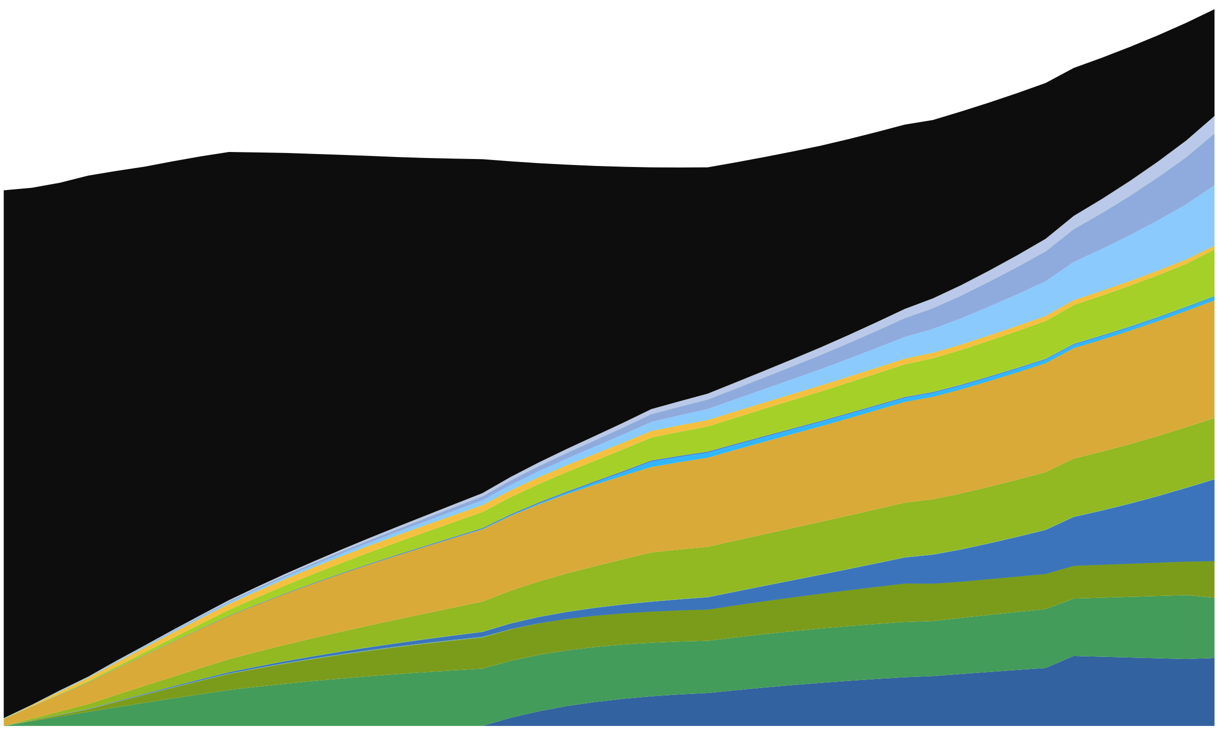
EXPLORING PATHWAYS: DEEP ENERGY AND GREENHOUSE GAS EMISSIONS REDUCTIONS BY 2050 IN BC COMMUNITIES



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MC[3]: Meeting the Climate Change Challenge
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MEETING THE CLIMATE CHANGE CHALLENGE

MC[3]: Meeting the Climate Change project brings together over 100 researchers, practitioners and policy-makers from non-governmental organizations, provincial ministries, and three of BC's universities to investigate climate change policy in British Columbia.

British Columbia (BC) is on the leading edge of a wave of local government innovation to address climate change in Canada. In response to the threat of anthropogenic climate change, the province introduced innovative policies that go far beyond those in other North American jurisdictions. These policies have created a unique research opportunity: the province is a 'living laboratory' of policy innovation for CO2 mitigation at the municipal and regional scales. There are three specific provincial policy drivers of climate action at the municipal level.

- A carbon tax, passed in 2008, has been remarkably efficient in reducing fuel use with no apparent adverse impact on the province's economy[1].
- The 2008 Climate Action Charter (CAC) mandated that signatory local and regional governments become carbon neutral in their operations by 2012. The Charter, a voluntary commitment, also included the measurement of community wide GHG emissions and the creation of compact and energy-efficient communities.
- The 'Green Communities' amendment to the Local Government Act which requires all local and regional governments to include climate change targets and strategies in Official Community Plans (OCP) and Regional Growth Strategies (RGS) (Bill 27).

MC[3] has completed 11 detailed community case studies that identified leading-edge innovations in local climate change actions as well as supported peer to peer dialogues and other events amongst Mayors and other decision-makers. One of the key outcomes was: Climate Change Adaptation and Mitigation: An Action Agenda for BC Decision-Makers[2]. The Action Agenda identifies 12 strategies to continue to advance the climate change leadership role in BC including a second iteration of the Climate Action Charter, an expansion of the carbon tax to the industrial sector and support for the expansion of district energy.

This report, prepared on behalf of one of our funding partners, BC Hydro, seeks to explore future energy and GHG emissions trajectories that achieve deep GHG emissions reductions and makes recommendations for policies that are required to achieve those targets.

THREE COMMUNITIES

This analysis zeroes in on three of the communities covered in the previous case studies to analyse the implications of achieving the Provincial target of an 80% reduction by 2050 over 2007 levels. The comparison of three different communities provides a thorough evaluation of exploring the realization of this target at different scales and geographical locations.

- The **City of Vancouver** is the largest municipality in British Columbia, has 624,00 people, and is located in the southeastern corner of the province, bounded to the west and north by Burrard Inlet and to the south by the Fraser River (a major shipping route).

[1] Elgie, S. and McClay, J. (2013). BC's carbon tax shift after five years: Results. An environmental (and economic) success story. Sustainable Prosperity. Retrieved March, 2014 from: http://www.sustainableprosperity.ca/article3685

[2] Dale, A. et al., (2013). Climate Change Adaptation and Mitigation: An Action Agenda for BC Decision-Makers.MC[3]. Retrieved March, 2014 from: http://www.mc-3.ca/news/summary-climate-action-agenda-bc-decision-makers

- The **City of Prince George** is a city of approximately 72,000 residents located at the confluence of the Fraser and Nechako rivers.
- The **City of Victoria**, the capital of British Columbia, is a community of 78,000 people located on the Southern tip of Vancouver Island.

THE CLIMATE CHANGE CHALLENGE

In May 2013, global carbon dioxide (CO_2) emissions reached 400 parts per million (ppm) likely for the first time in past 3 million years[3]. This milestone is an indication of the degree to which humans are impacting the atmosphere and the climate. This milestone also marks the beginning of *uncharted* territory, a period of uncertain and undesirable climatic and ecological change. Not only are global average temperatures increasing due to increased emissions from fossil fuel combustion, but positive feedback cycles threaten to compound those increases and/or hinder earth's ability to absorb these gases as the permafrost melts and forest fires increase, for example. Although mean temperatures have increased and are projected to continue to rise, perhaps the most important impact in climate change is the potential for more, and more severe, extreme and unusual events such as heavy precipitation, floods, hurricanes and droughts. Already the impacts of climate change are being felt around the globe as described in the fifth Intergovernmental Panel on Climate Change (IPCC) report[4].

- Changing precipitation or melting snow and ice are alternating hydrological systems, affecting water resources in terms of quantity and quality.
- Many terrestrial, freshwater and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances and species interactions.
- Negative impacts on crop yields have been more common than positive impacts
- Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability.

Without significant action to limit climate change, temperatures could exceed 2 degrees or more by 2050 and 4 degrees or more by 2100. To stay below 2 degrees, developed countries will need to cut their emissions by 80-95% below 1990 levels by 2050[5].

MODELLING

GHG emissions in a municipality are driven by a number of interacting variables including transportation, energy consumption in buildings and GHG emissions produced from solid waste. Modelling is one strategy that can be used to understand the implications of an 80% reduction in GHG emissions for those variables. A model can support policy makers and researchers in their efforts to think longer-term, clearly communicate cause and effect, and allow the assessment of the impacts of different scenarios without taking any real risks.

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[3] National Geographic Daily news. (2013) Available from: http://news.nationalgeographic.com/news/energy/2013/05/130510-earth-co2-milestone-400-ppm/

[4] Intergovernmental Panel on Climate Change (2014). Climate Change 2014: Impacts, Adaptation and Vulnerability. Retrieved March, 2014 from: http://ipcc-wg2.gov/AR5/images/uploads/IPCC_WG2AR5_SPM_Approved.pdf

[5] European Commission (2011). Roadmap for moving to a low-carbon economy in 2050. Retrieved March, 2014 from: http://ec.europa.eu/clima/policies/roadmap

GHGProof[6] is primarily used to analyze past and present land-use patterns, project the impact of future land-use patterns and policies in order to analyse GHG emissions, energy consumption and energy costs. All of the calculations, inputs and assumptions in GHGProof are visible to the user. Key strengths of the model include the following characteristics.

- **Integrative**: Seeks to address all major land-use impacts on GHG emissions, and some public and private energy costs.
- **Adaptable:** Can be used for a rigorous analysis of a large city or in a one-day workshop for a small community.
- **Affordable**: Free to use for non-profit purposes, open source.
- **Transparent**: All assumptions and calculations are visible and can be altered.
- **Scope:** Can be used at the scale of a large development, a municipal plan and a regional plan.
- **Policy relevant:** Allows local governments to develop or evaluate targets to address provincial legislation.
- **Accessible:** Uses simple Geographic Information Systems (GIS) analysis and an Excel-based calculator; limits number of inputs to those that have greatest potential GHG impacts.

MODELLING APPROACH

GHGProof normally uses a two-step process. In the first step GIS is used to develop a baseline and future scenarios of land-use in the city and in the second step, outputs from the GIS and other data sources are input into a series of worksheets. Due to scope limitations, the GIS analysis was not employed and instead a back-casting approach was used to identify what land-use conditions (mix of dwelling type, density, distance between destinations and dwellings, area of forest, area of agricultural land) would generate 80% GHG reductions by 2050 over 2007 levels.

In GHGProof key variables are distinguished as “aspects”. Aspects include transportation, energy generation, embodied energy, waste, agriculture, forest and land conversion. The total GHG for a community is defined as the sum of the GHG from each of the aspects:

$$GHG_{landuse} = GHG_{transport} + GHG_{energygen} + GHG_{waste} + GHG_{agriculture} + GHG_{forest} + GHG_{landconvert}$$

Where

$GHG_{transport}$ is the movement of goods and people.
$GHG_{energygen}$ is the generation of heat and electricity.
GHG_{waste} is liquid and solid waste produced.
$GHG_{agriculture}$ is the production of food.
GHG_{forest} is the area of forest land.
$GHG_{landconvert}$ is the area of land in natural or modified conditions.

A 2007 baseline was calculated as a basis against which the reductions are measured. Buildings, solid waste and transportation are calibrated against the 2007 Community Energy and Emissions Inventory. For example, the process of calibration in the baseline for residential buildings consists of the following approach. The number of residential buildings by type is identified; an average area is assigned to each building; average energy consumption per area is assigned; and a fuel mix is assigned to that energy consumption. Total energy

[6] GHGProof is available at http://www.sustainabilitysolutions.ca

consumption and GHG emissions for residential buildings is then calculated on the basis of the mix and number of dwellings. The resulting total energy consumption is then compared with the results from the Community Energy and Emissions Inventory and the energy consumption per area is scaled so that the model generates the total energy consumption indicated in the Community Energy and Emissions Inventory.

Following the calibration of the 2007 baseline year, a Business as Usual (BAU) scenario is generated. The BAU is primarily driven by population and number of households, however it does simply calculate per capita energy consumption and GHGs and then extrapolate these into the future. Each aspect is modified to reflect current policies at the federal, provincial and municipal governments. For example fuel efficiency in vehicles is adjusted to reflect federal government fuel efficiency standards as the stock of vehicles on the road evolves. Similarly, the stock of new dwellings evolves according to the introduction of new building codes and in this case the same mix of dwellings is assumed.

