TECHNICAL PAPER

City of Ottawa

2020

SSG whatIf?

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Terms and Acronyms

100% scenario	100% GHG reduction scenario
BAP	Business-as-Planned
CAFE	Corporate Average Fuel Economy
DE	District energy
EPA	Environmental Protection Agency
EV	Electric vehicle
GHG	Greenhouse gas
GJ	Gigajoule
GtCO2e	Gigatonnes carbon dioxide equivalent
HDV	High-density vehicle
HELP	Home Energy Loan Program
ICI	Institutional, commercial, and industrial
IESO	Independent Electricity System Operator
IPCC	Intergovernmental Panel on Climate Change
J	Joule
kWh	Kilowatt hour
MtCO2e	Megatonnes carbon dioxide equivalent
NEB	National Energy Board
OECD	Organisation for Economic Co-operation and Development
OPO	Ontario Planning Outlook
PACE	Property Assessed Clean Energy
PJ	Petajoule
PV	Photovoltaics
RNG	Renewable natural gas
ROPEC	Robert O. Pickard Environmental Centre
SCC	Social cost of carbon
tCO2e	Tonnes carbon dioxide equivalent
TGS	Toronto Green Standard
TJ	Terajoule
VKT	Vehicle kilometres travelled

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Note on Dates

The analysis was calibrated to 2016 to align with data sources from the Census of Statistics Canada. All charts relating to energy and emissions, therefore, span from 2016 to 2050.

The City of Ottawa's baseline year is 2012; an extrapolation has been made in order to draw trendlines between 2012 and 2016.

Charts related to actions or the impact of actions begin in 2020 to correspond with when the actions are expected to be implemented.

1. Executive Summary

This report describes a pathway for the City of Ottawa to achieve deep greenhouse gas (GHG) emissions reductions aligned with current science. The pathway requires a transition of the energy system to clean electricity by 2050 with a focus on energy conservation, energy efficiency, and the deployment of renewable natural gas (RNG).

The report addresses a series of big questions with respect to the City of Ottawa's efforts to address climate change. The questions are as follows:

1. What will it take to achieve GHG emissions reductions of 100% by 2050?
2. What level of emission reductions are required to align with the latest science, as described in the Intergovernmental Panel on Climate Change's (IPCC) report on limiting global warming to 1.5°C?[1]
3. What set of actions are required to achieve these levels of GHG emissions reductions?
4. What might Ottawa look like in 2050 if it has decarbonized?
5. What are the key initiatives required to make this happen?
6. What are the financial costs and benefits of emissions reductions for the community?

In order to answer these questions, a model of Ottawa's energy and emissions system was developed. Data was collected on buildings, energy consumption, transportation behaviour, vehicles, solid waste, wastewater, and other factors to represent all the activities that consumed energy and generated GHG emissions for the 2016 calendar year.

This report evaluates two future scenarios: the Business-as-Planned scenario ("BAP scenario") explores the outcomes of maintaining current policies, while the IPCC scenario ("100% scenario" or "1.5°C") evaluates a pathway that achieves reductions aligned with limiting global warming to 1.5°C.

Population, employment, and dwellings are critical determinants of community energy use and emissions. These variables are held constant across both scenarios in order to better compare the impact of the various actions.

Ottawa's population is projected to increase to 1.5 million people by 2050, adding 250,000 homes to the city. Employment is expected to scale with population, with 400,000 jobs added to the local economy between 2016 and 2050. The additional population and employment generates additional activity, which requires energy, and, given current technologies, will put upward pressure on GHG emissions. This report outlines a path to carbon neutrality for Ottawa, even with substantial population and economic growth.

[1] IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.

1.1. Carbon Budget

Scientists have quantified the remaining global GHG emissions that can be released to prevent global warming from exceeding 1.5°C of warming, which is considered a threshold for dangerous climate change. This is known as the global carbon budget. Each year, as human activity results in the release of additional GHG emissions into the atmosphere, the global carbon budget decreases.

What is Ottawa's fair share of the remaining global carbon budget? A network of major cities around the world has defined a method for allocating the remaining global carbon budget to cities. According to this method, the City of Ottawa's carbon budget between 2019 and 2050 is 58 MtCO2e. If GHG emissions are not reduced rapidly, Ottawa will exceed this carbon budget in less than 10 years.

1.2. Scenarios

The GHG emissions resulting from both scenarios are illustrated in Figure 1-1.

If no additional actions are taken, as would be the case in the BAP scenario, community-wide GHG emissions remain relatively constant until 2050 and Ottawa's cumulative emissions increase, exceeding the city's carbon budget. This trend is the result of an increasing population, whose emissions are only partially offset by a decrease in the heating requirement resulting from system efficiency improvements, from climate change itself, and other planned or implemented actions. GHG emissions are mostly eliminated in the 100% scenario, resting at 100 ktCO2e by 2050. resulting from a suite of actions that electrify heating and transportation while moving the city towards 100% clean electricity.

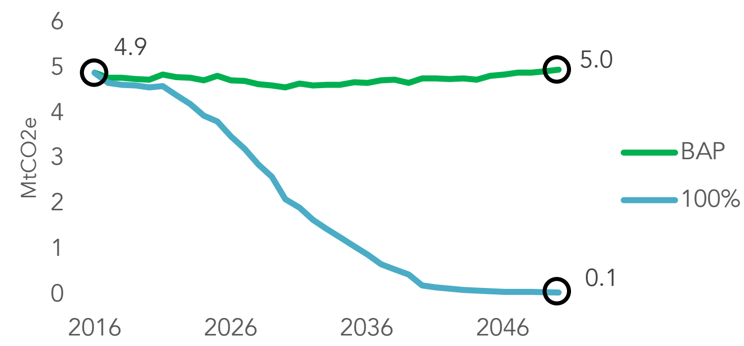

Figure 1-1: Total GHG emissions, BAP and 100% scenarios, 2016-2050.

1.3. Cumulative GHG Emissions

The IPCC report on 1.5°C[2] makes it clear that every tonne of GHG emissions matters, whether emitted in 2021, 2024, or 2036. This understanding shifts the focus from emission levels in particular years (i.e. 2030, 2050) to cumulative emissions over time. Table 1-1 provides a summary of the cumulative GHG emissions for both scenarios, as well as for key years for which targets have been established.

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[2] Ibid.

Table 1-1: Summary of GHG emissions for BAP and 100% scenarios.

Scenario	Description	GHG emissions (MtCO2e)			
		2012	2050	Change	2019-2050
BAP scenario	A non-aggressive pathway maintaining current policies.	6.3	5.0	-1.3	163
100% scenario	An aggressive pathway that aims to achieve a GHG reduction consistent with the Paris target of limiting warming to 1.5°C.	6.3	0.1	-6.2	58

1.4. Energy

This report frames community actions using the "Reduce-Improve-Switch" framework. This approach is adapted from similar approaches, such as the well-known Reduce-Reuse-Recycle (from the waste sector) and Avoid-Shift-Improve (from the transportation sector) frameworks. The Reduce-Improve-Switch framework's focus is first on reducing or avoiding consumption of energy, second on improving the efficiency of the energy system, and finally on switching from GHG-emitting fuels to zero-carbon or zero-carbon renewable ones.

Fuel switching from fossil fuels to electricity generated from zero-emissions sources, such as wind and solar, can increase the demands on existing the electrical grid, as new loads are added from transportation and heating. Efficiency measures, such as building retrofits, are, therefore, critical to reducing the additional burden on the grid. In the 100% scenario, despite increases in local renewable generation and efficiency measures, electricity demand rises to 45 petajoules (PJ) by 2050 from 28 PJ in 2016.

Overall energy consumption in Ottawa declines from 106 gigajoules (GJ) per capita/year in 2016 to 34 GJ per capita/year in 2050 in the 100% scenario, indicating a dramatic increase in energy efficiency. At the same time, changes in technology, such as the electrification of transport, will also lead to the deployment of more efficient energy systems.

1.5. The 100% Scenario

The 100% scenario represents a possible trajectory for achieving zero emissions by 2050 that involves phasing out all fossil fuels and is coupled with aggressive emissions reduction. To achieve this objective, the efficiency of the energy system is maximized and energy sources, such as renewable natural gas, renewable electricity, and waste heat, are incorporated. The primary strategy for reducing emissions is to maximize the electrification of heating and transportation, and add sufficient renewable energy, primarily wind and solar, to cover this consumption. Because the intermittent production of wind and solar electricity does not necessarily align with demand, this scenario relies on the grid to balance local electricity production and consumption with grid resources for storage and supply; however, this balancing was not explicitly modelled. The actions evaluated by the model apply existing, commercially available technologies; however, emerging technologies for energy management, generation, and storage will likely help facilitate this scenario.

1.6. Benefits and Costs

Ottawa will experience a wide range of benefits arising from efforts to reduce GHG emissions. These co-benefits fall into three categories: health, economic prosperity, and social equity. Examples of these benefits include:

- Cleaner air;
- More physical activity;
- Greater accessibility for youth and the elderly;
- Healthier buildings;
- New employment opportunities;
- Reduced household, business, and municipal operating costs;
- New business opportunities;
- Enhanced reputation;
- Decreased impact on biodiversity; and
- Greater consideration for future generations.

The analysis indicates that the 100% scenario can result in improved quality of life and enhanced economic opportunities. Investing now for a lower carbon future yields both financial and community benefits.

1.6.1. An Economy in Transition

In the short term, annual energy-related expenditures in the 100% scenario are somewhat higher than in the BAP scenario, as the 100% scenario demands up-front investments in efficiency and renewable energy that will lead to long-term savings. By the early 2030s, the annual net cost of the 100% scenario drops below the BAP scenario for the rest of the period because of saving from the investments—creating a net financial benefit for the community of $0.8 billion (in 2019 dollars). While the analysis indicates that there is a compelling economic argument for decarbonising the city, other barriers remain, including coordination of actions amongst relevant partners, lock-in of existing energy systems, capacity, access to capital, delivery mechanisms, and legal and policy barriers.

1.6.2. Reducing Household Energy Costs

Household expenditures on energy—natural gas, electricity, gasoline and diesel—are projected to decline in the 100% scenario. Reductions occur because the energy system is more efficient; it provides the same services with less energy overall. For example, vehicles become more efficient, dwellings are better insulated, residents spend less time in traffic, and heating systems are more efficient.

1.7. The Role of the Public Sector

The way in which strategies are implemented will influence the social benefits that the 100% scenario delivers. Some of the actions deliver significant economic returns. An important consideration is the respective roles of the City, other levels of government, and the private sector. In many cases, the City is uniquely able to unlock these opportunities.

The role of the City of Ottawa is multifold, including:

- **A mobilizer:** The City can engage people and other organizations around a vision, goals, objectives, and targets.
- **An innovator:** The City can directly and indirectly support innovation by reducing risk through investments, partnerships, or policies that support zero-carbon projects or enterprises.
- **A collaborator:** The City can advance efforts to collaborate in the energy transition with other levels of government, transit authorities, utilities, neighboring municipalities, regions, businesses, non-profit organizations, neighbourhoods, and governments in other parts of the world. Collaboration can take the form of shared targets, policies, joint projects, or investments. An example is a coordinated retrofit program between municipalities and utilities.

- **An investor:** The City can use its access to low-interest capital to make direct investments in areas like building retrofits and renewable energy technologies. Alternatively, or in tandem, the City can enable investments by third parties. For example, the City could use local improvement charges to finance building retrofits.
- **An implementer**: Through policies and incentives, the City can support businesses and households in the energy transition. For example, the City could enact a district energy connection bylaw that enables zero-carbon district energy systems.
- **An incubator**: The City can cultivate the development of new technologies or applications that enable the zero-carbon economy by supporting and attracting new and existing businesses, as well as by creating a hub or ecosystem in which the businesses and organizations support each other. For example, the City could create a zero-carbon business park or regulatory incentives for different levels of GHG performance for buildings that stimulate green innovations by the construction industry.

Despite an economic case for many of the actions incorporated within the 100% scenario, these actions are not being advanced by the private sector due barriers such as split incentives, unpredictable risks, and lack of access to capital. The public sector can play three key roles in overcoming these barriers to enable the pathways contemplated in the 100% scenario:

1. Identify the implementation strategies that maximize social benefits;
2. Create enabling conditions for private sector participation for those cases in which participation maximizes social benefit; and
3. Provide support or directly deliver those actions which are not delivered by the private sector.

1.8. Seven Recommendations

Seven high level recommendations were identified to support the City of Ottawa in advancing deep GHG emissions reductions aligned with scientific objectives.

1. The City of Ottawa should adopt a cumulative carbon budget for both the community and City corporate operations that is aligned with 2030 and 2050 GHG targets.
2. Responsibility for specific GHG emissions reductions in the community should be distributed across all departments in the City of Ottawa, aligning with a carbon budget approach.
3. Each department should develop a five-year implementation plan.
4. A community collaborative governance mechanism should be created to engage community leaders and stakeholders in the implementation process.
5. The City should develop program areas, including capacity and financing mechanisms, to advance the actions identified in this analysis.
6. The City should integrate climate action into its economic development strategy.
7. A transparent reporting framework should be developed and delivered to support collective learning and reporting on progress.

1.9. Six Programs

SSG undertook a mapping process to identify programs that will support the GHG actions identified and overcome key barriers. Some examples are outlined in Table 1-2. In most cases, each program can support multiple actions.

Table 1-2: Short-term implementation program.

Programs	Key barriers	Description
Program #1: Co-ordinating land-use policies	Lack of consideration of energy and GHG emissions in land-use planning.	The City seeks to embed policies that conserve energy (directly or indirectly) and reduce GHG emissions into the Official Plan, secondary plans, and relevant Master Plans.
Program #2: High-Performance Development Standard: Enhanced energy performance for new buildings	Split incentive between builder and owner that limits investments in energy efficiency.	The High-Performance Development Standard is a tiered set of performance measures that is required through the planning approval process. The first tier is implemented through the planning approval process, whereas the upper tiers are voluntary.
Program #3: Retrofit Accelerator Program: Transforming existing buildings	No systematic approach to large-scale retrofits currently exists.	A deep retrofits program is envisaged as a partnership with utilities, industry, and higher education. A financing package is developed using the PACE or LIC mechanism, combined with incentives from other levels of government and the utilities, with investment raised through a combination of community bonds and green bonds. Retrofits are targeted to groups of buildings—for example neighbourhoods or sectors (restaurants, grocery stores, etc.)—to pool risk and develop larger, more sophisticated, impactful projects. In addition to efficiency, the program includes district energy, solar photovoltaics (PV), energy storage, and air- and ground-source heat pumps.
Program #4: Renewable Energy Organization: Stimulating local renewable energy projects	Long-term investments required by local entities that deliver community benefits.	The membership of the organization includes municipalities, utilities, industries, and other partners. The organization advocates for, develops, commissions, and finances projects, depending on which strategy is appropriate in a particular context. Financing comes from community bonds/shares, loans, or grants from various levels of government.
Program #5: Electric Vehicle Working Group: Encouraging the adoption of electric vehicles	Lack of infrastructure and trust in a new technology.	A technical working group is established with representatives from each of the relevant organizations. The first deliverable is a five-year action plan/roadmap for electric vehicles in Ottawa.
Program #6: Education and Outreach Program: Engaging the community	Lack of awareness of the opportunities.	There are two key aspects to such a program: broad-based education and targeted stakeholder education. This program coordinates education and marketing efforts on behalf of the other programs, working with staff from the City, municipalities, and utilities.

The delivery of these programs will require the development of new capacity within the City of Ottawa, new financing strategies, and new partnerships and governance structures.

1.10. Tracking Progress

Tracking the progress of the 100% scenario described in this report helps to manage the risk and uncertainty associated with emissions reduction efforts, as well as external forces, such as evolving senior government policy and new technologies that may disrupt the energy system. Key motivations for monitoring and evaluation include:

- Verifying the rate of return for investors;
- Identifying unanticipated outcomes;
- Adjusting programs and policies based on their effectiveness;
- Managing and adapting to the uncertainty of climate change; and
- Managing and adapting to emerging technologies.

1.11. What Does the Future Look Like?

A future community that does not emit greenhouse gases can be difficult to picture. This section draws on the modelling results to describe what a day in the life of a person in Ottawa could look like in 2050.

A House in 2050

The average house size is the same as in 2016, but the dwelling is more likely to be an apartment or row house than a single-family home. Most new dwellings are within walking distance of bus rapid transit or a light rail train. The house doesn't use much energy, just 30% of what houses used in 2016. Solar panels are integrated into the roof, and gas stoves and fireplaces, if used, burn renewable natural gas. Most homes are heated with highly efficient electrical heat pumps. Others are heated with radiant floors using waste heat from nearby sewers that is transported through underground pipes; cooling is also provided in the summer through the same underground pipes.

Moving Around in 2050

In most neighbourhoods in the city, it is easy to walk to key destinations like schools, parks, grocery stores, and restaurants. If a resident is going somewhere less than 5 km away from home, they might cycle, rather than drive. Entire road lanes are physically separated for cyclists and cycling is integrated into the culture of the city. Priority is given to ploughing cycling roads in the winter. A personal transportation planner from the City visits each household and helps identify the best transportation options for trips for work and leisure, while saving money and increasing convenience. Private vehicles are easily accessible for all ages for trips that are too complex for transit, and too far for walking or cycling. Transit is much more extensive than in 2016.

Going to Work in 2050

Many more people walk and cycle (26% of total trips), and take transit (19%) to work, while fewer drive (52%) than in 2016. Some people travel to work only four days a week. The workplace incorporates more shared-office spaces and less floor space per employee. Offices are energy efficient, designed to high standards if new and retrofitted if not. Indoor air quality has improved. Office buildings generate energy with solar PV on rooves, parking lots, and facades, and are typically connected to a zero-emissions district energy system for heating and cooling.

Jobs in 2050

There are many new types of employment in 2050. The zero-carbon transition is estimated to have directly created 240,000 new person years of employment. A major sector in the construction industry is focused on upgrading the energy efficiency of buildings and constructing higher performance new buildings. Having retrofit the pre-2016 building stock, plans are underway to retrofit more modern buildings, emphasising net zero targets and embodied carbon. Companies involved in this industry undertake major construction projects, including neighbourhood-scale projects. Businesses involved in the retrofits possess expertise in finance, law, construction, and engineering. The renewable energy sector, particularly solar PV, energy storage, and district energy, has also grown significantly. The automotive industry has shifted towards electric vehicles, which has a negative impact on employment in maintenance and repairs.

1.12. Six Key Numbers

The carbon budget, 2020-2050
1.5 degrees: 58 MtCO2e

Total energy, 2050
BAP scenario: 74 GJ/capita
100% scenario: 34 GJ/capita

Total additional investment, present value, 2019$
$27.1 billion

Net benefit of zero-carbon investments, present value, 2019$
$4.7 billion

Average annual new person years of employment, 2020-2050
11,500

Cumulative value of avoided climate damage, 2020-2050, (Social cost of carbon, 3% discount rate)
$26.6 billion

Introduction:
Setting the Stage

2. Introduction: Setting the Stage

2.1. The Climate Emergency

In 2018, the Intergovernmental Panel on Climate Change (IPCC), the world's leading scientific body on climate change, released a report titled *Global Warming of 1.5°C*. The report indicated that the damage from climate change can be substantially reduced by limiting global warming to 1.5°C. However, if current annual greenhouse gas (GHG) emissions trends continue, we have less than ten years to have a better-than-even chance of keeping warming below 1.5 ºC.[3]

UN Secretary-General António Guterres recently opened a summit on climate change by stating: "We are here because the world is facing a grave climate emergency. Climate disruption is happening now, and it is happening to all of us. (…) We are in a battle for our lives. But it is a battle we can win."[4] Shortly after this speech, Mami Mizutori, the UN's special representative on disaster risk reduction, warned that relatively small-scale climate-related disasters, which cause death, displacement, and suffering, are happening "at the rate of one a week.[5]

In June 2019, Canada's House of Commons declared a climate emergency, joining France, Ireland, the United Kingdom, and Portugal. Major cities around the world, including New York, London, Sydney, and Paris, have all declared climate emergencies. 439 Canadian municipalities, including Ottawa, have also declared climate emergencies.

Society is at a pivotal moment. The next ten years will determine whether society can address climate change. Failure is not an option.

2.2. Travelling into the Future

Sustainability Solutions Group and whatIf? Technologies developed two scenarios to explore possible futures for the City of Ottawa. These scenarios are not predictions, but depictions of how the world may have changed at a given time in the future: a scenario is a state at a future time as imagined in the present.

2.3. Leading the Way to 100%

Many cities around the world are stepping up their ambition to respond to the latest science, and align their policies and operations with efforts to limit global warming to 1.5°C. This report assesses a trajectory for Ottawa to align with that objective.

[3] The remaining global carbon budget for having a 66% chance of limiting warming to 1.5 degrees is 420 GtCO2e. Global annual GHG emissions are approximately 42 MtC20e. IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, Maycock, M. Tignor, and T. Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.

[4] UN (2019). Guterres: Climate Action Is a "Battle for our Lives". https://unfccc.int/news/guterres-climate-action-is-a-battle-for-our-lives

[5] Harvey, F. (2019). One climate crisis disaster happening every week, UN warns. https://www.theguardian.com/environment/2019/jul/07/one-climate-crisis-disaster-happening-every-week-un-warns

The 100% scenario compiles several actions related to transportation, existing buildings, new buildings, renewable energy and energy storage, and waste.

This report provides an analysis of the expected effects of policies and actions proposed under the 100% scenario and compares them to the Business-as-Planned (BAP) scenario, which models energy use and emissions production if current sectoral trends continue.

2.4. A Comparison of the Scenarios

The table below shows the evolution of actions from the BAP scenario to the 100% scenario.

Table 2-1: Comparing Ottawa's two scenarios.

	Business-as-Planned scenario	100% scenario
LAND USE		
Spatial distribution	Meet Official Plan growth and distribution goals to 2031.	No change.
BUILDINGS		
New buildings		
Dwelling size	2016 dwelling sizes maintained.	2016 dwelling sizes maintained.
Building mix	Type shares of new dwelling units by 2046 Singles: 31% Doubles: 4% Rows: 37% Apartments: 28%	Maintain BAP allocation.
New buildings energy performance		
New homes	10% improvement every 5 years for new construction.	Increase the percent of new construction which is net-zero energy to 100% in 2030.

	Business-as-Planned scenario	100% scenario
		100% of new construction is net-zero energy after 2030.
New commercial buildings	10% improvement every 5 years for new construction.	100% of new commercial and retail construction meets passive house standard after 2030.
Existing buildings energy performance		
Retrofit older homes (pre-1980)	No retrofits.	Scale up rate of retrofits to 98% of all dwellings by 2040; achieve thermal savings of 70%; electrical savings of 30%.
Retrofit newer homes (post-1980)	No retrofits.	
Retrofits of small commercial and office buildings	No retrofits.	Scale up rate of retrofits to 98% of all buildings by 2040; achieve thermal savings of 60%; electrical savings of 30%.
Retrofits of commercial, office, and industrial buildings	No retrofits.	95% of the existing building stock is retrofit by 2040 with average savings of 50%.
Municipal buildings	Current efficiencies held constant.	99% of existing municipal buildings are retrofit to net zero emissions by 2040.
Federal buildings	15% savings for both heating and cooling for 50% of the buildings by 2030 and 15% for the remaining buildings by 2050.	95% of the existing building stock is retrofit by 2040 with average savings of 50%.
Use of heating pump space heating and cooling		
Low-rise residential	Fuel shares from 2016 maintained until 2050.	415,000 heat pumps installed by 2050 (74%/26% air/ground).
Apartments	Fuel shares from 2016 maintained until 2050.	146,000 heat pumps installed by 2050 (72%/28% air/ground).
Commercial	Fuel shares from 2016 maintained until 2050.	73% of the heat load served by heat pumps by 2050.
ENERGY GENERATION		
Solar PV – residential	No additional capacity added, current level maintained (72 kW).	174 MW by 2030; 320 MW by 2050 Capacity factor = 15%

	Business-as-Planned scenario	100% scenario
Solar PV – commercial	Current levels held (584 kW).	400 MW by 2030; 740 MW by 2050 Capacity factor = 15%
Solar PV – utility-scale	No additional capacity added.	No utility-scale installed; however, a portion of the residential and commercial capacity could be installed as utility-scale.
Hydropower	No additional capacity added.	18 MW by 2030; 36 MW by 2050 Capacity factor = 70%
Rural biogas	No additional capacity added.	6 MW 2030: ½ electricity generation and ½ RNG 2040: all RNG Additional CHP capacity at ROPEC to use all methane emissions (9.37 MW at 0.7 capacity factor starting in 2035).
District energy	Existing 2016 district energy is held constant through to 2050.	80% of existing commercial buildings; 80% of apartments; 15% of residential buildings; 100% of the system zero-carbon (geothermal) 23,394 homes served by expanded DE by 2050; 4,765,441 sqm non-residential floorspace served by expanded DE by 2050; Federal DE systems switched to geothermal by 2040; 3,325,612 sqm floorspace served by federal DE by 2050.
Energy storage	No storage deployed.	310 MW by 2030; 612 MW storage by 2050 Sufficient storage to reduce curtailment of renewable generation from 90% to 85%.
Wind	Existing 2016 capacity is held constant through to 2050.	1609 MW by 2030; 3218 MW by 2050 Capacity factor = 30%
Power to gas	None.	2030: 865 TJ H2 produced at 70% efficiency, half of waste heat is used. 2040: 95 TJ H2 produced at 80% efficiency, half of waste heat is used.

	Business-as-Planned scenario	100% scenario
		Produced H2 is injected into natural gas pipelines. H2 can displace up to 15% of natural gas by volume. H2 production is limited to the amount of natural gas in use in this scenario.
TRANSPORTATION		
Transit		
Expanded transit	Completion of the Confederation Line, Phase 1 and 2.	The frequency of LRT is increased to every 1.5 min. BRT speeds increase by 20% in dedicated bus lanes (currently every 5 minutes at peak times), and every 7.5 minutes for off-peak frequency (currently every 15 minutes for off-peak). Expanded transit to reflect "Ultimate Transit Network", rather than "affordable transit network".
Electrify transit system	100% electric by 2050.	100% electric by 2030.
Active transportation		
Increase/improve cycling and walking infrastructure	24-hr mode shares by 2050. Auto: 68.2% Transit: 15.6% Walk: 12.5% Bike: 3.8%	24-hr mode shares by 2030/2050. auto: 58%/55% transit: 20%/19% walk: 14%/15% bike: 8%/11%
Car-free zone	None.	ByWard Market and downtown Ottawa are car free; Wellington-Rideau, Sparks, Bank, and University of Ottawa campus are car free by 2030.
Congestion charge	None.	Congestion charge of $20 applied to the downtown core between 6:00 am and 10:00 am on weekdays.
Vehicles		
Electrify municipal fleets	None.	Municipal fleet is 60% electric by 2030 (starting in 2025). Municipal fleet is 100% electric by 2040 and later.

	Business-as-Planned scenario	100% scenario
Electrify personal vehicles	Vehicle fuel consumption rates reflect the implementation of the U.S. Corporate Average Fuel Economy (CAFE) Fuel Standard for Light-Duty Vehicles. 24,530 EVs (3.5%) in personal-use vehicle stock by 2035. 44,549 EVs (5.5%) in personal-use vehicle stock by 2050. 4.2% of new personal use vehicles are EVs by 2035.	2030: EVs compose 90% of new vehicle sales. 2040: EVs compose 100% of new vehicle sales. EVs only inside the area bounded by Bronson, Catherine St., and Queen Elizabeth Dr. (Rideau Canal) by 2028. (This is the area to which the congestion charge is applied.)
Car sharing/car cooperatives	Maintain share.	No change.
Parking management	No change.	No off-street parking within 500m of LRT: 50% reduction of parking in Centretown; double on-street parking fares during peak hours by 2050; vehicle kilometres travelled (VKT) reduction of 15% in relevant zones.
Electrify commercial vehicles	Phase 1 and Phase 2 of the United States Environmental Protection Agency (EPA) Fuel Standards for Medium- and Heavy-Duty Vehicles.	40% of heavy trucks are zero emissions by 2030. 100% of heavy trucks are zero emissions by 2040.
Electric vehicle only zone	No change.	EVs only inside the area bounded by Bronson Avenue, Catherine Street, and Queen Elizabeth Drive (Rideau Canal) by 2028. (This is the area to which the congestion charge is applied.)
WASTE		
Waste diversion	Waste diversion rates are held constant.	98% organics diverted by 2024. Achieve residential Ottawa waste diversion targets by 2030, increase paper diversion to 98%. Non-residential targets: - paper: 98%

	Business-as-Planned scenario	100% scenario
		- plastic/metal/glass: 50% All organic waste is sent to an anaerobic digester. All yard and leaf waste is used to produce RNG and displace natural gas use.
INDUSTRY		
Industry process improvements	Hold process efficiency constant.	Waste heat is captured: 2030: 700 TJ of waste heat displaces fossil gas. 2050: 1600 TJ of waste heat displaces fossil gas.

2.4.1. Energy Comparisons

An illustration of the energy mix in 2016 versus both scenarios in 2050 (Figure 2-1) indicates an overall decline in fossil fuels and gains in “other” power sources, including solar and district energy. In the 100% scenario, diesel and gasoline are increasingly displaced by “other” fuels, and the majority of natural gas is displaced with renewable natural gas.

At the same time, an illustration of the energy consumption by end use (Figure 2-2) shows that energy used for space heating declines significantly due to both decreased thermal demand (heating degree days) and improved building envelopes. In addition, transportation energy consumption declines by 64% in the 100% scenario over the BAP. Industrial manufacturing increases slightly in both scenarios as a result of the increase in population.

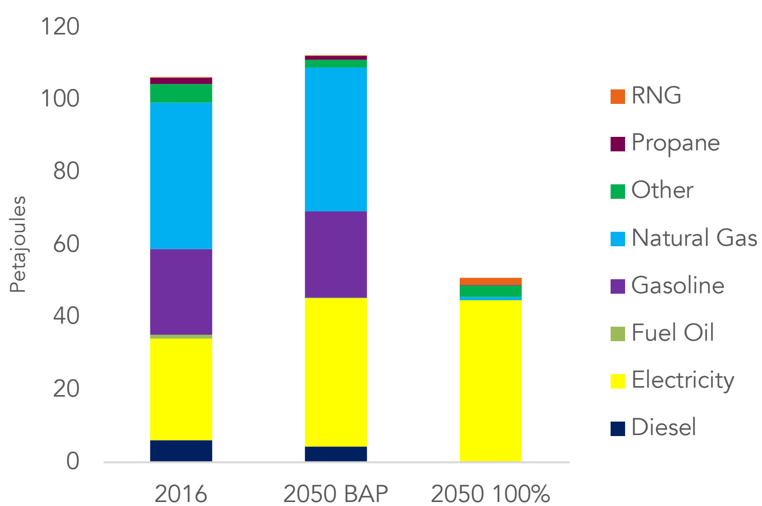

Figure 2-1: Energy consumption by fuel, 2016 baseline vs 2050 for each scenario.

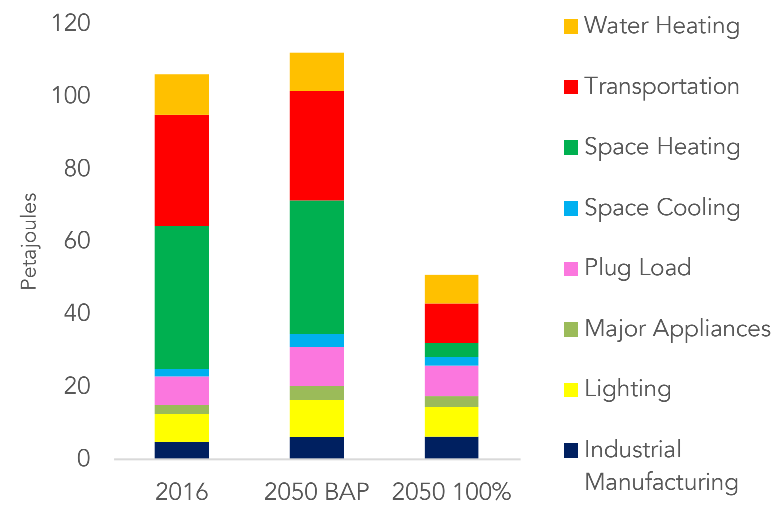

Figure 2-2: Energy consumption by end use, 2016 baseline vs 2050 for each scenario.

2.4.2. GHG Emissions Comparisons

GHG emissions reductions are deeper than energy savings. In the 100% scenario, GHG emissions drop by 99% compared to 2016 levels, despite an increase in the population. Figure 2-3 compares GHG emissions from different fuels in 2016 and 2050 for both scenarios.

A comparison by sector (Figure 2-4) shows that the remaining emissions in the 100% scenario are concentrated in the residential and commercial sectors. This is because some residential and commercial buildings and, to a lesser degree, waste and industry continue to use natural gas for space heating.

For more details on energy consumption and GHG emissions for the 100% scenario, see Appendix B.

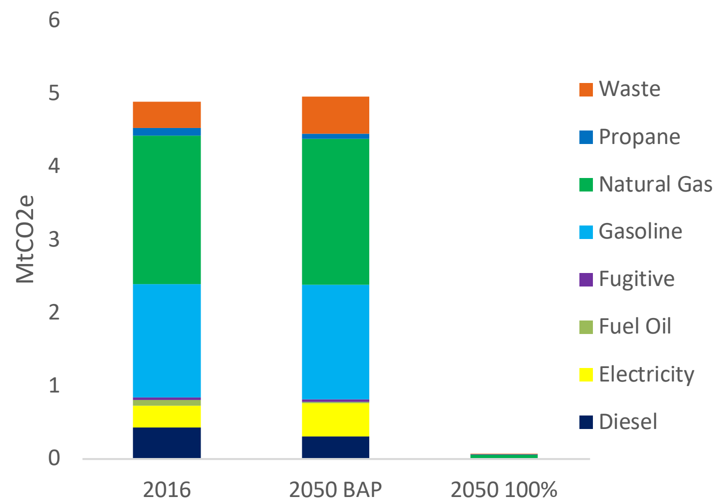

Figure 2-3: Annual GHG emissions by fuel, 2016 vs 2050 for each scenario.

