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Scenarios of technology adoption towards low-carbon cities

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H I G H L I G H T S

- Explores policy options in a city targeting an 80% GHG emission reduction target by 2050.
- Aggressive building code changes will have minimal impact on GHG mitigation.
- Support of low-carbon electricity for the majority of generation necessary by 2050.
- Internal combustion engine use must be mostly eliminated from the vehicle stock.
- Policies supporting elimination of physical exchange space should be promoted.

A R T I C L E I N F O

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A B S T R A C T

Technological change has often been presented as a readily accepted means by which long-term greenhouse gas (GHG) emission reductions can be achieved. Cities are the future centers of economic growth, with the global population becoming predominantly urban; hence, increases or reductions of GHG emissions are tied to their energy strategies. This research examines the likelihood of a developed world city (the Greater Toronto Area) achieving an 80% reduction in GHG emissions through policy-enabled technological change.

Emissions are examined from 3 major sources: light duty passenger vehicles, residential buildings and commercial/institutional buildings. Logistic diffusion curves are applied for the adoption of alternative vehicle technologies, building retrofits and high performance new building construction. This research devises high, low and business-as-usual estimates of future technological adoption and finds that even aggressive scenarios are not sufficient to achieve an 80% reduction in GHG emissions by 2050. This further highlights the challenges faced in maintaining a relatively stable climate. Urban policy makers must consider that the longer the lag before this transition occurs, the greater the share of GHG emissions mitigation that must addressed through behavioural change in order to meet the 2050 target, which likely poses greater political challenges.

1. Introduction

Cities are expected to play an important role in climate change mitigation, given their high current contribution to greenhouse gas (GHG) emissions and that population and economic activity are projected to continue to gravitate towards them (Kennedy et al., 2009; Hoornweg et al., 2011). Many global cities have already recognized their importance in addressing climate change and have begun to formulate policy for achieving long range targets at lower emissions levels. Technological change has often been held as a desirable and feasible means by which industrialized societies can transition to low-carbon economies (Pacala and Socolow, 2004; Meinshausen et al., 2009; Jacobson and Delucchi, 2011). Technological measures include fuel switching (i.e. coal to natural gas), adoption of renewable energy sources, installing carbon capture and storage systems and the transition to higher efficiency energy conversion technologies. How far – and how fast – new technologies (and the policies intended to stimulate their adoption) can reduce the emissions intensity of an urban region towards a level that is consistent with a low-risk climate change scenario has yet to be answered at an urban scale.

The Pathways to Urban Reductions in Greenhouse gas Emissions modeling tool, or PURGE, can be used to estimate the diffusion of these technologies in the urban context and the impact on future GHG emissions. The development of the PURGE model is described in Mohareb and Kennedy (2012a); the model is applied in that instance to quantify future business-as-usual (BAU) GHG emissions from the building, transportation and waste sectors using publically available data on technology stocks, energy consumption and population/economic growth. It should be noted that the model neglects the industrial sector and does not directly account for behavioural change. PURGE allows the examination of trends in

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Table 1
Summary of scenario options applied for the GTA to the PURGE model.

Scenario	Description
Transportation[1]	
T1 (BAU)	30/30/40 → BEV/HEV/PHEV
T2 (High)	30/20/20/10/20 → ICE-T/HEV/Diesel/PHEV/ICE conventional
T3 (Low)	40/30/30 → HFCV/BEV/PHEV
Residential buildings	
Building Code—Current (BAU)	35% reduction in building code in 2011
Building Code—Aggressive (Low)	35% reduction in building code in 2011, 25% in 2016, 25% in 2016
BR1—Option 1 (BAU)	Average of ECOEnergy retrofits savings applied by home vintage/type
BR2—Option 2 (High)	Average of bottom 50% of ECOEnergy retrofits savings applied by home vintage/type
BR3—Option 3 (Low)	Average of top 50% of ECOEnergy retrofits savings applied by home vintage/type
Commercial/Institutional buildings	
Retrofits—Current (BAU)	10% reduction in building by 2014
Retrofits—Aggressive (Low)	McKinsey projections by 2025
CIB1 (BAU)	New buildings with average energy use intensity of comparable LEED certified buildings
CIB2 (Low)	New buildings with greatest reduction in energy use intensity of comparable LEED certified buildings
Electricity	
Electricity-1 (BAU)	Current projection of grid intensity reduction to 2015, maintained 2015–2050
Electricity-2 (High)	2010 grid intensity projected to 2050
Electricity-3 (Low)	Current projection of grid intensity reduction to 2015, carbon-free grid by 2050