In this exercise a new scenario was generated using back casting in which policies and outputs were revised until the model generated a desired output, an 80% reduction in GHG emissions over 2007 levels by 2050. A new version of the model was developed to enable this process, which is called goal-seeking. Goal-seeking allows the user to adjust the magnitude and rate of application of policies and strategies in order to achieve a specific GHG reduction target.

An example of the policies, inputs and assumptions for City of Vancouver are included in Appendix 1.

Figure 1: Scope of issues addressed within GHGProof

LIMITATIONS

It is important to note that a model cannot determine outcomes with certainty, but rather will illuminate the effects of choosing between various scenarios and outcomes. Thus it is crucial that both the assumptions and the means of creating and presenting the model be fully transparent so that the user can understand the assumptions that underlie the results.

Scenarios are designed to enable users to make informed decisions in the context of a complex set of variables. A scenario is a view of what the future might turn out to be; it is not a forecast, but one possible future outcome. A good set of scenarios is both plausible and surprising, providing insights into a particular challenge and choosing different pathways.

For this report, GHGProof is used to explore the following variables.

- Alternatives: variations in housing types, locations and technologies can be expressed using different scenarios in the model.
- Consequences: the immediate and cumulative effects are expressed through the outputs of the analysis and through a GIS mapping exercise.
- Causations: causal bonds between alternatives and consequences are illustrated using transparent equations between assumptions and inputs.
- Time frames: periods of time between implementation of the alternatives and the unfolding of their consequences.

GHGProof uses a large number of assumptions, drawing where possible on local studies and otherwise employing provincial or national averages. In the baseline year (2007) , key assumptions are calibrated to align the model with the relevant categories from the Community Energy and Emissions Inventory data.

In this case, the assumptions were customised for each of the three municipalities that were analysed.

COMMUNITY ENERGY AND EMISSIONS INVENTORIES (CEEI)

The Community Energy and Emissions Inventory (CEEI) are a set of standardised inventories of GHG emissions for each municipality and regional government in British Columbia, accounting for GHG emissions from on-road transportation, buildings and solid waste. CEEI was designed to help local governments meet their commitments in the Climate Action Charter, a voluntary declaration that included a commitment to creating complete, compact, more energy efficient rural and urban communities[7]. The CEEI for each community is anticipated to be produced every two years and reports have been produced for 2007 and 2010 so far[8].

CEEI provides a standardised approach against which GHG emissions can be tracked over time. It also provides standardised data that enables the comparison of different communities against each other.

[7] Government of BC and Union of BC Municipalities (2007). BC Climate Action Charter. Retrieved March, 2014 from: http://www.cscd.gov.bc.ca/lgd/library/BC_CLIMATE_ACTION_CHARTER.pdf
[8] CEEI reports are available at: http://www.env.gov.bc.ca/cas/mitigation/ceei/reports.html

ENERGY AND GHG EMISSIONS TRENDS

GHG emissions for the three cities for the past three years show interesting trends (Table 1). GHG reductions are evident in all three cities, while at the same time population has increased.

Table 1: GHG emissions (2007-2010)

	2007	2010	% change	Population (% change)
Vancouver	2,460,158	2,327,491	-5.4	+5.4
Victoria	402,731	399,135	-0.9	+2.1
Prince George	661,560	639,842	-3.3	+3.0

To illustrate the significance of these reductions, data were projected outwards until 2050. If these types of reductions were maintained on a year over year basis, reductions would be -77%, -13% and -47% for Vancouver, Victoria and Prince George respectively (Figure 2). However, such projections are estimates in that two years is insufficient timeline on which to construct a trend, as either year could have been anomalous, due to weather, methodological changes in CEEI, or errors in CEEI.

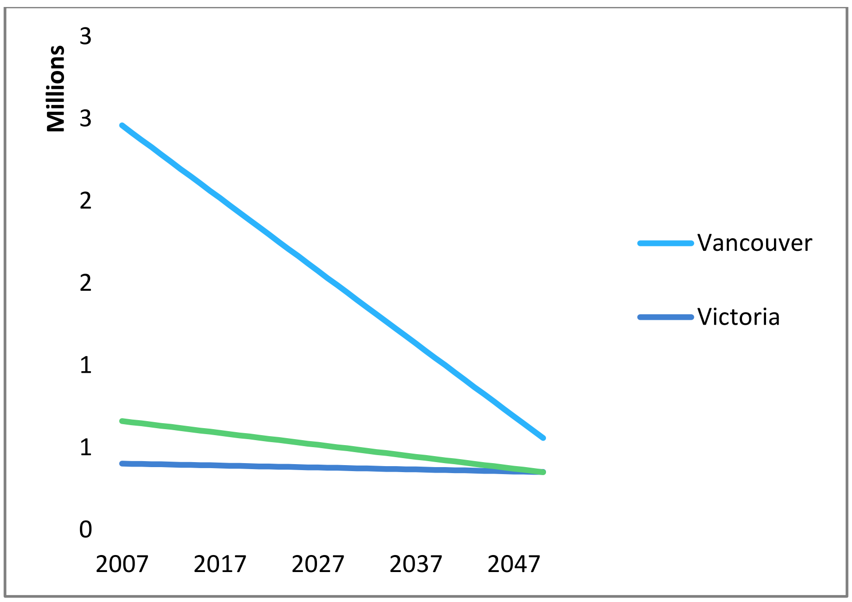


Figure 2: GHG emissions trends projected based on CEEI data (2007-2050)

The CEEI also provides insight into energy consumption. Each city has a different top line fuel in 2010, natural gas, electricity and gasoline in Vancouver, Victoria and Prince George respectively. Also in every case, the top line fuel has decreased over the time period. Natural gas consumption has declined in Vancouver and Prince George but not Victoria, and electricity has declined in Victoria and Prince George but not in Vancouver. Gasoline has increased in Prince George and Victoria but has declined in Vancouver (Figure 3-5).

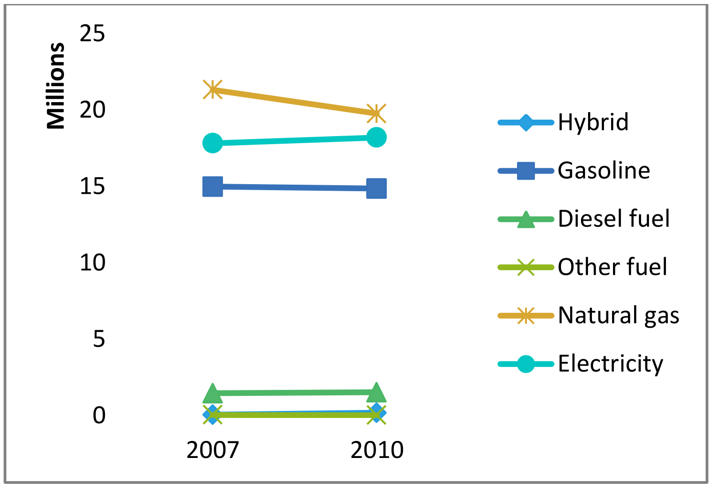


Figure 3: Energy consumption by fuel, City of Vancouver

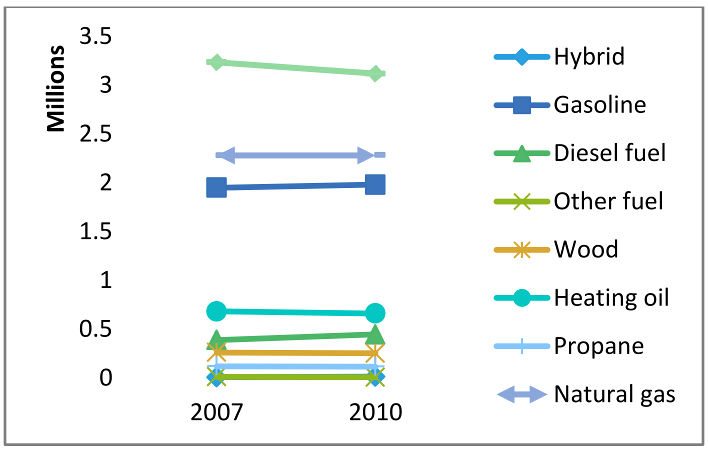


Figure 4: Energy consumption by fuel, City of Victoria

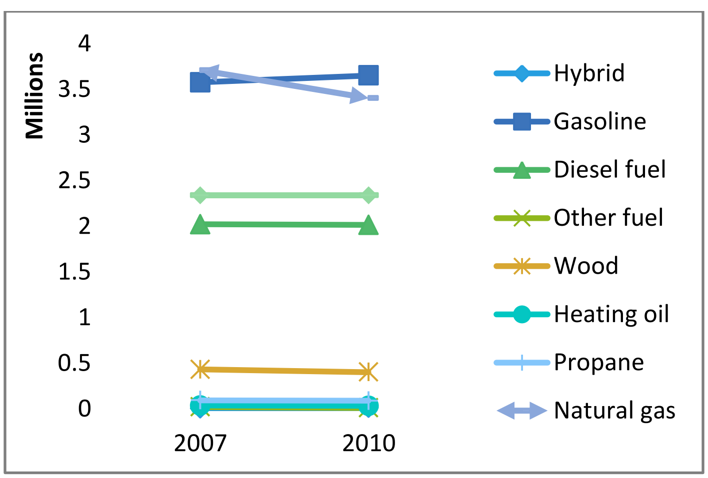


Figure 5: Energy consumption by fuel, City of Prince George

MODELLING METHODOLOGY

As a model, GHGProof is driven by population and households, as modelled by BC Stats. These two variables are held constant in all scenarios. In modelling each city, GHGProof was calibrated against the 2007 CEEI.

- Transportation is calibrated at the level of vehicle kilometres travelled (VKT).
- Buildings are calibrated at the level of GJ per square meter of each house.
- Solid waste is calibrated on the basis of waste produced per capita and GHG emissions per tonne of waste.

Models were constructed for each of the three cities in GHGProof. An example of the assumptions that were used for the City of Vancouver is included in Appendix 1. Three scenarios were considered for each City (Table 2).

Table 2: Scenarios

Scenario	Title	Description
Scenario 1	Business as usual	An extrapolation of 2007 levels until 2050 with the addition of Federal and Provincial policies on fuel efficiency and building codes.
Scenario 2	Moderate scenario (reflects the 2010 trajectories).	Adjusted business as usual to reflect the 2010 CEEI trajectory.
Scenario 3	80% reduction by 2050 over 2007 levels.	Ambitious GHG reductions to achieve 2050 targets

Because Scenario 1 was calibrated against the 2007 CEEI data, we were interested to understand what GHG emissions it would predict in 2010, the most recent year for which we have data (Table 3).