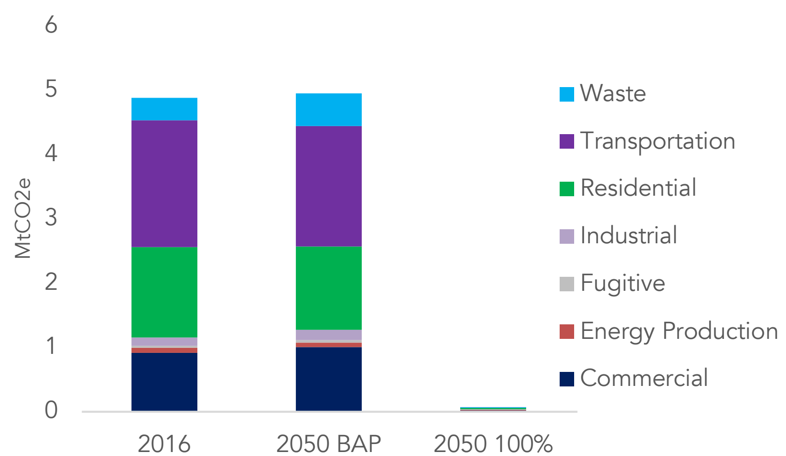

Figure 2-4: Annual GHG emissions by sector, 2016 vs 2050 for each scenario.

2.4.3. Financial impact

The 100% scenario is more costly to start out because of infrastructure investments, but creates greater savings over time, as expenditures on energy decline. Starting in 2032, savings begin to exceed costs.

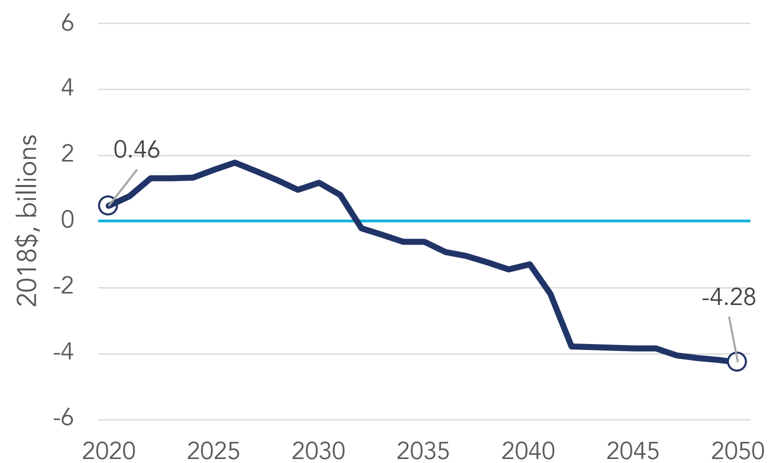

Figure 2-5: Annual net costs and savings for the 100% scenario.

The cumulative financial impact is illustrated in Table 2-2. In this analysis, the 100% scenario generates a financial return for the community; however, this financial return is contingent on the electricity grid being able to regulate temporal variation between wind and solar production and demand without significant investments in energy storage. Alternatively, if the provincial electricity grid becomes 100% clean prior to 2050, much of the investment in local generation, to the extent it’s required, will be driven more by the province.

Table 2-2: Comparison of the present value of the BAP and the 100% scenarios.

	Present value (2019$, billions)
Capital investment	(27.1)
O&M savings	0.6
Energy savings	13.4
Carbon price revenue	3.3
Revenue from energy generation	14.4
Total savings	**4.7**

2.5. Setting Targets

Targets provide milestones against which the City can evaluate progress and make course corrections. Targets that start more slowly and ramp up more quickly at the end of the period are used to reflect the fact that some initiatives may go slower than anticipated; these outcomes will have to be balanced with faster uptake of other actions. This also reflects the need to develop and deploy programs that become increasingly effective as they gain traction.

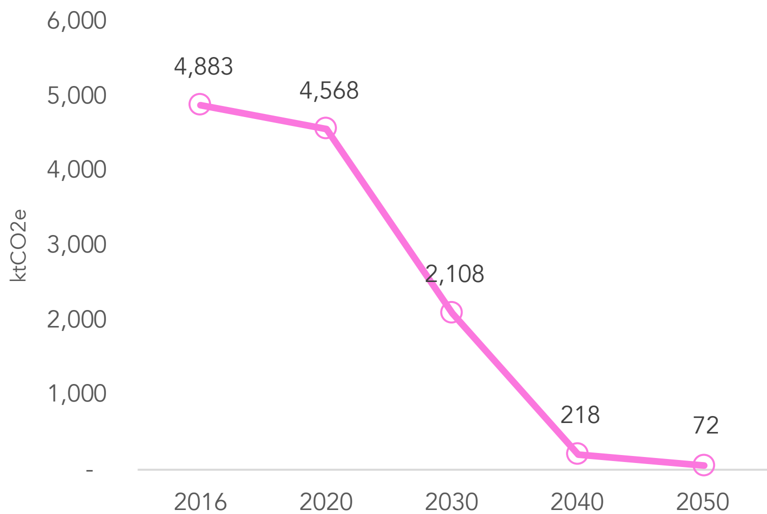

Figure 2-6: GHG emission trajectory of the 100% scenario.

Table 2-3: Ottawa's zero-carbon pathway by decade (ktCO2e).

Year	100% scenario [ktCO2e]	% reduction over 2016	Community targets (over 2012)	Corporate targets (over 2012)
2016	4,883	0%		
2020	4,568	4%	25%	25%
2030	2,108	54%	45%	50%
2040	218	95%	90%	100%
2050	72	99%	100%	
2020-2050	69,881			

Leading the way to 1.5°C

3. Leading the Way to 1.5°C

3.1. Introduction

A carbon budget provides a definitive limit for the total emissions a community can produce before becoming a positive contributor to catastrophic climate change. The carbon budget uses a measurement standard set by the Paris Agreement (2015) and the Intergovernmental Panel on Climate Change (IPCC). Under the Paris Agreement, signing countries aimed to reduce GHG emissions in order to limit the rise in global average temperature to well below 2°C above pre-industrial levels, and to pursue further efforts to limit the temperature increase to 1.5°C. There is an urgent need for all levels of government to work towards significant GHG emissions reductions because the number of years available to achieve the required reductions—and stay within the global carbon budget—is diminishing.

The IPCC warns of potential disasters should average temperatures rise by 2°C. The IPCC also recommends a stronger target of 1.5°C, which provides a greater buffer against potential disasters but requires countries to adopt net-zero emissions targets.

This carbon budget is primarily being developed for the City of Ottawa as a response to the City's declaration of a climate emergency. The carbon budget supersedes a previously established target to reduce GHG emissions by 80% below 2012 levels. The budget can provide the City with a rationale for embarking upon larger actions that may require more up-front expenditures. As such, the carbon budget can meaningfully guide financial decision making within the City with regard to infrastructure, asset, and long-term planning. For example, weighing the up-front costs of corporate vehicle fleet renewal against a carbon budget can help shift the decision from gas or hybrid vehicles to electric ones. Assigning dollar values to carbon, which is currently being done by the Pan-Canadian Framework, can provide a basis for the city to save money through avoiding carbon emissions.

In Canada, the City of Edmonton has notably adopted the carbon budget approach in their "Energy Transition Strategy", which is linked to local land-use planning. The Mayor and Council of Edmonton have recognized that the City needs to move further and faster to avoid climate risk that comes from warming past 2°C.[6] Globally, the European Union has also set a 1.5°C target with their own respective carbon budget.

3.2. Carbon Budgets

In order to prevent dangerous levels of climate change, the IPCC has quantified the total GHG emissions that can be emitted worldwide in order to limit the increase in global temperature. The latest science indicates that, in order to restrict warming to less than 2°C, total GHG emissions from all anthropogenic sources since 1870 likely need to be limited to about 3,400 gigatonnes carbon dioxide equivalent (GtCO2e). Approximately 2,230 GtCO2e had been emitted by the end of 2017, leaving a global carbon budget of approximately 1,170 GtCO2e to limit global warming to 2°C.[7] However, restricting GHG emissions to limit global

[6] Herring, J. (2019, August 8). City says emissions reductions targets won't be met under current plan. *The Edmonton Journal*, Retrieved from: https://edmontonjournal.com/news/local-news/energy-transition-update.

[7] IPCC. (2015). *Climate Change 2014: Synthesis Report*. Geneva, Switzerland: IPCC. Assumes a 66% degree of confidence.

warming to 1.5°C implies a global carbon budget of only 420 GtCO2e.[8] Both the 1.5°C and 2°C targets will be challenging for the world to achieve due, in part, to the fact that the proven global reserves of fossil fuels amount to over 3,000 GtCO2e, as shown in Figure 3-1 below.[9] Given the challenge, Canada has committed to the 1.5°C target, citing the need for global leaders to be ambitious and encourage as many countries as possible to participate.[10]

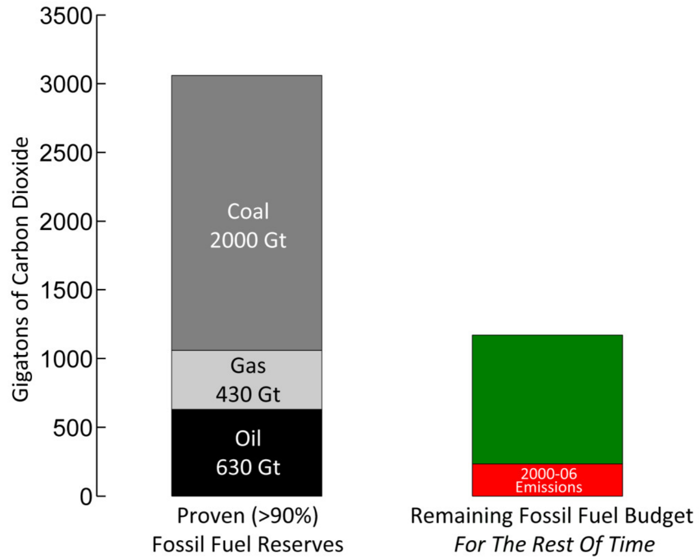

Figure 3-1: Comparing the global carbon budget to available fossil fuel reserves.[11]

3.3. A City-Specific Approach

This report calculates the carbon budget for Ottawa by extrapolating an approach developed by C40, a network of more than 90 leading cities committed to addressing climate change. These cities recognize their influence over a large proportion of the world's population and economy. They share their practices widely and aspire to influence other cities and national governments across the world.

Ottawa is not a member of C40 because of its relatively small population, but C40's approach for calculating carbon budgets is applicable to Ottawa and can place the city on an aggressive pathway to limiting climate change. The City of Ottawa is, however, a part of the Global Covenant of Mayors, where cities collectively have made a similar commitment to be leaders in preventing climate change.[12]

In 2017, C40 published a report titled *Deadline 2020: How cities will get the job done*. The report assessed the contribution of the C40 cities to the Paris Agreement's aspirations of keeping the rise in global average temperature well within 2°C and to pursue efforts limit global warming to 1.5°C. The report identified specific GHG emissions reduction trajectories for each of the C40 cities, as well as potential actions to achieve those trajectories.[13]

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[8] Rogelj, J., et al. (2018). Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte et al. In Press.

[9] Meinshausen, M. et al. Greenhouse-gas emission targets for limiting global warming to 2 °C. *Nature* 459, 1158 (2009). http://www.nature.com/nature/journal/v458/n7242/full/nature08017.html.

[10] Prystupa, M. (2015, December 7). Canada shocks COP21 with big new climate goal. *National Observer.* Retrieved from https://www.nationalobserver.com/2015/12/07/news/canada-shocks-cop21-big-new-climate-commitment.

[11] The Proportional Response (n.d) Fossil-Free MIT. Retrieved from http://www.fossilfreemit.org/science/#footnote_29_455.

[12] Global Covenant of Mayors. (nd.d). Retrieved from https://www.globalcovenantofmayors.org/our-cities/?search-city=

[13] Deadline 2020. (2017). C40 Cities. Retrieved from https://www.c40.org/researches/deadline-2020

C40 used a three-step approach to identify carbon budgets for its targeted cities:

1. Determine the global carbon budget for safe levels of warming below 1.5 and 2°C.
2. Identify an approach to allocate a fair portion of this budget to the C40 cities.[14]
3. Calculate the resulting total C40 carbon budget using the chosen approach in step 2 and the relevant carbon budgets in step 1.

Under step 1, member cities in C40 were allocated a collective budget of 22 GtCO2e between 2016 and 2100 to meet the 1.5°C limit and 67 GtCO2e for the 2°C limit. All other cities were given a limit of 307 GtCO2e in the 2°C scenario, and 97 GtCO2e in the 1.5°C scenario, as shown in Figure 3-2 below. C40 used the global carbon budgets with a 66% degree of confidence of limiting global temperature rises to 1.5 and 2°C respectively.

For step 2, C40 set a target for 2030 under which member cities need to achieve a reduction of 3.2 tonnes of carbon dioxide equivalent (tCO2e) per capita, to be consistent with a 2°C pathway.[15] By 2050, the selected cities are required to reach 0.9tCO2e. C40 did not prescribe an interim target for the 1.5°C scenario, but set a per capita target of 0 tCO2e by 2050 for limiting warming to 1.5°C.

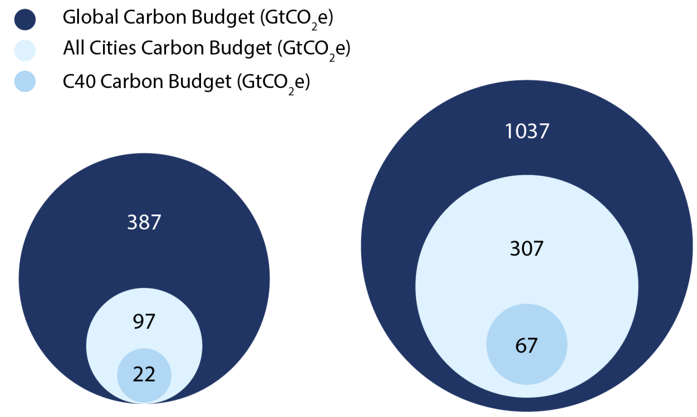

Figure 3-2: Global carbon budgets under the 1.5°C scenario (Left) and the 2°C scenario (right) used by C40.

[14] The challenge of how to allocate the budget to individual cities was a question subject to debate. After considering various approaches, C40 selected contraction and convergence, in which high emitters reduce emissions to a common per capita emissions rate and low emitters increase to that rate by a set date.

[15] For the selected C40 cities, 3.2 tCO2e per capita is approximately half of the current global per capita emissions.

3.4. A Carbon Budget for Ottawa

A carbon budget for Ottawa was developed using the following interim targets prescribed by C40 Cities:[16]

- Interim per capita targets of 3.2 tCO2e for 2030 in the 1.5°C and 2°C curves;
- 0.9 tCO2e per capita target for 2050 in the 2°C curve; and
- 0 tCO2e per capita target for 2050 under the 1.5°C curve,

Per capita GHG emissions were mapped out linearly between 2015 and 2030. Then, community-wide emissions were mapped from 2030 to 2050 using a convergence point of 3.2 tCO2e per capita by 2030. Future population projections were then multiplied against the per capita GHG emissions factor to generate total GHG emissions year over year.

For the 1.5°C scenario, 3.2 MtCO2e is used as a point of comparison to the 2°C scenario. An additional "strict" 1.5°C scenario is budgeted without an intermediate point to show the most aggressive pathway possible for Ottawa to limit climate change and keep within its carbon budget. The strict scenario does not permit a period of inactivity but requires rapid action most appropriate for a climate emergency. The strict scenario puts Ottawa in control of its carbon budget by requiring large up-front investments and work in carbon mitigation and sequestration,[17] building on momentum generated in the political and public realms. The strict scenario can adopt new technologies in energy generation or carbon sequestration as they become available, but will not rely on them to meet its climate goals. The strict scenario also makes later adopters to learn from the efforts made by the city.

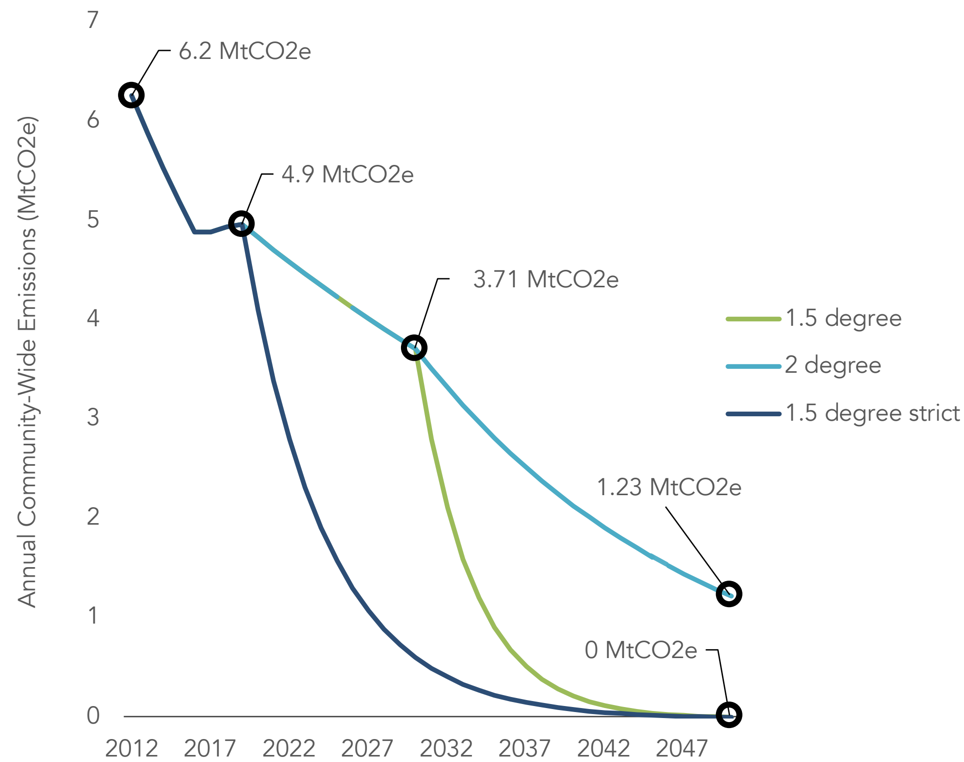

Table 3-1: GHG reduction curves for different temperature increases.

Figure 3-3 shows the trajectory of three possible carbon budget scenarios for Ottawa. Each scenario shows a descending value towards 2050. The steepest descent would take place under the strict 1.5°C scenario, which

[16] 0.01 was used instead of 0 to avoid nonsensical mathematical formulas.

[17] Carbon sequestration was not comprehensively evaluated as part of this project.

aligns with the Council mandated target of 100% emissions reductions. Without a convergence point at 3.2 tCO2e per capita, the strict scenario shows a sharp reduction of 25% from 2020 by 2030.

Figure 3-3 and Table 3-1 show the "gross" carbon budget between 2012 and 2050 for Ottawa, and the "net" budget from 2019 to 2050. The gross budgets are 66, 101, and 133 MtCO2e for the 1.5 strict, 1.5, and 2°C scenario respectively. The budget for the period between 2012 and 2019 has already been consumed, representing approximately 37.6 MtCO2e.

The strict 1.5°C target from 2012 to 2050 results in a carbon budget of 66 MtCO2e. In this scenario, the carbon budget from 2012 would be depleted in approximately 12 years (by 2023) given current GHG emissions rates in the city. From 2019, the remaining carbon budget is 29 MtCO2e and it would be depleted in 6 years. In comparison, the global carbon budget for the 1.5°C scenario runs out in 8 years at current rates of emissions.[18]

Table 3-2: Carbon budget.

Year	Population projections[19]	2°C [MtCO2e]	1.5°C beginning in 2030 [MtCO2e]	1.5°C "strict" [MtCO2e]
2012	935,000	6.26	6.26	6.26
2016	1,003,000	5.09	5.09	5.09
2019	1,040,000	4.96	4.96	4.96
2020	1,052,000	4.83	4.83	4.1
2030	1,160,000	3.71	3.71	0.61
2040	1,263,000	2.14	0.23	0.092
2050	1,367,000	1.23	0.014	0.014
Gross budget, 2012-2050		133	101	66
Net budget, 2019-2050		90	58	29

[18] See a real time "clock" of the global carbon budget here: https://www.mcc-berlin.net/en/research/co2-budget.html.

[19] Population projections provided by City of Ottawa Long Range Planning.

3.5. Carbon Budgets for the 100% Scenario

The Business-as-Planned (BAP) scenario projects cumulative GHG emissions from 2019 to 2050 will reach 151.7 MtCO2e by 2050. The 100% scenario reduces this by approximately 63% to 55.7 MtCO2e, which achieves both the 2°C budget requirement of 90 MtCO2e and the 1.5°C (non-strict) budget. There are two variations of the 1.5°C target. In the first case, when Ottawa converges on 3.2 tCO2e per capita by 2030 and then drops to zero emissions by 2050, the carbon budget is 58 MtCO2e. The second case (strict 1.5°C budget), and more rapid decline to 2050, results in a carbon budget of 29 MtCO2e. In the case of the strict budget, if current emissions patterns do not decrease, the budget would run out within 6 years, which is slightly faster than the 8.5 years remaining in the global carbon budget.[20]

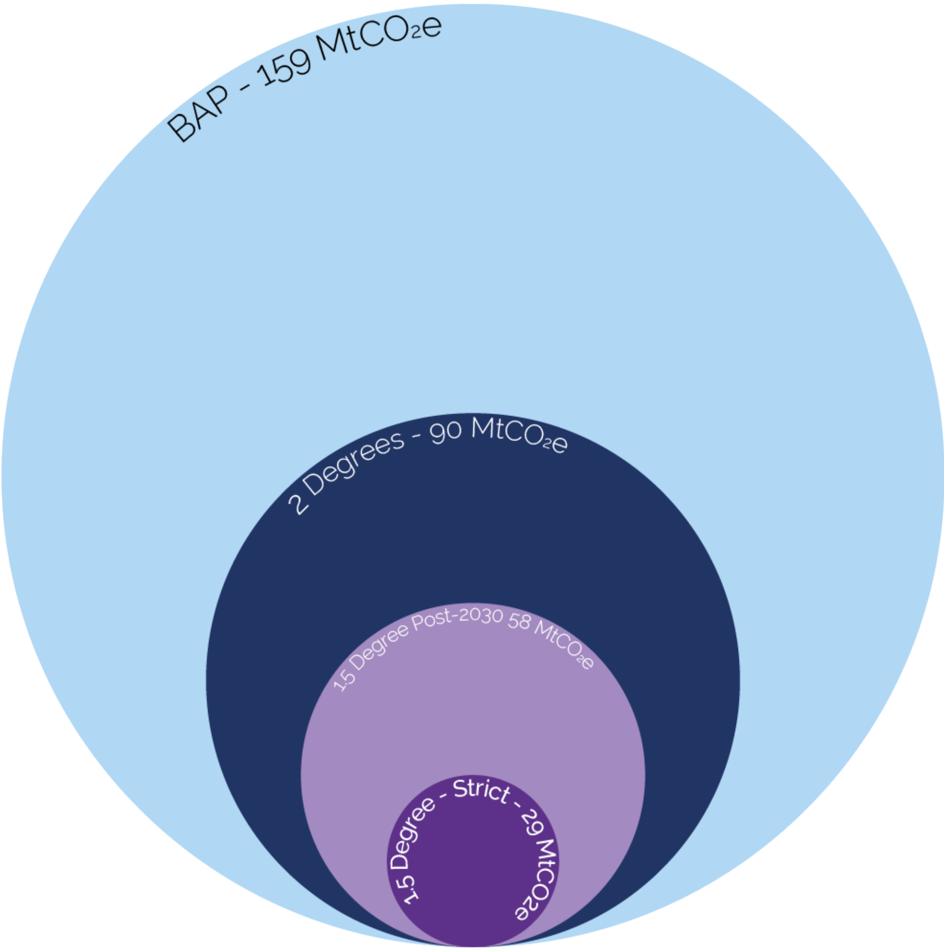

Table 3-3: Carbon budgets and scenario results for City of Ottawa (2019-2050).

3.6. Assumptions

This carbon budget approach makes the following assumptions:

1. **There is uncertainty in the global carbon budgets.** The global carbon budget is calculated based on complex models which continue to evolve.

2. **C40's selection of the contraction and convergence method is an appropriate and ethical choice.** The contraction and convergence method requires richer countries to reduce GHG emissions more rapidly while developing countries are able to grow their emissions in order to decrease poverty until there is a

[20] In the BAP scenario, the non-strict 1.5°C scenario would have a depleted budget in 16 years, while the 2°C scenario would have a depleted budget in 22 years.

convergence at a rate of per capita GHG emissions. For C40 and this carbon budget, the convergence date was set at 2030.[21]

3. **The target date of 2030 and interim per capita allocation of 3.2 tCO2e is an appropriate allocation for Ottawa**. Finally, the allocation of this analysis is not a strict application of C40's method, which involves trade-offs between cities to align with the global budget for cities. The trade-off analysis is not applied, as Ottawa was not part of the envelope of cities included in C40's analysis. Since the budget in this paper is based on a per capita allocation, if Ottawa's population increases more than current projections, so does its carbon budget. This makes sense if Ottawa is taking a greater share of a fixed global population, but if it implies that the global population is also increasing, than the per capita GHG emissions needs to decline in order to maintain a fixed budget.

Notwithstanding the assumptions involved in the analysis, a key observation is that there is an urgent need for significant GHG emissions reductions, as the number of years available to achieve the required reductions is diminishing.

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[21] C40 Cities: Deadline 2020.

A Pathway to 100X50

4. The100X50 Scenario

4.1. Summary

SSG used CityInsight, its energy, emissions, land-use, and finance model, to develop the 2016 greenhouse gas (GHG) inventory, a baseline, and a 2050 Business-as-Planned (BAP) scenario for Ottawa. This established the current (2016) energy and emissions context, and estimated likely energy use and emissions trends between 2016 and 2050.[22] Energy- and emissions-related policy and action options ("technology pathways") were modelled as the 100% scenario, considering the following sectors: new small buildings, existing small buildings, new large buildings, existing large buildings, transportation, renewable energy generation, energy storage, and solid and liquid waste.

The BAP scenario represents a continuation of current trends and policies in these sectors. In contrast, the 100% scenario includes detailed actions that improve the efficiency of existing buildings; have higher standards for new buildings; switch fuel to electricity or renewable natural gas for heating and vehicles; increase local or regional renewable energy and energy storage; enhance transit and active transportation; and increase waste diversion and the utilization of waste as an energy source.

In the BAP scenario, community-wide emissions are 4.9 megatonnes carbon dioxide equivalent (MtCO2e) in 2016 and remain relatively flat to 2050 (Figure 4-1). Ottawa's population is expected to increase, which would typically result in greater community emissions. However, improved vehicle fuel efficiency standards, decreased building heating requirements (a result of increasing average temperatures due to climate change), and gradual uptake of electric vehicles largely offset the impact of the increasing population.

The 100% scenario estimates a community-wide emissions decline to 0.1 MtCO2e by 2050, a 99% reduction from 2016 levels.

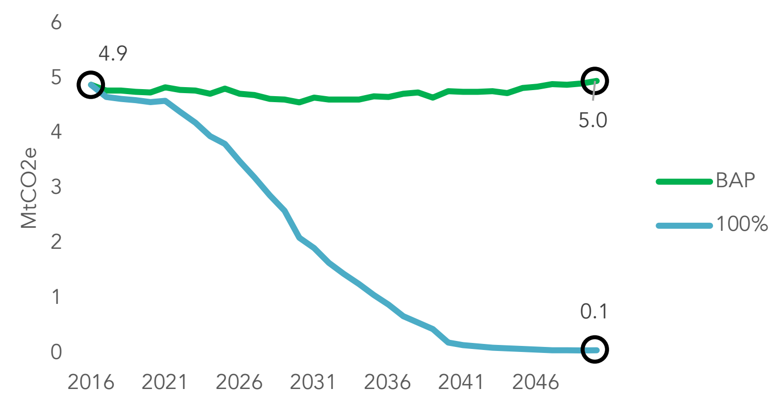

Figure 4-1: Total GHG emissions, BAP scenario and 100% scenario, 2016-2050.

Ottawa's energy use was 106 petajoules (PJ) in 2016 and is projected to increase to 112 PJ in the BAP, an increase of 6 PJ, or 6%. Under the 100% scenario, energy use would decrease to 51 PJ under baseline levels, a 52% reduction.

The 100% scenario modelling demonstrates that deep energy and GHG emissions reductions are possible by maximizing every opportunity for efficiency in the buildings sector, fuel switching from fossil fuels to

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[22] Note that, while 2012 is Ottawa's base year, 2016 was the baseline for modelling due to the availability of data.

renewable energy and electricity in all sectors, and making a small reduction to the emissions factor of grid electricity.

The implementation of the 100% scenario requires scaling up current actions and initiating new ones. The analysis indicates that this pathway is physically and technically plausible and will result in considerable energy savings, financial savings, and reductions in GHG emissions. This technical paper, combined with the research in the Phase One and Two Pathway Analysis papers, provides several recommended actions for Ottawa to embark upon a zero-carbon pathway.

4.2. Methodologies and Assumptions

Many sources of data were used to develop the carbon-reduction model for Ottawa. These were provided by the City, utilities, provincial sources, and federal sources. Some key assumptions included: the City's population, land-use, dwelling mix, and employment projections as developed for the 2020 Official Plan; transit network options as developed for the 2020 Transportation Master Plan; and building code amendments and electricity generation mix forecasts generated by the Province. These assumptions are built into the BAP scenario and inform the 100% scenario. More detail on the relevant sectors can be found below and in the Data, Methodologies, and Assumptions Manual.

	2016				2051				Units
Population	1,003,898				1,376,775[23]				people
Building area per person	77.3				81.1				m2/person
Annual vehicle kilometres travelled (internal trips)	5.7 billion				9.6 billion				km
Transportation mode split*	v	t	w	b	v	t	w	b	%
Internal trips	74	12	10	4	76	14	5	5	
External outbound trips	87	11	1	1	64	10	1	25	
External inbound trips	73	25	0	2	61	24	0	15	
Electric vehicle uptake rate	2-3% of market share by 2040								%/year
Electricity emissions factor	28.9				37.4				gCO2e/kWh
Average building efficiency	New construction 10% more efficient every 5 years beginning 2018								%/year
Fuels GHG intensity	CO2		CH4		N20				
Gasoline	2,316		0.32		0.66				G/L
Natural gas	49								kgCO2e/GJ
Diesel	2,690		0.07		0.21				G/L
Fuel oil (res.)	2,560		0.03		0.01				G/L

*v = vehicle, t = transit, w = walking, b = bicycling

Table 4-1: Central BAP assumptions.

4.3. GHG Emissions Reductions

Figure 4-2 illustrates the emissions reduction impacts of the 100% scenario actions relative to the BAP scenario. Emissions reductions from each action

[23] This table was calculated based on an energy generation of population projections. Subsequent modelling updates increased the population projection to 1.5 million.

are represented by different colours, while remaining GHG emissions are represented by the grey area. In the 100% scenario, GHG emissions in Ottawa are 99% below 2050 levels in the BAP scenario.

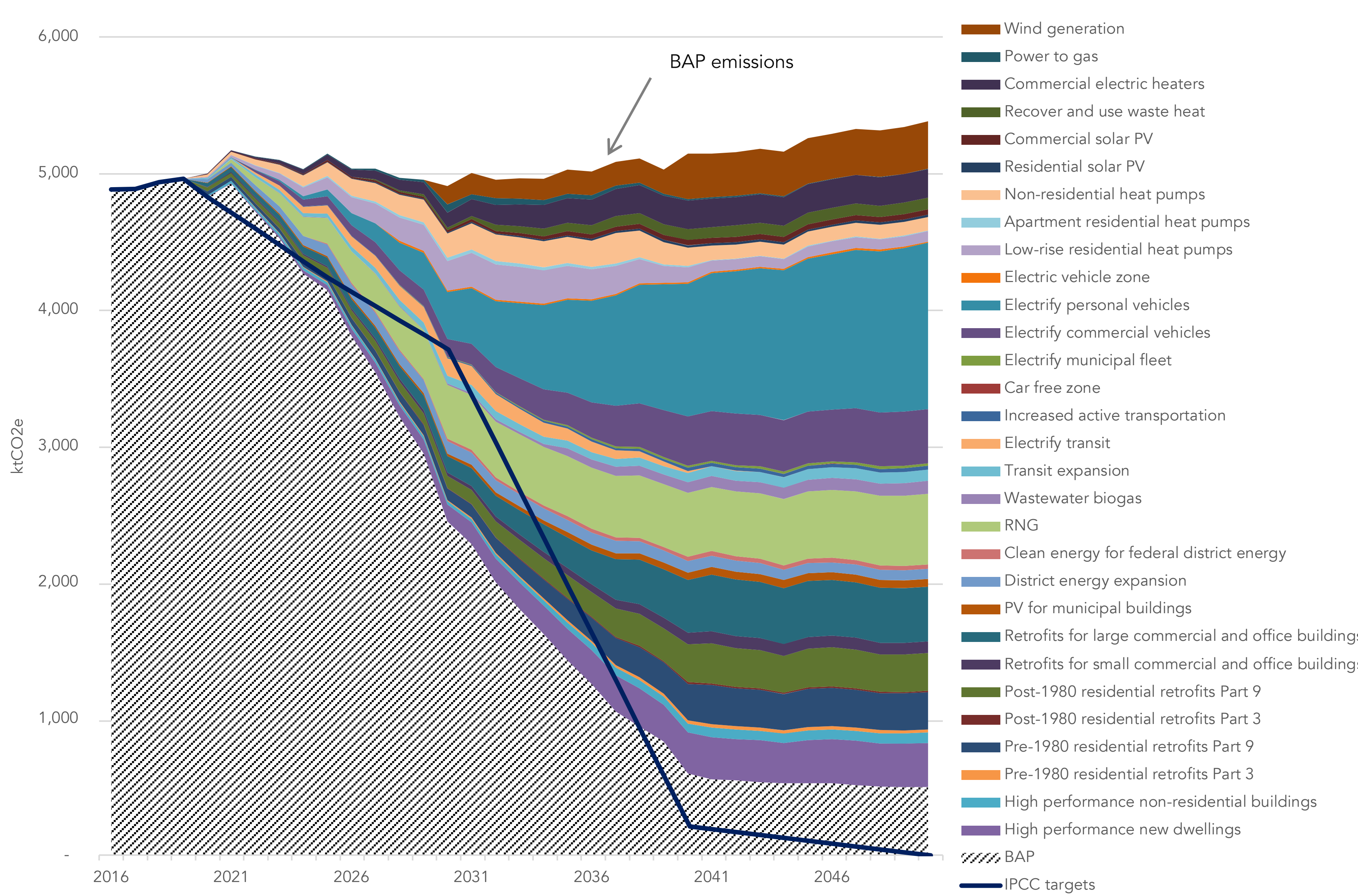

Figure 4-2: GHG reduction wedge diagram for the 100% scenario.

