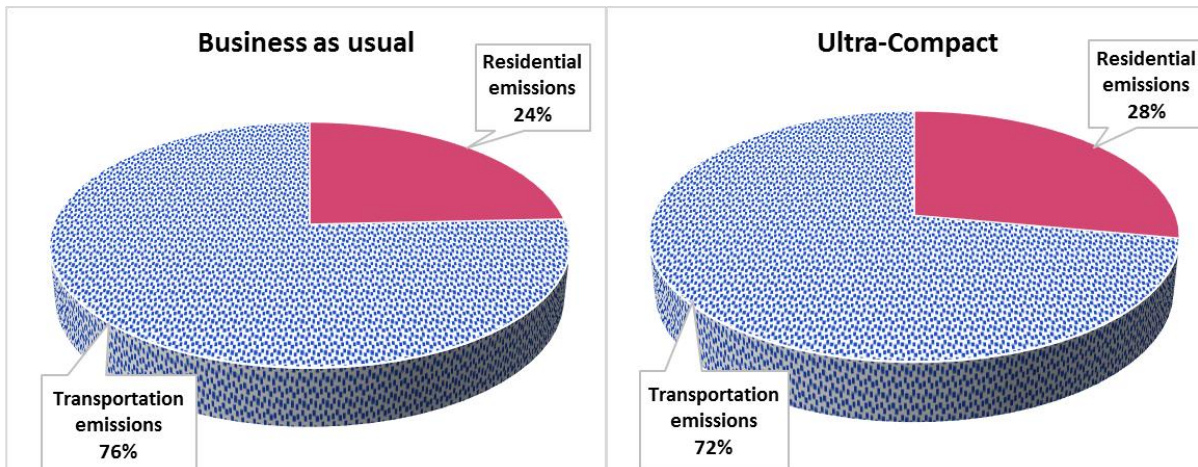
The decrease in per-capita emissions from the base level in 2007 is illustrated as percentages in Figure 9. The ultra-compact strategy appears to deliver a significant GHG emissions reduction at 34% below the base case. However, the BAU case too has a 9% decrease, indicating an improved state regarding emissions at personal level.



**Figure 9: Projected decrease in per-capita GHG emissions from base level under different growth scenarios**

Figure 10 depicts the change in the contribution made by transportation and residential sectors to the overall emissions under ultra-compact growth strategy (with ASP). It can be seen that the share of transportation in emissions reduces from 76% to 72% due to densification.





**Figure 10: Effect on the share of residential and transportation emissions due to ultra-compact development**

Among all density scenarios, the ultra-compact scenario exhibited the best performance in terms of GHG emissions reduction, as expected. The ultra-compact scenario assigns the increased population to the urban core area, and allows further developments in the city center, which will permit higher population density and lower GHG emissions. If trip origins and destinations get closer through densification, passengers are more likely to choose transit and active transportation instead of car use. Further, for those passengers who do not switch to sustainable modes (i.e. continue driving personal vehicles), VKT will still be less due to shorter travel distances. However, the city's targeted emissions reduction is 33% below the 2007 level. As such, the municipality cannot meet the above target even with the ultra-compact scenario, as the overall emissions increase from 2007 levels under this strategy as well. Therefore, it is recommended that the city considers other factors such as mixed land use to reduce GHG emissions in order to meet the specified emissions targets.

Scenarios considering development under a predefined ASP with population allocation quotas showed higher levels of GHG emissions compared to those without an ASP, possibly because of the limitations posed on densification due to the imposition of sectoral quotas. However, the suburban development scenario showed a different trend. Suburban development without ASP showed higher GHG emissions than that with ASP. This is due to the fact that the scenario without ASP will allow for even further suburban development than that with ASP. For example, according to the suburban development scenario without ASP, Sector 7 (which has a high number of trips originated) is expected to have a population growth of 3%, and accordingly the total population will be 17,558. However, with ASP the total population assigned to this sector is 24,055, which is higher than that of without ASP, thereby increasing the population density towards the city centre away from the suburbs. Thus, the existence of ASP results in city core densification, and limits suburban distribution. If the same population were allowed to move further into suburbs without ASP, these trips would result in longer commuter distances and higher use of private vehicles, thus increasing emissions. Therefore, the suburban development scenario without ASP will allow for even further suburban development, lower population density, and higher GHG emissions.

This study analyzed the effect of dwelling type selection on GHG emissions in the municipality in addition to population density. Dwelling type has a higher impact on GHG emissions in comparison to population density, as the per-capita emissions decrease within the study period in reality. Single family detached houses account for the highest portion of GHG emissions from the residential sector. This is primarily due to the increased heated floor area in single family units compared to multifamily housing.