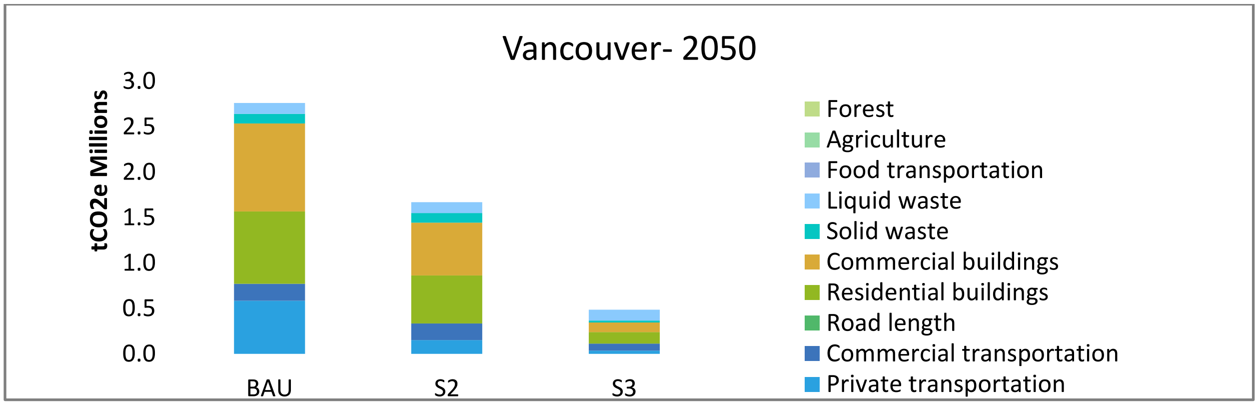
Table 3: Comparison of results between CEEI and GHGProof (Scenario 1)

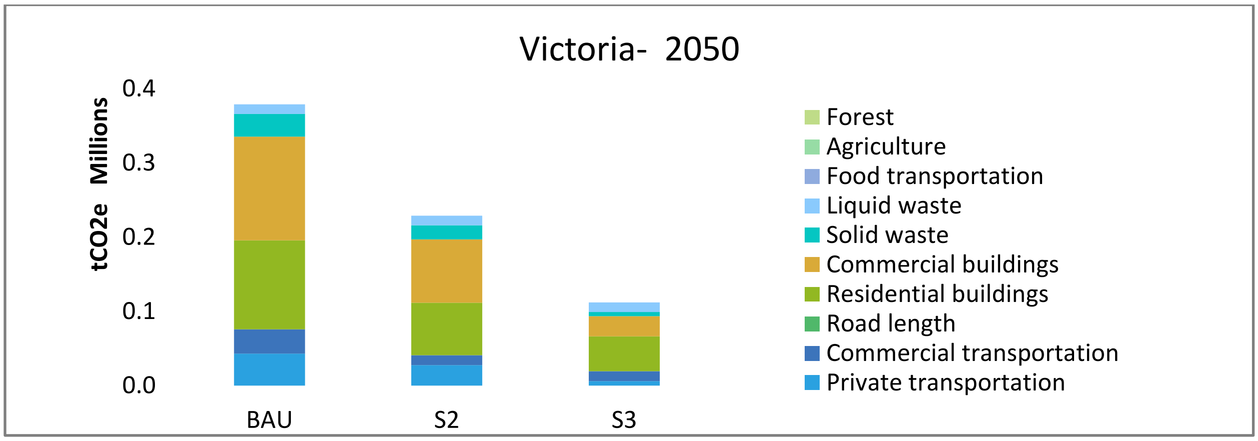
City	Year	CEEI (tCO2e)	GHGProof (tCO2e)	Difference (tCO2e)	% difference	Liquid waste (tCO2e) in GHGProof
Vancouver	2007	2,454,094	2,460,158	-86,310	0%	+76,810
	2010	2,457,336	2,327,491	+129,845	+6%	+81,173
Victoria	2007	413,731	402,731	+11,000	+3%	+10,012
	2010	419,784	399,135	+20,649	+5%	+10,187
Prince George	2007	659,489	661,560	-2,071	0%	+11,771
	2010	671,403	639,842	+31,561	+5%	+11,949

Some of the difference between the GHGProof results and the CEEI data for 2010 data can be attributed to addition of GHG emissions in the GHGProof analysis. Nevertheless, t is clear that Scenario 1 in general anticipates greater increases in GHG emissions than were experienced in the 2010 CEEI. This is not necessarily unexpected, as Scenario 1 was intended to illustrate business as usual from 2007 condition outwards. In fact, what the CEEI data illustrates is that these three municipalities have been successful in reducing GHG emissions using additional strategies and policies between 2007 and 2010.

RESULTS

Figure 6 shows the results of the three scenarios for each of the cities modelled. The Business as usual (BAU) scenario represents what would happen if there was no significant policy change- in other words policies from 2007 were carried out until 2050. Transportation represents the largest part of Prince George's emissions relative to the other two cities, in which buildings contribute proportionately more. Note that the scales are not equivalent.





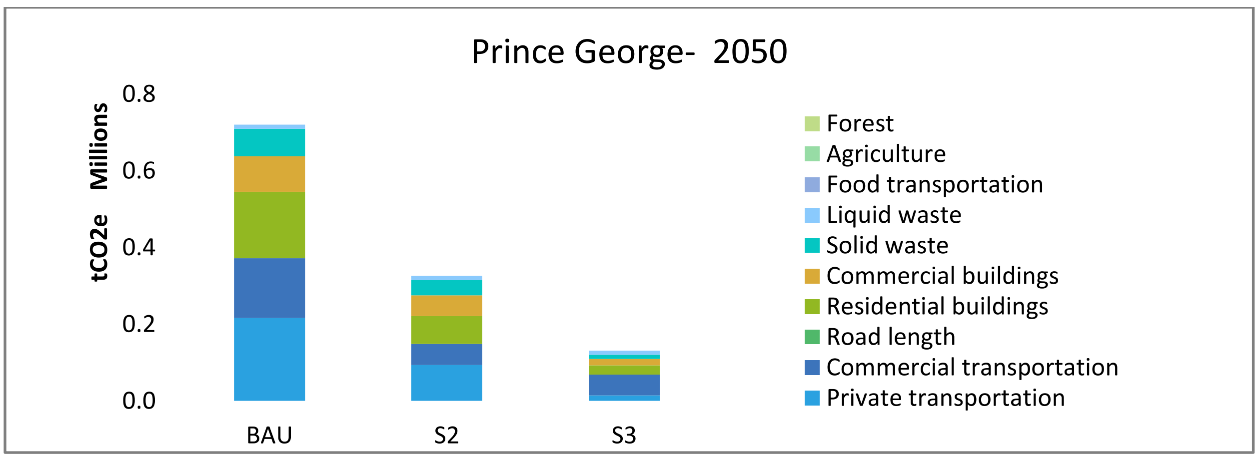


Figure 6: GHG emissions by theme in 2050 for each scenario

On a per capita basis, GHG emissions decline across all scenarios, including the BAU scenario (Figure 7). In large part, the decline in the BAU is due to the federal fuel efficiency standard. The increasing populations also means that per capita GHG reductions need to be greater than 80% to achieve an absolute reduction of 80%.

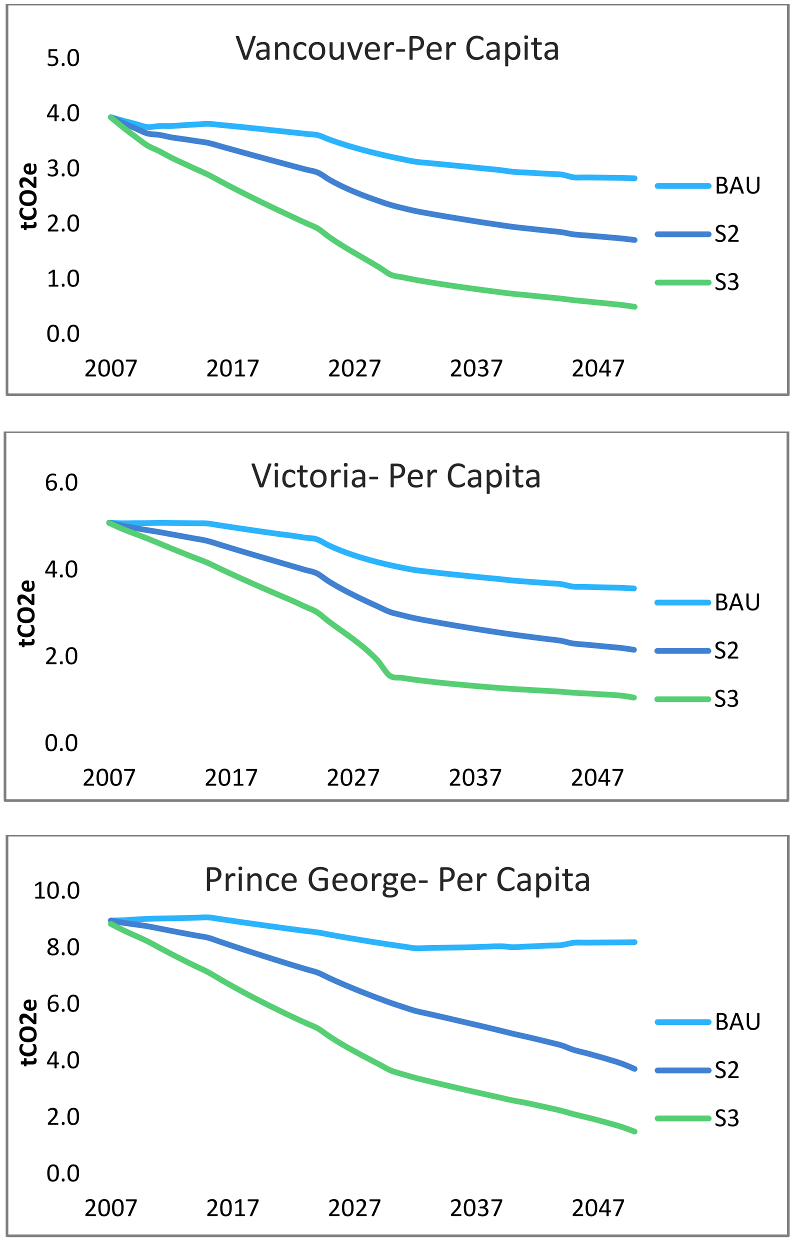


Figure 7: Per capita GHG emissions over time for each city

The GHG emission trajectories are steep to achieve an 80% reduction and every sector is squeezed (Figure 8). The timeline of the federal emissions standards creates the 'bottlenose dolphin' effect, in which emissions are driven down more quickly until 2030 and then decline more gradually thereafter. In Vancouver and Victoria, transportation emissions are compressed to a greater degree than Prince George, where alternatives to the gasoline engine and vehicular travel are more complex.