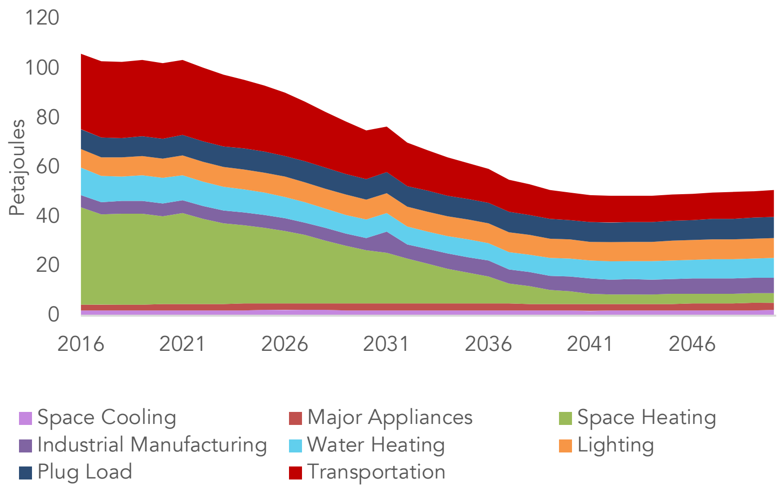

Figure 4-3: 100% scenario energy consumption by sector, 2016-2050.

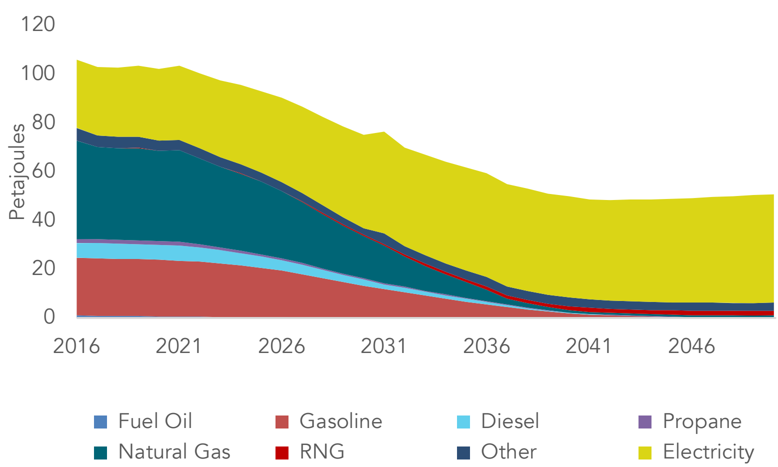

Figure 4-4: 100% scenario energy consumption by fuel, 2016-2050.

4.4. Energy Consumption

Ottawa's primary fuel sources in 2016 are natural gas (38%), electricity (26%), and gasoline (22%). Diesel, fuel oil, propane, and other sources make up the remainder. In the 100% scenario, electricity becomes the dominant energy source (88%), and overall fossil fuels are reduced from 69% to 2%.

Buildings were the largest energy consumer in Ottawa in 2016, collectively using 70.6 PJ (67% of community energy use). Actions in the 100% scenario include deep energy retrofits for existing residential and non-residential buildings, implementing a high performance building standard to improve energy efficiency of new buildings, increasing use of air-source and ground-source heat pumps and fuel switching from natural gas to electricity (to power heat pumps) for space heating. These actions are projected to collectively decrease building energy use by 52% to 33.8 PJ.

The transportation sector is the second highest energy consumer, accounting for 29% of community energy use, or 30.6 PJ. In the 100% scenario, transportation emissions are reduced by various actions, including expedited uptake of electric vehicles; congestion charges; increased on-street parking prices; a reduction in vehicle kilometres travelled (VKT); more compact and dense land-use and the build-out of the master cycling plan; and an increase in the share of walking, cycling, and transit trips. Overall, transport-related energy consumptions drops by 64% by 2050.

Improvements to vehicle efficiency fuel standards drive some of the decrease in vehicle energy use, but the majority of energy savings are a result of electrification of personal and commercial vehicles, as well as the complete electrification of the City's municipal vehicles and the transit system.

Overall, the 100% scenario results in a total energy use decrease from 105.7 PJ in 2016 to 33.6 PJ in 2050. This is a 68% reduction from the 2016 baseline and a 55% reduction over the BAP scenario in 2050.

4.4.1. Per Capita Energy

Per capita energy use decreases in both scenarios. In the BAP scenario, energy use decreases by 32 gigajoules (GJ)/person. Although the population is increasing, space heating and water heating demands decrease due to smaller homes, increased energy efficiency, and reduced heating demand (due to a decrease in heating degree days from climate change-induced warming). In the 100% scenario, per capita energy use in Ottawa decreases from 106 GJ/person to 34 GJ/person in 2050. This represents a 68% reduction from 2016 and a 55% reduction over the BAP scenario in 2050 (Figure 4-5).

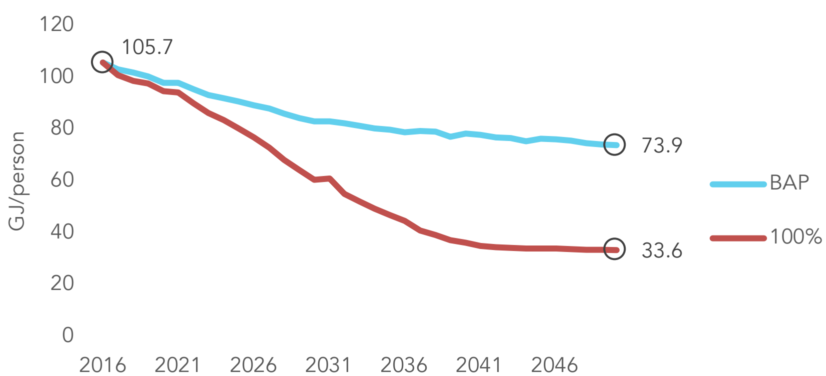

Figure 4-5: BAP and 100% scenario energy use per capita, 2016-2050.

4.5. GHG Emissions

The 100% scenario enables Ottawa to achieve emissions reduction of 99% from 2016 levels by 2050. Total GHG emissions decline from 4.9 MtCO2e in 2016 to 0.1 MtCO2e in 2050. The BAP scenario projects a GHG emissions decrease from 4.9 tonnes carbon dioxide equivalent (tCO2e) to 3.3 tCO2e per capita (-33%), largely due to decreased heating degree days.

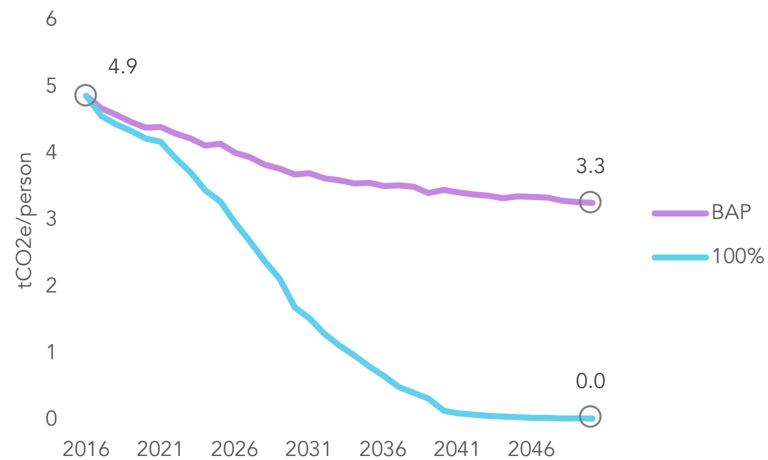

Figure 4-6: BAP and 100% emissions per capita (tCO2e/person), 2016-2050.

4.6. GHG Emissions by Sector

The 100% scenario results in GHG emissions reductions in all sectors. Interventions in the transportation sector reduce related emissions by 99.9%, representing the greatest change of any sector. GHG emissions from waste are reduced by 97.1% from 2016 to 2050 as a result of increased waste diversion and the capture of methane from waste to be used for renewable natural gas (RNG). GHG emissions from residential buildings are reduced by 98.5%, while GHG emissions from commercial and industrial buildings are reduced by 97.4% and 96.9%, respectively. Fugitive emissions, which are emissions that escape from the natural gas distribution system, and emissions from district energy production also decrease by 98% and 86%, respectively.

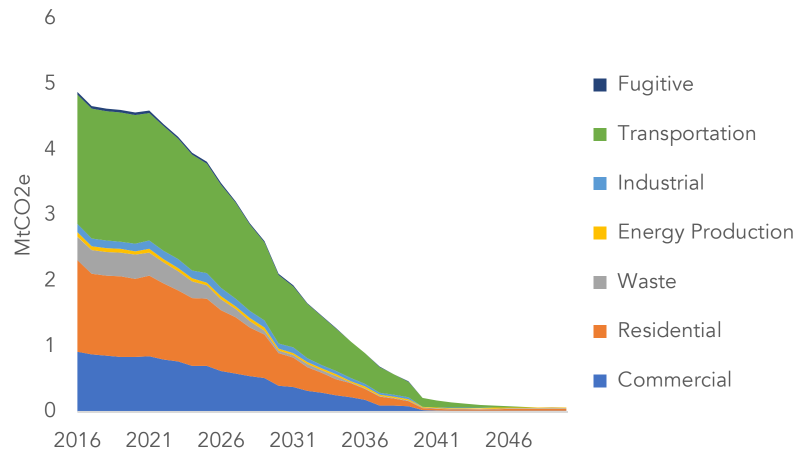

Figure 4-7: 100% scenario emissions by sector, 2016-2050.

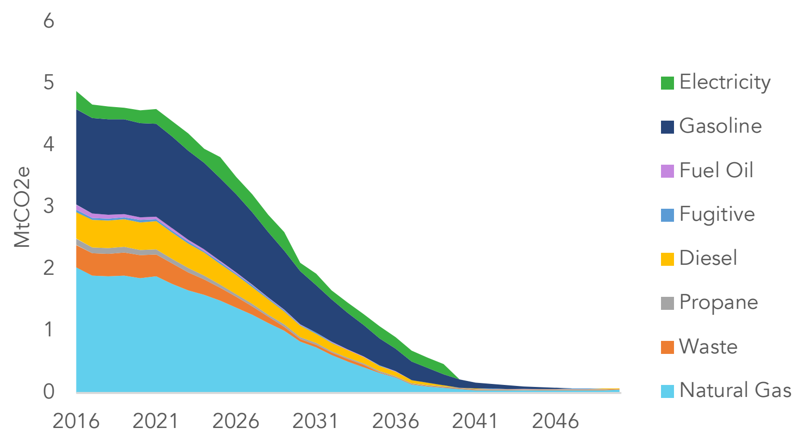

Figure 4-8: 100% scenario emissions by source, 2016-2050

4.7. GHG Emissions by Fuel Type

The 100% scenario shifts from carbon-intensive fuel sources to renewable energy and electrification. In 2016, the highest emitter by fuel type was natural gas (used in buildings), accounting for 42% of total emissions. Gasoline (used in transportation) accounted for 32% of total 2016 emissions. In 2050, natural gas use decreases by 97.6%, but increases its share of emissions to 67% as other emitting fuels decrease in use. GHG emissions from gasoline are projected to decrease by 99.98%, mostly due to electrification of vehicles. GHG emissions associated with electricity production are expected to decrease by 100% over the time period due to renewable electricity generation.

4.8. Land-Use and Transportation Actions

The land-use action commences with an intensification of development near the city centre and LRT lines, with decreased development occurring in the periphery. Increased development intensity reduces overall VKT and shifts mode share away from private vehicles. The Transit Concept

Network[24] is built out and there is increased transit access in the city. The land-use action also incorporates additional actions to increase cycling, walking, transit use, and car sharing.

This is accompanied by fuel switching of commercial, personal, and city/corporate vehicles from fossil fuels to electricity. As technologies improve and policies like carbon pricing come into effect, the commercial industry will move towards increased electrification, albeit at a slower rate of adoption than for personal vehicles. The City will also transition to a zero emissions fleet by 2040. Greater detail on action development in the land use and transportation sector can be found in Appendix 8.1.

Table 4-2: Land-use and transportation actions in the 100% scenario.

Land-use actions	
100% scenario assumptions	
Land use	90% of new development is in urban zones or adjacent to existing or new LRT, BRT by 2025.
Active transport	
Enhanced bicycle infrastructure, increased walking	50% mode shift to walking and cycling away from vehicles and driving in selected land-use zones. Use 2 km maximum distance for walking trips and 5 km for cycling trips.
Vehicle technology	
Commercial vehicles	40% of heavy trucks are zero emissions by 2030; 100% by 2040.
Zero emissions municipal fleets	Municipal fleet is 100% zero emissions by 2040.
Electrify personal vehicles	90% of new vehicles sold are electric by 2030; 100% by 2050.
Enhanced transit	
Enhanced transit	LRT frequency is increased to 90 seconds at peak times, surrounding area trains are adjusted to match. BRT speed is increased by 20% through prioritized lanes and stop lights. 100% of transit vehicles are electric by 2030. The Transit Network Concept is completed.
Transportation Demand Management (TDM)	
Parking fees	Increase parking fees in city-controlled areas by a factor of two by 2050.
Congestion pricing	Congestion charge of $20 applied to the downtown core between 6:00 am and 10:00 am on weekdays by 2030.
Car-free zones	Car-free areas in Downtown, Byward Market. Wellington-Rideau area, Sparks, Bank, and University of Ottawa campus area by 2030.

[24] The Transit Concept Network was provided by the City's Transportation Department.

4.9. Land-Use and Transportation Energy

4.9.1. Transportation Modeling Assumptions

The BAP scenario assumes that electric vehicles make up 2-3% of the market share by 2040 and that their market share remains constant thereafter, with the adoption being in personal vehicles and no adoption in the commercial fleet. The transit fleet is electrified by 2050. The total vehicles number is proportional to households and distances traveled is proportional to building locations. Mode share assumptions were based on the City's transportation model data for 2011 and 2031 and held constant post 2031. The fuel standards were based on the U.S. Corporate Average Fuel Economy (CAFÉ) Standard for light duty vehicles and phase 1 and phase 2 of U.S. Environmental Protection Agency's (EPA) Heavy Duty Vehicle (HDV) standards for medium and heavy-duty vehicles.

4.9.2. Transportation Energy by Fuel

Using over 31 PJ of energy annually in 2016, Ottawa's transportation sector accounted for 29% of total community energy. In the 100% scenario, transportation energy consumption declines by 64% from the 2016 baseline to 10.9 PJ in 2050. By 2050, fossil fuels used for transportation energy decrease by approximately 90.97-100% per vehicle type, as fossil fuels are replaced by electricity.

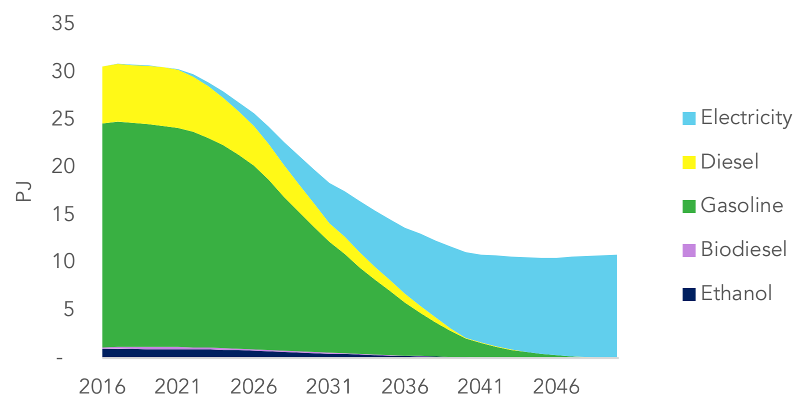

Figure 4-9: 100% scenario transportation energy use by fuel type, 2016-2050.

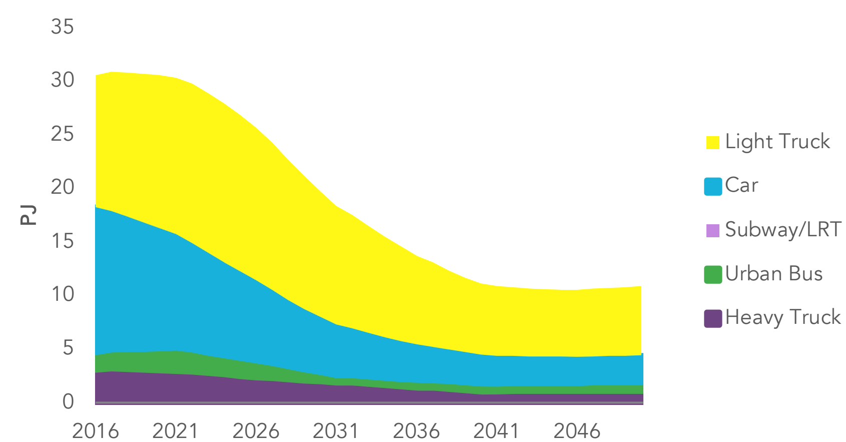

Figure 4-10: 100% scenario transportation energy use by vehicle type, 2016-2050.

4.9.3. Transportation Energy by Vehicle Type

Light trucks and cars represent the greatest energy consumers by vehicle type, accounting for 40% and 44% of energy use, respectively. The 100% scenario projects that light trucks (including SUVs and “crossover” vehicles) will become dominant in the mid-2020s and will climb to use 59% of transportation energy by 2050 (Figure 4-11).

In 2016 the Ottawa LRT and bus system accounted for 5.6% of transportation energy. By 2050, transit use will account for 7.5% of total transportation energy use in the 100% scenario. Transit infrastructure is projected to increase by 2050, and the entire transit fleet and rolling stock is expected to be electric.

Figure 4-11 shows the transition of personal vehicle types from carbon-based fuel to electricity-based fuel. Light trucks will continue to grow in consumer preference and will reduce their energy use by becoming increasingly electric. By 2050, they will become the dominant energy user despite increases in efficiency. Meanwhile, heavy trucks transition to nearly 100% electric in the 100% scenario and reduce energy use by 64%.

Transportation needs will generally grow in step with population growth; however, greater efforts encouraging active transportation will reduce energy use in this sector by 2050.

The length of internal trips sees an increase of 3 km, as more population is added to the city core. Increasing vehicle fuel efficiency will also contribute to reduced energy use in the transportation sector. Further background to transport and land-use actions can be found in the Appendices.

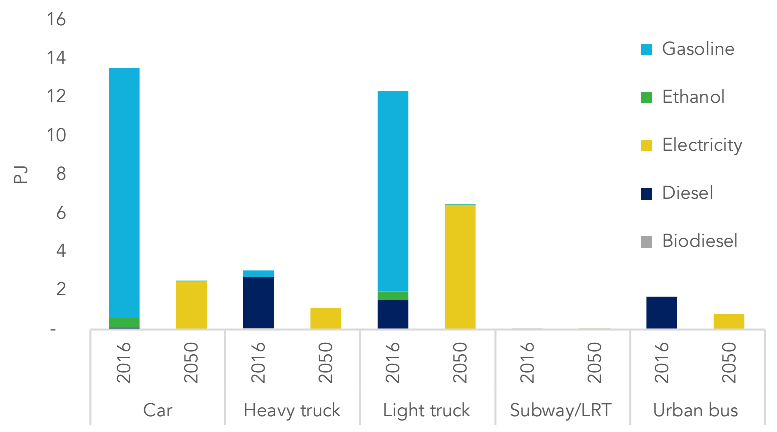

Figure 4-11: Transportation energy use by vehicle type and fuel, 100% scenario 2016 and 2050.

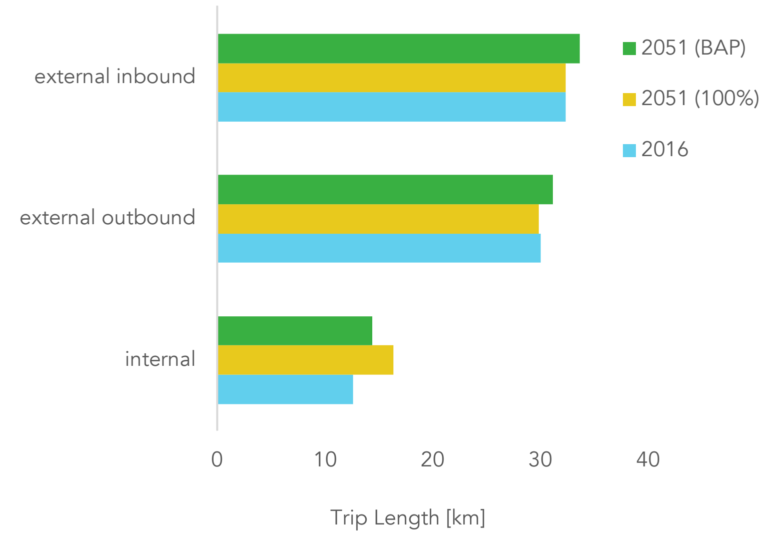

Figure 4-12: Trip length by trip type, 100% scenario, 2050.

4.9.4. Land-Use and Transportation Sector Emissions

In 2016, GHG emissions from transportation were dominated by gasoline (78%), while diesel fuel accounted for 22% of emissions. In the 100% scenario, electric vehicles replace the internal combustion engine across the transportation fleet (personal, municipal fleet, freight, and buses). The elimination of carbon-intensive fuel sources is critical to reducing emissions from transport, but the overall emissions reduction is accelerated by reduced VKT as a result of an increased share of transit use, as well as active transport modes. These factors result in an 99% decline in GHG emissions in the transportation sector.

In 2016, cars and light trucks accounted for about 84% of Ottawa's total transportation emissions, while heavy trucks and buses accounted for approximately 16%. The market share of light trucks increases in the 100% scenario, thereby increasing the share of its GHG emissions slightly from 40% to 49%. However, overall emissions for light trucks falls by 99%, from 798,000 MtCO2e to 4,895 MtCO2e by 2050, as a result of increased electrification and vehicle efficiency.

Total GHG emissions from vehicles decrease by 99% between 2016 and 2050 in the 100% scenario, as well as by 99% from the BAP scenario.

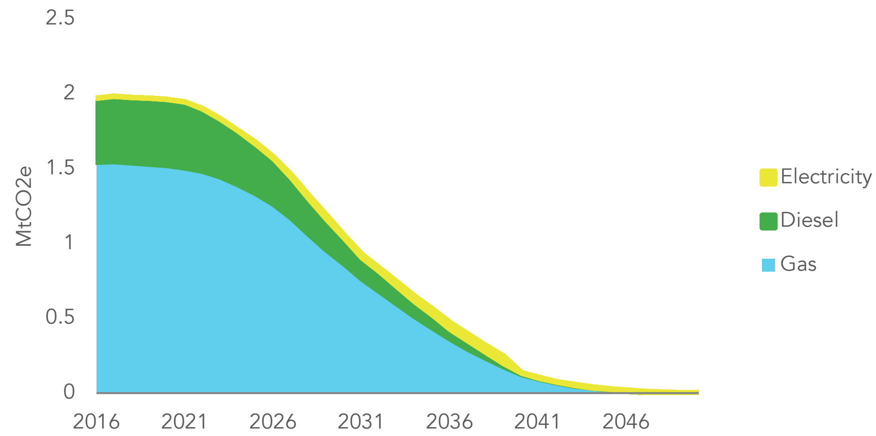

Figure 4-13: Transportation GHG emissions by source, 100% scenario, 2016-2050.

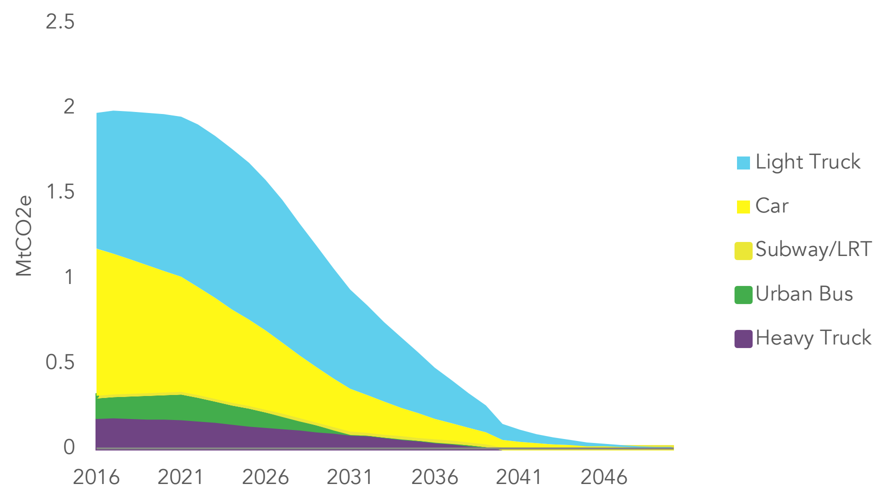

Figure 4-14: Transportation GHG emissions by vehicle type,100% scenario, 2016-2050.

Cars and light trucks were the primary source of transportation GHG emissions in 2016, producing a combined 1,700 ktCO2e. In the 100% scenario, they are still the dominant source of transportation GHG emissions, accounting for 68% of emissions in 2050; however, total transportation emissions fall to 10 ktCO2e.

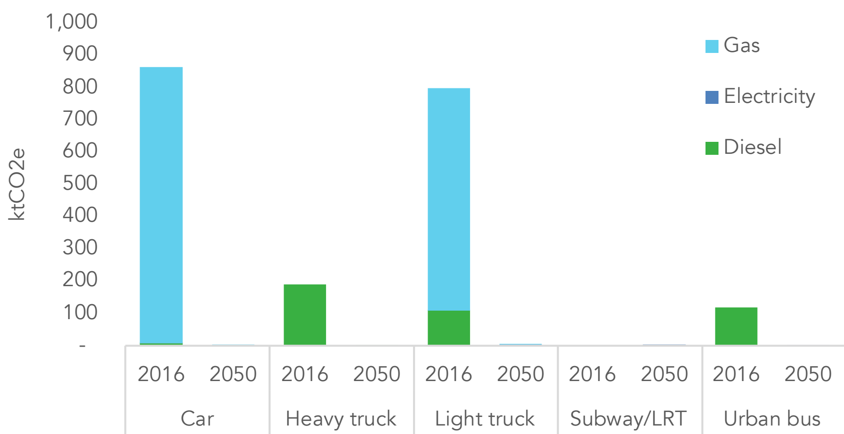

Figure 4-15: Transportation GHG emissions by source and vehicle type, 2016 and 2050.

4.10. Buildings Actions

In the low-carbon analysis of buildings in Ottawa, building types were classified and modelled according to existing residential, new residential, existing non-residential, and new non-residential categories. Low-carbon actions for each building type were developed under the 100% scenario.

New residential buildings will be more efficient than the current Ontario Building Code in the 100% scenario. By 2030, all new construction will meet net-zero energy standards. By 2050, all new homes will also achieve Passive House standards. Non-residential buildings will follow a high-performance standard similar to those in the Toronto Green Standard. For existing buildings, low-carbon actions focus on reducing electricity and thermal energy demand by applying efficiency retrofits that increase in scale over time.

An action was also developed for fuel switching for thermal heat demand in buildings. Air-source and ground-source heat pumps are used in new buildings and installed during retrofits of existing buildings. More information on the development of zero-carbon buildings is detailed in Appendix 8.2

Table 4-3: Building-related actions in the 100% scenario

100% scenario assumptions	
New buildings	
Dwelling size	Maintain 2016 size of dwellings.
Building mix	Maintain Business-as-Planned allocation.
Net-zero buildings	100% of new construction is net-zero energy by 2030.
Efficiency of new non-residential buildings	Apply high performance building targets similar to the Toronto Green Standard (TGS) timeline up to 2030.
Existing buildings	

100% scenario assumptions	
Retrofit older homes (pre-1980) Retrofit newer homes (post-1980)	Retrofit 98% of all dwellings by 2040; achieve thermal savings of 70% and electrical savings of 30%.
Retrofits of small commercial and office buildings	Retrofit 98% of all buildings by 2040; achieve thermal savings of 60% and electrical savings of 30%.
Retrofits of commercial, office, and industrial buildings	95% of the existing building stock is retrofitted by 2040 with average energy savings of 50%.
Recommissioning of commercial and institutional buildings	Recommission all buildings over 200,000 ft2 and 40% of buildings over 25,000 ft2 every 10 years with average energy savings of 10%.
Municipal buildings	99% of existing municipal buildings are retrofit to net-zero emissions by 2040.
Heat pumps	
Residential heat pumps	560,350 installed by 2050.
Heat pumps - commercial buildings	73% of floor space.

The BAP assumes that building efficiency would improve by 10% every 5 years based on Ontario building code. New floorspace projections were based on existing persons per unit (for residential), and floorspace (m2) per employee per job (for non-residential space).

The efficiency of existing buildings was assumed to remain constant from 2016 to 2050. A decrease in heating and an increase in cooling degree days were projected using “Statistically Downscaled Climate Scenarios,” developed by the Pacific Climate Impacts Consortium and applied to the Ottawa Region.

4.10.1. Buildings Sector Energy

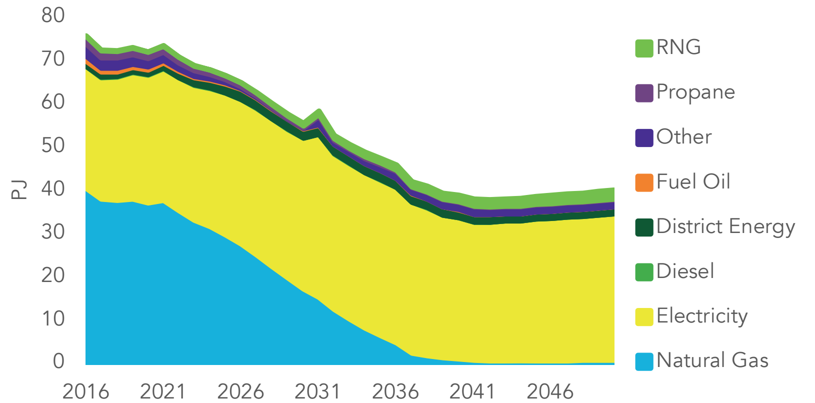

Figure 4-16: 100% scenario building energy use by fuel, 2016-2050.

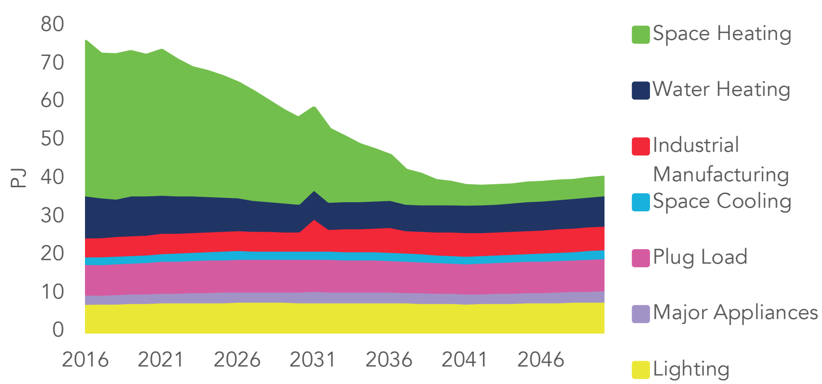

Figure 4-17: 100% scenario building energy use by end use, 2016-2050.

The buildings sector sees an overall reduction of energy use from 75.5 PJ in 2016 to 40.1 PJ in 2050 under the 100% scenario. Electricity consumption increases by 20% over this period, primarily resulting from fuel switching away from natural gas. Natural gas, propane, diesel, and fuel oil consumption decreases by between 90% to 99%. District energy, currently employed by federal buildings, expands in the 100% scenario to other buildings and accounts for 4% of energy consumption, a 33% increase from 2016. The use of renewable natural gas for space heating also grows in the 100% scenario, as more wastewater and solid waste gases are captured; however, this source accounts for a small proportion of energy demand in 2050 (approximately 5%).

A 47% decrease in building energy use from 2016 to 2050 under the 100% scenario is primarily the result of deep energy retrofits to existing buildings and improvements to the energy efficiency of new residential buildings. Appendix 8.1 provides more information regarding these actions. Space and water heating shifts to the use of air-source and ground-source heat pumps in residential and commercial buildings. As a result, space heating consumes 90% less energy in 2050 than in 2016, and water heating energy use declines by 29% over the same period. Space cooling increases its energy consumption by 9%, industrial manufacturing by 27%, major appliances by 19%, lighting by 8%, and plug load by 7%.

Notwithstanding the population growth in the scenario, a reduction in heating degree-days (and thus reduction in demand for energy to heat buildings) results in only moderate growth of energy consumption in the BAP scenario. The same reduction in heating degree-days is applied to the 100% scenario. There is a smaller increase in cooling degree days over the period.

