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Understanding energy systems change in Canada: 1. Decomposition of total energy intensity

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ABSTRACT

Between 1995 and 2010, the total energy intensity (E/GDP, PJ/Gross Domestic Product in 2002$) of the Canadian economy declined by 23% or −2.64 MJ/$. To understand why, the Logarithmic Mean Divisia Index (LMD-I) method was used to decompose a large body of government statistical data supporting the observed E/GDP decline. The analysis shows that (a) 48% (1.27 MJ/$) of the decline was associated with an inter-sector structural change in the economy (i.e. an increased contribution to the total GDP of the low energy-using commercial and institutional sector compared with the high energy-using manufacturing and heavy industry sectors); (b) 24% (0.62 MJ/$) was attributed to the impact of the Canadian GDP growing faster than population; (c) 22% (0.58 MJ/$) of the decline was associated with an overall decrease in business energy intensity. A deeper analysis of business sectors shows a positive impact of 0.4 MJ/$ from increased energy intensity in the oil and gas sector, offset by a 0.98 MJ/$ decline due to energy intensity declines in the other business sectors; (d) 6.3% (0.17 MJ/$) of the decline was associated with an improvement in the energy intensity of households, mostly from residential energy use rather than personal transportation energy use. These results provide insights for policy makers regarding those aspects of the Canadian economy that contribute to, or work against, efforts to transform energy systems toward sustainability.

1. Introduction

Canada's per capita greenhouse gas (GHG) emissions are amongst the highest in the world, and more than 80% of these emissions are linked to energy (E, synonymous with fuel and electricity in this document) production and use. Developing strategies to transform Canada's energy systems by reducing demand, improving efficiency or changing the source of fuel and electricity to lower GHG emissions would benefit from a detailed understanding of the trends and drivers that have defined past energy use.

When historical data for Canada (1981 to 2010) are used to calculate the Kaya factors (Kaya and Yokobori, 1993), the results (Fig. 1) reveal continuous growth in population (P) and per capita GDP, stable carbon intensity (GHG/E), but significant decline in the total energy intensity of the economy (E/GDP), particularly from the mid-1990's onward (Fig. 1B).

To put these changes in energy intensity within an international context we note that in 1995, Canada's total E/GDP ratio was about twice than that of European countries (OECD/IEA, 2011) and over the next 15 years, it declined by 24% or −2.64 MJ/$. In comparison, the total E/GDP of European countries declined by 18%, so the energy intensity of the Canadian economy in 2010 was still 1.9 times higher than in Europe (OECD/IEA, 2011).

To decompose Canada's total E/GDP change over the 1995–2010 period, the Logarithmic Mean Divisia Index–I (LMDI-I) method of Ang (2004) was applied to the database resource embedded in the Canadian Energy System Simulator (CanESS V6) model from whatIf? Technologies Inc., Ottawa. Index decomposition analysis was first developed by Divisia (1925) for application in economics and later adapted to energy analysis by Boyd et al. (1988). Early methods utilized arithmetic means and produced imperfect factorization and problematic second order residual terms with unclear physical meaning. The introduction of a logarithmic mean approach by Ang and Choi (1997) provided a method for decomposition to produce perfect factorization of energy trends, and LMDI-I is now the preferred approach for decomposition analysis of structural, efficiency and activity trends in energy and energy intensity analyses (Ang and Zhang, 2000; Ang and Liu, 2001; Ang, 2004; Ang et al., 2010).

A sizeable literature now exists in this field (see Su and Ang, 2012), focused on industrial energy use, including studies based on Canadian data (Torrie et al., 1989; Gardner, 1993; Nanduri et al., 2002; Palmer,