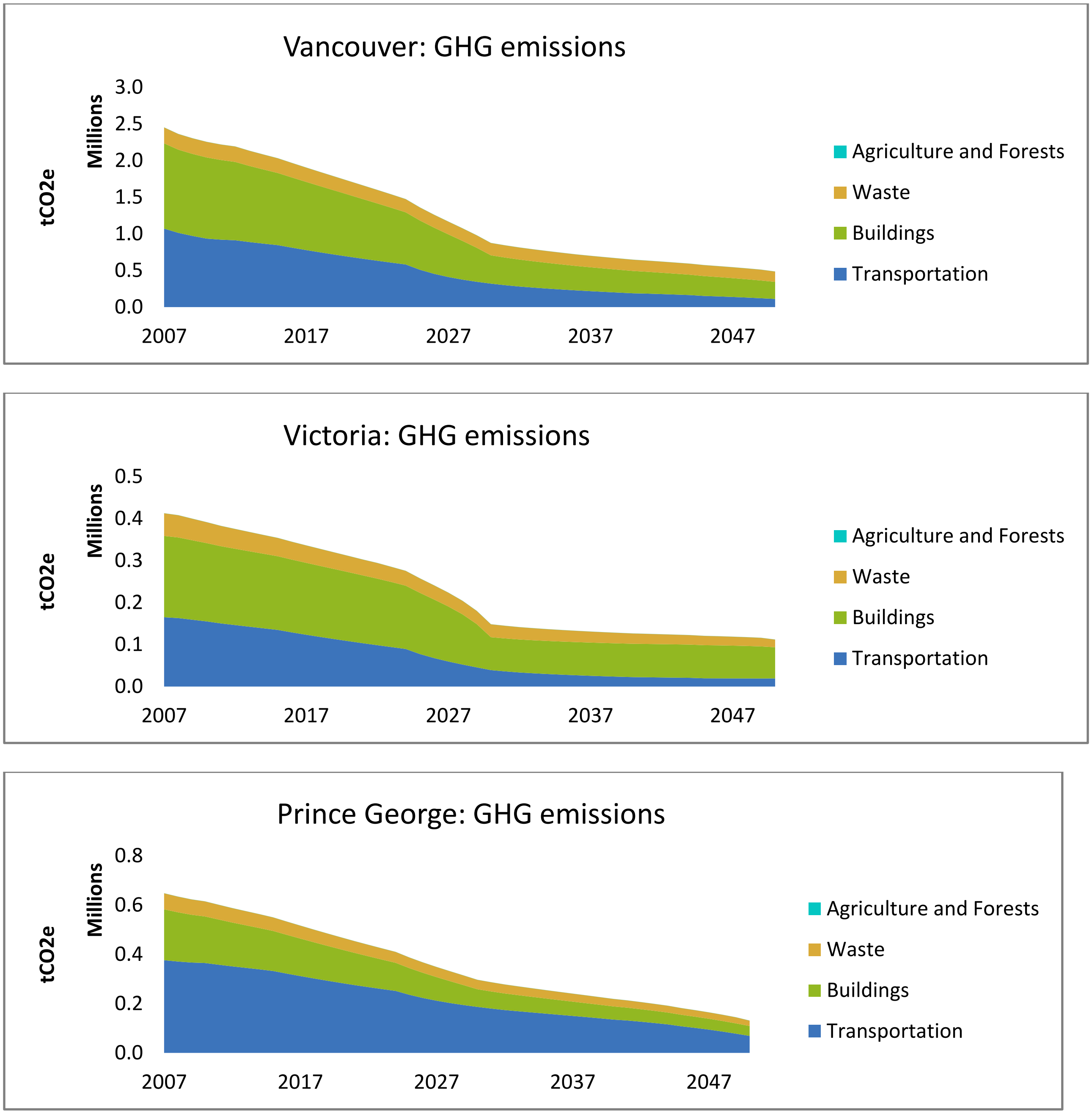
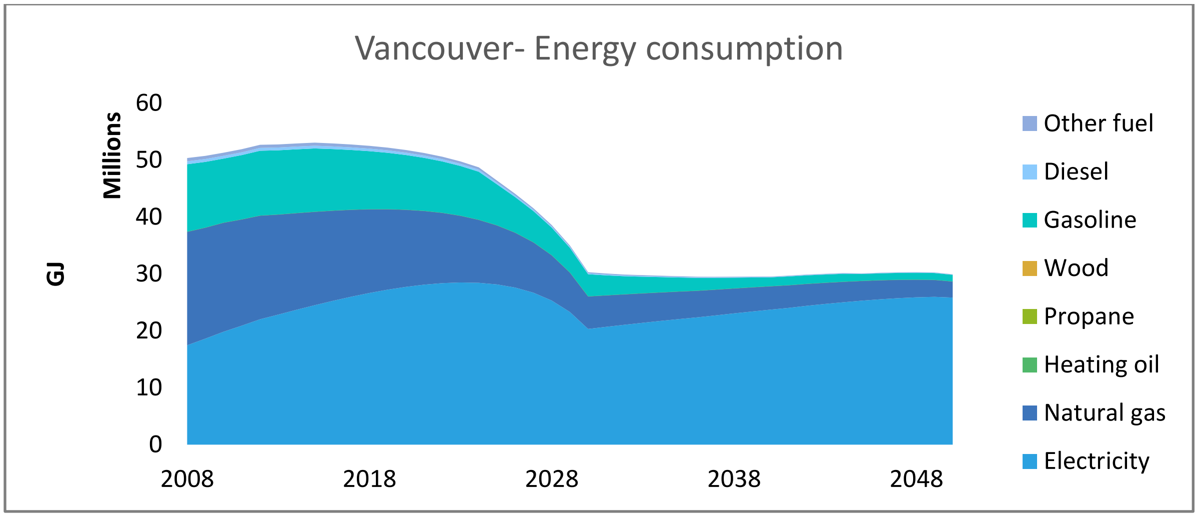
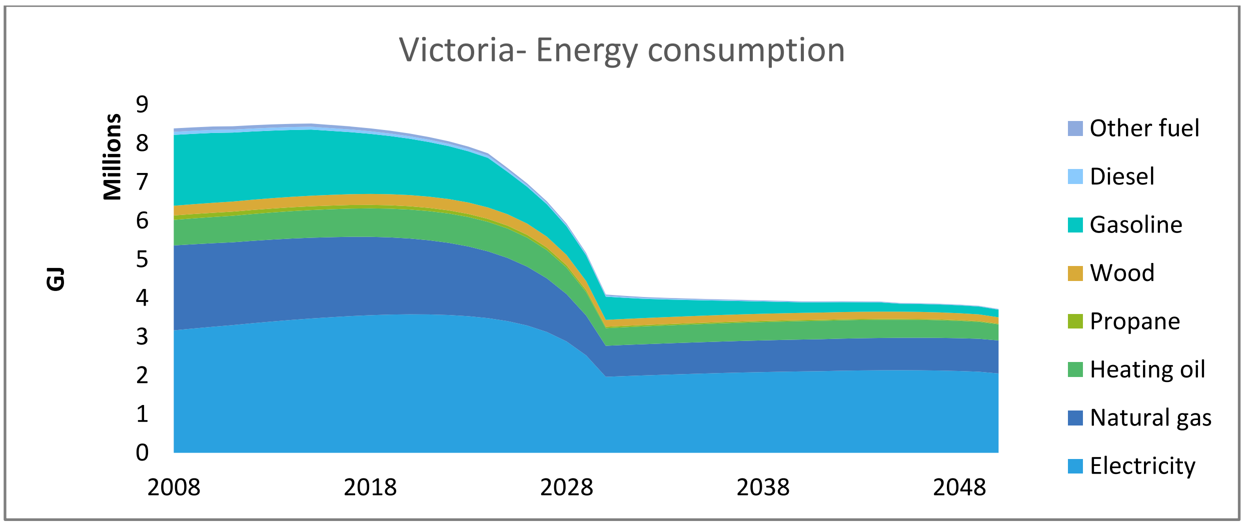


Figure 8: 80% reduction in GHG emissions by 2050 by city

Energy trends push this idea further, because of energy switching from natural gas to electricity that offsets gains in efficiency from electricity conservation in buildings. Fuel switching is also occurring in vehicles, as the fleet switches from gasoline to electric vehicles. Gasoline and diesel use is driven down as vehicles become increasingly efficient, people shift to other modes of transportation, trip length decreases due to densification and the fleet shifts to electric vehicles. The majority of the efficiency gains occur by 2030, again driven by federal fuel efficiency standards.





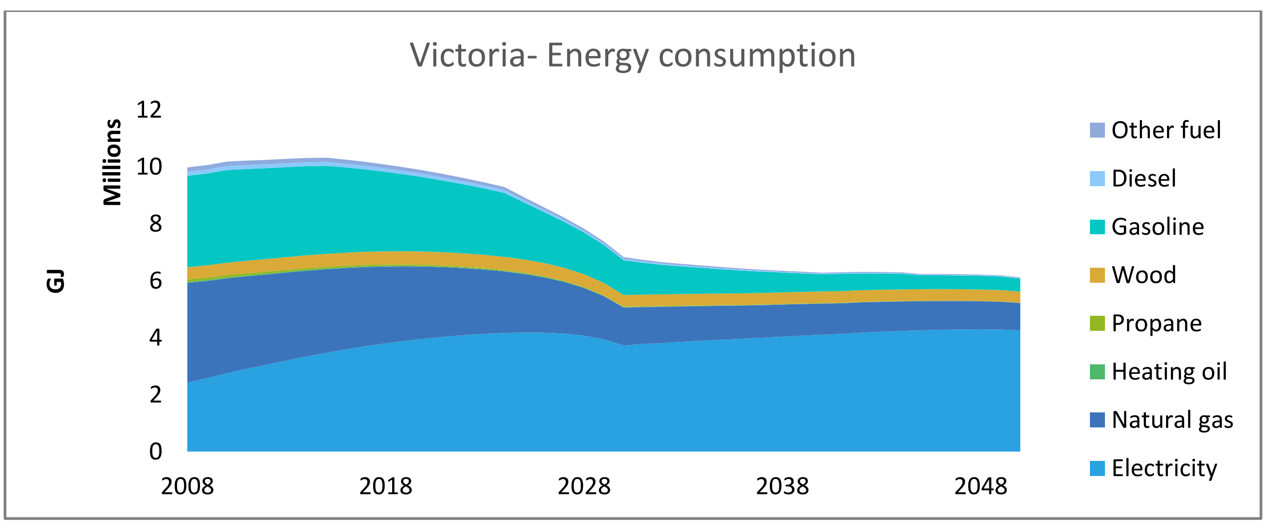


Figure 9: Energy consumption by fuel type to achieve an 80% reduction by 2050

Gasoline and diesel use is driven down as vehicles become increasingly efficient, people shift to other modes of transportation, trip length decreases due to densification and the fleet shifts to electric vehicles (Figure 10 and 11). The majority of the efficiency gains occur by 2030, again driven by federal fuel efficiency standards.

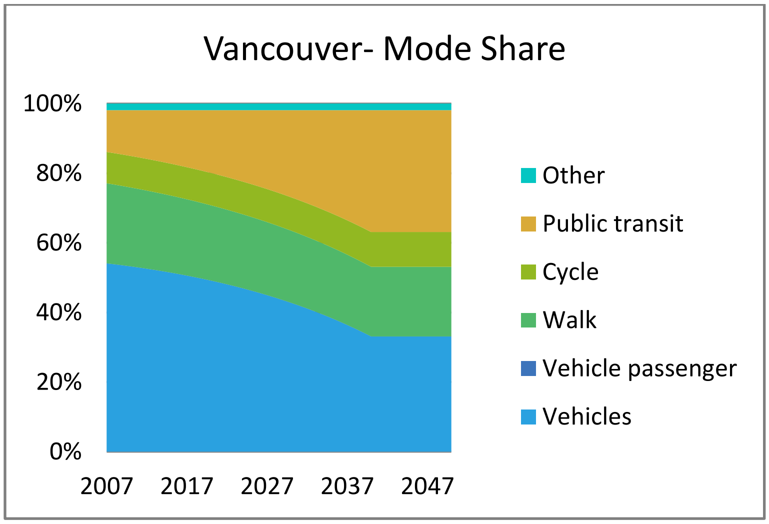


Figure 10: Mode split in Vancouver to achieve an 80% reduction in GHG emissions by 2050

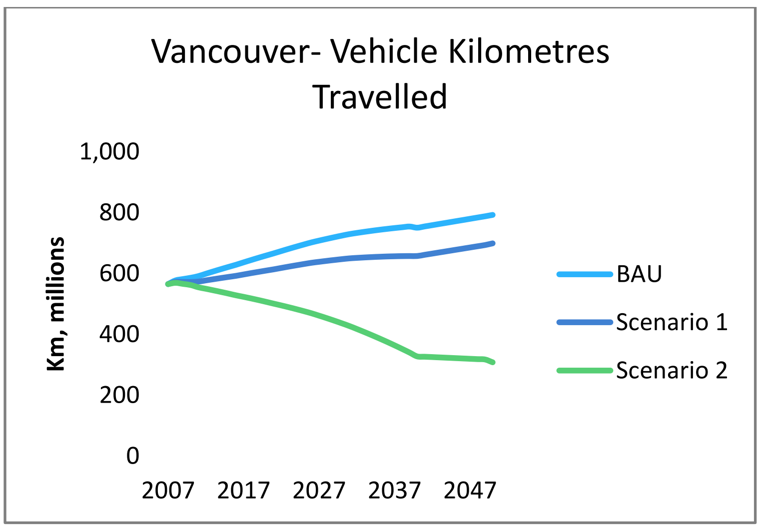


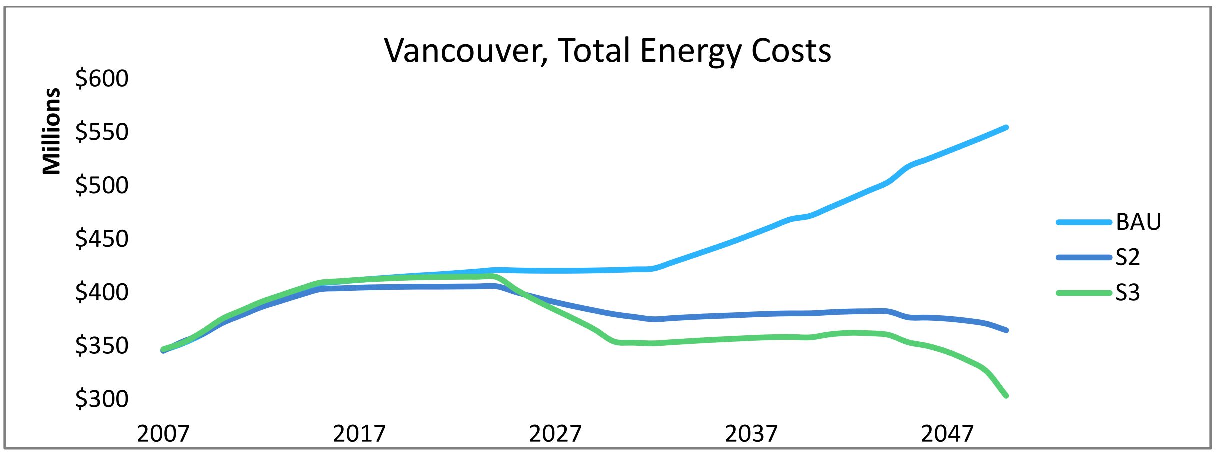
Figure 11: Vehicles kilometres travelled in Vancouver to achieve an 80% reduction in GHG emissions by 2050