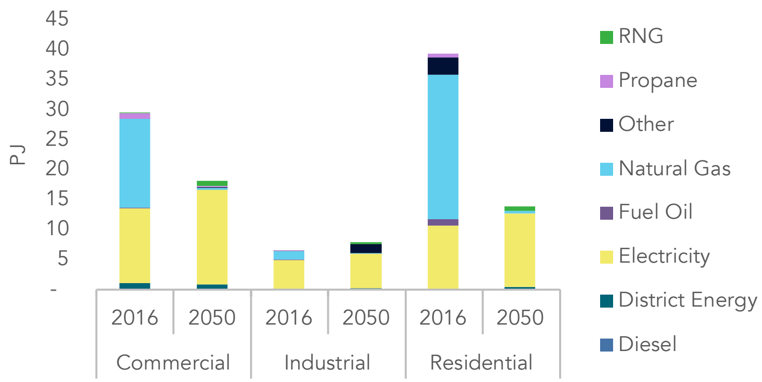

Figure 4-18: Energy use by building type and fuel, 2016 and 2050.

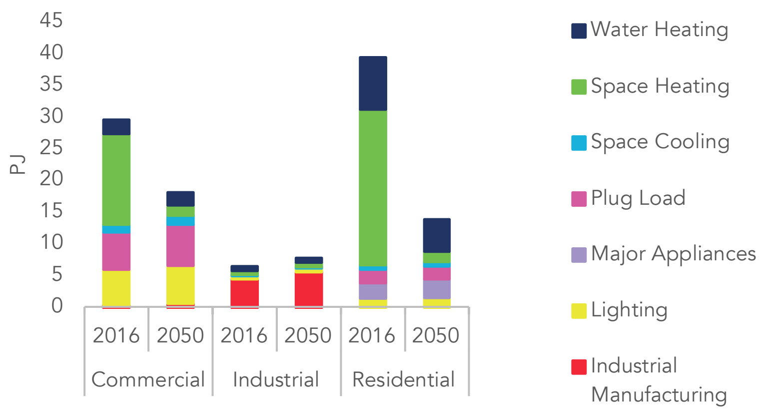

Figure 4-19: Energy use by building type and end use, 2016 and 2050.

By 2030, 100% of new institutional, industrial, and commercial (ICI) buildings achieve Passive House levels of low energy consumption performance; 100% of new residential buildings achieve net-zero energy by 2030; and 27% of existing buildings are retrofitted to achieve a 50% energy reduction.

Electricity becomes the primary fuel for all building types. District energy use increases in the industrial and residential sector due to an expansion of the existing federal systems and the addition of new district energy systems.

The 100% scenario projects commercial building efficiencies for new buildings using a similar approach to the Toronto Green Standard (TGS). Existing commercial buildings target the same retrofit and recommissioning schedule as residential buildings, resulting in a 38% energy reduction.

Residential energy use per household declines from 105.6 GJ to 23.4 GJ between 2016 and 2050 in the 100% scenario, a reduction of 78%. Compared to the BAP scenario, the 100% scenario results in a 64% reduction.

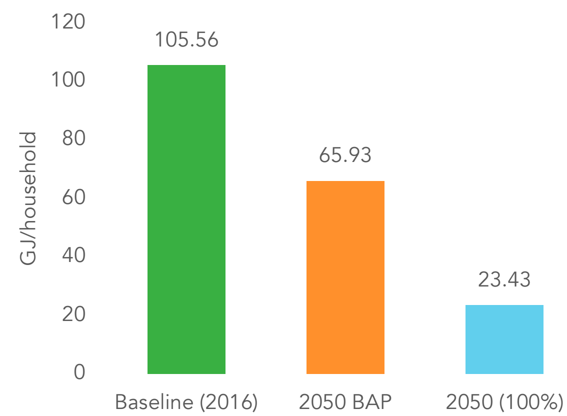

Figure 4-20: Residential energy per household, 80% scenario.

4.10.2. Buildings Emissions

In 2050, natural gas accounts for 79% of building emissions and remains the largest emitting fuel source in the 100% scenario. However, through efforts such as fuel-switching and energy efficiency measures, emissions from natural gas decrease by 98% from the 2016 baseline. Natural gas use will not be eliminated, as a small proportion of buildings will continue to use natural gas for space heating and water heating by 2050. GHG emissions from propane and fuel oil, and diesel (from generators) decrease by between 90% and 99.7% as they decline in use.

The switch to heat pumps for space heating and cooling is effective in reducing buildings emissions. These reductions are augmented by increased building efficiency.

In the 100% scenario, GHG emissions from space heating decrease by 99.6%% from 2016 to 2050. GHG emissions from water heating, plug loads, major appliances, space cooling, and lighting decrease marginally, due to increased local renewable electricity generation displacing fossil fuel-based electricity generation from the bulk transmission grid.

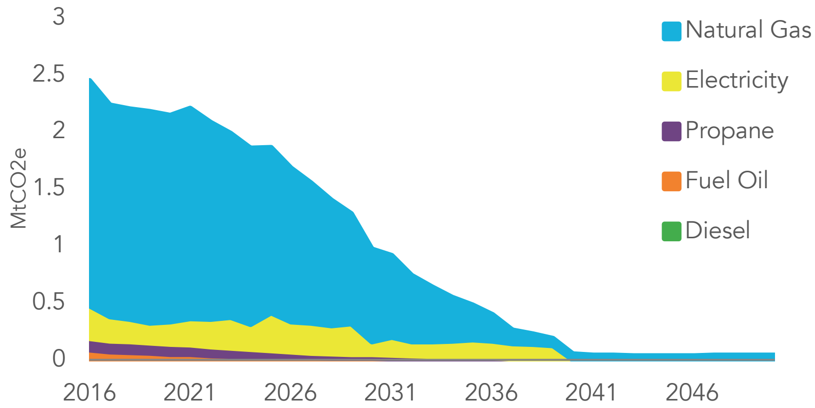

Figure 4-21: GHG emissions by source, 2016-2050.

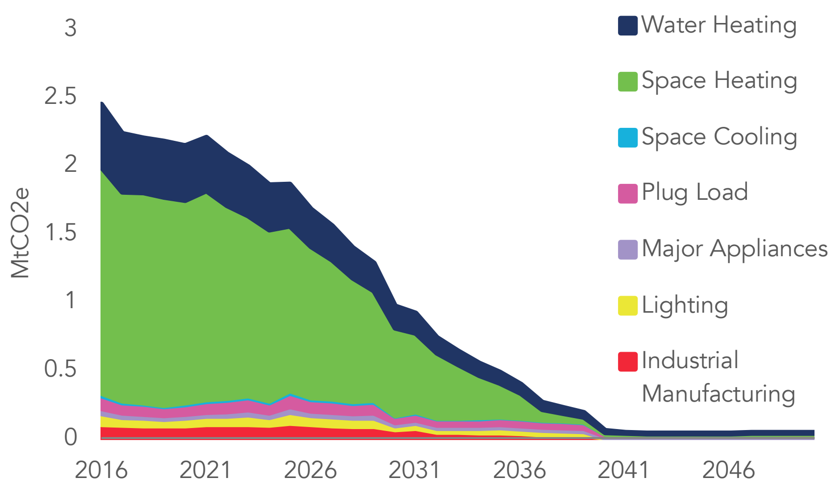

Figure 4-22: GHG emissions by end use, 2016-2050.

In 2016, residential and commercial buildings account for more than 94% of building GHG emissions, primarily from natural gas consumption, with the remaining 6% coming from industrial buildings. By switching to electricity and reducing overall consumption, GHG emissions are reduced by 97% in industrial buildings, 97% in commercial buildings, and 99% in residential buildings by 2050.

Space heating and water heating are the primary non-industrial source of GHG emissions in 2016. By switching to heat pumps and changing the energy source to electricity from natural gas, GHG emissions are reduced by 99.5% for space heating and 98.8% for water heating by 2050.

Industrial processes accounted for 4% of GHG emissions in 2016.

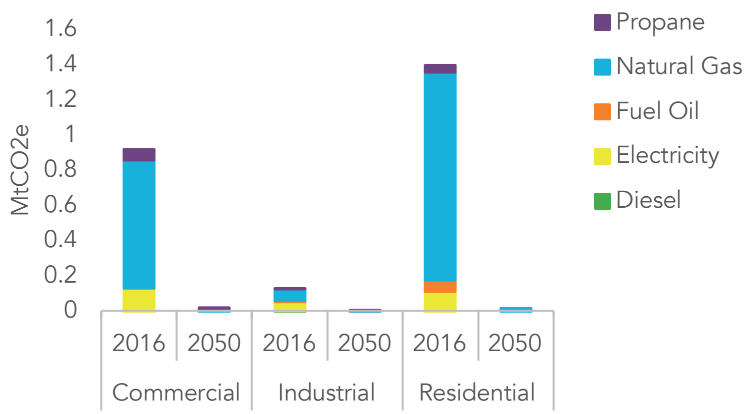

Figure 4-23: GHG emissions by building type and source, 2016 and 2050.

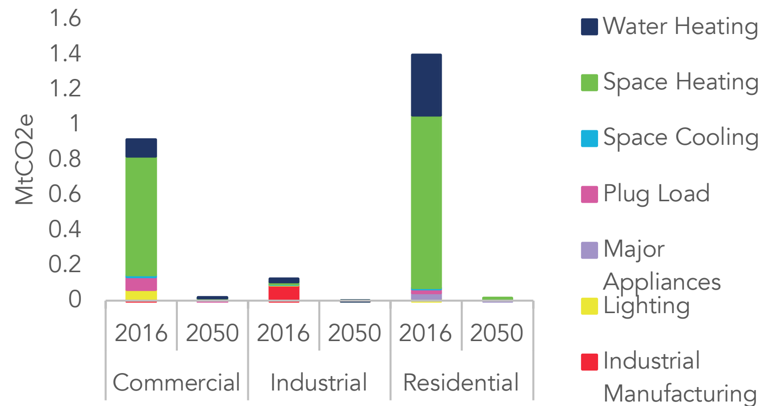

Figure 4-24: GHG emissions by building type and end use, 2016 and 2050.

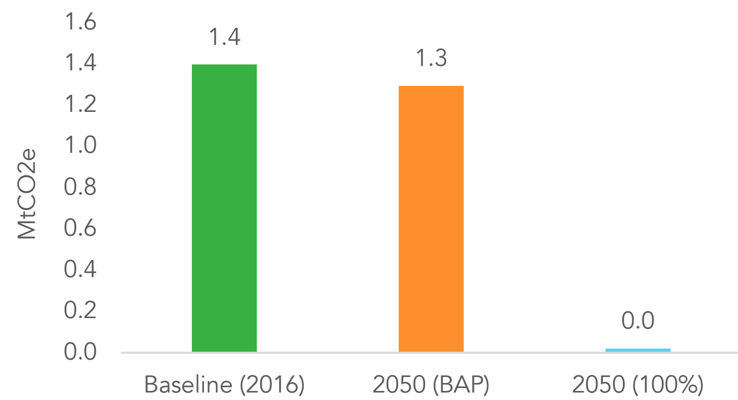

Figure 4-25: Residential emissions per household, 2016 and 2050.

In the 100% scenario, residential GHG emissions decrease by 98.5% on a per household basis by 2050. These savings are a result of retrofits to existing buildings to maximize energy efficiency, net-zero standards for new dwellings, the adoption of energy-efficient heating sources, and fuel switching away from fossil fuels.

4.11. Waste Actions

The 100% scenario models actions to meet Ottawa's waste diversion target by 2042, then furthers these goals (see Tables 4-4 and 4-5 for a breakdown of targets). By 2050, nearly 100% of organics are diverted from the landfill and processed to produce renewable natural gas. Wastewater treatment is modelled to phase out natural gas use.

Table 4-4: 100% scenario waste sector actions.

Action	100% scenario
Waste diversion	Achieve Ottawa waste diversion targets by 2030. Route all organic waste to anaerobic digesters. All yard and leaf waste composted.
Renewable natural gas generated from wastewater and landfill	Gas produced from anaerobic digestion and landfill gas is used as renewable natural gas, displacing conventional natural gas use.
Rural biogas	520 GJ by 2050.

The following table further breaks down Ottawa's waste diversion goals, which are expected to be met by 2030 in the 100% scenario.

Table 4-5: Municipal waste diversion targets, 100% scenario

Municipal capture rates (%)	2010	2042	100% scenario
Diversion values for the residential curbside program[25]			
Paper & fibre	80	95	95
Metals	60	95	95
Glass	57	95	95
Recyclable plastics	57	95	95
Green bin organics	28	90	90
Leaf & yard waste	99	99	99
Diversion values for the residential high-density program[26]			
Paper & fibre	50	90	90
Metals	25	95	95
Glass	63	95	95
Recyclable plastics	39	90	90

4.11.1. Waste Modelling Assumptions

Under the BAP scenario, emissions projections for waste were derived using projected population growth and existing rates of waste produced per capita with no reduction in per capita waste assumed. The 2016

[25] Based on data in *City of Ottawa Residential Curbside Waste Characterization Study Green Bin Program Rollout 2010 Final Report*, Viridis Environmental Incorporated.

[26] 2010 capture rate for high density residential based on summary of data from audits completed in 2005 and 2006 per *City of Ottawa Solid Waste Services Division Multi-Unit Waste Characterization Study Quarterly Reports*, Integrated Environmental Waste Services.

diversion rate of 47% was assumed constant to 2050. In addition, the model assumed no new technology for carbon emissions reductions in solid waste or wastewater treatment facilities was adopted beyond 2016.

4.11.2. Waste Sector Emissions

In 2016, Ottawa produced over one million tonnes of solid waste (Figure 4-26). Almost 70% of it was disposed in landfills, while 20% was recycled and 10% was biologically treated (through composting and/or anaerobic digestion).

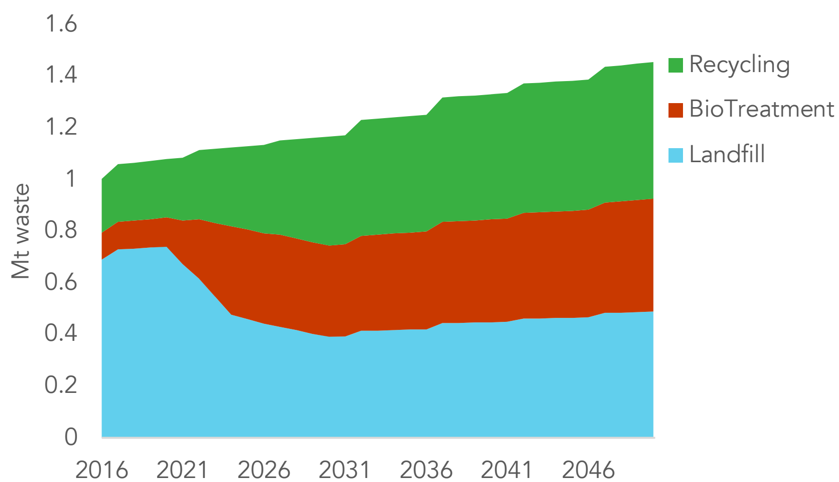

Figure 4-26: Solid waste by treatment type,100% scenario, 2016-2050

In 2050 in the 100% scenario, solid waste sent to the landfill will drop to 34%, with the remainder being anaerobically digested.

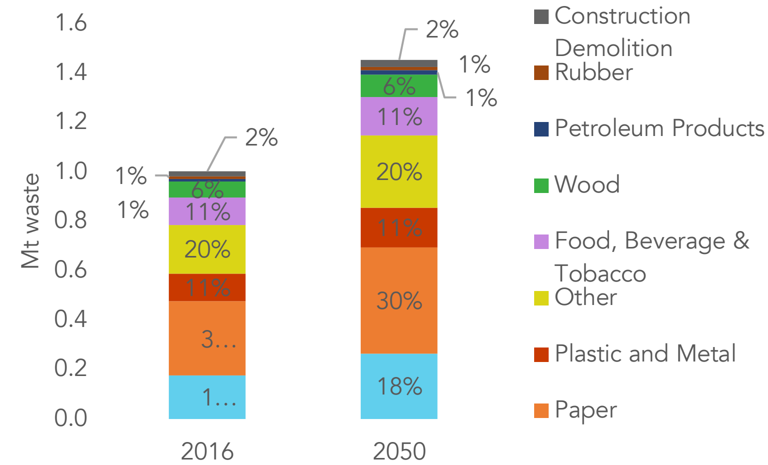

Figure 4-27: Solid waste tonnage by type,100% scenario, 2016-2050.'

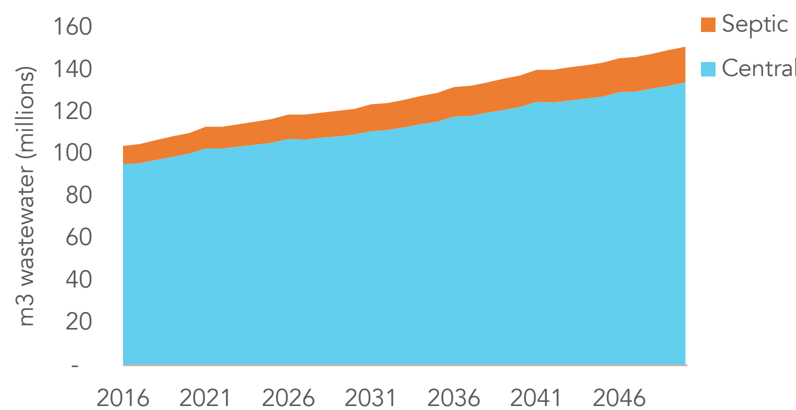

Figure 4-28: Wastewater volume by treatment type,100% scenario, 2016-2050.

Solid waste production is expected to scale with population, increasing by over 450,000 tonnes by 2050. Notable increases in paper, wood waste, plastic and metal, and compost are expected.

Over 100 million cubic metres of wastewater was treated in Ottawa in 2016. The vast majority of it was treated by a central treatment facility (ROPEC). Less than 10% was treated by septic fields. In the 100% scenario, wastewater production is expected to increase in step with population, rising by 48% between 2016 and 2050.

In the 100% scenario, the reduction in waste GHG emissions reaches approximately 97% by 2050 as a result of increased methane capture and near perfect diversion rates, whereby all organic material is used to make RNG.

Emissions associated with the energy used at recycling facilities is accounted for in the buildings sector. Similarly, emissions associated with the transportation of waste are accounted for under the transportation sector. Landfill emissions include those from open and closed landfills.

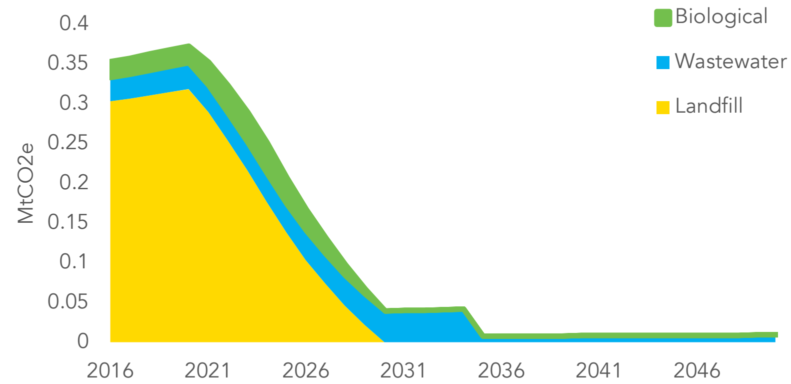

Figure 4-29: Solid and liquid waste emissions,100% scenario, 2016-2050.

4.12. Energy Sector Actions

Increased uptake of renewable energy technologies is modelled in the 100% scenario. In order to realize this trajectory, increased ambition from all levels of government and the private sector is required. The model examined various technologies, including solar PVs, increased uptake of district energy, and hydropower. Renewable natural gas is also extracted and used for heating or in industrial processes. Wind power presents an opportunity, but will have to be sourced regionally because it won't be a strong energy producer for Ottawa. Renewable energy is paired with energy storage technologies or other grid management approaches to make best use of peak and surplus times for energy generation. More information on the development of this action can be found in the Appendices.

Table 4-6: Energy sector actions.

Technology	100% scenario
Residential/commercial Rooftop solar PV	320 MW by 2050 (residential).
	740 MW by 2050 (commercial).
	140 MW by 2050 (utility scale).[27]
Hydropower	36 MW by 2050.
Wind power	3218 MW by 2050.
District energy (DE)	DE supplies80% of existing commercial buildings, 80% of apartments, and 15% of residential buildings, other than apartments. 100% of the system is zero-carbon. 23,394 homes served by DE by 2050 8,091,053 sqm non-residential floorspace served by DE by 2050.
Federal government System	System is fueled by geothermal energy only by 2040.
Energy storage	Enhancement to renewable energy generation and modelled in alignment with those actions.
Renewable natural gas	520 GJ per year.
Air-source and ground-source heat pumps	By 2050, 414,691 heat pumps installed in low-rise buildings and 145,659 heat pumps installed in apartments. Heat pumps account for 73% of commercial heat load.

[27] The 140 MW in the utility category was not included in the 100% scenario modelling.

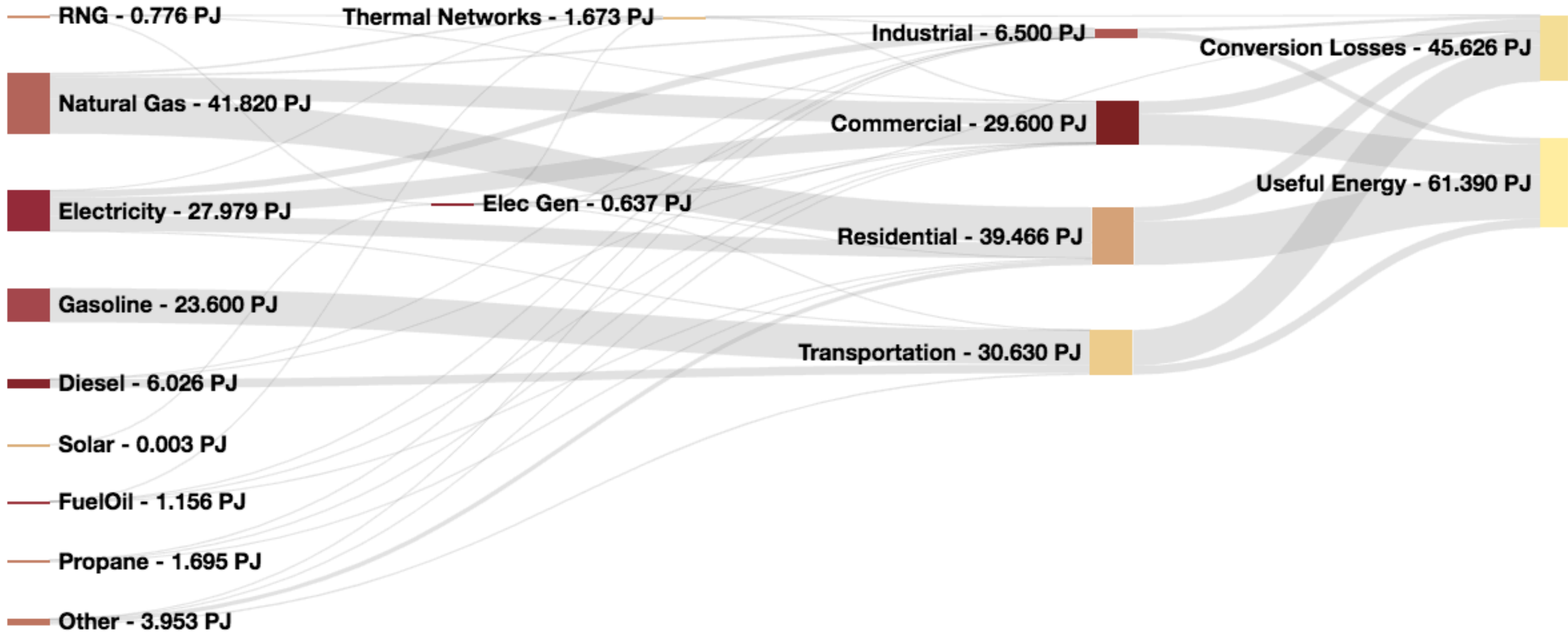

Figure 4-30: Energy flow, 2016 baseline.

4.12.1. Energy Modeling Assumptions

To build the energy portion of the model, the IESO's 2016 Ontario Planning Outlook (OPO) and National Energy Board's (NEB) 2016 Ontario projected electricity generation capacity were referenced. These documents show that, from 2016 onwards, the electric grid experiences a slight increase in carbon intensity as nuclear power's share is reduced, and this capacity is replaced by natural gas. Starting in 2035, natural gas generation holds constant, maintaining the carbon intensity at its 2035 level.

4.12.2. Energy Flow and Conversions

Energy flow by fuel and sector are shown in Sankey diagrams for the 2016 baseline and the 100% scenario (Figures 4-30 and 4-31). In 2016, the ratio of useful energy to conversion losses is 1.35:1, with large conversion losses coming from transportation and the relative inefficiency of vehicle internal

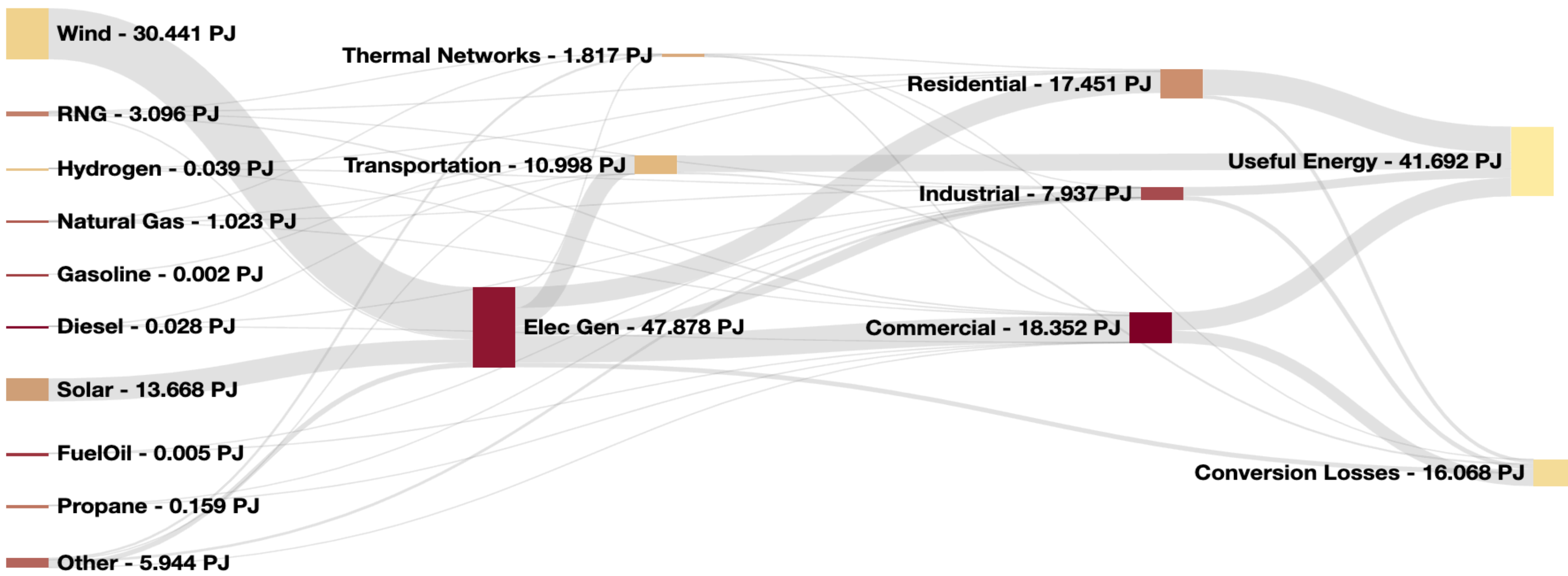

Figure 4-31: 100% scenario energy flow, 2050.

Local renewable electricity generation in 2016 amounts to 0.64 PJ, from hydro and solar PV generation. The district energy network (thermal network) generates 1.67 PJ serving the federal government building stock. Natural gas provides 41.8 PJ, making it the primary provider of thermal energy for buildings, particularly in the residential sector.

In the 100% scenario, the ratio of useful energy to conversion losses climbs from 1.35:1 to 2.6:1 by 2050. The gain in useful energy is mostly a result of fuel switching to electric heat pumps, the growth of electric vehicles, and the growth in the share of renewable electricity sources. Local electricity

combustion engines. Losses also come from inefficient buildings, particularly the thermally inefficient pre-1980 stock.

generation increases from 0.64 PJ to 47.9 PJ in 2050 as a result of the above actions. The district energy network (thermal network) increases from 1.67 PJ to 1.82 PJ to serve more than 23,000 homes and 4.7 million m2 of non-residential floor space.

The Sankey diagram (Figure 4-32) also shows the roughly 50% split in fuel and electricity consumption in the transportation and residential sectors. Fuel sources become increasingly decentralized by 2050 in the 100% scenario.

The Clean Energy Economy

5. The Clean Energy Economy

5.1. Financial Modeling Assumptions

To develop the financial model, energy cost intensities were derived from both the National Energy Board (NEB) Energy Futures 2016 projections (for electricity, natural gas, fuel oil, gasoline, and diesel oil) and a Fuels Technical Report prepared for the Government of Ontario (for propane). Capital cost assumptions were based on recent peer-reviewed reports.

5.2. Investments and Expenditures

The financial model evaluated total expenditures, including capital investments, operating costs (including for fuel and electricity), carbon credits, and revenues from investments in local generation. Table 5-1 summarizes the categories of expenditures evaluated.

Table 5-1: Categories of expenditures evaluated.

Category	Description
Residential buildings	Cost of dwelling construction; operating and maintenance costs (non-fuel).
Residential equipment	Cost of appliances and lighting, heating, and cooling equipment.
Personal-use vehicles	Cost of vehicle purchase; operating and maintenance costs (non-fuel).
Residential fuel	Energy costs for dwellings and residential transportation.
Residential emissions	Costs resulting from a carbon price on GHG emissions from dwellings and transportation.
Commercial buildings	Cost of building construction; operating and maintenance costs (non-fuel).
Commercial equipment	Cost of lighting, heating and cooling equipment.
Commercial vehicles	Cost of vehicle purchase; operating and maintenance costs (non-fuel).
Non-residential fuel	Energy costs for commercial buildings, industry, and transport.
Non-residential emissions	Costs resulting from a carbon price on GHG emissions from commercial buildings, production, and transportation.
Energy production emissions	Costs resulting from a carbon price on GHG emissions for fuel used in the generation of electricity and heating.
Energy production fuel	Cost of purchasing fuel for generating local electricity, heating, or cooling.
Energy production equipment	Cost of the equipment for generating local electricity, heating, or cooling.

Category	Description
Energy production revenue	Revenue derived from the sale of locally generated electricity, RNG, or heat. This is treated as a negative expenditure in the analysis.
Municipal capital	Cost of the transit system additions (no other forms of municipal capital assessed).
Municipal fuel	Cost of fuel associated with the transit system.
Municipal emissions	Costs resulting from a carbon price on GHG emissions from the transit system.

5.3 Financial Analysis of the 100% Scenario

5.2.1. Summary of Financial Results

The actions in the 100% scenario require investments now that result in long-term savings and, in the case of local electricity and renewable natural generation, revenues. As compared with the Business-as-Planned (BAP) scenario, incremental expenditures in buildings, vehicles, and other energy-related equipment and infrastructure increase costs in the short term, but result in long-term savings (Figure 5-1). As described below, incremental investments in the 100% scenario, as compared to the BAP, average around $1.6 billion per year for much of the program. In the last few years of the period analyzed, investment in the zero-carbon pathway falls below the BAP primarily because of the decreased costs of electric vehicles relative to the internal combustion engine. Also, operation and maintenance costs are lower for electric vehicles (and other electric technologies), and these savings are incorporated in the total net expenditures shown here.

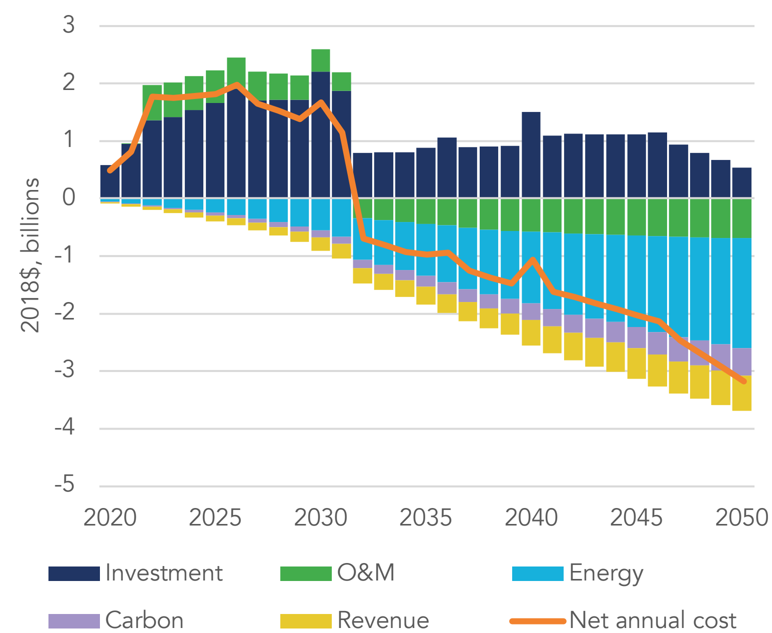

Figure 5-1: Expenditures, savings, and revenues from the 100% scenario relative to the BAP scenario, 2020-2050. (Values are presented as costs in this figure, so expenditures are above the line and savings and revenue are below the line.)