## 5 Conclusions and recommendations

This research investigated the impact of potential growth scenarios on achieving GHG emissions targets in a fast-growing municipality. There are three main findings from this study. First, the results of the study indicated that transportation related emissions account for the major portion of urban GHG emissions, and that these can be reduced through planning strategies aimed at reducing trip lengths and promoting transportation mode shift. This mode shift can be supported by developing low-or-zero emission pathways for land transportation by focusing on transportation infrastructure [65]. A sustainable transportation infrastructure system is a safe, high-quality, and economical transportation infrastructure system that is environmentally and ecologically sound and accessible to all users. Moreover, a sustainable infrastructure system would be a positive contributor to regional development.

Second, dwelling type and choice of fuel has a considerable impact on residential energy intensity. While even the business-as-usual scenario demonstrates a reduction in per capita emissions compared to base level in 2007, more emissions reduction benefits can be obtained by operating under a planned growth strategy. In conclusion, it was confirmed that densified growth with a higher share of multi-unit residential development will enable the highest GHG emissions reductions at municipal level.

Third, even though total GHG emission is expected to increase, the per capita GHG emission would reduce for the 25-year period. Some local governments use per capita GHG emission reduction as their targets. These targets do not achieve the real GHG emission reduction, especially if they expect higher than average population growth. Therefore regional energy and emission plans should look into both emission reduction strategies and GHG sinks.

### 5.1 Lessons learned

Lessons learned in conducting this study inform regional growth planning and the setting of realistic GHG emissions targets. Despite the benefits of such planning, the public has yet to embrace densified neighbourhoods in municipalities. Public preference research shows that the public exhibit “NIMBY” or “not in my back yard” preferences regarding the residential density of the region. Residents were much more likely to assign denser building types to other sectors of the city than those in which they currently reside. The survey experiment suggested that sending a positive message to the residents regarding the public benefits of densification is likely to increase willingness to accept residential densification. There can be significant conflict between residents, other stakeholders, and local government when implementing optimal growth plans. Public participation is crucial throughout the process to maximize opportunities for education, and respond to concerns expressed by the stakeholders. Local governments should act as a bridge between the interests of planners, developers, and the community, in planning and in identifying options for non-government actors to contribute actively to GHG emissions reduction. If energy consumption for end uses is reduced by retrofitting older homes and building new homes with new technologies for superior energy performance, the overall residential energy demand can be reduced [66][67]. Furthermore, substituting conventional energy sources (e.g. natural gas) with renewable energy sources (RES) would substantially reduce GHG emissions [42]. However, home retrofitting and construction of energy efficient homes involve additional expenditure for residents, as well as community developers. Therefore, incentives should be implemented to promote residential energy efficiency. These initiatives would be reinforced by introducing local by-laws for new house construction [67].

Pre-sustainability era master plans are unlikely to result in achievement of sustainability targets. Emissions simulations for scenarios including allocations from the ASP resulted in higher GHG emissions projections than those which excluded the ASP allocations. Hence, municipal growth plans should be continually revised to suit upcoming environmental demands. One issue with ASP is that the subject

municipality does not at present have a strategy to optimise the population numbers allocated to a sector under ASP, even though the allocation is done in tandem with the 20 year growth projection analysis. This results in less than optimal outcomes regarding emissions when ASP are implemented. Thus, the municipality should consider a new strategy in deciding the quotas allocated to different geographic sectors.

## **5.2 Suggestions for future**

Municipalities should extend their climate action agendas from mitigation strategies to climate change adaptation strategies. It is important to identify the linkages and trade-offs between the two strategies. Developing an integrated climate action approach would enable better preparedness for the future. Regional growth planning should also consider diverse sustainability parameters (i.e. social, economic and environmental). An integrated framework that is sensitive to changing sustainability demands would assist in this cause. There is no panacea for sustainable regional growth planning challenges. Each growth policy should be customized to suit regional demands. For example, Lee and Lee (2014) stated that GHG emissions plans should be customized for regions to accommodate the differences in the electricity grid in each place [10]. Translation of detailed studies into policies and by-laws is a challenge for local governments. Even though population density is the universal parameter used in this regard, other parameters such as mixed land use (combining residential and commercial uses in the same area or in the same building) deserve further study. An optimization-based approach can assist in developing a holistic framework for determining growth parameters such as population distribution in sectors and housing split.

Uncertainties in data, modelling, and defining scenarios contributed to the key limitations present in this study. While data uncertainty has been addressed through the use of Monte Carlo simulation in defining residential energy intensities, further work needs to be done in refining the uncertainties associated with scenarios and model development regarding urban growth planning. Municipalities need to be provided with comprehensive and inclusive tools to take a rational and optimized approach in defining their urban density plans and growth models. A fuzzy-based approach can be taken in accounting for data uncertainties, and to integrate community and decision-maker preferences into growth scenarios. Beyond the initiatives considered in this study, other technical and behavioural improvements would enable aiming for better GHG emissions reduction targets in the residential sector. Finally, it would be fruitful to further engage with the multiple stakeholder groups making up a given community to learn how framing different urban development scenarios affect their attitudes towards the growth of the city.

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