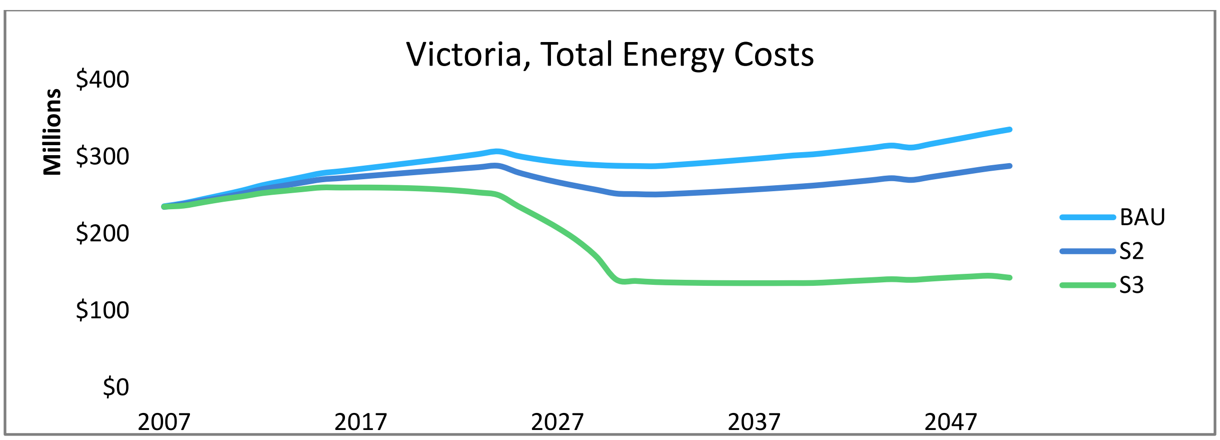
Energy costs decline as energy consumption declines, but some of the decline is offset by fuel switching from cheaper natural gas (on a per GJ basis) to more costly electricity (Table 4).

Table 4: Energy cost escalation assumptions

	2007 ($/GJ)	2050 ($/GJ)
Electricity	$20	$29
Natural Gas	$15	$18
Heating Oil	$29	$29
Propane	$25	$32
Wood	$12	$12

There are still significant financial benefits, for example in the order of $250 million on annual energy costs of $550 million for the City of Vancouver. In all three scenarios, business as usual costs increase gradually mitigated by the aggressive fuel efficiency standard and as the fuel efficiency standard stabilises in 2030, and are driven upwards by continuing population growth (Figure 12) .





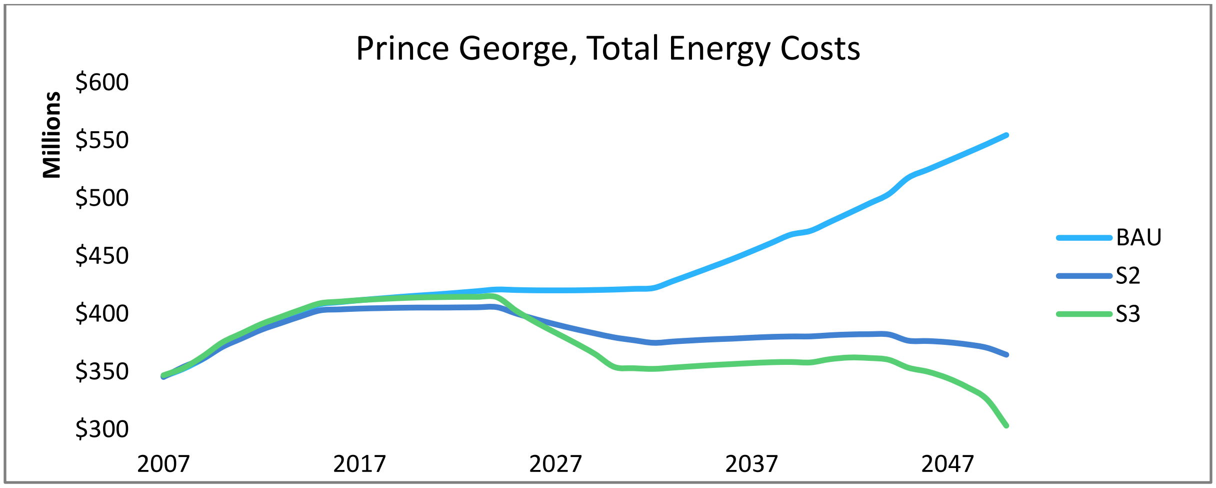
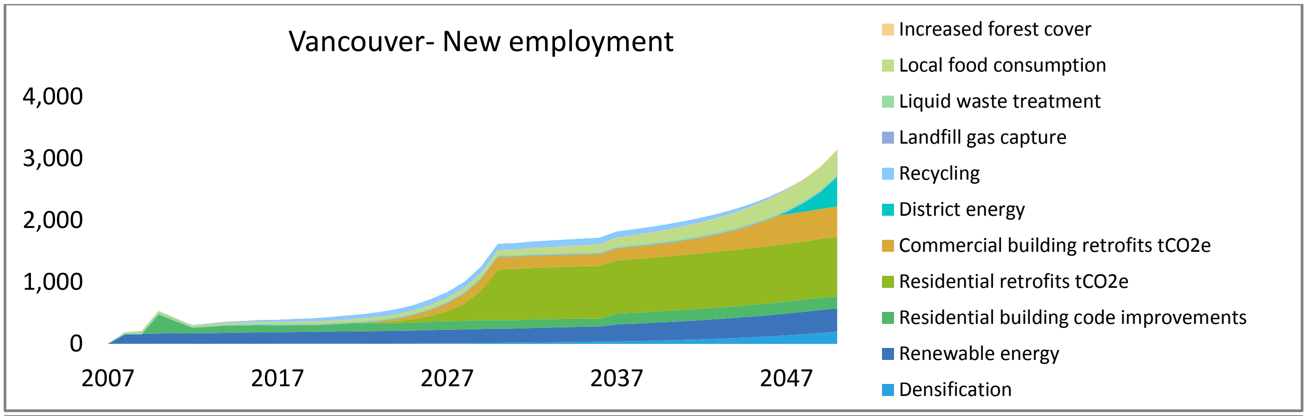
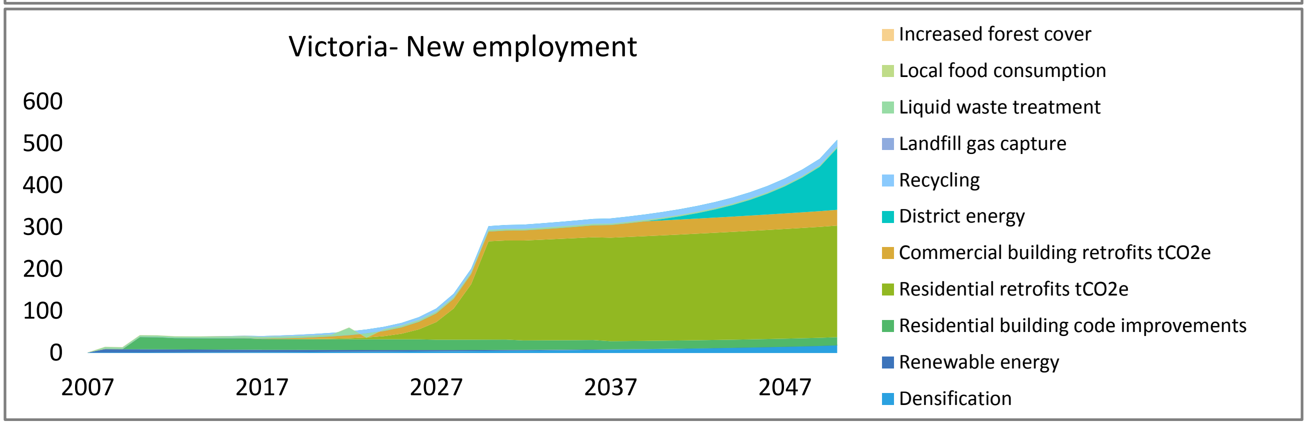


Figure 12: Annual energy costs for all three scenarios until 2050

GHG reductions and energy conservation generate employment. Employment generation is identified for each strategy to illustrate the level of effort involved in achieving the targets. For example, the model shows that Vancouver will generate approximately 3,000 new jobs per year in achieving an 80% reduction in GHG emissions by 2050. The bumps near the front of the chart are driven by an increase followed by a decline in the rate of new construction. The sharp upward curve around 2027 is the result of increasing levels of energy retrofits, a labour intensive endeavour. In the chart for Prince George, renewable energy is a more significant source of job creation to offset the heating oil and propane in that city's fuel mix. District energy doesn't become a significant source of employment until 2040, when land-use patterns have shifted to provide the density necessary to make district energy cost-effective.





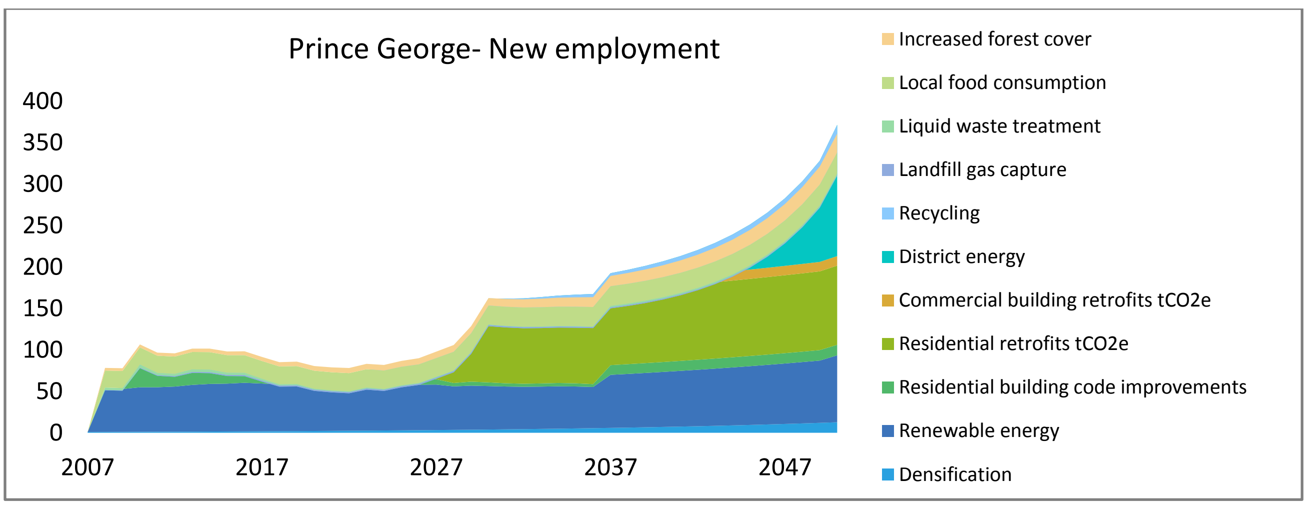


Figure 13: Employment generated for each city as a result of an 80% reduction in GHG emissions by 2050

STRATEGIES

A combination of strategies was used for each city in order to achieve the 80% reduction over 2007 by 2050. The combination of strategies is generally consistent with some variations to reflect the particular circumstances of each City (Table 5).