BAU = business-as-usual; BEV = battery electric vehicles; HEV = hybrid electric vehicles; PHEV = plug-in hybrid electric vehicles; T—ICEV = turbo internal combustion engine vehicles; hydrogen fuel cell vehicles; LEED = Leadership in energy and environmental design.[1]Share of new vehicle sales in 2050.

technology adoption consistent with policy measures being applied by local and senior levels of government, through the development of sigmoidal (logistic) diffusion curves (Grubler, 1997). These diffusion curves capture components of technological adoption such as growing awareness of the technology and price decline due to increases in production (i.e. economies of scale; Grubler et al., 1999). A summary of the PURGE model's methodology is provided in Supplementary materials section S1. In this study, projections are applied to the Greater Toronto Area (GTA), a region that is representative of much of North America given that post-WWII infrastructure investments are a primary influence its urban landscape. Examples of post-WWII infrastructure in this case include suburban development with segregated land uses, which are dependent on extensive road networks to enable the automobile as the primary mode of transportation. The Greater Toronto Area is a 7150 km^2 region incorporating the City of Toronto (Canada's largest city), and four neighbouring jurisdictions. These jurisdictions partially act as commuter cities to Toronto and its central business district, but have also developed as economic centres in their own right. Characteristics such as low population density, high proportion of single-family dwellings and reliance on automobiles all present a significant challenge to GHG mitigation within the City of Toronto, and more prominently in these nearby regional municipalities.

The emission reduction gaps that low carbon technologies must bridge are expansive; Meinshausen et al. (2009) suggest that a peak CO_2e concentration of 450 ppm would likely limit warming to below 2 °C, avoiding some of the most severe consequences of climate change. To achieve this concentration, a policy target suggested by the Intergovernmental Panel on Climate Change (IPCC) states that Annex I nations (identified under the Kyoto Protocol) need to reduce their GHG emissions by 80–95% from a 1990 baseline by 2050 (IPCC, 2007). Our previous study of current energy and technology policies in the Greater Toronto Area (GTA; the region surrounding the C40 city; C40 Cities, 2011) examined expected GHG emissions reductions under a BAU scenario and found reduce emissions from 35 in 2010 to 24 Mt CO_2e by 2050, largely as a consequence of the decarbonizing of the provincial electricity grid (from 0.17 to 0.02 kg CO_2e/kW h; Mohareb and Kennedy, 2012a). More aggressive approaches must be taken in the major emitting sectors (transportation and buildings) in order to achieve the 80% reduction target by 2050, i.e. 7 Mt per annum (applying a 1990 baseline using Statistics Canada, 2006; Harvey, 1993).

This paper discusses the use of the PURGE model to examine a number of different mitigation scenarios that have been developed within the literature or from public data sources, allowing the exploration of urban emissions under possible alternative technology futures (Table 1). The scenarios assessed include the three largest sectors currently contributing to direct GHG emissions in the GTA (focusing on scope 1 and 2 emissions, neglecting emissions associated with materials, food, processing of fuel and exportation of wastes): private transportation, residential buildings and commercial/institutional (C/I) buildings. To provide context as to how much the building/transportation sectors contribute to regional GHG emissions, total emissions from the GTA from buildings, transportation (ground and aviation), industry (both process- and energy-related emissions), and waste in 2009 were estimated to be 54 Mt CO_2e, whereas the sectors assessed here are estimated to release 37 Mt CO_2e in 2010 using the PURGE model estimates (CivicAction, 2011). Further analysis of the impacts of specific technology transition pathways is provided by varying the underlying drivers of the dynamics of emissions (population and economic growth), as well as the electricity grid emission intensity that contributes to some upstream emissions. While some of the strategies provided below can be attributable to provincial or federal governments, they do not represent a comprehensive list of scenarios that these higher levels of government may take. However, these scenarios do capture programs (home energy retrofits, incentives for battery-based vehicle adoption, investment in public transit) that have been or are currently partially funded by the provincial and/or federal government.

2. Urban scenarios for GHG mitigation through technological change

Future GHG emissions from the GTA, and indeed all global cities, will greatly depend on three primary urban characteristics; population growth, economic growth and technology stock. Population growth stimulates demand for all sources of GHG emissions, especially energy services provided within the three main sectors (transportation, residential buildings and commercial/institutional buildings) of urban GHG emissions. While current GTA population