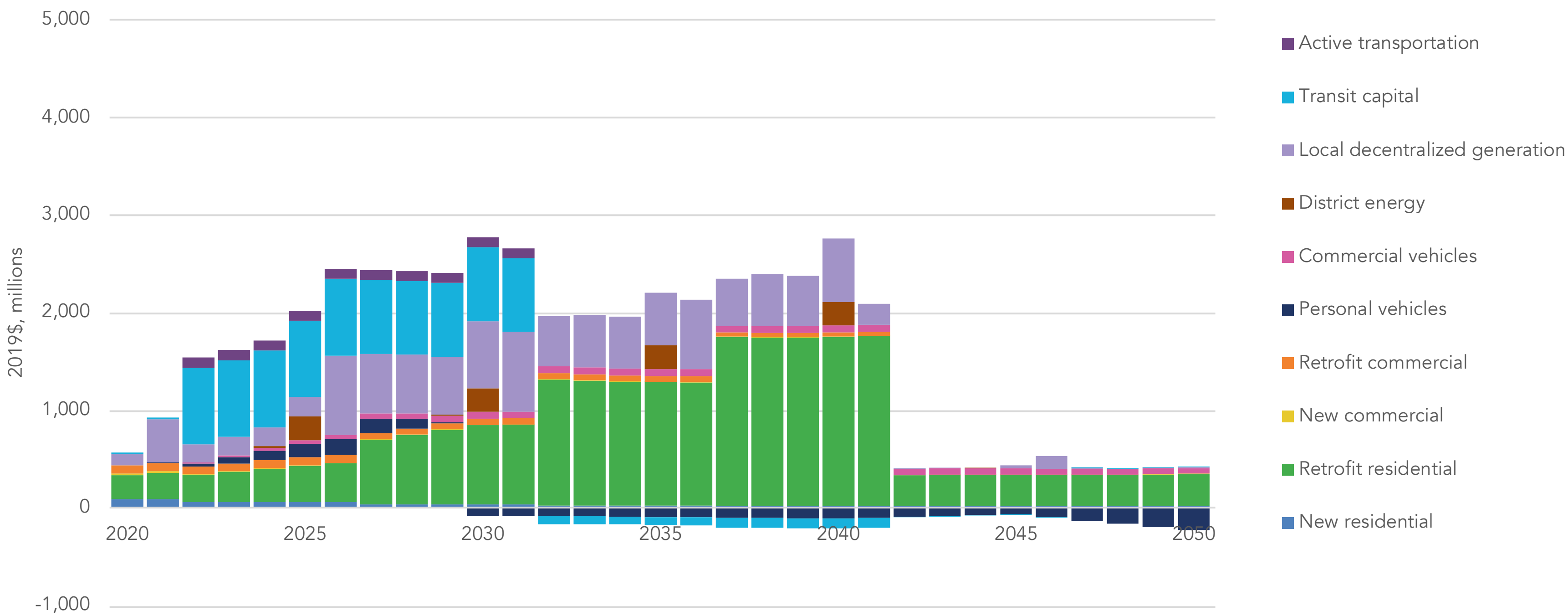

Figure 5-2: Capital investments by sector, 100% scenario, 2020-2050.

In the 100% scenario, incremental investments peak at nearly $3 billion in 2030, before declining by 2040 (Figure 5-2). Cumulative investment in the 100% scenario reaches $46.2 billion. The present value of these investments in 2019 is $27 billion, using a discount rate of 4.5%. Typically, the incremental investments are positive, but in the case of personal and commercial vehicles, there is an exception that arises.

On the other side of the ledger are fuel and electricity cost savings, the monetary value of the carbon reductions resulting from carbon pricing, and revenues from locally generated energy. The largest contribution to the value of the 100% scenario comes from lower energy bills. Cumulative energy savings reach $32.8 billion, with a present value in 2019 of $13.4 billion.

Carbon pricing effectively increases the value of fuel and electricity savings modestly in the first half of the program, and more significantly in the later years as the effective carbon price increases. The cumulative premium over the 2018-2050 period totals $8.2 billion, with a present value of $3.3 billion.

Finally, the 100% scenario includes investments in local energy generation facilities in Ottawa that generate a steadily growing stream of revenue with a cumulative total of $35.2 billion and a present value of $14.4 billion by 2050.

The above categories of investments, energy savings, carbon credits, and energy generation revenue are summarized in Figure 5-3 below. On an annual basis, the investments exceed the savings and revenues until the breakeven point in the early 2030s. Then, the net benefits begin to exceed the annual costs by an ever-widening margin. By 2050, the net payback from the plan as a whole reaches $31.8 billion, with a present value of $4.7 billion.

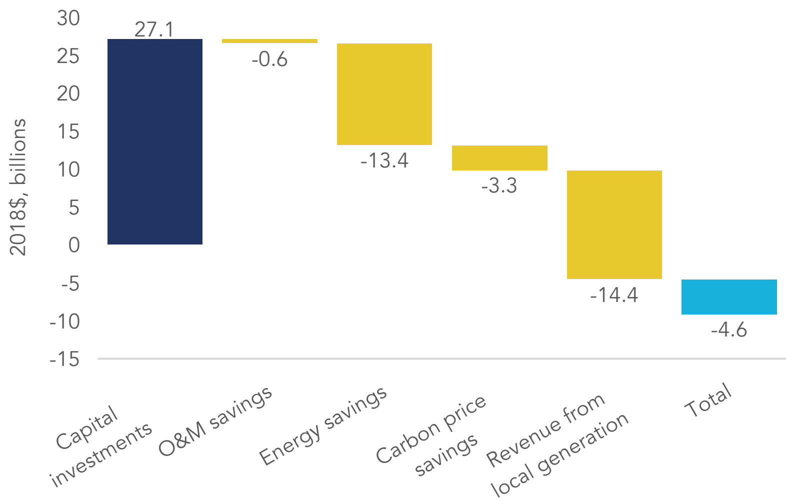

Figure 5-3: Present value of investments and savings, 100% scenario, 2020-2050.

Table 5-2: Summary of cumulative investments, savings, and revenue for the 100% scenario relative to the BAP, 2020-2050 (billions of 2019$). (In the convention used in this graph, investments are shown as negative and savings and revenues as positive.)

	Undiscounted	Net present value (3% discounting rate)
Capital investments	-46.2	-27.1
O&M savings	1.9	0.6
Energy savings	32.8	13.4
Carbon price savings	8.2	3.3
Revenue from local generation	35.2	14.4
Net cost of the program	31.8	4.7

5.2.2. Employment Impacts

The 100% scenario generates 350,000 person years of employment between 2020 and 2050, an average of 11,500 per year. Nearly half of these person years of employment are involved in the installation of renewable energy systems and building retrofits.

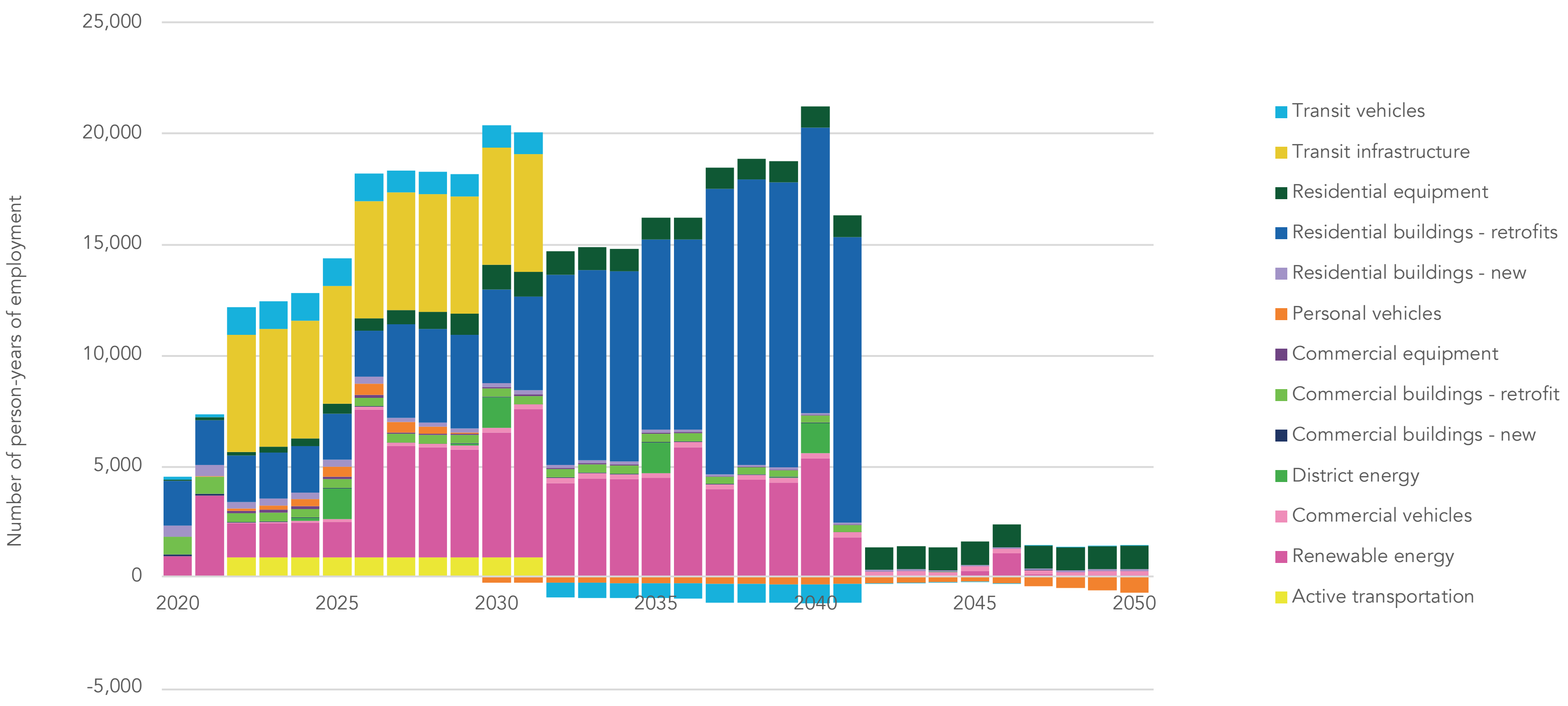

Figure 5-4: Person years of employment resulting from the 100% scenario, 2020-2050.

5.2.3. Details of Incremental Costs and Saving

Figure 5-5 provides a detailed year-by-year breakdown of the investments, fuel and electricity savings, carbon credits, and energy generation revenue in the 100% scenario. The value of the cost savings increases dramatically as the time period progresses.

5.2.4. Fuel and Electricity Costs

Total fuel and electricity expenditures for the BAP and 100% scenarios are illustrated in Figure 5-6. In 2016, households, businesses and other organizations in Ottawa paid out $2.9 billion for fuel and electricity, which climbs to $4.4 billion in the BAP, but falls to $2.5 billion in the 100% scenario.

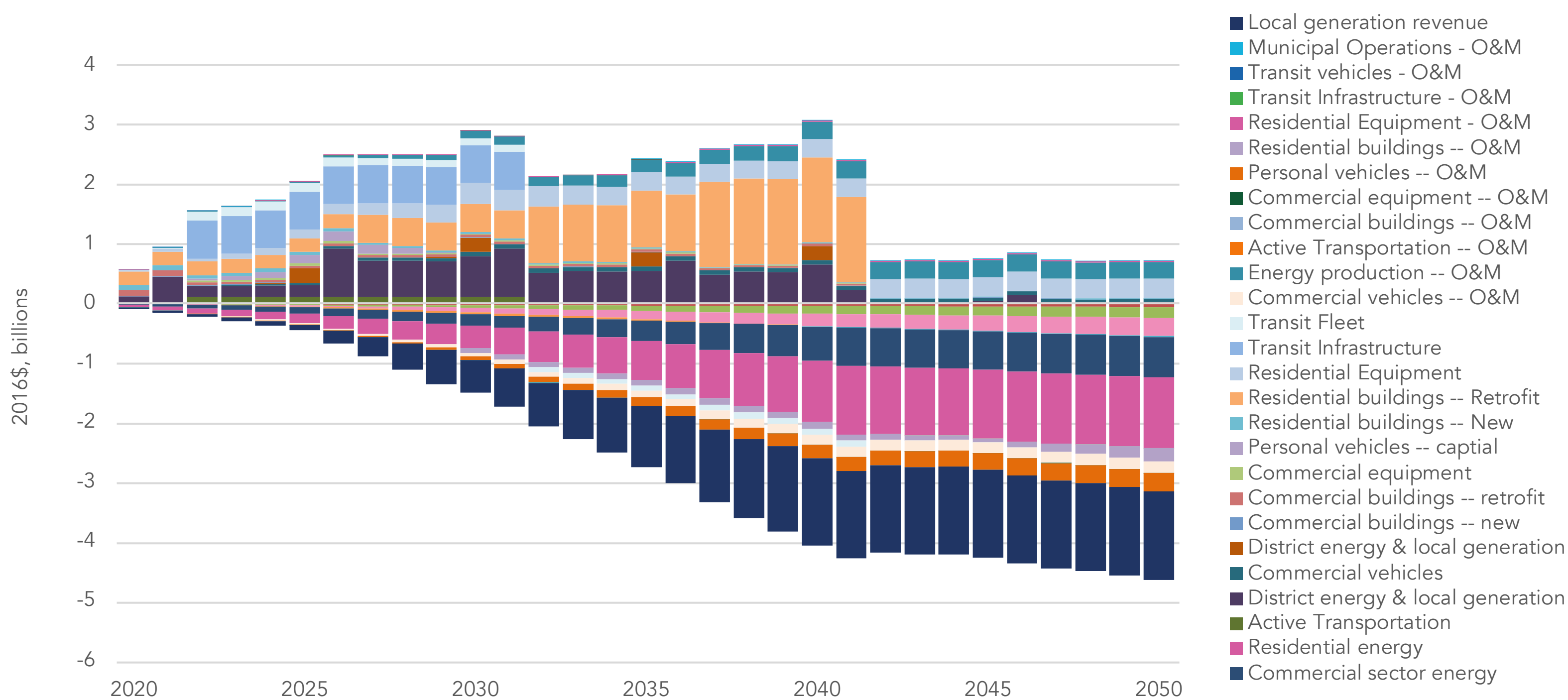

Figure 5-5: Annual incremental expenditures, 100% scenario over BAP scenario, 2016–2050

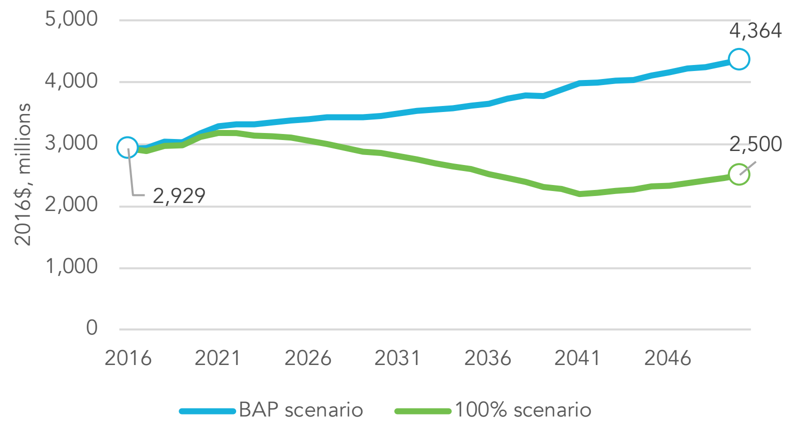

Figure 5-6: Total annual energy expenditures, BAP and 100% scenario, 2016-2050.

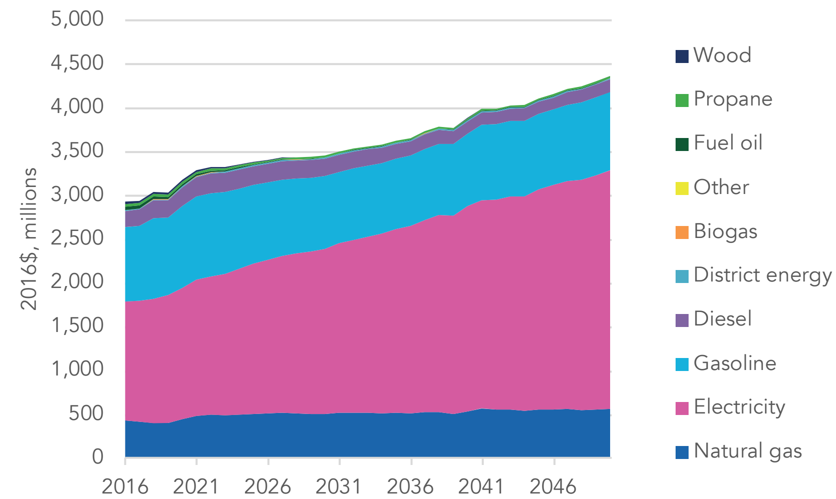

Figure 5-7: Total annual energy expenditure by fuels, BAP, 2016–2050.

Transportation fuels (gasoline and diesel) in the 100% scenario account for 35% of this total, while electricity costs comprise 46%. Because natural gas is so much cheaper than gasoline and electricity, it contributes only 15% to total energy expenditures in the region. In the BAP scenario, energy prices are projected to increase, but ongoing improvements in the efficiency of vehicles and buildings offset some of the increase so that real growth in total energy spending is about 1% per year, reaching $4.4 billion by 2050.

In the BAP scenario, the share of expenditures on electricity continues to increase towards 2050. In the 100% scenario, over 97% of energy expenditures are on electricity by 2050, with the majority of the remainder spent on natural gas and gasoline.

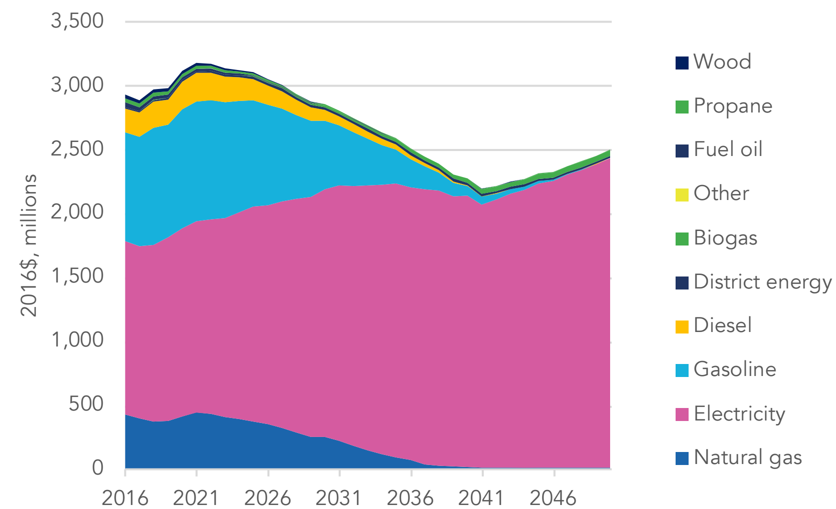

Figure 5-8: Total annual energy expenditures by fuel, 100% scenario, 2016–2050.

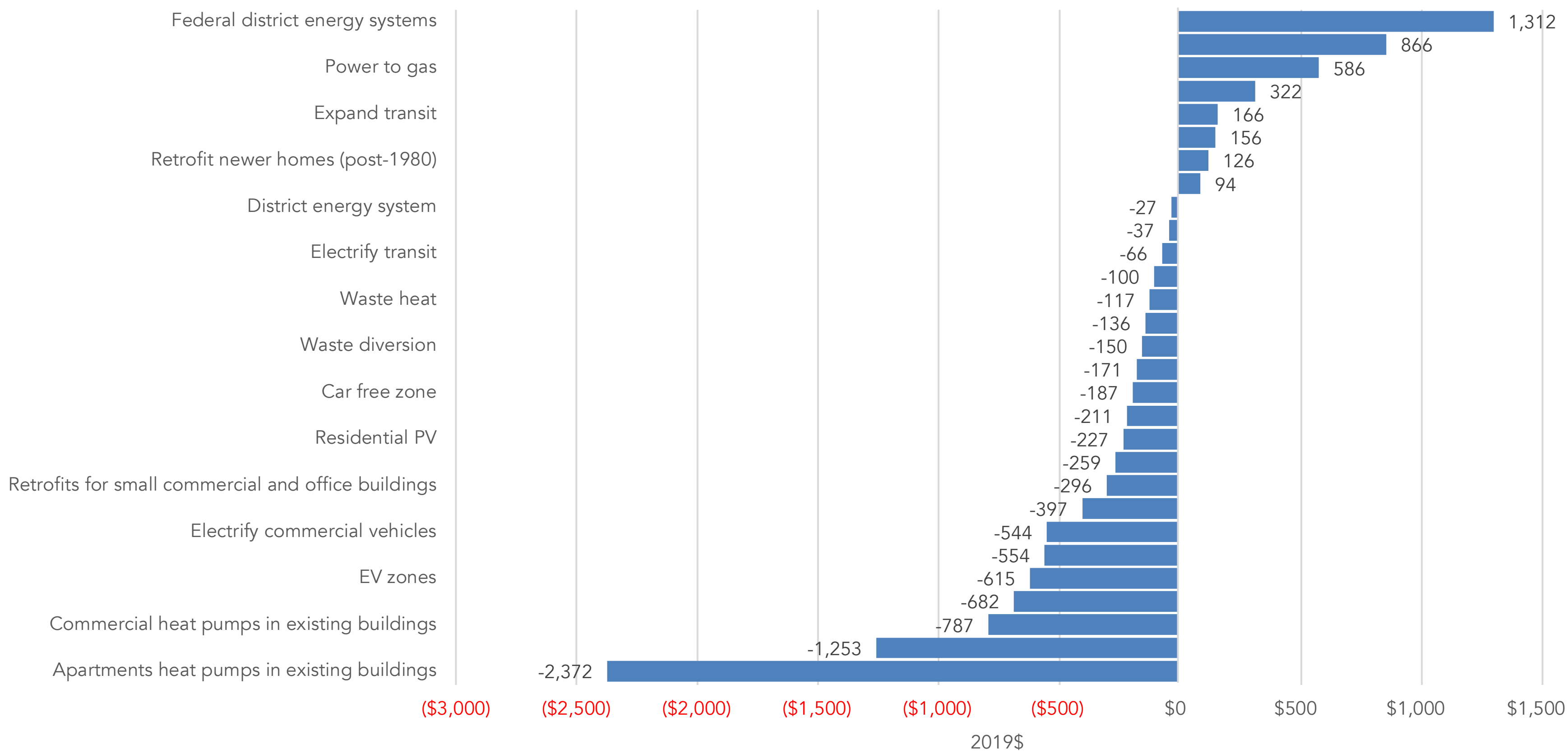

Figure 5-9: Marginal abatement costs of the actions in the 100% scenario.

5.2.5. Marginal Abatement Cost

When evaluated as individual measures, 18 of the 26 actions in the 100% scenario result in savings in present dollars, discounted at 4.5%, over the period from 2020 to 2050. Figure 5-9 illustrates the marginal abatement cost for each of the actions in terms of the cost or savings per tonne of GHG emissions reduced. This indicates that bundling can be a key strategy to help offset those actions with a less attractive investment portfolio.

The overall finances for each action are summarized in Table 5-3. Savings include all savings associated with the action, including reduced energy expenditures and operating expenses, and avoided carbon price costs. Note that, while actions are presented individually in Figure 5-9 and Table 5-3, there are feedback effects between the actions, and all of the actions are required to achieve the 100% objective.

Table 5-3: Marginal abatement costs of the actions in the 100% scenario.

Action	Cumulative emissions reduction (ktCO2e) 2019-2050	Cost of Investment ($, millions)	Gain of Investment ($, millions)
Netzero homes	6,010	3,160	4,190
New commercial buildings	1,416	97	659
Retrofit older homes (pre-1980)	5,503	3,945	3,087
Retrofit newer homes (post-1980)	5,440	3,948	3,260
Retrofits for small commercial and office buildings	1,586	166	635
Retrofits for commercial, office and industrial buildings	7,353	586	2,488
Municipal buildings retrofits	1,066	783	2,119
Low-rise residential heat pumps in existing buildings	3,933	2,101	836
Apartments heat pumps in existing buildings	354	728	1,569
Commercial heat pumps in existing buildings	3,982	250	3,384
Residential PV	346	402	481
Commercial PV	802	1,005	1,114
Hydropower	139	103	180
Expand wastewater treatment plant biogas generation	1,369	102	152
District energy system	2,454	268	333
Federal district energy systems	630	912	85
Wind	5,133	3,405	6,904
Expand transit	2,085	4,586	4,240
Electrify transit	1,471	201	298
Increase/improve cycling & walking infrastructure	435	461	84
Car-free zone	3	0	1
Electrify municipal fleets	275	2	29
Electrify personal vehicles	19,450	0	4,108
Electrify commercial vehicles	7,122	0	3,877
Waste diversion	11,413	0	1,717
Power to gas	213	132	7
EV zones	260	5	165
Waste heat	1,504	0	177
Electric water heaters in residential and commercial buildings	4,387	782	370

Co-benefits

6. Co-Benefits of Low-Carbon Actions

6.1. Introduction

Planning for a zero-carbon future is an ambitious and broad undertaking. This task is being executed at a time when cities are grappling with a high degree of complexity in societal, economic, and environmental domains. This chapter addresses the positive connections between actions for reducing greenhouse gas (GHG) emissions and other City objectives. The "collateral benefits" (or co-benefits, for short) of emissions reduction actions can engage and improve quality of life for diverse communities within Ottawa.[28] The analysis and assessment of co-benefits and co-harms provide insight into the selection of low-carbon pathways, and aid in the development of new and innovative methods for implementing zero-carbon pathways.

6.2. Definitions and Characteristics

Co-benefits and co-harms are secondary effects that result from actions that reduce GHG emissions. The term co-benefits and its corollary, co-harms, have a variety of synonyms, including ancillary effects and ancillary benefits and costs, and an equal variety of definitions. For the purposes of this paper co-benefits or co-harms are assumed to be any benefits or harms from actions intended to reduce GHG emissions.

Co-benefits and co-harms are not equal: they have different categories of effects. Similarly, not all co-benefits are equal. One set of criteria by which to consider the co-benefits of initiatives and actions to reduce GHG emissions follows:[29]

- **Synergies:** Many low-carbon actions, such as transit, energy efficiency, and compact urban design, have multiple socio-economic benefits.
- **Urgency:** Some actions are associated with a higher degree of urgency in order to avoid loss of inertia on actions already started, lock-in effects,[30] irreversible outcomes, or deferred costs that become elevated as a result of deferment. This may occur with road infrastructure decisions, major ecosystems displacement, and urban form, such as sprawl. Some emissions reductions actions require time to realize their effects, making early initiation paramount.
- **Costs:** The cost of early action is generally lower than later action, because delayed action involves ongoing investments in infrastructure, activities, and utilities that are higher emitting than low-carbon solutions. Examples include renewable energy infrastructure, transit, and investments in energy efficiency.
- **Longevity:** Related to urgency, the longevity of planning and development decisions locks cities into their effects for decades, if not centuries.

[28] OECD. (2000). *Ancillary Benefits and Costs of Greenhouse Gas Mitigation*. OECD Publishing.
[29] Adapted from Fay, M., Hallegatte, S., Vogt-Schilb, A., Rozenberg, J., Narloch, U., & Kerr, T. (2015). *Decarbonizing development: Three steps to a zero-carbon future*. The World Bank.

[30] Lock-in effect refers to implementation of a strategy or action that improves performance of an object or activity in the short term but is prohibitive of future change. Lock-in effect can refer to building upgrades or land use. For example, in a building where quick retrofits are undertaken, no additional improvements in the equipment installed can be expected over the course of its lifetime without considerable additional expense. In this way, lower levels of energy reductions can be locked in for a long period.

- **Distribution effects:** Low-carbon actions have different impacts on different subsets of the population, including income levels, generations (including future generations), and ethnicities.

Table 6-1 summarizes the co-benefits and co-harms of the 100% scenario that would not occur under the Business-as-Planned (BAP) scenario.

Table 6-1: Summary of impacts of 100% scenario.

1. Health						
Co-benefits/ co-harms	Impact overview	Land-use	Buildings	Transportation	Energy	Waste
1.1 Air quality	Improvement in air quality.	Conditional on design to reduce exposure of pedestrian to air pollution.		Improved: reduced combustion of gasoline and diesel in vehicles.	Improved: reduced natural gas combustion.	Improved: reduced emissions from waste treatment processes and management.
1.2 Physical activity	Increased active transportation mode share.			Improved: large increase in walking and cycling trips.		
1.3 Noise	Decreased exposure to engine noise.		Improved: insulation in buildings reduces exterior noise.	Improved: decreased engine noise from combustion engines.		
1.4 Accessibility (distance)	Destinations are more accessible.	Improved: dwellings are in closer proximity to commercial destinations.		Improved: dwellings are centered around transit corridors and hubs, and employment zones.		
1.5 Buildings	Building quality is improved to make buildings more comfortable and efficient, including		Improved: indoor environments from enhanced building performance requirements and retrofits.			

	during extreme weather events.					
2. Economic prosperity						
Co-benefits/ co-harms	Impact overview	Land-use	Buildings	Transportation	Energy	Waste
2.1 Employment	New employment opportunities are created.		Improved: new jobs will be created in retrofit fields, as well as in new construction, as a result of enhanced building codes.	Improved: new jobs will be created in high-tech sectors; however, jobs will be lost in maintenance. Jobs may also be lost as autonomous vehicles replace drivers of cabs and delivery vehicles, and the overall number of vehicles in the city.	Improved: new jobs will be created in supplying, installing, and maintaining solar PV, heat pumps, district energy, biogas, and energy storage.	Improved: new jobs will be created in recycling and waste diversion.
2.2 Household disposable incomes	The impact on household incomes is mixed.	Negative: increased intensification of land-use likely increases housing costs.	Improved: household energy costs decline.	Improved: household energy costs from transportation decline.	Improved: household energy costs decrease as a result of improved efficiency	

2. Economic prosperity						
Co-benefits/ co-harms	Impact overview	Land-use	Buildings	Transportation	Energy	Waste
2.3 Economic development	New economic sectors emerge.	Improved: new investment opportunities in land development.	Improved: new investment opportunities in retrofits and new builds.	Improved: new investment opportunities in vehicles.	Improved: new investment opportunities in renewable energy and district energy. Additionally, energy dollars will stay within the city with local generation.	Improved: new investment opportunities in waste diversion and energy recovery from waste.
2.4 Municipal finances	Municipal finances associated with existing services are more stable; New services are required. Mobilization of capital is required to finance the actions.	Improved: reduced per dwelling unit servicing costs.	Unknown: conditional on the policies and mechanisms to support retrofits.	Unknown: conditional on the policies and mechanisms to support EVs and mode shifts.	Improved: opportunities to generate financial returns from renewable energy generation.	Likely improved: solid waste management costs will decline, and revenue will be generated from waste.
2.5 Innovation	The 100% scenario will stimulate innovation.	Improved: policy and fiscal innovations are likely.	Improved: scaled up approaches to renovations, retrofits, and green building technology.	Improved: increased uptake of EVs.	Improved: mass deployment of renewable energy systems.	Improved: waste diversion strategies.

2. Economic prosperity						
Co-benefits/ co-harms	Impact overview	Land-use	Buildings	Transportation	Energy	Waste
2.6 Reputation	Ottawa's reputation is enhanced.	Improved: the emphasis on walkable urban form results in increased livability.	Improved: high-performance buildings are further developed in Ottawa.	Improved: Ottawa has an enhanced transit system.	Improved: renewable energy and district energy improve Ottawa's reputation as a climate leader.	Improved: Ottawa becomes known for its advanced waste management systems and circular economy innovation.
2.7 Social capital	People interact more as a result of mixed-use development and increased walking and cycling.	Improved: increased mixed-use spaces result in more mixing of people.		Improved: people interact more when walking or cycling.		
2.8 Environmental capital	There are more opportunities for green space in Ottawa. There is reduced pressure on green space outside of Ottawa.	Improved: additional intensification may create additional opportunities for green space.			Improved: energy generation in the city boundaries decreases the need for new generation capacity in green spaces beyond the city.	

Co-benefits/ co-harms	Impact overview	Land-use	Buildings	Transportation	Energy	Waste
3. Social equity						
3.1 Poverty	Housing costs increase, but the cost of transportation decreases.	Negative: intensification can increase housing costs; could be mitigated by affordable housing policies.	Improved: social housing is retrofit: operating costs of housing decline.	Improved: cost of moving around the city declines due to enhanced walking, cycling and transit, and overall decline in vehicle kilometres travelled (VKT).	Mixed: opportunities to participate in the renewable energy economy may be limited for those in poverty; district energy can provide secure and cost-effective heating and cooling.	
3.2 Elderly	Accessibility for the elderly improves. The built environment is healthier.	Improved: destinations are more accessible via walking, cycling, and transit.	Improved: buildings are healthier and more resilient.	Improved: walking and transit infrastructure is improved. Autonomous vehicles provide a new option for travel.	Improved: air conditioning from heat pumps is widespread, reducing the impacts of heat waves on the elderly.	
3.3 Children	Accessibility for children increases. The built environment is healthier.	Improved: destinations are easier to access by walking, cycling, or transit.	Improved: buildings offer healthier and more resilient environments.	Improved: walking and transit infrastructure is improved. Autonomous vehicles provide a new option for travel.		

Co-benefits/ co-harms	Impact overview	Land-use	Buildings	Transportation	Energy	Waste
3. Social equity						
3.4 Intergenerational equity and resilience	The burden on future generations is decreased. Stranded costs are avoided by acting quickly where possible.	Improved: damage from climate change is reduced.	Improved: damage from climate change is reduced.	Improved: damage from climate change is reduced.	Improved: damage from climate change is reduced. Stranded costs are avoided.	Improved: damage from climate change is reduced.

6.3. Advancing Health

6.3.1. Cleaner Air

Air quality in the scenario is improved by reducing the combustion of fossil fuels in the geographic area of Ottawa, including in buildings, industry, and transportation.