Table 5: Combination of measures implemented to achieve 80% reduction

	Vancouver	**Victoria**	**Prince George**
Trip length	Declines by 47%	Declines by 32%	Declines by 36%
Vehicular mode share	Declines by 40% with balance going to walking, cycling and transit	Declines from 60% to 35%	Declines from 88% to 60%
Fuel efficiency	Increases to 50 km/l	Increases to 50 km/l	Increases to 35 km/l
Electric vehicle uptake	60% of the vehicle fleet	55% of the vehicle fleet	60% of the vehicle fleet
Public transit efficiency	Doubles in efficiency	+42% in efficiency	+42% in efficiency
Electric public transit	Increases to 33% of the fleet	Increases to 33% of the fleet	Increases to 33% of the fleet
Commercial transit, GHG reduction	Decreases by 60%	Decreases by 60%	Decreases by 65%
Electricity emissions factor	Falls to 3.5 kgCO2e/GJ	Falls to 2.5 kgCO2e/GJ	Falls to 4 kgCO2e/GJ
Electricity share, residential	Increases from 38% to 90%	Increases from 47% to 86%	Increases from 27% to 85%
Natural gas share, residential	Falls from 62% to 10%	Falls from 14% to 1%	Falls from 59% to 5%
Electricity share, commercial	Increases from 51% to 90%	Increases from 51% to 90%	Increases from 48% to 85%
Natural gas share, commercial	Decreases from 49% to 10%	Decreases from 49% to 10%	Decreases from 52% to 15%
Dwelling mix	Single detached fall from 15% to 6% of the total dwellings	Single detached fall from 19% to 8% of the total dwellings	Single detached fall from 67% to 50% of the total dwellings
New construction-residential and commercial	50% energy savings over existing buildings	70% energy savings over existing buildings and 60% for commercial buildings.	50% energy savings over existing buildings
Retrofits	50% of the buildings achieve savings of 50% or more.	75% of the buildings achieve savings of 60% or more.	25% of the buildings achieve savings of 25% or more.
District energy	15% of residential buildings are connected to district energy, achieving energy savings of 60%	15% of residential buildings are connected to district energy, achieving energy savings of 70%	15% of residential buildings are connected to district energy, achieving energy savings of 50%
Solid waste	Per capita solid waste falls from 1.32 tonnes per person to 0.35 tonnes per person	Per capita solid waste falls from 1.93 tonnes per person to 0.5 tonnes per person	Per capita solid waste falls from 2.9 tonnes per person to 1 tonne per person
Diversion rate	Increases from 60% to 85%	Increases from 60% to 85%	Increases from 55% to 80%

The relative impact of the different strategies is illustrated in the following wedge diagrams. In the charts below, each of the strategies is evaluated on the basis of their contribution to the GHG reduction. The dark blue area is the remaining GHG emissions and each of the other colours represents a GHG reduction. Note that these charts represent one way to illustrate the GHG reductions based on an arbitrary set of categories. For example, renewable energy could also be represented as fuel switching to electricity and be bundled with fuel switching from gasoline. Further, the wedge type diagram does not capture the interaction between each of the variables- for example reduced vehicle travel is connected to densification.