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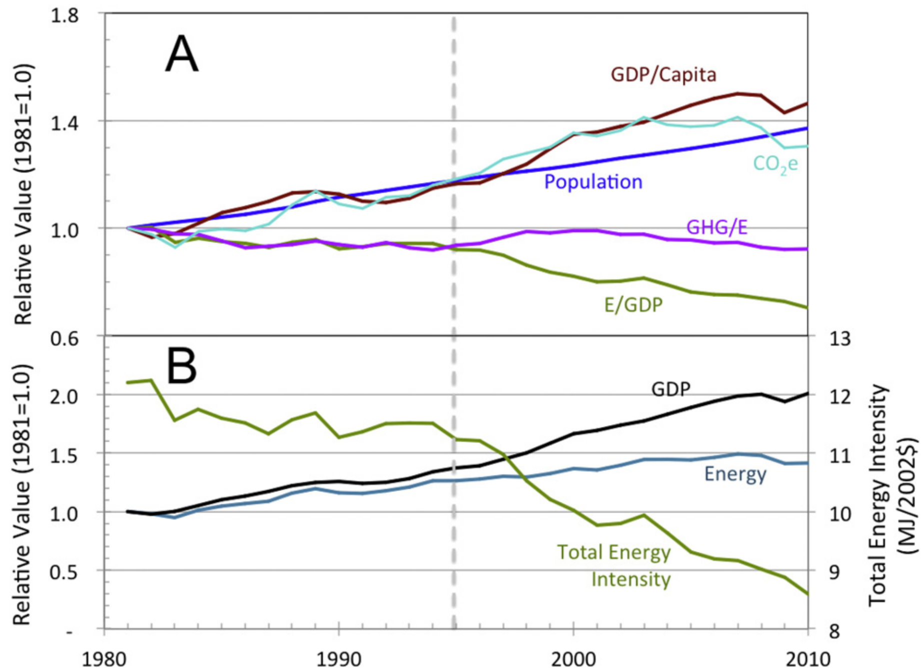

Fig. 1. A. Changes in Kaya factors for energy-based emissions in Canada, 1981–2010 where CO_2e [Mg] = Population [capita] × GDP/Population [$/capita] × Energy use/GDP [GJ/$] × GHG/Energy use [$MgCO_2e$/GJ]. B. The decoupling of GDP and energy growth after 1995.

2003; Bataille and Nyboer, 2005; Steenhoff and Weber, 2011; De Cian et al., 2013; Ang and Xu, 2013). The majority of these studies focus only on changes in energy use within the business sectors of the economy.

This work differs from previous decomposition analyses of Canadian energy use by (a) including all primary and secondary fuel and electricity use from both the business and household economies; (b) conducting separate decomposition analyses for the business economy energy use (on a per GDP basis) and the household economy energy use (on a per capita basis, linked to the comprehensive analysis by GDP/capita); (c) applying the decomposition analysis to the total Δ(E/GDP) values rather than changes in energy use, and (d) generating a one-to-one correspondence between GDP and E values that produces decomposition factors which sum exactly to the total Δ(E/GDP). The goal was to generate a comprehensive and internally-consistent factorization of the Δ(E/GDP) for the Canadian economy over the 1995–2010 period.

2. Methodology

2.1. Data sources

The population, economic (GDP) and energy data used for this analysis are from CANSIM (2015), the main socio-economic statistical database maintained by the Government of Canada. CANSIM employs the North American Industry Classification System (NAICS) that facilitates the pairing of energy and economic data sets. For GDP and population data, CANSIM was accessed directly, but for the energy data we rely on the Canadian Energy Systems Simulator (CanESS, Version 6.0) from whatIf? Technologies Inc. (Ottawa, ON). CanESS uses CANSIM energy data to develop a detailed, historical calibration of Canadian fuel and electricity production and consumption by province, fuel source and sector. CanESS also draws on specialized information from various sources for energy consumption by sub-sector and end-use. For the industrial sectors, we also make use of the CIEEDAC Database on Energy, Production and Intensity Indicators for Canadian Industry (CIEEDAC, 2015).

2.2. Sectoral classification of E and GDP data

For these calculations, a data set is required that contains annual data for 1995 to 2010 for energy use by each of the business economy as well as for the household economy. To achieve this comprehensive coverage, total energy use (E) is separated into that portion directly associated with producing the goods and services that comprise GDP (i.e. the business economy, E_B) and that portion associated with residential and personal transportation (i.e. the household economy, E_H) such that:

$$E = E_B + E_H \tag{1}$$

$$\text{with } E_B = \sum_i E_i \tag{2}$$

$$\text{and } E_H = E_{Res} + E_{PT} \tag{3}$$

where;

i is an index representing sectors of the business economy (defined in Table 1),
E_{Res} is residential fuel and electricity consumption, and
E_{PT} is personal transportation energy consumption.

As shown in Table 1A, the sector definitions for the business economy reflect well-defined industries (e.g. oil and gas, electric power) or a group of activities with similar E/GDP ratios (e.g. energy intensive industry, commercial and institutional buildings). The sector definitions also allow a one-to-one mapping of national energy and economic databases at the level of the six defined sectors so that individual sector E_i/GDP_i values can be calculated for each year over the study period.

The result is a partitioning of total E/GDP for Canada into two additive components that form the basis for our decompositional analysis:

$$\frac{E_B}{GDP} = \sum_i \left[\frac{GDP_i}{GDP} \times \frac{E_i}{GDP_i}\right] = \sum_i S_i I_i \tag{4}$$