Several studies have concluded that substantive morbidity and mortality benefits arise from improved air quality, especially from the reduction of micro-particulates that result from lower amounts of combusted fuels.[31]

Improvements in fuel-efficiency, increased use of public transport, fewer diesel combustion engines, and electrification of transport all contribute to improved air quality and better health outcomes. Traffic-related air pollution at relatively low concentrations in Ontario is associated with increased mortality from cardiovascular disease[32] and, more generally, with the increased prevalence of asthma and allergic diseases.[33] An assessment for Toronto found that living near major roadways and highways increases the risk of heart disease.[34] Children living near major highways are at higher risk of developing asthma and reduced lung function.[35]

In the 100% scenario, combustion of fossil fuels is nearly eliminated in furnaces, industrial activities, and vehicles between 2018 and 2050. Air pollutants associated with the combustion of fossil fuels include sulphur dioxide, nitrogen oxides, ground-level ozone, particulate matter, carbon monoxide, volatile organic compounds, and others.

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[31] Barrett, B., et al. (2016). Mindful Climate Action: Health and Environmental Co-Benefits from Mindfulness-Based Behavioral Training. *Sustainability*, *8*(10), 1040. doi: 10.3390/su8101040

[32] Chen, H., et al. (2013). Long-term exposure to traffic-related air pollution and cardiovascular mortality. *Epidemiology*, 24(1), 35–43.

[33] Bowatte, G., et al. (2015). The influence of childhood traffic-related air pollution exposure on asthma, allergy and sensitization: a systematic review and a meta-analysis of birth cohort studies. *Allergy*, 70(3), 245–256.

[34] Beckerman, B. S., et al. (2012). The association between chronic exposure to traffic-related air pollution and ischemic heart disease. *Journal of Toxicology and Environmental Health*, 75(7), 402–411.

[35] Brugge, D., Durant, J. L., & Rioux, C. (2007). Near-highway pollutants in motor vehicle exhaust: A review of epidemiologic evidence of cardiac and pulmonary health risks. *Environmental Health*, 6, 23.

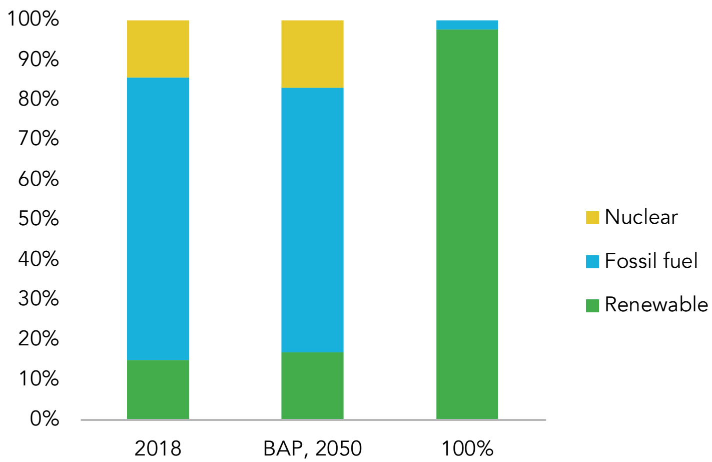

Figure 6-1: Ottawa energy source shares by type

Under the 100% scenario, Ottawa's transportation sector realizes significant reduction in air pollutants due to the electrification of vehicles and an annual decrease of 1 billion VKT as a result of efforts to increase walking, cycling, and transit.

As fossil fuel combustion declines, air pollutants will be reduced, as will related health effects, such as premature deaths and hospitalizations, and the prevalence of asthma and allergic diseases.[36]

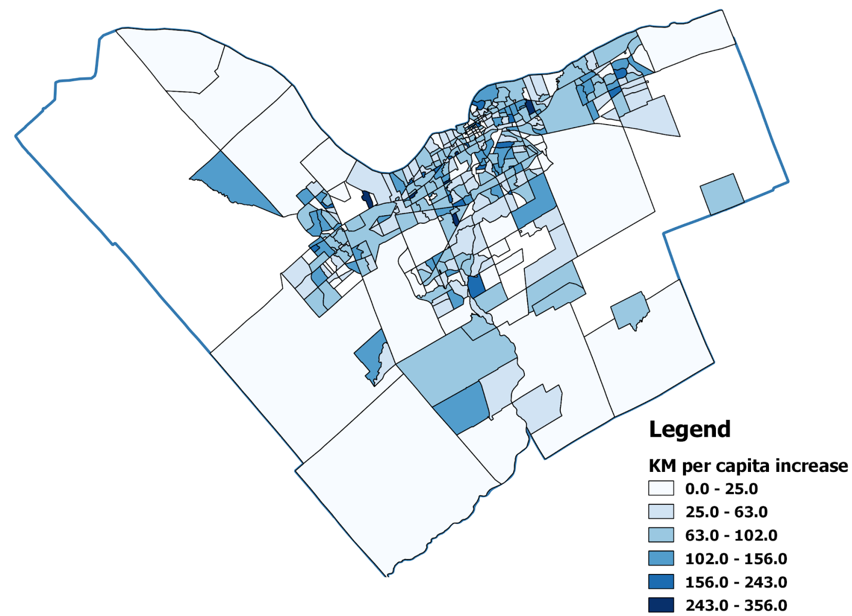

Figure 6-2: Increase in km of active transportation in the 100% scenario over BAP, by zone, 2050

6.3.2. A More Active City

Walking and cycling rates increase dramatically in the 100% scenario over the BAP, with increased frequency of cycling trips and more people cycling and walking. Figure 6-2 illustrates the per capita increase in kilometres of active transportation in the 100% scenario by zone. There is a wide variation in walking and cycling rate increases between zones. This is a

[36] Bowatte, G., et al. (2015). The influence of childhood traffic-related air pollution exposure on asthma, allergy and sensitization: a systematic review and a meta-analysis of birth cohort studies. *Allergy*, 70(3), 245–256.

function of varying opportunities to reduce trips based on existing active transportation mode share, trip length, proximity to destinations, and access to transit.

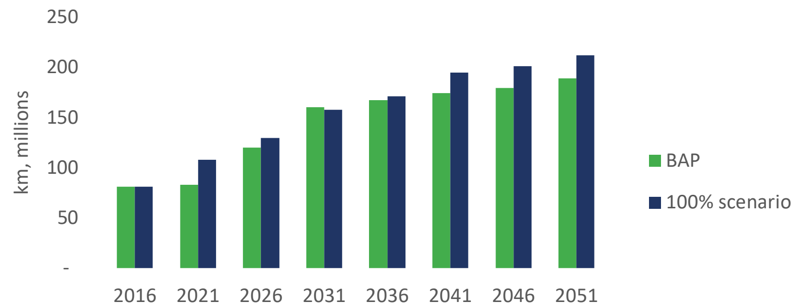

Figure 6-3: Increase in walking km in the two scenarios by the population of the City.

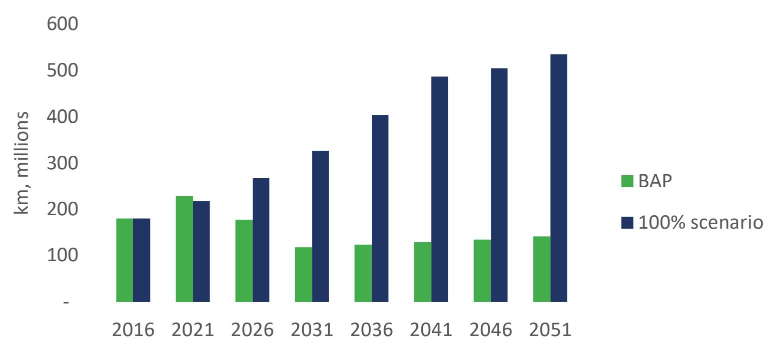

Figure 6-4: Increase in cycling km in the two scenarios by the population of the City.

In the 100% scenario, Ottawa's population walks 212 million kilometres in 2050 versus 189 million in the BAP scenario, an increase of 12%. The total kilometres cycled more than double in the 100% scenario. In the 100% scenario, the *cumulative* active (walked and cycled) kilometres travelled between 2020 and 2050 increases by nearly 7.6 billion kilometers relative to the BAP scenario.

Studies from Copenhagen[37] and Shanghai[38] have shown that all-cause mortality was 30-40% less among those who cycled compared to those who did not use active transport or get equivalent amounts of leisure-time exercise. A 19% reduction in all-cause mortality risk has been shown to occur with 30 minutes of daily moderate-intensity activity, 5 days per

[37] Andersen, L. B., Schnohr, P., Schroll, M., & Hein, H. O. (2000). All-cause mortality associated with physical activity during leisure time, work, sports, and cycling to work. *Archives of Internal Medicine*, 160(11), 1621–1628.

[38] Matthews, C. E., et al. (2007). Influence of exercise, walking, cycling, and overall nonexercise physical activity on mortality in Chinese women. *American Journal of Epidemiology*, 165(12), 1343–1350. https://doi.org/10.1093/aje/kwm088

week. Children who walk or bike to school are fitter than those who travel by car or bus.[39]

6.3.3. A Quieter City

Two trends contribute to reduced noise in the scenario: there is less driving, as illustrated by Figure 6-5, particularly in the downtown core. In addition, the driving that does happen is quieter, since most vehicles will be electric vehicles (EVs) and electric motors are quieter than internal combustion engines. This has a notable positive impact on health. Traffic-related noise has been associated with several health impacts, including cardiovascular disease,[40] annoyance,[41] sleep disturbance, and heart attacks.[42]

6.3.4. A More Accessible City

Accessibility to transit significantly increases in the 100% scenario relative to the BAP, as illustrated in Figure 6-6. In addition, overall access to transit as a result of transit actions and policies is greater for residents across the city in the 100% scenario.

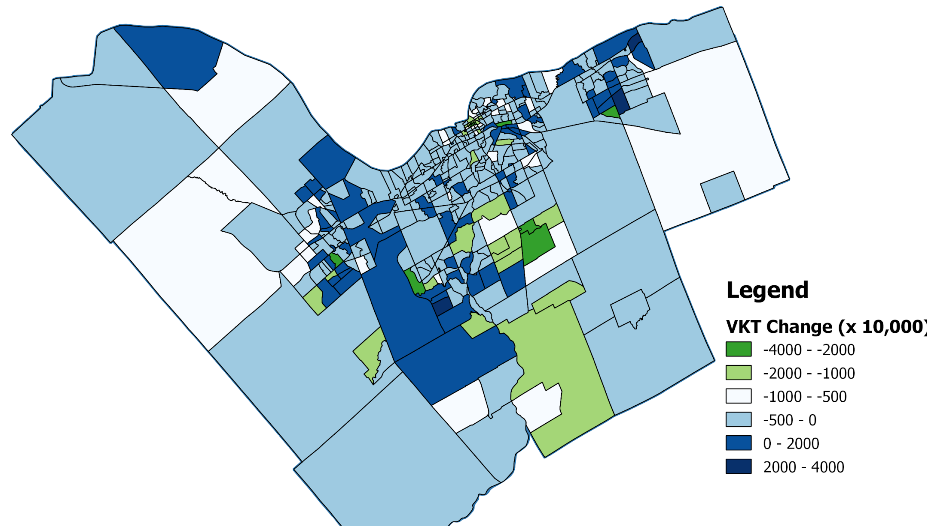

Figure 6-3: Increase/decrease in VKT by car in the 100% scenarios over the BAP, by zone, 2050.

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[39] Voss, C., & Sandercock, G. (2010). Aerobic fitness and mode of travel to school in English schoolchildren. *Medicine and Science in Sports and Exercise*, 42(2), 281–287. https://doi.org/10.1249/MSS.0b013e3181b11bdc

[40] Curran, J. H., Ward, H. D., Shum, M., & Davies, H. W. (2013). Reducing cardiovascular health impacts from traffic-related noise and air pollution: intervention strategies. *Environmental Health Review*, *56*(02), 31–38. doi: 10.5864/d2013-011

[41] Miedema, H. M. E., & Oudshoorn, C. G. M. (2001). Annoyance from Transportation Noise: Relationships with Exposure Metrics DNL and DENL and Their Confidence Intervals. *Environmental Health Perspectives*, 109(4), 409–416.

[42] De Nazelle, A., et al. (2011). Improving health through policies that promote active travel: A review of evidence to support integrated health impact assessment. *Environment International,* 37(4), 766–777.

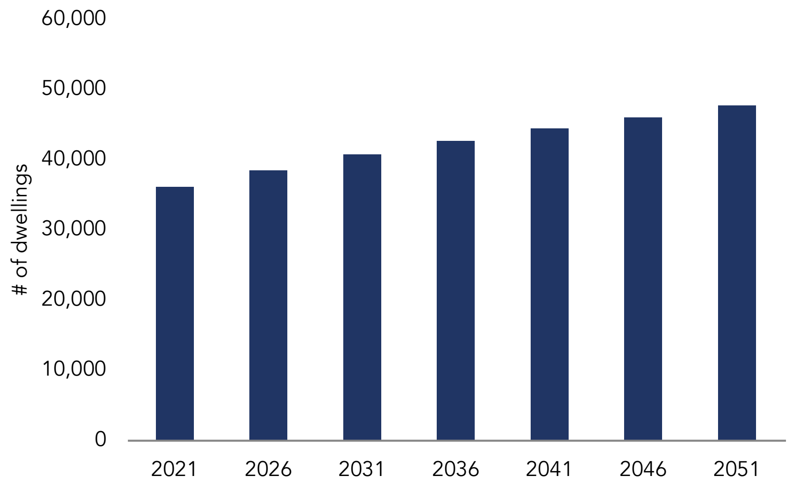

Figure 6-6: Change in dwelling units within 1 km of rapid transit in the 100% scenario over the BAP.

Increased transit use helps decrease the negative health and social impacts of private vehicle use and vehicle infrastructure.[43] In addition, three common types of transportation-related" community severances" are addressed by the 100% scenario.[44] Traffic barriers are reduced by new walking and cycling infrastructure. In addition, psychological barriers triggered by perceptions related to traffic noise or road safety are reduced due to decreased vehicular traffic and increased walking and cycling.

6.3.5. Healthier Buildings

By 2040, almost all pre-2016 building stock is retrofitted under the 100% scenario (see Figure 6-7), improving indoor environmental quality. As people typically spend 90% of their time indoors,[45] indoor health conditions are an important determinant of health. The retrofits will address the phenomenon of "sick building syndrome", prevalent in many buildings of the 1980s and 1990s, as heating and ventilation systems are replaced or retrofit. The improved energy performance of the buildings will also positively affect health by improving indoor temperatures in winter and reducing the emission of toxic pollutants to the local environment. The cost of energy to provide basic services will be reduced, reducing stress on low income households.

[43] Rode, P., Floater, G., Thomopoulos, N., Docherty, J., Schwinger, P., Mahendra, A., & Fang, W. (2017). Accessibility in Cities: Transport and Urban Form. *Disrupting Mobility Lecture Notes in Mobility*, 239–273. doi: 10.1007/978-3-319-51602-8_15

[44] Bradbury, A., Tomlinson, P., & Millington, A. (2007). Understanding the evolution of community severance and its consequences on mobility and social cohesion over the past century. European Transport Conference 2007, Creating a Livable Environment Seminar, Association for European Transport and Contributors.

[45] U.S. Environmental Protection Agency (EPA). 1989. *Report to Congress on Indoor Air Quality — Vol. II: Assessment and Control of Indoor Air Pollution*. EPA/400/1-89/001C. Washington, D.C.: US EPA. Retrieved from http://tinyurl. com/CCN-2013-R017E

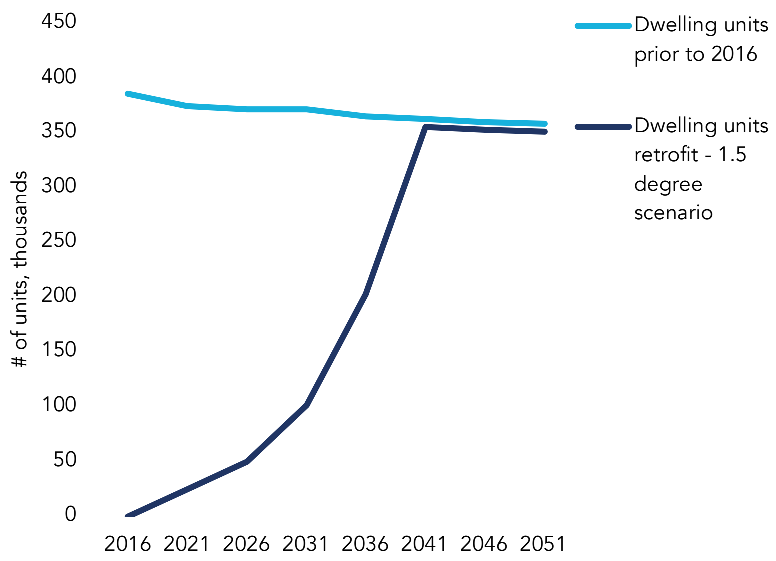

Figure 6-7: Number of units constructed prior to 2016 retrofit by 2050 relative to total dwelling units construction prior to 2016 in the 100% scenario.

6.3.6. Investing in Economic Prosperity

Economic prosperity is defined by the UK Sustainable Development Commission as the capability to flourish.[46] In articulating this definition, the authors cite broad questions posed by economist Amartya Sen about how people are able to function: Are they well nourished? Are they free from avoidable morbidity? Do they live long? Can they take part in the life of the community? Can they appear in public without shame and without feeling disgraced? Can they find worthwhile jobs? Can they keep themselves warm? Can they use their school education? Can they visit friends and relations if they choose?[47]

As the UK Sustainable Development Commission argued, its definition of economic prosperity is consistent with preventing dangerous levels of climate change.

46 Jackson, T. (2009). p.21 *Prosperity without growth: economics for a finite planet*. London; Sterling, VA: Earthscan.

47 Nussbaum, M., Sen, A., & Research, W. I. for D. E. (1993). *The Quality of Life*. Oxford University Press.

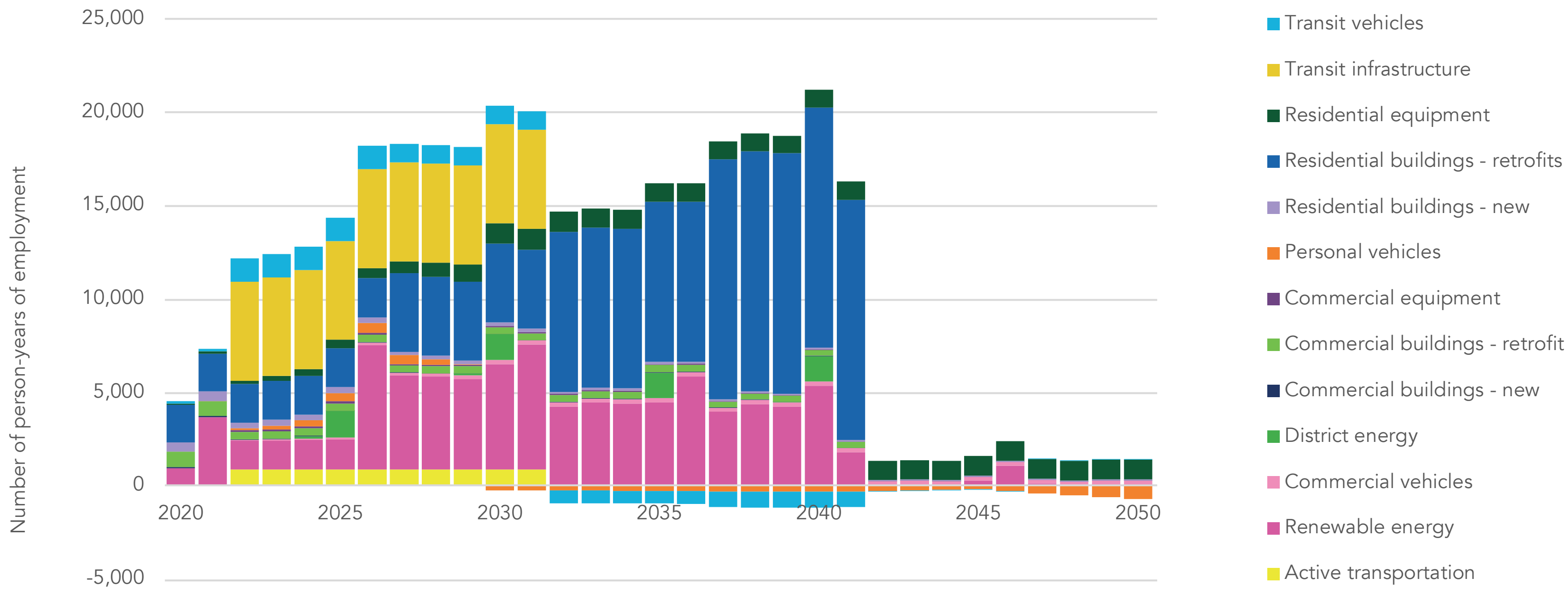

Figure 6-8: Person years of employment, 100% scenario, 2020-2050.

6.3.7. New Job Opportunities

Transitioning to a low- or zero-carbon economy will have four categories of impacts on labour markets: additional jobs will be created in emerging sectors, some employment will be shifted (e.g. from fossil fuels to renewables) between sectors, certain jobs will be reduced or eliminated (e.g. combustion engine vehicle mechanics), and many existing jobs will be transformed and redefined.[48]

Figure 6-8 uses employment multipliers to illustrate the effect of projected investments in the 100% scenario on person-years of employment, over and above the jobs associated with the BAP scenario. Over 240,000 person-years of employment, or an average of 8,000 person years of employment per year, are added to the economy. These do not necessarily represent net new jobs, as some jobs may be displaced or eliminated, but they represent new employment opportunities within the city.

[48] Martinez-Fernandez, C., Hinojosa, C., & Miranda, G. (2010). Green jobs and skills: the local labour market implications of addressing climate change. *Working Document, OECD.* Retrieved from http://www.oecd.org/regional/leed/44683169.pdf

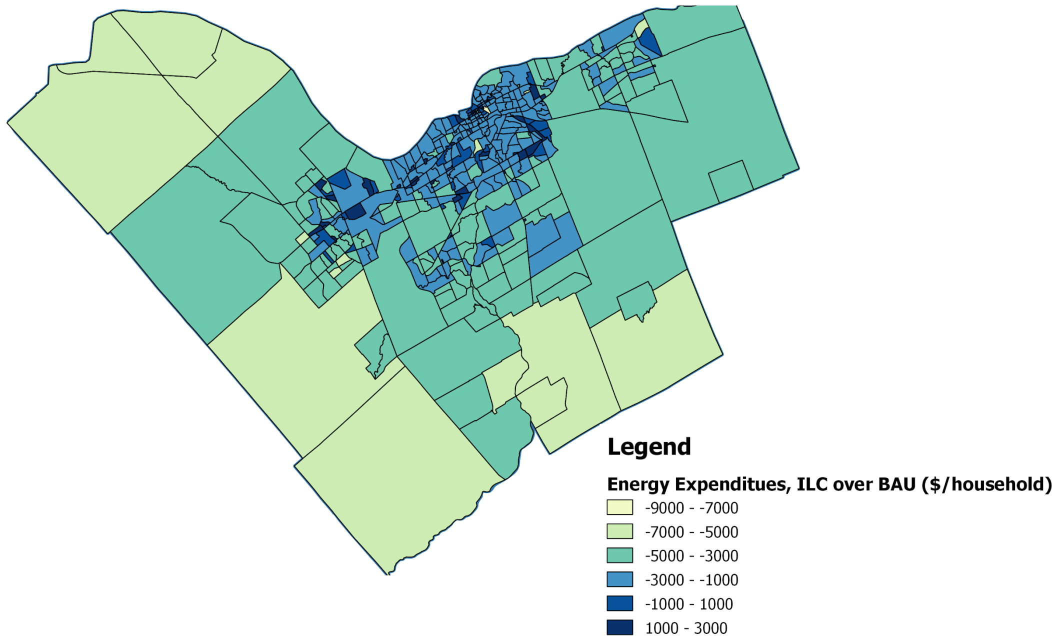

Figure 6-4: Changes in household income in the 100% scenario versus the BAP scenario, 2051.

6.3.8. Cost Savings for Households

Measures to reduce GHG emissions result in reduced household energy costs, as energy requirements for electricity, as well as heating and cooling dwellings, decline across the city (see Figure 6-9), with the exception of a few neighbourhoods (indicated in dark blue in Figure 6-9). Savings from significant efficiency gains are partially offset by the switch from cheaper natural gas to more costly electricity to power heat pumps for heating in buildings. For dwellings in some neighbourhoods, annual heating, cooling, and electricity savings rage from $2,000 to $4,000. Due to district energy expansion and renewable energy use, costs are also resilient against fluctuations in global commodity prices.

The increased focus on intensification in the BAP and 100% scenarios may drive up housing prices and stimulate lower-cost development on the outskirts of the city or in neighbouring municipalities. Additional suburban development may increase energy consumption and emissions from commuter and freight transportation over the study period.[49] However, increases in traffic can be mitigated using road pricing measures and

[49] Gaigné, C., Riou, S., & Thisse, J.-F. (2012). Are compact cities environmentally friendly? *Journal of Urban Economics*, *72*(2), 123–136.

enhanced transit. Another consideration is the potential for a rebound effect, whereby households use the financial savings resulting from energy efficiency gains to access services that use more energy and increase GHG emissions. The additional financial resources may, however, increase wellbeing, particularly for low-income households.

6.3.9. Stimulating Investment

Municipal policy levers can unlock major economic opportunities, which can lead to new opportunities for social and for-profit enterprises in the city. The actions and initiatives recommended under the 100% scenario unlock investment opportunities in buildings, the energy system, the transportation system, and solid waste.

By 2050, cumulative investment in the 100% scenario totals $36.8 billion with a present value of $24.6 billion, using a discount rate of 3%.

An ancillary co-benefit of 100% scenario initiatives is the stimulation of risk mitigation within the private sector for the benefit of society as a whole. For example, using global fossil reserves is incompatible with emissions reductions targets.[50] Enterprises or investors with ownership of these reserves face a risk that these assets may be stranded. Actions to reduce GHG emissions help to refocus the economy on low-carbon solutions; delaying policies on climate action increases the risk of stranded assets.[51] On the opportunity side, new markets and investment opportunities are emerging; Ottawa's Smart City 2.0 strategy—with its emphasis on technological development and a knowledge-based economy—directly aligns with these opportunities.[52]

In addition to new investment opportunities, 100% scenario actions result in lower operating costs for businesses as energy costs are reduced in nearly every neighbourhood across the city. However, fuel switching from cheaper natural gas to more expensive electricity to operate heat pumps does result in cost increases in a small number of neighbourhoods.

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[50] Carbon Tracker Initiative. (2011). *Unburnable carbon: Are the world's financial markets carrying a carbon bubble?* Retrieved from http://www.carbontracker.org/wp-content/uploads/2014/09/Unburnable-Carbon-Full-rev2-1.pdf

[51] Nelson, D., Herve-Mignucci, M., Goggins, A, Szambelan, S., Vladeck, T., & Zuckerman, J. (2014). *Moving to a low-carbon economy: The impact of policy pathways on fossil fuel asset values*.

[52] City of Ottawa. (2017). Smart City 2.0. Retrieved from https://documents.ottawa.ca/sites/default/files/smart_city_strategy_en.pdf

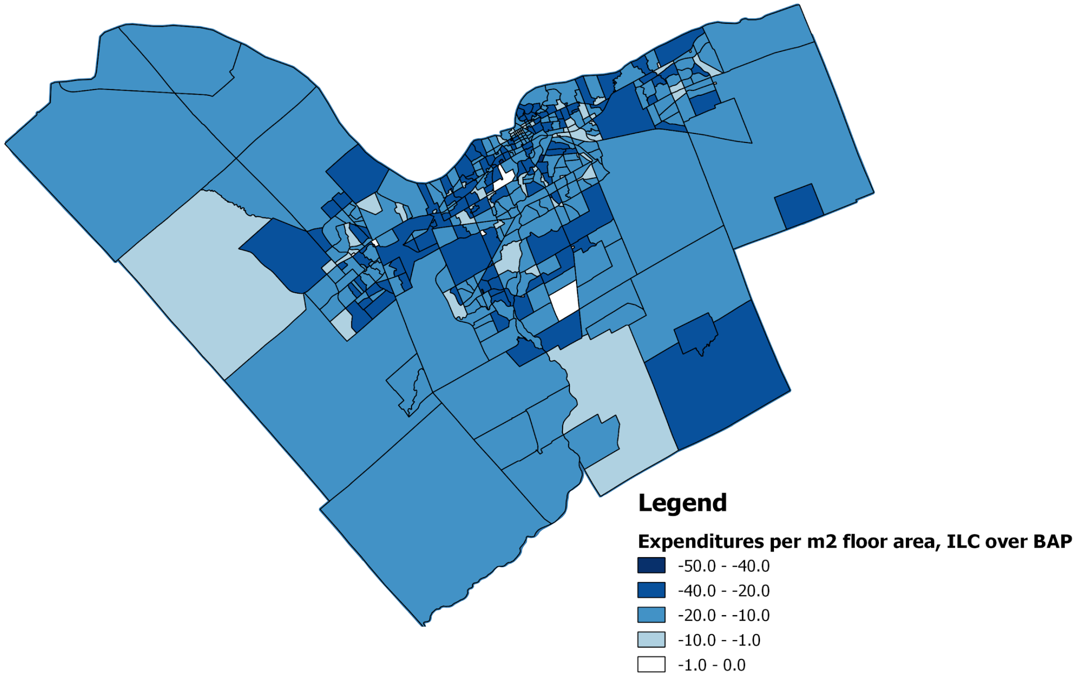

Figure 6-5: Impact on energy costs for commercial/industrial floor space in the 100% scenario over BAP, by zone.

6.3.10. Municipal Finances

Actions to reduce GHG emissions can impact both municipal revenues and expenditures in a variety of ways. Sprawling patterns of urban growth result in higher municipal capital and operation costs than compact forms of development, an outcome that correlates with GHG emissions.[53] Building a denser city, as recommend by the 100% scenario, has the added benefit of freeing up municipal funds for low-carbon investments by resulting in savings on capital and operational costs.

In the 100% scenario, dwellings and commercial space that are projected in areas with lower accessibility to rapid transit under the BAP scenario move to corridors with access to rapid transit and potential for district energy.

[53] Litman, Todd (2016). *Understanding Smart Growth Savings*. Victoria Transport Policy Institute.

6.4. Stimulating Innovation

Initiatives that reduce GHG emissions will stimulate innovation as enterprises reposition themselves and invest in research and development to provide new services, test new business models, and enter new markets. This will trigger a process of technology diffusion, experimentation, and adaptation.

Innovation has a powerful effect on productivity and economic growth. It also creates opportunities to advance well-being. In addition to the technological innovations associated with the 100% scenario (e.g. hydrogen fuel vehicles, electric vehicles, batteries, solar photovoltaics, etc.), there are also social innovations, such as energy cooperatives and car sharing, which attract less attention. Some innovations, such as microgrids, decentralized generation and storage, and advanced district energy, may disrupt major established energy delivery systems. District energy, passive houses, and microgrids are examples of systems innovations, rather than technology innovations. These are just a few examples of how zero-carbon innovation is transforming society. Actions to reduce GHG emissions can support and encourage innovations and innovators.[54]

Innovation can also exacerbate inequality, as some low-productivity jobs remain while new companies accumulate capital and profits.[55] However, previous eras of innovation-led structural change indicate that this process can also result in job creation, productivity increases, and growth by creating new categories of work, rather than competing with existing consumers.

6.4.1. Reputation

Improved branding and image positivity for Ottawa are potential co-benefits of climate action. The Brand Finance Company valued the City of Vancouver's Greenest City brand at $31 billion, finding it to be associated with the environment, "green living," and environmental leadership, ahead of other cities, including San Francisco, Singapore, Sydney, Shanghai, and Hong Kong.[56] Various related rankings, including the Sustainable Cities Index,[57] the Green City Index,[58] and RepTrak,[59] contribute to municipal brand positioning with respect to climate action and sustainability. Implementation of the 100% scenario initiatives and policies would significantly enhance Ottawa's standing internationally as a beacon of action on climate change and the clean economy. Since Ottawa is the nation's capital, this would have a positive influence on the reputation of Canada as a the whole.

6.4.2. Enhancing Social Capital

Economic prosperity also involves non-financial forms of capital, such as social capital, which is defined by the Organisation for Economic

[54] Willis, R., Webb, M., & Wilsdon, J. (2007). *The Disrupters: Lessons for low-carbon innovation from the new wave of environmental pioneers*. Retrieved from http://sro.sussex.ac.uk/47867
[55] Fankhaeser, S., Sehlleier, F., & Stern, N. (2008). Climate change, innovation and jobs. *Climate Policy*, *8*(4), 421–429.
[56] City of Vancouver. (n.d.). *Written evidence of the City of Vancouver- Appendix 82*. Retrieved from http://vancouver.ca/files/cov/Evidence-Edgar-Baum-Vancouver-brand-valuation.pdf
[57] Arcadis. (n.d.). Sustainable Cities Index 2016. Retrieved November 11, 2016, from https://www.arcadis.com/en/global/our-perspectives/sustainable-cities-index-2016
[58] Economist Intelligence Unit. (2011). *US and Canada green city index: Assessing the environmental performance of 27 major US and Canadian cities*. Retrieved from http://www.siemens.com/entry/cc/features/greencityindex_international/all/en/pdf/report_northamerica_en.pdf
[59] City RepTrak 2015- Most Reputable Cities. (n.d.). Retrieved November 11, 2016, from https://www.reputationinstitute.com/Resources/Registered/PDF-Resources/City-RepTrak-Report-2015.aspx

Cooperation and Development (OECD) as the links, shared values, and understandings in society that enable individuals and groups to trust each other and work together.[60]

Actions that encourage people to walk and cycle increase opportunities for people to make new and different connections, and simply to engage with one another. The average time individuals spend walking and cycling outside in 2050 in the 100% scenario is 19 hours per year, nearly two times that of the 11 hours in the BAP.[61] Walking and cycling encourage brief conversations or human interactions that encourage a sense of trust and build relationships that most people find comforting.[62]

6.4.3. Impact on Biodiversity

The co-benefits and co-harms of actions to reduce GHG emissions on ecosystems are complex and seldom considered.[63] While GHG emissions are a threat to biodiversity and ecosystems, as well as human well-being, and potentially our survival, all forms of energy generation, including renewables, have a spatial footprint (Figure 6-11). The footprint can include mining, production wells, distribution lines, transformer stations, and other infrastructure that disrupts a variety of ecological systems, including water courses and habitat for biodiversity. The 100% scenario has a similar footprint on the landscape to the BAP, despite the increase in footprint of the wind generation.