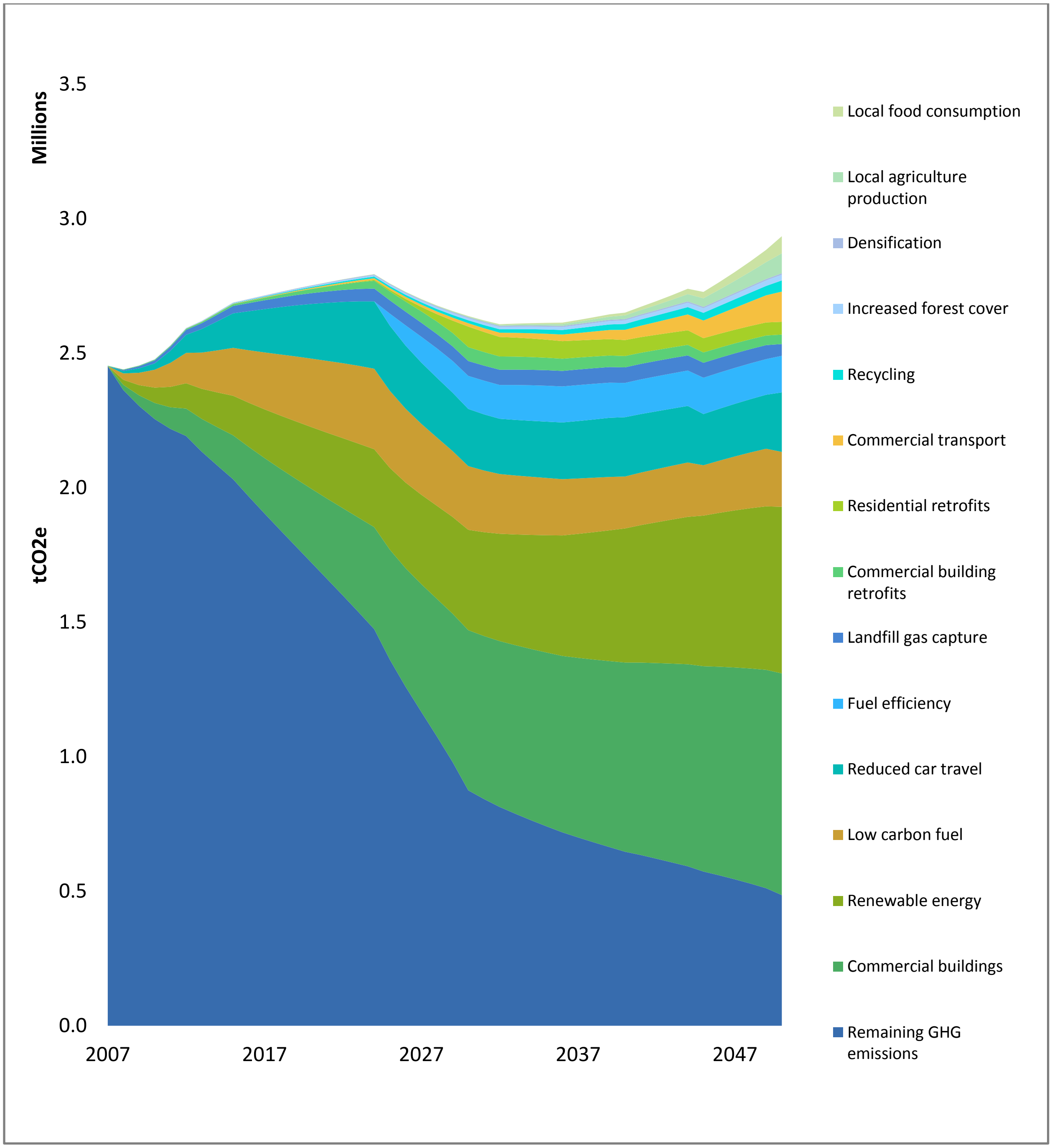


Figure 14: Vancouver, GHG Reductions by Strategy, 80% reduction over 2007

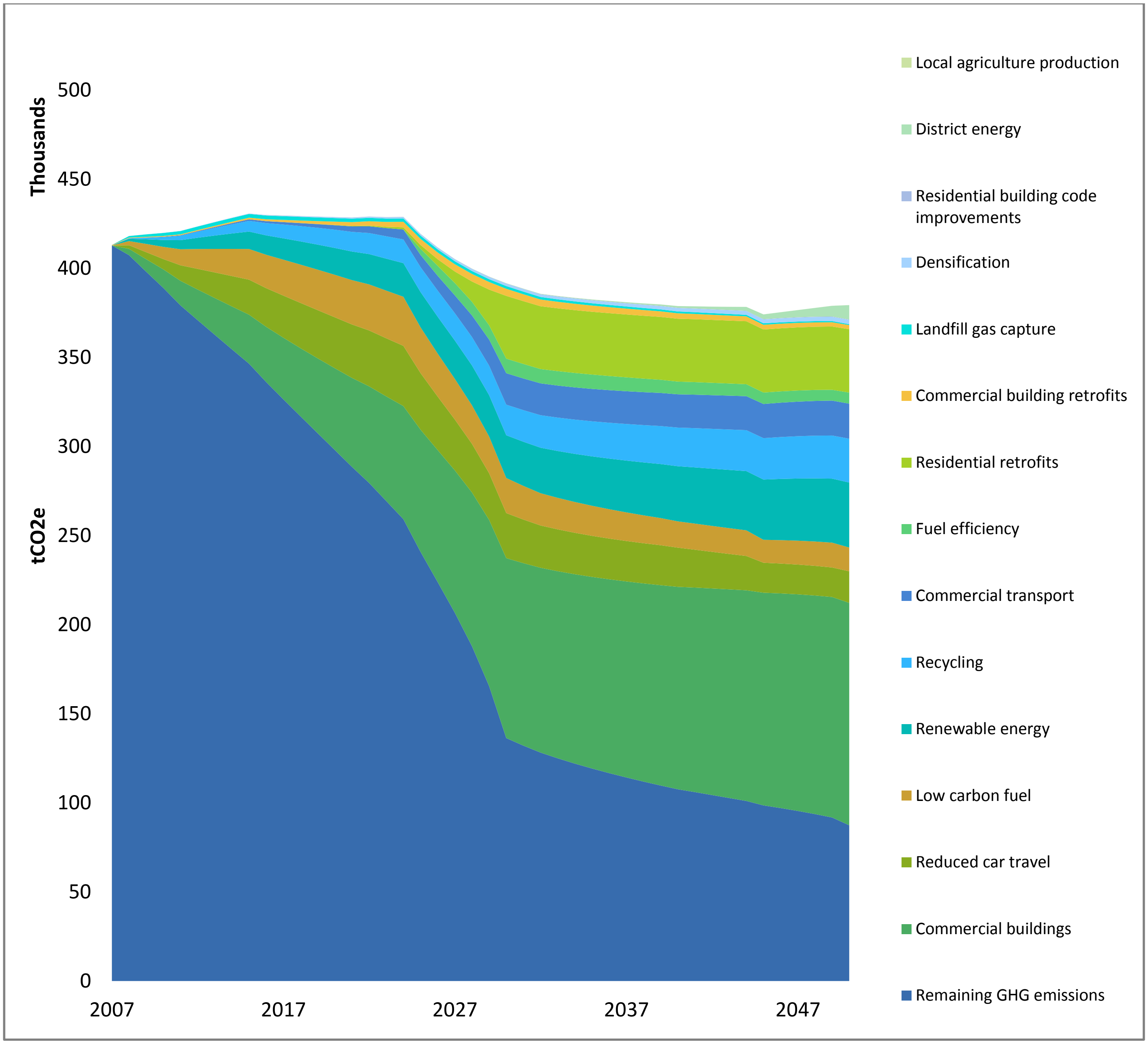


Figure 15: Victoria, GHG Reductions by Strategy, 80% reduction over 2007

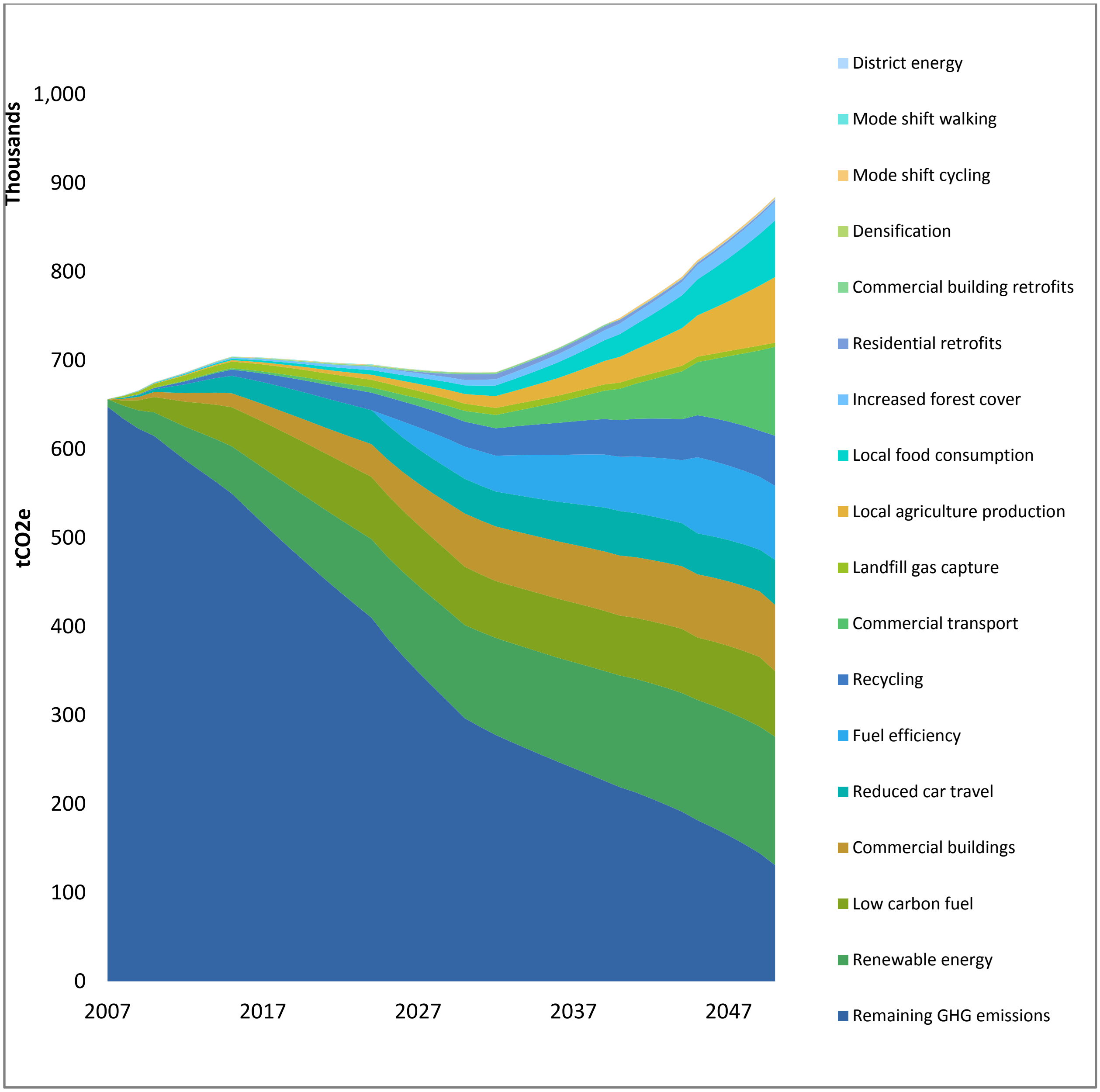


Figure 16: Prince George, GHG Reductions by Strategy, 80% reduction over 200

OBSERVATIONS

The analysis gives rise to a number of policy directions for local and provincial governments to achieve deep GHG emissions reductions by 2050.

In the absence of significant action by municipalities and other adaptation and mitigation strategies, GHG emissions will climb significantly by 2050 for all three communities, driven by projected population increases. From an energy and GHG emissions perspective, the population increase is a double-edged sword. New development driven by an increasing population creates an opportunity for the community to reconfigure its housing mix, in favour of mixed-use development and higher density. This type of development incentivizes walkability and enhances the feasibility of district energy and public transit. A municipality that is not 'growing' faces significant challenges in adapting its existing infrastructure to more sustainable investments. On the other hand, there are more people, potentially with more vehicles and more dwellings; it is critical that all new dwellings at the margin are increasingly efficient and less dependent on fossil fuels.

The existing building stock requires a sustained and comprehensive retrofit program that targets deep energy savings (in the order of 50% or more) and fuel switching to renewable energy, particularly for heating. Natural gas, propane and heating oil have to be minimised or eliminated.

Commercial buildings need to be a major focus, particularly for highly urbanised cities such as Vancouver and Victoria.

New construction also requires ambitious energy savings targets as this reduces the retrofit burden going forward with targets in the range of 60to 75% reductions.

Clean electricity is critical to all strategies—this includes fuel switching from natural gas, heating oil and propane in buildings and from gasoline to electric vehicles. The implications of increasing the fossil fuel generation mix in the electricity supply are significant, for example, if the emissions factor for electricity increases from 6 kgCO2e/kg to 12 kgCO2e/kg (for perspective, Ontario's emission factor was 417 kg CO2e/GJ in 2011), Victoria's target shifts from an 80% reduction in 2050 to a 73% reduction. Municipalities can deploy solar PV energy generation to contribute to the increased transition to clean energy. In particular, renewable energy sources have a key role to play. For example, BC's natural resources will continue to form the province's competitive advantage in the green economy.

Commercial transportation is a challenge for municipalities. Federal efficiency regulations will contribute to reductions but new and creative strategies to reduce emissions from commercial transportation will need to be developed. Fuel-switching from gasoline to electricity for commercial vehicles will likely be an important strategy.

Waste prevention and waste diversion efforts are important GHG reduction strategies. Landfills generate methane, a potent GHG. For example in Vancouver in 2007, emissions in a landfill with methane capture technology exceeded the emissions from commercial transportation.

CONCLUSION

Notably, 80% GHG reductions are not inconceivable for any of the three communities analysed. Based on the data, one can conceive how with a sustained effort, innovative policy development, policy alignment and policy congruence and existing technologies, all three can achieve 80% GHG reductions. We anticipate that these reductions can also be achieved without negatively effecting economic development, and in fact, the strategies to achieve the reductions will generate employment and financial savings for households and businesses. Further research remains to explore the synergies and co-benefits of activities that reduce GHG emissions and result in energy efficiency. Significant policy changes, such as the generation of electricity using natural gas as currently proposed by the Provincial Government may, however, make the targets extremely challenging as clean electricity, even at the margins is critical to achieving the targets for all three cities.

APPENDIX

1. City of Vancouver GHGProof- policies, inputs and assumptions

	BAU	S2	S3	By year	Units	Reference 2007
Agriculture and forests	No					
		Targets				
Transportation						
Trip length	11.4	9.0	6.0	2040	km	11.4
Mode share						
Vehicle	59.0%	40.0%	35.0%			
Walk	15.0%	22.0%	20.0%	2040	%	13%
Cycle	4.0%	8.0%	15.0%	2040	%	4%
Public transit	22.0%	30.0%	30.0%	2040	%	17%
Private transport fuel efficiency	25.0	40.0	50.0	2050	km/l	9.8
Private transport fuel emissions factor	2.50	1.60	1.00	2050	kgCO2e/l	2.50
Walking: # of dwellings <400m to CBD	24%	24%	40%	2030	%	4%
Cylcing: # of dwellings <1000m to CBD	24%	24%	26%	2030	%	21%
Transit: # of dwellings <400m to transit stop	15%	15%	30%	2030	%	21%
Walking: Proporition of trips <400m to CBD	24%	24%	24%	2030	%	24%
Cylcing: Proportion of trips <1000m to CBD	24%	24%	24%	2030	%	24%
Transit: Proportion of trips <400m to transit stop	15%	15%	15%	2030	%	15%
Public transit fuel efficiency	30.0	40.0	60.0	2050	km/l	30
Public transit fuel emissions factor	1.92	1.60	1.30	2050	kgCO2e/l	1.9
Commercial transportation, 2050 fleet energy reduction	1%	3%	60%	2030	%	1%
Buildings						
Electricity, emissions factor	6.90	5.00	3.50	2050	kgCO2e/GJ	6.9
Energy mix- residential						
Electricity	38%	60%	90%	2050	%	38%
Gas	62%	40%	10%	2050	%	62%
Heating oil	0%	0%	0%	2050	%	0%
Propane	0%	0%	0%	2050	%	0%
Wood	0%	0%	0%	2050	%	0%
Energy mix- commercial						
Electricity	51%	70%	90%	2050	%	51%
Gas	49%	30%	10%	2050	%	49%
Heating oil	0%	0%	0%	2050	%	0%
Propane	0%	0%	0%	2050	%	0%
Wood	0%	0%	0%	2050		0%
Dwelling mix						
Single Detached	15%	12%	6%	2030	%	19%
Attached	23%	24%	26%	2030	%	21%
Apartment<5 storeys	26%	27%	28%	2030	%	24%
Apartment> 5 storeys	36%	37%	40%	2030	%	35%
Detached						
Energy reducton for new buildings	25%	25%	50%	2030	%	30%
% of existing buildings upgraded	0%	0%	50%	2030	%	0%
Energy savings in existing buildings	10%	10%	50%	2030	%	10%
Row						
Energy reducton for new buildings	25%	25%	50%	2030	%	30%

% of existing buildings upgraded	0%	0%	50%	2030	%	0%
Energy savings in existing buildings	10%	10%	50%	2030	%	10%
Apartments<5 storeys						
Energy reducton for new buildings	25%	25%	50%	2030	%	30%
% of existing buildings upgraded	0%	0%	50%	2030	%	0%
Energy savings in existing buildings	10%	10%	50%	2030	%	10%
Apartments > 5 stories						
Energy reducton for new buildings	25%	25%	50%	2030	%	30%
% of existing buildings upgraded	0%	0%	50%	2030	%	0%
Energy savings in existing buildings	10%	10%	50%	2030	%	10%
Mobile homes						
Energy reducton for new buildings	25%	25%	50%	2030	%	30%
% of existing buildings upgraded	0%	0%	50%	2030	%	0%
Energy savings in existing buildings	10%	10%	50%	2030	%	10%
Commercial buildings						
% energy savings new build	2%	10%	50%	2030	%	1%
% of commercial builings retrofit per year	1%	5%	50%	2030	%	0.0%
Energy savings from retrofits	5%	20%	50%	2030	%	5%
Community energy						
Community energy-detached	5.0%	10.0%	15.0%	2050	% of dwellings	1
Community energy-row	5.0%	10.0%	15.0%	2050	% of dwellings	1
Community energy- apartments <5	5.0%	10.0%	15.0%	2050	% of dwellings	1
Community energy apartments>5	5.0%	10.0%	15.0%	2050	% of dwellings	1
Energy savings from DE	45%	45%	60%	2050	%	25.0%
Solid waste						
Solid waste diversion rate	60%	75%	85%	2050	%	58%
Waste production rate	1.07	1.07	0.35	2050	tonnes/capita	1.32
Agriculture and forest						
Area of local farms	8,500	10,000	10,000	2050	%	297
Intensity of prodction	0.58	0.40	0.20	2050	ha/capita	0.58
Percent of production locally consumed	5%	75%	75%	2050	%	5%
Area of forest	1,142	2,000	5,000	2050	hectares	1,142

BAU

	Factor			2007
General	1. Total Households		101.0%	270,039
	2. Total Population		101.0%	623,505
	3. People per household		100.1%	2.3
	4. Year			2007
Transportation	5. Average trip length		100%	11.4
	6. Walk to town centre		98%	108,016
	7. Cycle to town centre		99%	108,016
	7. Transit route, 500m		96%	216,031
	8. Road length, asphalt		100%	533
	9. Road length, gravel		100%	26
Buildings	10. Detached		19%	52,409
	11. Row houses		21%	57,554
	12. Apartments <5 storeys		24%	65,664
	13. Apartments >5 storeys		35%	94,412
	14. Mobile homes			2
	Community energy-detached	3,761	121%	1
	Community energy-row	4,464	122%	1
	Community energy- apartments <5	5,080	122%	1
	Community energy apartments>5	7,234	123%	1
Waste	20. Solid waste, no gas collection			0
	21. Solid waste, gas collection			825,726
	22. Liquid waste, primary treatment		0%	1
	23. Liquid waste, secondary treatment		0%	1
	24. Liquid waste, tertiary treatment			270,039
	25. Liquid waste, septic		101%	0
Forest and agriculture	26. Agriculture, total area of farms		107%	297
	28. Agriculture, local consumption		100%	5%
	29. Agricultural land- perennial cover		107%	2
	30. Agricultural land- till		103%	5
	31. Agriculture no-till		107%	2
	32. Beef and heifer cows		105%	9
	33. Dairy cows		100%	1
	34. Forest, absorption		100%	1,142
	35. Forest- wood removals		111%	100
	36. Forest- fuel removals		131%	1
Goal seeking	Total			
	% Change			

A. Assumptions

Themes	*Factor*		*Assumptions*		*Variable*		*Year*
Transportation	1. Trip length		1.1 Trips per person per day	#	2.58		
			1.2 Trips per year	#	941		
			1.3 Trips by automobile				
			BAU	%	58%	linked	
			Scenario 1	%		linked	
			Scenario 2	%		linked	
			1.4 Average fuel consumption				
			BAU	km/l	9.83	linked	
			Scenario 1	km/l	9.83	linked	
			Scenario 2	km/l	9.83	linked	
			1.7 Fuel emissions factor: fuel				
			BAU	kgCO2e/l	2.5		2050
		0.02734375	Scenario 1	kgCO2e/l	1.6		2050
		27.34375	Scenario 2	kgCO2e/l	1		2050
			1.8 Cost of fuel	$	$1.24		
			1.9 Annual vehicle replacement	%	4.0%	linked	
			Gasoline	l/GJ	28.16		
	2. CBD, 400m		2.3 Trips within 400m				
			BAU	%	24%		2030
			Scenario 1	%	24%		2030
			Scenario 2	%	24%		2030
			2.4 % of trips willing to walk				
			BAU	%	21%		2030
			Scenario 1	%	21%		2030
			Scenario 2	%	21%		2030
	3. CBD, 1000m		2.3 Trips within 1000m				
			BAU	%	24%		2030
			Scenario 1	%	24%		2030
			Scenario 2	%	24%		2030
			2.4 % of trips willing to cycle				
			BAU	%	21%		2030
			Scenario 1	%	21%		2030
			Scenario 2	%	21%		2030
	3. Public transport, 400m		3.3 % of trips shifted to public transport				
			BAU	%	15%		2030
			Scenario 1	%	15%		2030
			Scenario 2	%	15%		2030
			3.6 Public transit efficiency				
			BAU	km/l	30		2030
			Scenario 1	km/l	40		2030
			Scenario 2	km/l	60		2030
			3.7 Emissions factor: public transit				
			BAU	kgC02e/km	1.92		2030
			Scenario 1	kgC02e/km	1.60		2030
			Scenario 2	kgC02e/km	1.30		2030
			3.8 Cost per kilometre: public transit	$/km	$0.50		2031
	4. Road length, asphalt		4.1 Emissions factor: asphalt road	tCO2e/km	760	vestigal	
			4.2 Road construction cost	$/km	$1,000,000	vestigal	
			4.3 Lifetime	yrs	40	vestigal	
	5. Road length, gravel		5.1 Emissions factor: gravel road	tCO2e/km	387.6	vestigal	
			5.2 Road construction cost	$/km	$750,000	vestigal	
			5.3 Lifetime	yrs	40	vestigal	
	6. Commercial transportation		6.1 Commercial transportation emissions	tCO2e/capita	0.2		
			BAU reduction per year	%	1.0%		2030
			Scenario 1 reduction per year	%	3.0%		2030
			Scenario 2 reduction per year	%	60.0%		2030
Buildings			7.2 Emissions factor: buildings				
			BAU	kgCO2e/GJ	34.08	linked	
			Scenario 1	kgCO2e/GJ	34.08	linked	
			Scenario 2	kgCO2e/GJ	34.08	linked	
			7.3 Cost of energy				
			Electricity	$/GJ	$29		2050
			Natural gas	$/GJ	$18		2050
			Heating Oil	$/GJ	$29		2050
			Propane	$/GJ	$32		2050
			Wood	$/GJ	$12		2050
			7.4 Investment strategy cots				
			Renewable energy investment cost	$/GJ	$20		

A. Assumptions

	Residential retrofit costs	$/GJ	$10	
	Commercial retrofit costs	$/GJ	$7	
	District energy investment costs	$/GJ	$25	
	Recycling-investment	$/tonne	$50	
	Landfill gas	$/tCO2e	$10	
	Liquid waste upgrade	$/household	$400	
	Local food consumption	$/ha	$15,000	
	Agricultural practices change	$/ha	$6	
	Reforestation	$/ha	$1,000	
Dwelling mix				
	S1		100.00%	
	Single Detached	%	15.0%	2030
	Attached	%	23.0%	2030
	Apartment<5 storeys	%	26.0%	2030
	Apartment> 5 storeys	%	36.0%	2030
	S2			
	Single Detached	%	12.0%	2030
	Attached	%	24.0%	2030
	Apartment<5 storeys	%	27.0%	2030
	Apartment> 5 storeys	%	37.0%	2030
	S3			
	Single Detached	%	6.0%	2030
	Attached	%	26.0%	2030
	Apartment<5 storeys	%	28.0%	2030
	Apartment> 5 storeys	%	40.0%	2030
Detached	7.1 Energy/area	GJ/m2	0.75	
	7.4 Average size	m2	172	
	Energy reducton for new buildings			
	BAU	%	45%	2030
	Scenario 1	%	25%	2030
	Scenario 2	%	50%	2030
	% of existing buildings upgraded			
	BAU	%	0%	2030
	Scenario 1	%	0%	2030
	Scenario 2	%	50%	2030
	Energy savings in existing buildings			
	BAU	%	10%	2030
	Scenario 1	%	10%	2030
	Scenario 2	%	50%	2030
Row	8.1 Energy/area	GJ/m2	0.63	
	8.4 Average size	m2	68	
	Energy reducton for new buildings			
	BAU	%	45%	2030
	Scenario 1	%	25%	2030
	Scenario 2	%	50%	2030
	% of existing buildings upgraded			
	BAU	%	0.0%	2030
	Scenario 1	%	0%	2030
	Scenario 2	%	50%	2030
	Energy savings in existing buildings			
	BAU	%	10%	2030
	Scenario 1	%	10%	2030
	Scenario 2	%	50%	2030
Apartments<5 storeys	9.1 Energy/area	GJ/m2	0.63	
	8.4 Average size	m2	104	
	Energy reducton for new buildings			
	BAU	%	45%	2030
	Scenario 1	%	25%	2030
	Scenario 2	%	50%	2030
	% of existing buildings upgraded			
	BAU	%	0%	2030
	Scenario 1	%	0%	2030
	Scenario 2	%	50%	2030
	Energy savings in existing buildings	%		
	BAU	%	10%	2030
	Scenario 1	%	10%	2030
	Scenario 2	%	50%	2030
Apartments > 5 stories	9.1 Energy/area	GJ/m2	0.63	
	8.4 Average size	m2	40	
	Energy reducton for new buildings			
	BAU	%	45%	2030
	Scenario 1	%	25%	2030

		Scenario 2	%	50%	2030
		% of existing buildings upgraded			
		BAU	%	0%	2030
		Scenario 1	%	0%	2030
		Scenario 2	%	50%	2030
		Energy savings in existing buildings			
		BAU	%	10%	2030
		Scenario 1	%	10%	2030
		Scenario 2	%	50%	2030
	Mobile homes	9.1 Energy/area	GJ/m2	1.05	
		8.4 Average size	m2	169	
		Energy reducton for new buildings			
		BAU	%	45%	2030
		Scenario 1	%	25%	2030
		Scenario 2	%	50%	2030
		% of existing buildings upgraded			
		BAU	%	0%	2030
		Scenario 1	%	0%	2030
		Scenario 2	%	50%	2030
		Energy savings in existing buildings			
		BAU	%	10%	2030
		Scenario 1	%	10%	2030
		Scenario 2	%	50%	2030
	Commercial buildings	Commercial energy			
		Energy savings from new build			
		BAU		2%	2030
		Scenario 1		10%	2030
		Scenario 2		50%	2030
		11.2 Emissions factor: buildings			
		BAU	kgCO2e/GJ	28	linked
		Scenario 1	kgCO2e/GJ	20	linked
		Scenario 2	kgCO2e/GJ	15	linked
		11.3 Energy cost			
		BAU	$/GJ	$24	2050
		Scenario 1	$/GJ	$24	2050
		Scenario 2	$/GJ	$28	2050
		% of commercial buildngs retrofited			
		BAU	%	1%	2030
		Scenario 1	%	5%	2030
		Scenario 2	%	50%	2030
		Energy savings from retrofits			
		BAU	%	5%	2030
		Scenario 1	%	20%	2030
		Scenario 2	%	50%	2030
	Community energy	13.1 Threshold	kwh/m2/yr	50	
		Energy savings due to district energy			
		BAU	%	45%	2050
		Scenario 1	%	45%	2050
		Scenario 2	%	60%	2050
	14. Solid waste	14.1 Emissions factor, L0	kgCH4/tonne	72	
		14.2 Emissions factor, k		0.046	
		14.3 Number of years to degrade	years	10	
Waste		14.4 Emissions factor, L0	kgCO2e/tonne		
		14.5 Emissions factor: solid waste- gas collection	%	75%	
		Solid waste production rate			
		BAU	tonnes/capita	1.07	
		Scenario 1	tonnes/capita	1.07	
		Scenario 2	tonnes/capita	0.35	
		Solid waste diversion rate			
		BAU	%	75%	2050
		Scenario 1	%	75%	2050
		Scenario 2	%	85%	2050
	15. Liquid waste	15.1 Emissions factor: tertiary	kgCO2e/capita	123	
		15.2 Emission factor: secondary	kgCO2e/capita	123	
		15.3 Emissions factor: preliminary	kgCO2e/capita	123	
		15.4 Emissions factor: septic	kgCO2e/capita	205	
		15.5 Infrastructure cost	$/capita	$3,100	
Forest and Agriculture	16. Agriculture, local production	16.1 Emissions factor, imported	kgCO2e/kg	3.6	
		16.2 Emissions factor, local production	kgCO2e/kg	0.13	
		Intensity of production			
		BAU	ha/capita	0.58	2050
		Scenario 1	ha/capita	0.40	2050

		Scenario 2	ha/capita	0.20	2050
		16.4 Weight of food/year	kg	580	
	17. Agriculture	17.1 Emissions factor: perennials (hay)	tCO2e/ha	0.3	
		17.2 Emissions factor: till	tCO2e/ha	0.4	
		17.3 Emissions factor: no-till	tCO2e/ha	0.3	
		17.4 Emissions factor: beef	tCO2e/head	1.2	
		17.5 Emissions factor: dairy	tCO2e/head	2.0	
	18. Forest	18.1 Absorption factor	tCO2e/ha	4.0	
		18.2 Emissions factor: soil	tCO2e/ha	1.5	
		18.3 Emissions factor: wood removal	tCO2e/m3	0.4	
		18.4 Emissions factor: fuel removal	tCO2e/m3	0.1	
Costs	19. Costs	Social cost of carbon	$/tCO2e	$ 150	
		Carbon tax	$/tCO2e	$ 25	
		Renewable energy investment cost	$/GJ	$ 988,059	
		Residential retrofit costs	$/GJ	$ 10	
		Commercial retrofit costs	$/GJ	$ 7	
		District energy investment costs	$/GJ	$ 5,528	
		Recycling-investment	$/tonne	$ 50	
		Landfill gas	$/tCO2e	$ 10	
		Liquid waste upgrade	$/household	$ 400	
		Local food consumption	$/ha	$ 15,000	
		Agricultural practices change	$/ha	$ 6	
		Reforestation	$/ha	$ 3,000	
Employment		Densification	#	2.20	
		Direct	#	0.00	
		Indirect	#	0.00	
		Induced			
		Residential retrofit costs	#	4.60	
		Direct	#	4.90	
		Indirect	#	3.80	
		Induced			
		Commercial retrofit costs	#	7.00	
		Direct	#	4.90	
		Indirect	#	4.80	
		Induced			
		Renewable energy	#	4.60	
		Direct	#	4.90	
		Indirect	#	3.80	
		Induced			
		Recycling-investment	#	7	
		Direct	#	4	
		Indirect	#	3	
		Induced			
		Landfill gas	#	6.70	
		Direct	#	3.50	
		Indirect	#	3.20	
		Induced			
		Liquid waste upgrade	#	6.70	
		Direct	#	3.50	
		Indirect	#	3.20	
		Induced			
		Local food consumption	#	0.50	
		Direct	#	0.00	
		Indirect	#	0.00	
		Induced			
		Reforestation	#	0.10	
		Direct	#	0.00	
		Indirect	#	0.00	