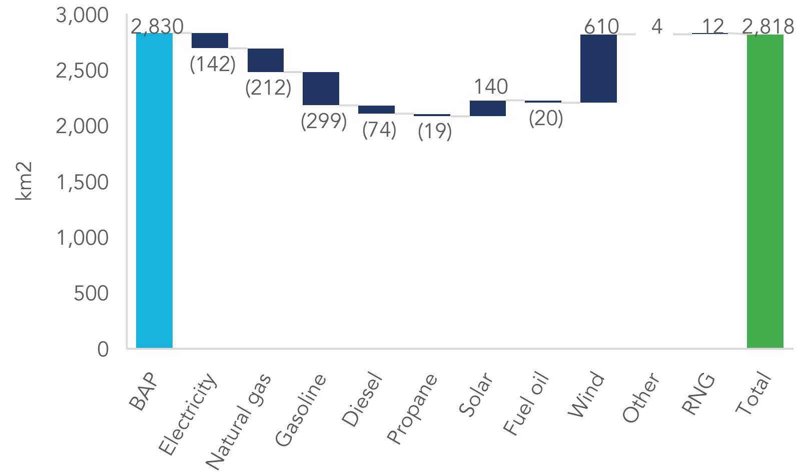

Figure 6-11: Reduced energy sprawl as a result of the 100% scenario.

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[60] OECD. (n.d.). *OECD Insights: What is social capital?* Retrieved from http://www.ingentaconnect.com/content/oecd/16815378/2007/00002007/00000001/0107101ec007

[61] This estimate is calculated based on a walking rate of 4 km/h and a cycling rate of 15 km/h.

[62] Leyden, K. (2003). Social capital and the built environment: The importance of walkable neighbourhoods. *American Journal of Public Health*, 93(9), pp. 1546-1551.

[63] McDonald, R. I., Fargione, J., Kiesecker, J., Miller, W. M., & Powell, J. (2009). Energy Sprawl or Energy Efficiency: Climate Policy Impacts on Natural Habitat for the United States of America. *PLoS ONE*, *4*(8), e6802.

6.5. Social Equity

Equity is the absence of avoidable or remediable differences among groups of people, whether those groups are defined socially, economically, demographically, or geographically, according to the World Health Organization.[64] Social equity implies fair access to livelihood, education, and resources; full participation in the political and cultural life of the community; and self-determination in meeting fundamental needs.[65]

Not all individuals or all communities are equally affected by climate change.[66] People living in different geographies with different capacities and different jobs will experience climate change effects differently. Climate change vulnerability is the degree to which people and places are at risk from the impacts of climate change. The concept also takes into account how well they can cope with those impacts.[67]

Climate change resiliency is essentially the flip side of vulnerability. The Asian Development Bank describes it as "the ability to survive and recover from changing climatic conditions".[68] Some aspects of resilience include physical and psychological health, social and economic equity and well-being, availability of information, integration of governmental and non-governmental organizations, and social capital and connectedness.[69]

Climate change amplifies vulnerability and hampers adaptive capacity, especially for the poor, women, the elderly, children, and ethnic minorities. These demographics tend to lack power and access to resources, adequate urban services, and functioning infrastructure. For example, poverty makes it harder to meet basic needs in the face of rising food, water, or energy prices—a possible outcome of climate change. Similarly, following a disaster, it is much harder for low-income communities to rebuild, as fewer low-income people are likely to have insurance.

6.5.1. Poverty

Dense, well-managed urban development and the provision of accessible, affordable public transport can have a positive direct effect on the poor and other disadvantaged groups by increasing their ability to access goods, services, and economic opportunities. In addition, in the 100% scenario, all neighbourhoods with a concentration of low-income people will experience a decline in building-related energy costs in 2050 as compared with the BAP scenario.

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[64] World Health Organization. (2011, June 8). Equity. Retrieved from http://www.who.int/healthsystems/topics/equity/en/

[65]Summers, J. K., & Smith, L. M. (2014). The role of social and intergenerational equity in making changes in human well-being sustainable. *Ambio*, 43(6), 718–728. https://doi.org/10.1007/s13280-013-0483-6

[66] Rudolph, L., Gould, S., and Berko, J. (2015). Climate Change, Health and Equity: Opportunities for Action. Oakland, CA: Public Health Institute. Retrieved from https://www.phi.org/uploads/application/files/h7fjouo1i38v3tu427p9s9kcmhs3oxsi7tsg1fovh3yesd5hxu.pdf.

[67] IPCC, 2014. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (Field CB, Barros VR, Dokken DJ, et al., eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2014.

[68] Asian Development Bank. (2014). *Urban Climate Change Resilience: A Synopsis*. Manila, Philippines. Retrieved from http://www.adb.org/sites/default/files/ publication/149164/urban-climate-change-resiliencesynopsis.pdf

[69] U.S. Environmental Protection Agency. (2008). Reducing urban heat islands: compendium of strategies: trees and vegetation. US EPA, Climate Protection Partnership Division, Office of Atmospheric Programs. Retrieved from http://www.epa. gov/heatisland/resources/pdf/TreesandVegCompendium. pdf

6.5.2. A City for the Elderly

Increased access to public transportation and autonomous vehicles as assessed in the 100% scenario can benefit those who cannot drive or cannot afford an automobile, including low-income groups, the elderly, and the physically impaired.[70]

The well-being of the elderly will also improve because land-use intensification in the 100% scenario facilitates more active lifestyles. The built environment in the 100% scenario also includes major improvements to walking and cycling infrastructure that encourage physical fitness and exercise. Oxygen uptake and flexibility both increase with physical activity,[71] and physical activities increase psychological and spiritual health. According to one author, "physical activity in the natural environment not only aids an increased life-span, greater well-being, fewer symptoms of depression, lower rates of smoking and substance misuse, but also increases the ability to function better at work and home".[72]

In addition, the elderly will experience decreased respiratory and health issues due to lower levels of ozone and other air pollutants.[73] The elderly may also experience improved mental health linked to decreased isolation and strengthened community networks from living in denser neighbourhoods with more accessible transit and active transportation networks.

Retrofitting buildings for energy efficiency can also reduce the impact of heat on the elderly, a high-risk population for severe heat stroke, heat exhaustion, fainting, swelling, or heat cramps during a heat wave. The 100% scenario includes continuing the ambitious schedule of renovations for social housing that the City of Ottawa has already committed to.

6.5.3. A City for Children

The two most significant immediate benefits of the 100% scenario are increased accessibility and reduced air pollution. As an alternative to being driven by their parents, children can walk, cycle, and use transit for access to destinations. In the 100% scenario, destinations are more accessible to dwellings as a result of intensification, and enhanced walking, cycling, and transit options.

Air pollution is a particular concern for children, since their immune systems and lungs are not fully developed. In addition, children tend to spend more time outside, increasing exposure to pollutants from the combustion of fossil fuels. The reduced air pollution associated with the 100% scenario will, therefore, result in proportionately higher benefits for children, particularly as related to bronchitis and chronic cough.[74]

6.5.4. A City for Future Generations

Climate change represents a burden on future generations. The burden to act increases the longer action is delayed. This is highlighted by a landmark

[70] Jackson, R. and C. Kochtitzky. (2010). *Creating a Healthy Environment: The Impact of the Environment on Public Health*. Centers for Disease Control and Prevention. Sprawl Watch Clearinghouse Monograph Series.

[71] Morris, N. (2003). *Health, Well-being and Open Space.* OPENspace: the Research Centre for Inclusive Access to Outdoor Environments. Edinburgh College of Art and Heriot-Watt University.

[72] Ibid., p.17.

[73] Frumkin, H. (2002). Urban Sprawl and Public Health. *Public Health Reports*, 117, 201-217

[74] Schwartz, J. (2004). Air pollution and children's health. *Pediatrics*, *113*(4 Suppl), 1037–1043.

constitutional climate lawsuit filed against the American government by 21 youth from across the United States in 2015. The youth successfully asserted that, in causing climate change, the U.S. government violated the youngest generation's constitutional rights to life, liberty, and property, and failed to protect essential public trust resources.[75]

The social cost of carbon (SCC) has been used in regulatory processes in Canada and the US to reflect the impacts of climate change on society. The SCC attempts to add up the quantifiable costs and benefits of a tonne of carbon dioxide. While the estimates of SCC are highly uncertain, it is one of the best ways to reflect future damages to ensure that decision-making that has implications for future emissions accounts for those implications.

The SCC includes assumptions about future conditions, including population size, economic growth, rate of climate change, and the impact of climate change on those conditions, based on global climate and economic models. The discount rate is a significant assumption within the models, as it determines the future value of damage from climate change. Discounting reflects the idea that people would rather have $100 now than $100 in ten years. From an ethical perspective, a higher discount rate indicates that future generations are worth less than current generations; for this reason, the Stern Review[76] recommends a discount rate of 1.4%, well below traditional discount rates. As Stern pointed out in a subsequent article, "A 2% pure-time discount rate means that the life of someone born 35 years from now (with given consumption patterns) is deemed half as valuable as that of someone born now (with the same patterns)".[77] The Government of Canada recommends a discount rate of 3% in circumstances where environmental and human health impacts are involved.[78] This rate was used to align with standard practices in Canada.

The 100% scenario analysis presents the SCC for all remaining GHG emissions in the scenario using the 3% discount rate recommended by the federal government. This cost reflects the impacts of catastrophic but unlikely climate impacts, described as the 95th percentile because they are considered less likely to occur.

The results of the SCC for remaining and avoided emissions associated with the BAP and 100% scenarios are illustrated in Figure 6-12. The cumulative SCC between 2016 and 2050 in the BAP is $41 billion. In the 100% scenario, it is $14.6 billion. Thus, the value of the avoided emissions, as represented by the SCC, is $14.6 billion in 2016 dollars.

[75] Our Children's Trust. (2016). Landmark US federal climate lawsuit. Retrieved November 14, 2016, from https://www.ourchildrenstrust.org/us/federal-lawsuit

[76] Stern, N. (2006). *The Stern review on the economic effects of climate change*. Cambridge University Press.

[77] Stern, N. (2015). Economic development, climate and values: making policy. *Proc. R. Soc. B*, *282*(1812), 20150820. https://doi.org/10.1098/rspb.2015.0820

[78] Environment and Climate Change Canada. (2016). *Technical update to Environment and Climate Change Canada's social cost of greenhouse gas estimates*. Retrieved from http://ec.gc.ca/cc/BE705779-0495-4C53-BC29-6A055C7542B7/Technical%20Update%20to%20Environment%20and%20Climate%20Change%20Canadas%20Social%20Cost%20of%20Greenhouse%20Gas%20Estimates.pdf

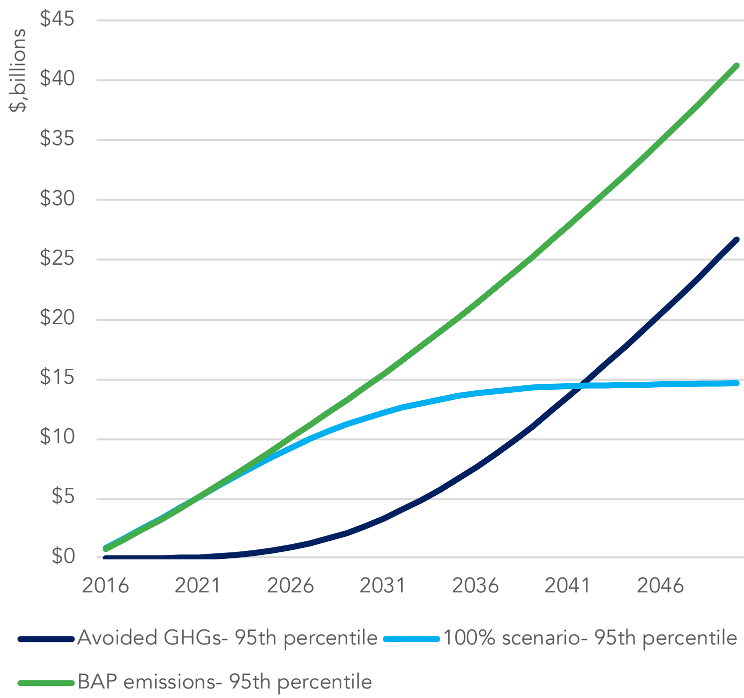

Figure 6-12: Social cost of carbon, cumulative $2016 at a 3% discounting rate, 95th percentile.

Recommendations

7. Recommendations

7.1. Introduction

The analysis in this report indicates that there is a pathway for the City of Ottawa to achieve deep GHG emissions aligned with scientific evidence. This pathway will require an unprecedented mobilization by the City and its partners.

7.2. Seven Recommendations

1. The City of Ottawa should adopt a cumulative carbon budget for both the community and City corporate operations that is aligned with 2030 and 2050 GHG targets.
2. Responsibility for specific GHG emissions reductions in the community should be distributed across all departments in the City of Ottawa, aligning with a carbon budget approach.
3. Each department should develop a five-year implementation plan.
4. A community collaborative governance mechanism should be created to engage community leaders and stakeholders in the implementation process.
5. The City should develop program areas, including capacity and financing mechanisms, to advance the actions identified in this analysis.
6. The City should integrate climate action into its economic development strategy.
7. A transparent reporting framework should be developed and delivered to support collective learning and reporting on progress.

7.3. Implementation Programs

Despite a compelling economic case for many of the actions incorporated within the 100% scenario, these actions are not being advanced by the private sector for a variety of reasons. Within this context, the public sector must play three key roles to enable the trajectories contemplated in the 100% scenario:

1) Identify the implementation strategies that maximize social benefits;
2) Create enabling conditions for private-sector participation for those cases in which participation maximizes social benefit; and
3) Provide support or directly deliver those actions which are not delivered by the private sector.

SSG undertook a mapping process to identify programs that will overcome key barriers and support the actions identified in the 100% scenario. In most cases, each program can support multiple actions.

Table 7-1: Short-term implementation plan.

Programs	Key barriers	Description
Program #1: Co-ordinating land-use policies	Lack of consideration of energy and GHG emissions in land-use planning.	The City seeks to embed policies that conserve energy (directly or indirectly) and reduce GHG emissions into the Official Plan, secondary plans, and relevant Master Plans.
Program #2: High-Performance Development Standard: Enhanced energy performance for new buildings	Split incentive between builder and owner that limits investments in energy efficiency.	The High-Performance Development Standard is a tiered set of performance measures that is required through the planning approval process. The first tier is implemented through the planning approval process, whereas the upper tiers are voluntary.
Program #3: Retrofit Accelerator Program: Transforming existing buildings	No systematic approach to large-scale retrofits currently exists.	A deep retrofits program is envisaged as a partnership with utilities, industry, and higher education. A financing package is developed using the PACE or LIC mechanism, combined with incentives from other levels of government and the utilities, with investment raised through a combination of community bonds and green bonds. Retrofits are targeted to groups of buildings—for example neighbourhoods or sectors (restaurants, grocery stores, etc.)—to pool risk and develop larger, more sophisticated, impactful projects. In addition to efficiency, the program includes district energy, solar photovoltaics (PV), energy storage, and air- and ground-source heat pumps.
Program #4: Renewable Energy Organization: Stimulating local renewable energy projects	Long-term investments required by local entities that deliver community benefits.	The membership of the organization includes municipalities, utilities, industries, and other partners. The organization advocates for, develops, commissions, and finances projects, depending on which strategy is appropriate in a particular context. Financing comes from community bonds/shares, loans, or grants from various levels of government.

Program #5: Electric Vehicle Working Group: Encouraging the adoption of electric vehicles	Lack of infrastructure and trust in a new technology.	A technical working group is established with representatives from each of the relevant organizations. The first deliverable is a five-year action plan/roadmap for electric vehicles in Ottawa.
Program #6: Education and Outreach Program: Engaging the community	Lack of awareness of the opportunities.	There are two key aspects to such a program: broad-based education and targeted stakeholder education. This program coordinates education and marketing efforts on behalf of the other programs, working with staff from the City, municipalities, and utilities.

The delivery of these programs will require the development of new capacity within the City of Ottawa, new financing strategies, and new partnerships and governance structures.

7.4. Tracking Progress

Tracking the progress on the required changes described in this report should be incorporated into the City's actions. Tracking progress is critical because it helps manage the risk and uncertainty associated with these efforts, as well as the impact of external forces, such as evolving senior government policy and new technologies, that can disrupt the energy system. Key motivations for monitoring and evaluation include:

- Evaluating the return on investment;
- Identifying unanticipated outcomes;
- Adjusting programs and policies based on effectiveness;
- Managing and adapting to the uncertainty of climate change; and
- Managing and adapting to new opportunities, such as emerging technologies.

Appendices

8. Appendices

8.1. Actions Development

Until such time as transportation becomes zero-emission, land use and its connection to transportation present a large opportunity for emissions reductions. In these sectors, energy use is related to urban density. Ottawa's current Official Plan, represented in the BAP scenario, projects the majority of population growth to be outside of the greenbelt area, contributing to greenfield development. This outward development pattern will increase vehicle trips while decreasing walking, cycling, and transit trips. 2018 development applications are mapped in Figure 8-1, demonstrating the extent of suburban development in that year.

Table 8-1: Land Use Actions.

Action	BAP scenario	100% scenario
Land Use	60% of new dwellings allocated to intensification zones by 2046	Same as BAP scenario

The 100% scenario and BAP scenario concentrate 60% of new residences in the central area of the city or adjacent to rapid transit stops, assigned in the City's "Transit and Transit Priority Network Concept" of the 2013 Transportation Master Plan.[79] This pattern of development fits a transit-oriented development model.

The growth pattern of this model overlaps with several 100% scenario transportation actions where the "Transit Concept Network" is built out and there is increased transit access in the city. The land-use action also corresponds to increased cycling, walking, transit use, and car sharing.

The BAP and 100% scenarios both use 60% intensification land use assumptions in which 60% of new households in designated urban areas are allocated to intensification zones. The allocation of new households between 2018 and 2046 to urban and rural area types is shown in Table 8-2. The resulting allocation of new households to traffic zones is shown in Figure 8-1.

Table 8-8-2: Households added to development areas, 2018-2046.

Development type	Single	Semi	Row	Apt
Urban intensification	7,436	4,285	11,206	49,379
Additional intensification	5,349	2,108	18,637	-
Urban greenfield	25,480	1,333	27,659	2,878
Urban expansion	10,480	630	12,372	2,609
Rural	10,982	190	1,394	405
Grand total	59,727	8,546	71,268	55,271

[79] Ottawa Transportation Master Plan, Network Concept. Retrieved from https://documents.ottawa.ca/sites/default/files/documents/tmp_map_4_en.pdf

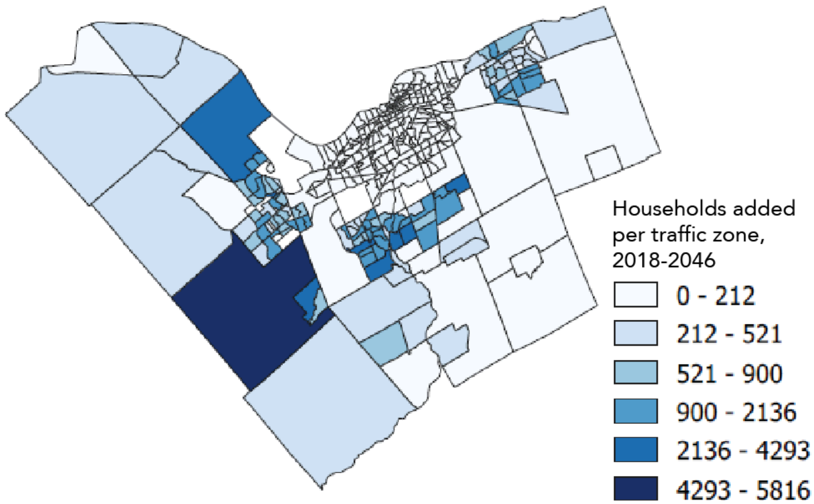

Figure 8-1: Households per traffic zone, 2046.

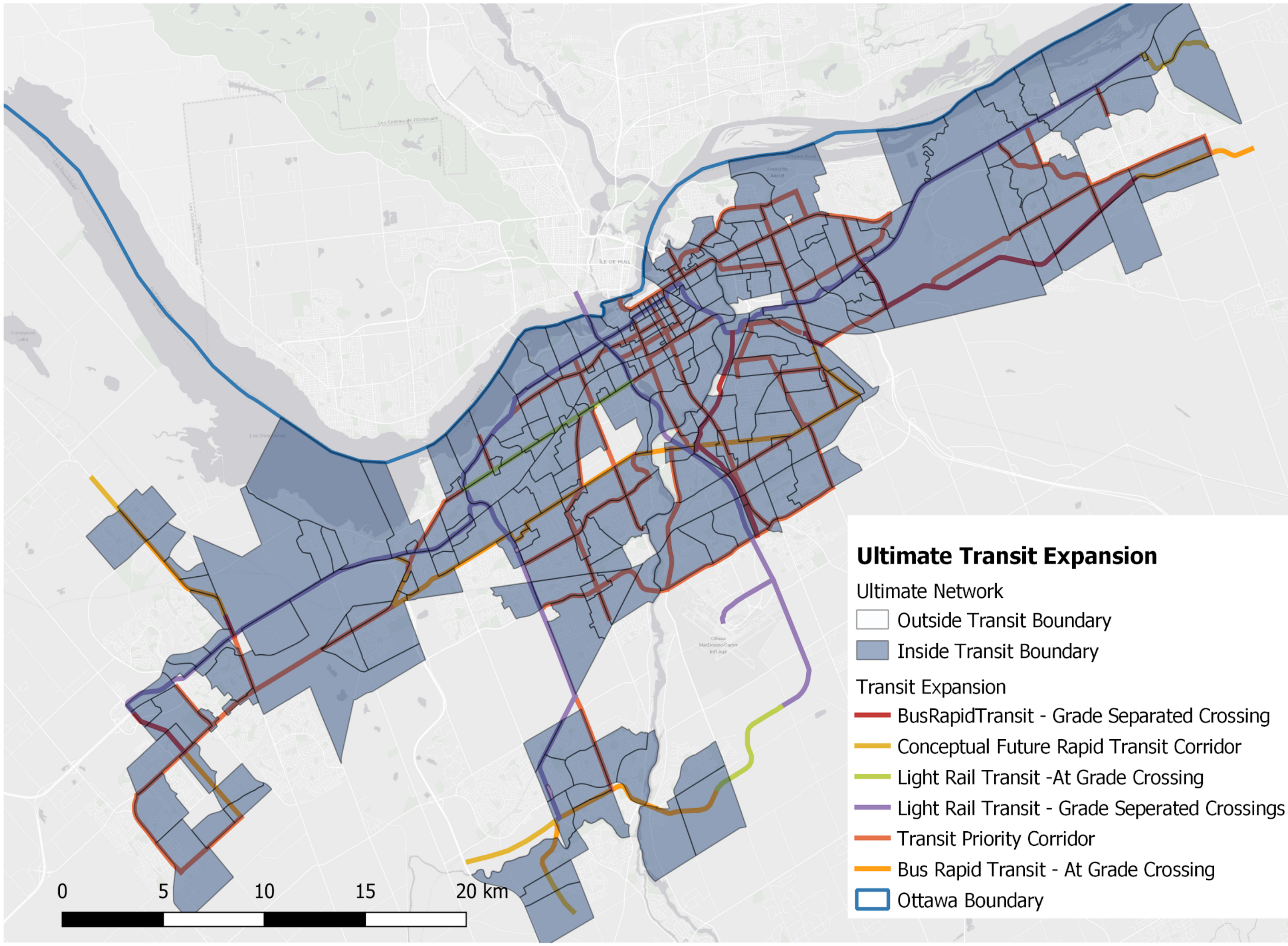

Figure 8-2: 100% scenario development areas in Centretown and adjacent to rapid transit (Selected Transit-Oriented Development Land Use Zones). While the Ultimate Transit Expansion was used to identify transit-accessible zones, the Network Concept Transit System, was modeled.

The 100% scenario reduces single-use residential districts that favour single-detached housing, leading to more compact communities with denser housing stocks

The housing stocks was held constant in the BAP and 100% scenarios as illustrated in Figures 8-3. In the 100% scenario, the share of single-detached housing falls from 45% to 39% in the BAP scenario.

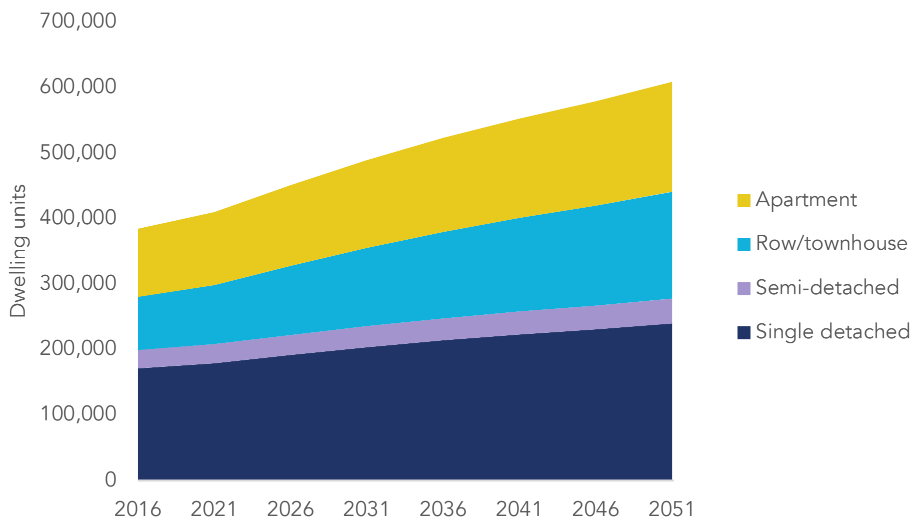

Figure 8-3: Housing stock y dwelling type in the BAP and 100% scenarios.

8.1.1. Active Transportation

Table 8-3: Active transportation actions.

Action	BAP scenario	100% scenario
Enhanced bicycle infrastructure, increased walking	No change	50% mode shift to walking and cycling away from vehicles and driving in selected land use zones. Use 2 km maximum distance for walking trips and 5 km for cycling trips.

In the 100% scenario, better infrastructure is introduced to encourage cycling and walking. This includes a complete build out of the bike lanes described in Ottawa's Transportation Master Plan, and increased densification (described in the land-use actions section above), where more amenities are available within 2 km walking distances from homes and workplaces. As a result of these actions in the 100% scenario, 50% of trips of 2 km and 5 km distances could shift towards walking and cycling, respectively.

Figures 8-5 and 8-6 show person-trips by distance under the BAP and 100% scenario. The x-axis illustrates the choice of travel dependent upon the distance of the destination.

The 100% scenario shows a sharp increase in trips of less than 5 km travelled by bicycle (dark blue bars), and a corresponding decrease in trips by vehicle (light blue bars). Trips shorter than 2km are more likely to be completed by walking in the 100% scenario compared to the BAP. Personal vehicle trips are generally reduced by switching short trips to active modes and increasing transit trips for medium distance trips (IE 7km - 35km).

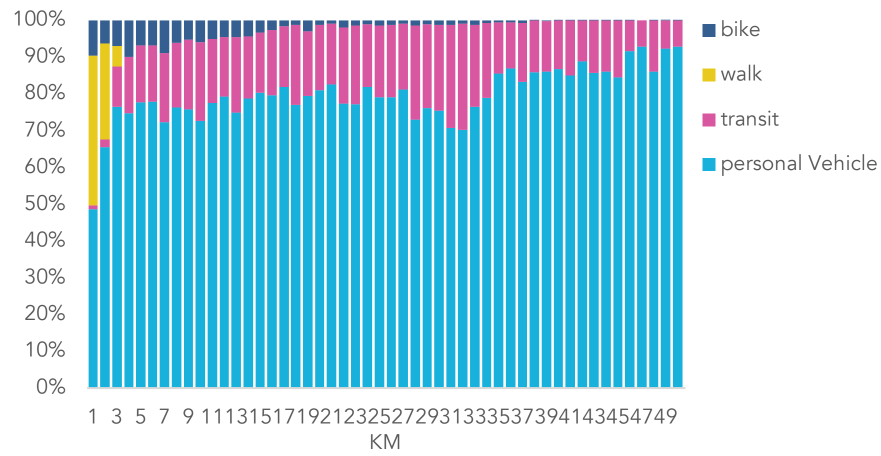

Figure 8-4: BAP scenario modeshare by trip length 2016- 2050.

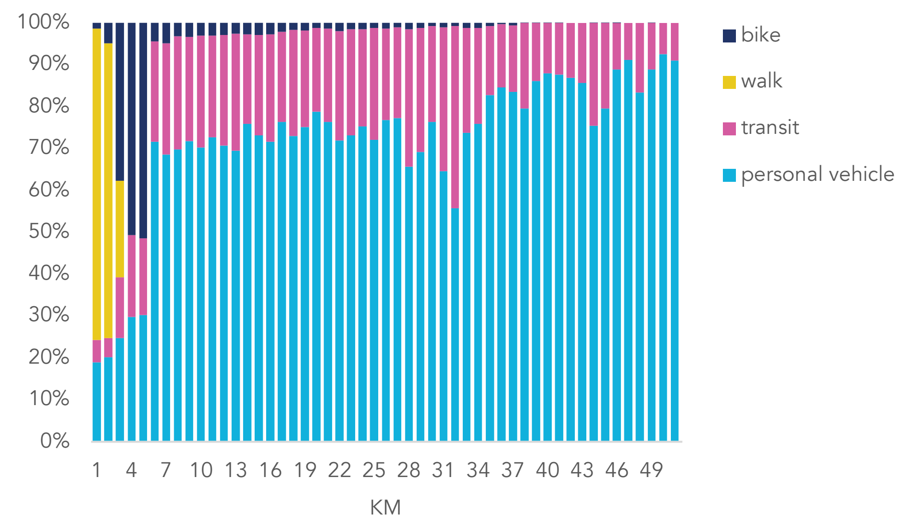

Figure 8-5: 100% scenario modeshare by trip length, 2016- 2050.

8.1.2. Vehicle Technologies

In the 100% scenario, electric vehicle consumer adoption cycle modelling for personal vehicles anticipates growth in EV sales towards 2030, levelling off at 100% by 2050 (Figure 8-7).

Table 8-4: Vehicle technology actions.

Actions	BAP scenario	100% scenario
Commercial vehicles (corporate fleets, delivery trucks, etc.)	10% of heavy trucks are zero emissions by 2030; 40% by 2040.	40% of heavy trucks are zero emissions by 2030; 100% by 2040.
Electrify municipal fleets (except transit)	Municipal fleet is 40% electric by 2040.	Municipal fleet is 60% electric by 2030; 100% electric by 2040.
Electrify transit	100% electric by 2050.	100% electric by 2030.
Electrify personal vehicles	33% of new vehicle sales by 2050.	90% of new vehicle sales by 2030; 100% by 2040.
Autonomous vehicles	No change.	No change.

Commercial vehicles are a challenge for electrification due to their size, extra weight when moving goods, and longer distances travelled. As technologies improve and policies, such as carbon pricing, come into effect, the commercial industry will move towards increased electrification (or perhaps fuel-cell-powered vehicles), albeit at a slower rate of adoption than for personal vehicles. The City will also transform its vehicle fleet to become 100% zero-emission by 2040 in the 100% scenario.

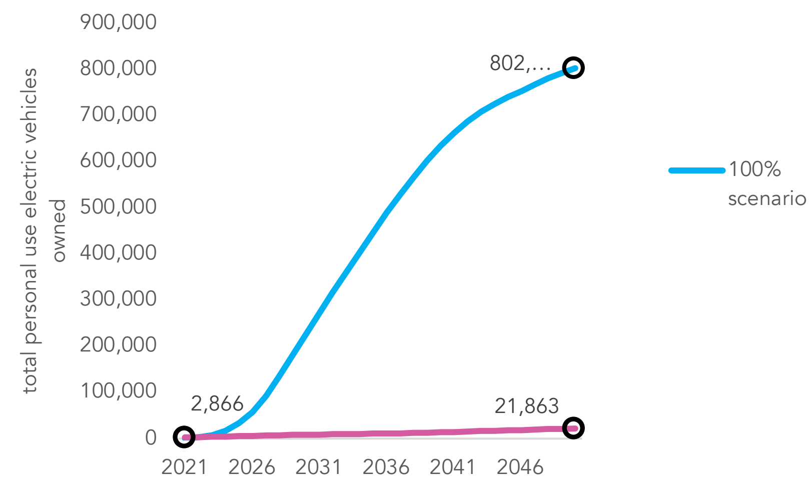

Figure 8-6: Electric Vehicle Adoption, BAP scenario versus 100% scenario.

Autonomous vehicle (AV) modelling was based on a scenario developed by the Rocky Mountain Institute,[80,81] with input from Ottawa's Stakeholder Working Group. The action assumes that personal vehicle ownership declines by 50% by 2050, but personal VKT increases by 150%, as convenient access to AVs encourages more car trips; however, this action was not included in the 100% scenario. New population cohorts (young

[80] Johnson, C., & Walker, J. (2016). Peak car ownership: The market opportunity of electricity automated mobility services. Rocky Mountain Institute. Retrieved from https://rmi.org/Content/Files/CWRRMI_POVdefection_FullReport_L12.pdf

[81] Horl, S, Ciari, F., & Axhausen, K. (2016). Recent perspectives on the impact of autonomous vehicles. Retrieved from https://www.ethz.ch/content/dam/ethz/special-interest/baug/ivt/ivt-dam/vpl/reports/2016/ab1216.pdf

and elderly, for example) will have increased access to vehicles as well, further increasing car trips.[82]

The 100% scenario includes a car sharing action in which upcoming LRT stations and areas in Centretown offer increased car share options. The service would include one- and two-way trips. This service is phased out by 2050 in the 100% scenario, as it is replaced by autonomous vehicle use.

8.1.3. Enhanced Transit

A suite of transit improvements was introduced in the 100% scenario, in consultation with the City's Transportation Services Department. The City currently planned transit expansion includes the completion of Phases 1 and 2 of the Confederation Line, which is included in the BAP scenario.

Table 8-5: Enhanced transit actions.

Action	BAP	100% scenario
Enhanced transit	Completion of the Confederation and Trillium Line Phases 1 and 2	LRT frequency is increased to every 90 seconds at peak times, surrounding area trains are adjusted to match. BRT speed is increased by 20% through prioritized lanes and stop lights. 100% of Transit vehicles (rail, bus, Paratranspo and support vehicles) are electric by 2030. The Network Concept system is completed.

The 100% scenario includes actions to move to the Transit Concept Network, as detailed in the City's Transportation Master Plan. This includes increased bus-rapid transit (BRT) lines and transit priority corridors in the south and east of the city (see Appendix 8.8), accompanied by increased residential development and employment around transit nodes. In order to reduce GHG emissions, the 100% scenario also modelled transit to be 100% electric by 2040.

100% scenario actions also include increasing the frequency of LRT to every 90 seconds and organizing the adjacent LRT network to coordinate. BRT speed is increased by 20% through prioritized lanes and stop lights in areas where BRT have separated lanes.

[82] Ticoll, D. (2015). *Driving changes: Automated vehicles in Toronto*. Retrieved from https://www1.toronto.ca/City%20Of%20Toronto/Transportation%20Services/TS%20Publications/Reports/Driving%20Changes%20(Ticoll%202015).pdf

Further, in 2050 the mode shift for transit increases to capture 19% of internal trips, up from 12% in 2016 (percentages are on a 24-hour basis). Transit increases its share of external outbound trips from 11% to 14% in 2050, and from 25% to 35% of external inbound trips (Figure 8-8).

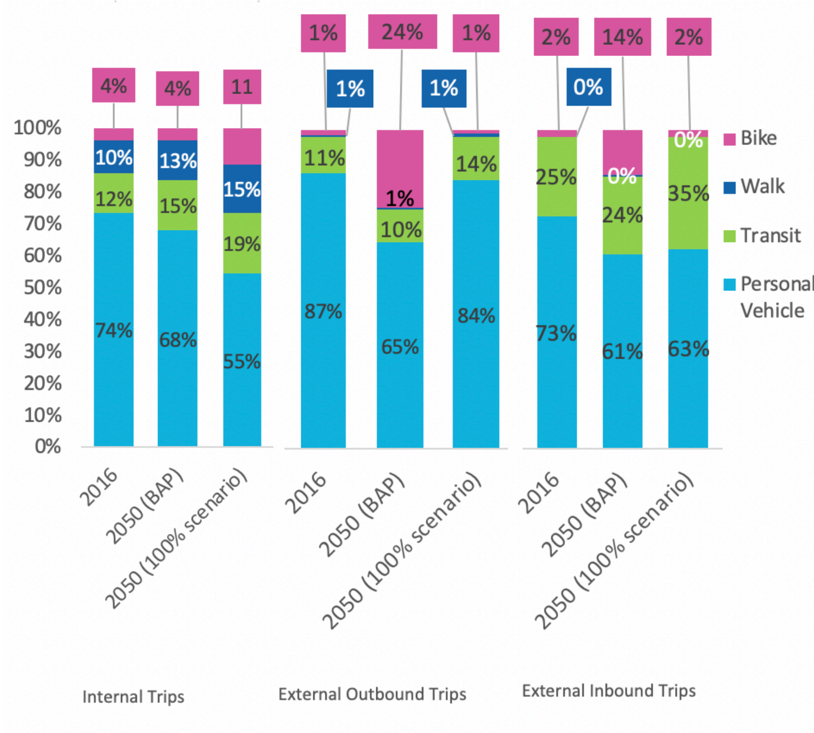

Figure 8-7: BAP scenario and 100% scenario mode share, 2050.

8.1.4. Transportation Demand Management

Table 8-6: Transportation demand management actions.

Actions	BAP	100% scenario
Parking fees	Current parking fees maintained.	Increase parking fees in city-controlled areas by a factor of 2 by 2050.
Congestion pricing	No pricing.	Congestion charge of $20 applied to the downtown core between 6:00 am and 10:00 am on weekdays, in place by 2030.
Car-free zones	No car-free zones.	Car-free areas place in the following areas by 2030: Downtown, Byward Market, Wellington-Rideau area Sparks, Bank, and Ottawa-U campus area.
EV zones	No EV zones.	EVs only inside the area bounded by Bronson Avenue, Catherine Street, and Queen Elizabeth Drive (Rideau Canal) by 2028.

The 100% scenario includes several actions to incentivize alternative modes of travel over vehicle trips. Modelling was coordinated between the City's transportation department and CityInSight. The 100% scenario increases parking fees and implements a congestion pricing zone around the downtown area. The congestion zone is bounded by Bronson St., Catherine St., and Queen Elizabeth Dr. (Figure 8-9). The bounded area, called the Cordon Zone, applies a $20[83] fee to vehicles crossing it between 6:00-10:00am Monday to Friday. Similarly, the 100% scenario includes a 2x factor cost increase for on-street and city-owned parking by 2050.

Car-free areas are also included in the 100% scenario, implemented where population density exceeds 5,000 people per km^2, and in areas where higher shares of active transportation take place: downtown, the Byward Market, Wellington-Rideau, and the area bounded by Sparks, Bank, and the Ottawa-University campus (Figure 8-10). Vehicle mode share is reduced to zero in these zones. EV-only zones are also introduced beginning in 2028.

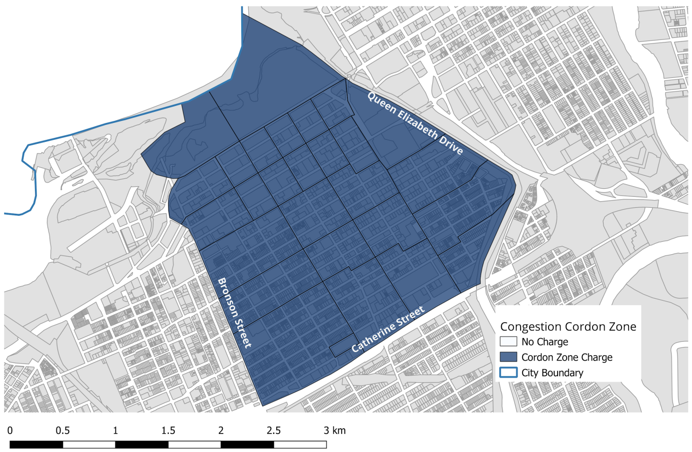

Figure 8-8: Congestion pricing zone, in place by 2030.

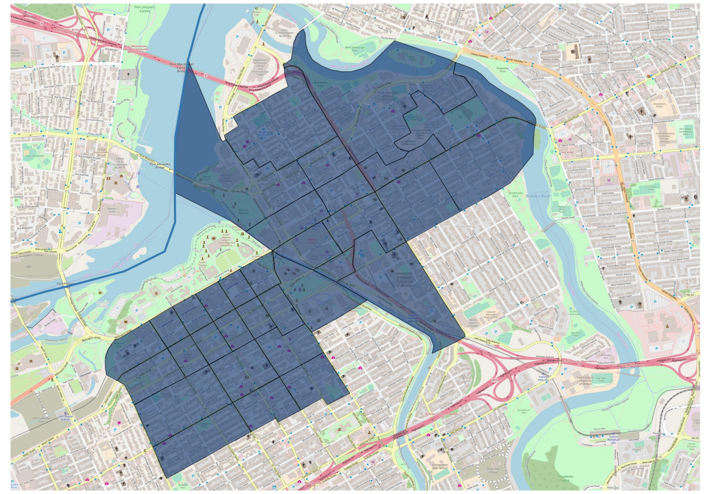

Figure 8-9: Car-free zone in Central Ottawa, in place by 2050.

[83] In order to test the impact of a cordon charge, a significant fee of $20, was tested -slightly more than the fee of 11.50 pounds ($18.85CAN) used in the UK. See: https://tfl.gov.uk/modes/driving/congestion-charge.

8.2. Low-Carbon Buildings Actions

Table 8-7: BAP scenario and 100% scenario new building actions.

Actions	BAP	100% scenario
Dwelling size	2016 dwelling sizes maintained.	No change.
Building mix	Shares of new dwelling units by 2046 singles: 31% doubles: 4% rows: 37% apartments: 28%.	No change.
Net-zero homes	2016 efficiencies held constant.	100% of new construction is net-zero energy by 2030.
Efficiency of new homes	10% improvement every 5 years for new construction.	100% of new construction is net-zero energy by 2030.
Efficiency of new non-residential buildings	10% improvement every 5 years for new construction.	100% of new commercial and retail construction meets passive house standard by 2030.

Low-carbon analysis of buildings in Ottawa classified and modelled building types as existing residential, new residential, existing non-residential, and new non-residential. Low-carbon actions for each building type were developed under the 100% scenario.

8.2.1. New Buildings

Under the 100% scenario, new residential buildings will be far more efficient than the current Ontario Building Code up to 2030. By 2030, all new construction will meet net-zero energy standards. All new construction of non-residential buildings achieves Passive House levels of performance by 2030.

Dwelling sizes and building mix are also set to change as the city densifies. Under the 100% scenario, as the average size of a dwelling unit decreases, the share of single-detached dwelling units decreases and the share of apartments and rowhouses increases. Densification zones identified under the land-use actions (Figure 8-2 Selected Transit Oriented Development Zones) shows areas where 90% of new development will occur in the 100% scenario.

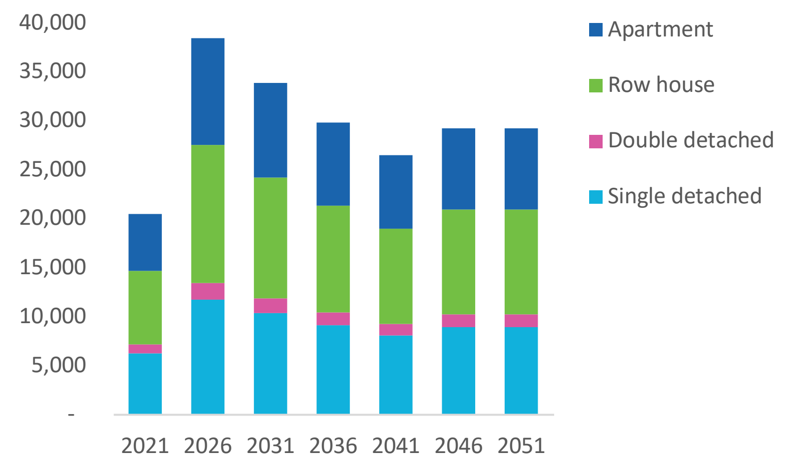

Figure 8-10: New homes meeting net zero target, 100% scenario.

8.2.2. Existing Buildings

The actions in the 100% scenario for existing buildings focus on reducing electricity and thermal energy demand by applying efficiency retrofits that increase in scale over time. Deep retrofits achieving >50% energy reductions in existing buildings is targeted. The energy reduction goal is ambitious but in line with research conducted by Natural Resources Canada (NRCan) and Sustainable Buildings Canada. Aggregated retrofits, including lighting upgrades, HVAC upgrades or renovations, boiler replacements, and wall replacements that can be prefabricated, could reduce total energy use by 50% .[84] Wall replacements are often costly but programs such as NRCan's Prefabricated Exterior Energy Retrofit (PEER) or the European EnergieSprong program aim to reduce those costs, creating shorter payback periods, and should be explored for the Ottawa context.

Table 8-8: Existing buildings actions.

Action	BAP	100% scenario
Retrofit older homes (pre-1980) Retrofit newer homes (post-1980)	No retrofit program.	Retrofit 98% of all dwellings by 2040; achieve thermal savings of 70% and electrical savings of 30%.
Retrofits of small commercial, and office buildings	No retrofits program.	Retrofits 98% of all buildings by 2040; achieve thermal savings of 60% and electrical savings of 30%.
Retrofits of commercial, office, and industrial buildings	No retrofits program.	95% of the existing building stock is retrofitted by 2040 with average savings of 50%.
Municipal buildings	Current efficiencies held constant.	99% of existing municipal buildings are retrofit to net zero emissions by 2040.

The 100% scenario sees 95% of commercial buildings retrofit by 2050, achieving at least 50% energy reductions in each building. Buildings are also regularly recommissioned every 10 years to achieve a 10% energy savings.[85] The 100% scenario assumes that recommissioning reduces building emissions to effectively negate the efficiency decline associated with aging building energy systems. Multi-family residential buildings were not included in this action as they are included under the residential retrofit actions.

Leading by example, municipal buildings reach net-zero emissions by 2040 under the 100% scenario.

8.2.3. Heat Pumps

The heat pumps action was developed during Phase 1 of Energy Evolution. The analysis found that fuel switching from natural gas to electric heat pumps is an effective action to reduce community GHG emissions. Notable barriers related to cost and payback periods are present in this action, especially when considering the low cost of natural gas and the up-front

[84] Sustainable Buildings Canada. (2016). Energiesprong Summary Report. Retrieved from https://sbcanada.org/wp-content/uploads/2017/09/Energiesprong-Summary-Report.pdf

[85] Assumption based on research found in: Frappe-Seneclauze, T., Heerema D., & Wu, K. (2017). *Deep emissions reduction in the existing building stock.* The Pembina Institute.

cost of the equipment. Ground-source heat pumps can cost $20,000-40,000 per unit depending if they used horizontal or vertical loops (respectively), while air-source heat pumps can cost $4,000 per unit.[86]

Table 8-9: Heat pump actions.

Action	BAP	100% scenario
Residential heat pumps - air source	Maintain current number.	414,500 installed by 2050.
Residential heat pumps - ground source	Maintain current number.	145,800 installed by 2050.
Heat pumps - commercial buildings	Maintain current number.	73% of heat load by 2050.

The 100% scenario makes use of strong incentive programs from various governmental bodies, along with carbon pricing policy implemented in the near future. Promotional activities and support are provided by various local entities, including the City and retailers. With these strategies in place, Phase 1 research estimates 1.5% of low-rise buildings, apartments, commercial (office) buildings, and institutional buildings will be retrofitted with heat pumps each year between 2018 and 2030, and 3% between 2031 and 2050, where equipment prices decrease and longer-term pricing signals and incentive programs have been established.

8.3. Energy Sector Actions

Zero-carbon energy actions consist of generating local renewable energy and fuel switching away from fossil fuels. A plethora of renewable energy technologies are currently available and are viable in Ottawa's context. Phase 1 of Ottawa's Energy Evolution examined the viability of renewable energy technologies and their ability to reduce GHG emissions in the city, and the following section examines how to integrate those actions in the 100% scenario.

Table 8-10: Energy actions.

Action	BAP	100% scenario
Residential/commercial rooftop solar PV -	95 MW	320 MW by 2050 (residential)
		740 MW by 2050 (commercial)
		140 MW (Utility) (not modelled in the 100% scenario)
Utility-scale solar PV	Current levels held	Current levels held
Hydropower	No additional capacity added	36 MW by 2050
Renewable natural gas	N/A	6 MW until 2030 50/50 RNG vs electricity generation, after 2040, all RNG totaling 520 TJ per year; waste streams (leaf and yard waste and organic waste is directed to an anaerobic digester, which is then fed into the natural gas

[86] Phase 1 ETS: Pathway analysis on Heat Pumps. Retrieved from https://documents.ottawa.ca/sites/default/files/energy_evol_pathways_en.pdf

Action	BAP	100% scenario
		distribution system, which generates 1.4 petajoules (PJ).
District energy	Existing 2016 DE capacity is held constant through to 2050 (1184 TJ)	DE supplies: 80% of existing commercial buildings 80% of apartments 15% of residential buildings other than apartments 100% of the systems are zero-carbon (geothermal)
Wind	N/A	3,218 MW by 2050
Energy storage	No storage deployed.	Enhancement to renewable energy, equivalent to 613 MW installed.
Power to hydrogen	N/A	2040: 60 TJ and 2050: 48 TJ hydrogen produced at 80% efficiency; half of waste heat is used. At 2030, although it is not modelled, power to methane is an optional alternative pathway.
Air-source & Ground-source heat pumps	By 2050, 23,700 heat pumps installed in low-rise buildings, 8,100 heat pumps in apartments, and 5% of commercial floor space.	By 2050, 414,691 heat pumps installed in low-rise buildings, 145,659 heat pumps in apartments, and 73% of commercial heat load.

The 100% scenario modelled the energy generation approaches summarized in Table 8-10.

8.3.1. Wind

There are currently three wind generation facilities to the south and east of Ottawa with a total capacity of 162 MW. The 100% scenario assumes that an average of 100 MW of wind will be added each year between 2020 and 2050 in the broader region. The installation of wind power is intended to balance the solar PV production, reducing the fluctuating renewable capacity on the grid.

8.3.2. Solar Photovoltaic

Solar PV is the energy strategy with the greatest potential to add significant renewable energy to Ottawa. Phase 1 analysis largely attributed this to the good solar resource in the Ottawa Valley and the relatively large variety of commercially viable solar power applications.[87]

The 100% scenario assumes that solar capacity will be scaled up with increased installations on residential and commercial rooftops, and through ground-mounted utility-scale solar fields. 20% of residential buildings with pitched roofs are targeted to have solar PV by 2050,

[87] Ottawa Phase 1 ETS Summary Report and Directions. Retrieved from https://documents.ottawa.ca/sites/default/files/energy_evol_phase1_en.pdf

generating 320 MW of energy. The commercial sector will generate 740 MW by covering 68% of current commercial rooftop space with solar panels.

8.3.3. Hydroelectric Power

Ottawa Hydro currently generates nearly 10% of the city's electricity and has already built or recommissioned generation stations in areas with the largest potential. However, several smaller sites along the Ottawa and Rideau River were identified for their potential to build mini-hydro generation sites. The proposed mini-hydro plants will not store water in a reservoir or dam, but rely on smaller height drops, often using a canal or pipe, to direct water towards a generator.[88]

The 100% scenario adds 36MW of hydro energy from the mini-hydro plants by 2050. This is achieved through 6 installations along the Rideau River and an installation at the Robert O. Pickard Environmental Centre to capture wastewater outflow to generate 11.9 MW of electricity in total. There will also be two refurbishments of existing hydro plants to generate an additional 22 MW of capacity.[89]

8.3.4. District Energy

District energy (DE) is a technology capable of capturing zero-carbon energy from multiple sources and efficiently distributing it to buildings clustered in a neighbourhood or block. The central system can replace decentralized boilers, HVAC systems, and chillers in individual buildings, and create efficiencies of scale. DE systems can quickly incorporate new sources of renewable energy, transitioning from fossil fuel sources, such as natural gas.

In the 100% scenario, the City aggressively increases DE capacity from its five existing facilities, scaling up to meet the heating and cooling demands for 80% of existing commercial buildings, 80% of apartments, and 15% of other residential buildings by 2050. 100% of the system is powered by zero-carbon sources. The Phase 1 pathway analysis identified opportunities to use biomass, waste heat, geothermal heating and cooling, ground source heat pumps, and scaled-up solar PV to power mechanical systems (Figure 8-10).[90] By 2050 however, the system will exclusively use geothermal energy.

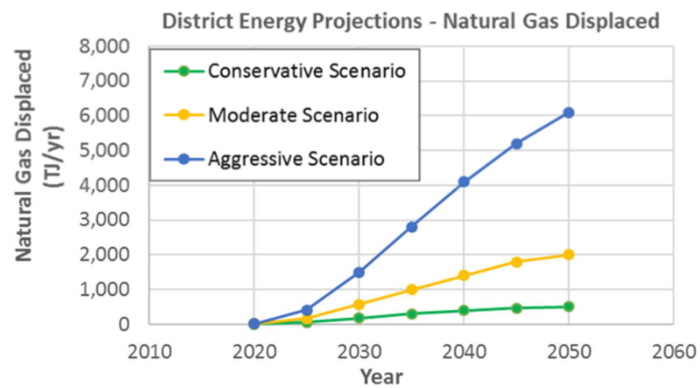

Figure 8-11: Natural Gas Displaced in Ottawa by DE systems increasingly relying on low-carbon sources[91]

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[88] Ottawa Phase 1 ETS Summary Report and Directions.

[89] Phase 1 ETS: Pathway analysis on hydro energy.

[90] Phase 1 ETS: Pathway analysis on District Energy.

[91] Ibid.

8.3.5. Energy Storage

Energy storage enables time shifting between renewable energy generation and demand for power, increasing the percentage of power that is generated by renewables that can be used, and decreasing the reliance on fossil fuel-based peaking plants. For this reason, in modelling, energy storage is assumed to increase the capacity factor for renewable energy. For Ottawa, a target of 612 MW was identified for 2050. Curtailment rates, or the act of reducing or restricting energy delivery from a generator to the electrical grid, are limited to 85-90%, enabled by sufficient storage capacity.

8.3.6. Renewable Natural Gas

Renewable natural gas is chemically similar to conventional natural gas, but is produced from biogenic sources, such as municipal solid waste and farm waste. The collected gas is then upgraded and injected into the natural gas grid. Also, RNG can be produced from power to gas, wherein excess electricity is used to produce hydrogen, which is blended into the gas grid.

In Ottawa, renewable natural gas is introduced in the 100% Scenario with intention of locally producing the fuel and displacing imported natural gas. Biogas is collected and used as a source of electricity (6 MW). After 2030, half of the biogas is processed into renewable natural gas with the purpose of displacing externally sourced natural gas used to meet space heating and other needs.

8.4. Development of the 100% Scenario

The actions development process for the 100% scenario began with extensive research on fourteen "pathways" to reduce energy use and GHG emissions at the city scale in two phases. Phase 1 of Ottawa's Energy Evolution examined the viability of renewable energy technologies and their ability to reduce GHG emissions in the city, and the electrification of cars and light trucks.[92] Then, pathway analysis for Phase 2 of Energy Evolution was completed for the following areas:

1. **Transportation:** strategies for car-free areas, electrifying heavy duty vehicles, land-use change, increased cycling infrastructure, increased car sharing, the use of autonomous vehicles, and road pricing.
2. **Existing small buildings:** strategies to reduce energy and emissions through retrofits, fuel switching, and increased renewable energy use. This sector primarily focused on residential buildings.
3. **New small buildings:** similar to existing small buildings, with discussion on more efficient building standards (Passive House and net-zero) and reduced single-detached housing.
4. **Existing large buildings:** strategies for deep energy retrofits, commissioning, energy audits, and fuel switching for large institutional, commercial, and industrial buildings (ICI), and large multi-family buildings.
5. **New large buildings:** strategies for new large ICI and multi-family buildings include fuel switching, increased building efficiency standards, and building orientation.

[92] Phase 1 of the analysis is available on the City of Ottawa's Energy Evolution website.

6. **Energy Storage:** strategies to store energy, particularly renewable energy, for use at times with high electrical demand.
7. **Solid Waste:** strategies to increase waste diversion from all building types and increase methane capture from wastewater.

The pathway analysis papers were discussed and refined by several stakeholder workshops hosted by the City of Ottawa in late 2018.

Actions considered in the pathway papers were modelled in the 100% scenario from 2017 to 2050. The scenario illustrates anticipated energy use and GHG emissions production for the city if it implements the actions to address energy and emissions.

Note that a scenario—as applied in this context—is an internally consistent view of what the future might turn out to be—not a forecast, but one possible future outcome. Similar to the BAP scenario, the 100% scenario projection is one of many possible views of the future; in this case, one that assumes that several energy and GHG emissions reducing policies, actions, or strategies identified in Phase 1 and 2 of the Energy Evolution are implemented. The 100% scenario incorporates actions determined in the pathway analysis and other studies to be the best ones to undertake to reach the 100% reduction target that was mandated. The scenarios are coherent in describing the relationships between different variables and reflecting an evolution of current physical stocks, such as buildings and vehicles. In other words, scenarios as developed in this analysis cannot reflect a physically impossible trajectory.

8.5. Modelling

Part of scenario development is the modelling process, which serves to shed light on both the impacts of actions, as well as how they impact one another. Thirty-two actions were modelled in the 100% scenario.

Modelling assumptions and parameters were developed for each action and are explained in detail in the Data, Methods, and Assumptions manual provided to the City.

Each action was modelled using CityInSight in two steps: assumptions for each of the actions were modelled to quantify the emissions reduction impact against the BAP scenario; then the 100% scenario was developed, wherein all actions were modelled together to capture feedback between them.

Feedback among the actions can significantly influence the emissions reductions associated with an action. For example, when modelled against the BAP scenario, a shift to increased walking mode share represents reduced gasoline use and associated emissions if a vehicle trip is avoided. However, within the 100% scenario, eliminating a vehicle trip in 2050 will actually have minimal emissions impact due to the majority of vehicles being electric by that time.

Due to actions' feedbacks, the sequence in which the actions are implemented in the model influences the outcome associated with a particular action. In general, actions that reduce consumption and maximize efficiency are prioritized and deployed prior to actions related to fuel switching and local energy generation. Examples include prioritizing mode share shifts to walking and cycling prior to electrification of the vehicle fleet, or prioritizing retrofits and improved building standards to buildings before switching to renewable energy. Figure 8-13 illustrates a schematic of actions sequencing, grouped into two categories, as they were implemented in the model.

Several underlying assumptions were unchanged between the BAP scenario and the 100% scenario. These include the population and employment projections, building growth projections, climate projections (heating and cooling degree days), the provincial grid emissions factors, and vehicle fuel efficiency standards.

These underlying assumptions are held constant in the 100% scenario for two reasons:

1. They are underlying drivers that are not associated with the implementation of an emissions reduction action and are required to be held constant in order to provide a consistent comparison between the 100% scenario and the BAP scenario.
2. The city has little influence over the drivers of energy and emissions in this area, and therefore cannot implement actions to address them.

CityInSight Model Sequence

Decrease Consumption

1. Compact Land use
2. Reduce dwelling sizes of residential homes
3. Reduce proportion of single-detached homes
4. Increase building efficiency of new dwellings, and new commercial buildings
5. Increased share of Net-Zero Homes
6. Retrofits of homes pre-1980
7. Retrofits of homes post-1980
8. Retrofits for institutional, commercial, office, and industrial buildings
9. Recommissioning of large buildings
10. Reduced vehicle ownership through increased car share and autonomous vehicles
10. Decrease vehicle trips
11. Increase walking trips in 2km range
12. Increase cycling trips in 5km range
13. Expand Transit
14. Introduce car free zones
15. Introduce a congestion charge in Downtown Ottawa
16. Increase parking rates
17. Increase waste diversion rates
18. Industrial process efficiency increased

Switch to Renewables & Increase Local Generation

1. Installation of heat pumps: air and ground source residential
2. Installation of heat pumps: air and ground source commercial
3. Solar PV - Increase proportion of buildings with net metering
4. Solar Hot Water / Heating proportion increases
5. Solar PV - Ground mounting increases
6. Energy Storage capability increases
7. Local Hydro-power capacity increases
8. Biogas capacity increases
9. District Energy capacity is increased and increasingly uses low-carbon sources
10. Wind Energy capacity increases
11. Electrification of transit, municipal fleets, commercial vehicles, and personal vehicles

Figure 8-12: Actions sequencing in the CityInsight model.

8.6. 100% scenario Summary Tables

100% scenario community energy summary, 2050.				
Energy by end use (TJ)	2050	Share 2050	% +/- 100% scenario 2050 vs 2016	% +/- 100% scenario 2050 vs BAP 2050
Commercial	22,791	39%	-23.0%	-41%
Industrial	8,401	14%	29.4%	-2%
Residential	15,223	26%	-61.4%	-63%
Transportation	11,790	20%	-61.5%	-65%
Total	58,204	100%	-45.2%	-52%
Energy by end use (TJ)	2050	Share 2050	% +/- 100% scenario 2050 vs 2016	% +/- 100% scenario 2050 vs BAP 2050
Diesel	6,027	6%	-99.2%	-99%
Electricity	28,085	26%	80.0%	12%
Fuel oil	1,151	1%	-98.1%	-89%
Gasoline	23,581	22%	-100.0%	-100%
Natural gas	40,416	38%	-96.8%	-97%
Other	5,142	5%	-11.6%	92%
Propane	1,695	2%	-88.4%	-83%
Renewable natural gas	49	0%	3115.7%	100%
Total	106,145	100%	-45.2%	-52%
Energy by end use (TJ)	2050	Share 2050	% +/- 100% scenario 2050 vs 2016	% +/- 100% scenario 2050 vs BAP 2050
Industrial processes	6,943	12%	40.7%	1%

Lighting	9,510	16%	25.0%	-16%
Major appliances	3,231	6%	31.3%	-22%
Plug load	10,053	17%	26.7%	-16%
Space cooling	2,627	5%	26.5%	-33%
Space heating	5,278	9%	-86.6%	-86%
Transportation	11,790	20%	-61.5%	-65%
Water heating	8,774	15%	-21.3%	-24%
Total	58,204	100%	-45.2%	-52%
Energy per capita (GJ/person)	38.7		-64%	-52%

100% scenario community GHG emissions summary, 2050.				
Emissions by sector (tCO2e)	2050	Share 2050	% +/- 100% scenario 2050 vs 2016	% +/- 100% scenario 2050 vs BAP 2050
Fugitive	1,165	1%	-96.92%	-97%
Waste	11,857	12%	-96.65%	-97%
Commercial	33,849	34%	-96.32%	-96%
Energy production	10,096	10%	-85.92%	-86%
Industrial	18,018	18%	-86.14%	-86%
Residential	23,248	23%	-98.34%	-98%
Transportation	2,522	3%	-99.87%	-100%
Total	100,756	100%	-97.94%	-98%
Emissions by source (tCO2e)	2050	Share 2050	% +/- 100% scenario 2050 vs 2016	% +/- 100% scenario 2050 vs BAP 2050
Fugitive	1,165	1%	-96.9%	-97%
Waste	11,857	12%	-96.6%	-97%
Propane	12,056	12%	-88.4%	-88%
Fuel oil	1,522	2%	-98.1%	-98%

Diesel	3,687	4%	-99.1%	-99%
Gasoline	283	0%	-100.0%	-100%
Electricity	831	1%	-99.7%	-100%
Natural gas	69,355	69%	-96.6%	-97%
Total	100,756	100%	-97.9%	-98%
Emissions per capita (tCO2e/person)	.07		-98%	-98%

8.7. Emission Factors

Category	Description	Comment
Natural gas	49 kg CO2e/GJ	Environment and Climate Change Canada. *National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada*. Part 2. Tables A6-1 and A6-2, Emission Factors for Natural Gas.
Provincial electricity grid	2016: CO2: 28.9 g/kWh CH4: 0.007 g/kWh N2O: 0.001 g/kWh 2050: CO2: 37.4 g/kWh CH4: 0.009 g/kWh N2O: 0.001 g/kWh	National Energy Board. (2016). *Canada's Energy Future 2016.* Government of Canada. Retrieved from https://www.neb-one.gc.ca/nrg/ntgrtd/ftr/2016pt/nrgyftrs_rprt-2016-eng.pdf.
Gasoline	g/L CO2: 2316 CH4: 0.32 N2O: 0.66	Environment and Climate Change Canada. *National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada.* Part 2. Table A6–12 Emission Factors for Energy Mobile Combustion Sources.
Diesel	g/L CO2: 2690.00 CH4: 0.07 N2O: 0.21	Environment and Climate Change Canada. *National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada.* Part 2. Table A6–12 Emission Factors for Energy Mobile Combustion Sources.
Fuel oil	Residential g/L CO2: 2560 CH4: 0.026 N2O: 0.006	Environment and Climate Change Canada. *National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada*. Part 2. Table A6–4 Emission Factors for Refined Petroleum Products.

Category	Description	Comment
	Commercial g/L CO_2: 2753 CH_4: 0.026 N_2O: 0.031 Industrial g/L CO_2: 2753 CH_4: 0.006 N_2O: 0.031	
Propane	g/L Transport CO_2: 1515.00 CH_4: 0.64 N_2O: 0.03 Residential CO_2: 1515.00 CH_4 : 0.027 N_2O: 0.108 All other sectors CO_2: 1515.00 CH_4: 0.024 N_2O: 0.108	Environment and Climate Change Canada. *National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada*. Part 2. Table A6–3 Emission Factors for Natural Gas Liquids. Table A6–12 Emission Factors for Energy Mobile Combustion Sources.
Coal	0.088 kg CO_2e/MJ	Environment and Climate Change Canada. *National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada.* Part 2. Table A6–3 Emission Factors for Natural Gas Liquids.
Waste	Landfill emissions are calculated from first order decay of degradable organic carbon	Landfill emissions: *IPCC Guidelines Vol 5*. Ch 3, Equation 3.1

Category	Description	Comment
	deposited in landfill. Derived emission factor in 2016 = 0.015 kg CH4/tonne solid waste (assuming 70% recovery of landfill methane); 0.050 kg CH4/tonne solid waste not accounting for recovery.	
Wastewater	CH4: 0.48 kg CH4/kg BOD N2O: 3.2 g / (person * year) from advanced treatment 0.005 g /g N from wastewater discharge	CH4 wastewater: *IPCC Guidelines Vol 5*. Ch 6, Tables 6.2 and 6.3; MCF value for anaerobic digester. N2O from advanced treatment: *IPCC Guidelines Vol 5*. Ch 6, Box 6.1. N2O from wastewater discharge: *IPCC Guidelines Vol 5*. Ch 6, Section 6.3.1.2.

8.8. Transit Maps