Energy Conversion and Management 156 (2018) 178–191

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Mapping Canadian energy flow from primary fuel to end use

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ARTICLE INFO

Keywords:
Energy flow
Sankey diagrams
Primary energy
End use energy
Demand sectors
Canada

ABSTRACT

This paper interprets the energy flow from available primary fuel to end use in all of the provinces and territories in Canada for the year 2012 using Sankey diagrams. These flow charts illustrate energy production, imports, exports, and local consumption by economic sector, and quantify the amount of useful and rejected energy. The inflow and outflow values could help determine existing energy efficiencies and energy intensity improvement potential. The total energy available in the energy flow path for all of the provinces and territories is 27,494 PJ including imports. The diagrams clearly indicate that fossil fuels dominate Canada's energy mix. Approximately 99% of the fuel in Alberta came from fossil sources in 2012 and approximately 76% of Canada's energy came from fossil sources. Alberta produced the highest amount of available energy in Canada (11,986 PJ); the lowest came from the territories (72.7 PJ). Among the non-fossil generation, hydro-electricity dominated, followed by nuclear, wind, and biomass, respectively. The overall share of thermal-based generation (fossil-fuel, nuclear, and biomass) was found to be 37.1% of Canada's produced electricity (2,222 PJ) in 2012. An analysis of rejected and useful energy indicated that the transport sector showed the poorest energy efficiency. This pictorial view of energy flow could help policy makers set targets for improving energy efficiency, select strategies for the reduction of greenhouse gases emissions, and help satisfy the vast global climate change challenges.

1. Introduction

The energy sector contributes to all socio-economic development indicators that enhance government revenues and improves lifestyles in both developing and industrialized countries. However, the energy sector also contributes to the environmental footprint in that it emits greenhouse gases (GHGs) [1]. Fossil energy is used in excess to satisfy rapid global growth [2]. Global energy sources mainly consist of solid and liquid fossils [3]. Fossil-based energy emits GHGs, which leads to global warming. Increasing the penetration of energy efficient technology could reduce GHG emissions by up to 50% by the year 2030 [4]. Increasing economic growth with less energy use and fewer GHG emissions is becoming more prevalent around the world [5]. For instance, China consumes the most energy and releases the most carbon dioxide of any country [6]. Recent work by Huang et al. [7] identifies determining factors behind China's overall energy intensity and Zhang et al. [8] identifies industrial carbon emission intensity reduction pathways. Additionally, in Denmark, primary energy demand decreased by 0.6% between 1990 and 2010 and final energy consumption increased by 4.9% due to the implementation of energy efficiency improvement programs [9]. A detailed understanding of energy demand and supply flow is required in order to design and implement such a program. Therefore, it is important to study energy flows in different ways and different sectors in a system.

Canada has the largest hydrocarbon base in North America and is at the upper ranking of energy production and exports irrespective to all types of energy. For example, crude oils and natural gas are 5th and 4th, respectively, in production and export in the world market; uranium is 2nd both in production and export in the world market; and hydroelectricity and biofuel are 3rd and 5th, respectively, in production in the world [10]. Canada has allocated $195 million under the ecoENERGY Efficiency program over five years [11]. In Canada, energy consumption increased by about 23% over the last two decades [12]. Canada's energy expenditure is largely in the residential, commercial, and industrial sectors. About $152 billion was spent on energy to operate heating and cooling devices, appliances, cars, and industrial processes in 2009. This is equivalent to about 11% of the country's GDP [13].

Canada has a complex energy flow. Energy production, local consumption, and inter-provincial and international exports and imports are common in Canada. The residential, commercial and institutional, industrial, transportation and agriculture sectors are all energy demand sectors. Canada's energy consumption in 2012 was 8735 PJ. The industrial sector consumed the largest share of end use energy (38.38%), followed by transport (29.65%), residential (16.70%), commercial and institutional (12.24%), and agriculture (3.03%). The energy used by

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https://doi.org/10.1016/j.enconman.2017.11.012
Received 16 August 2017; Received in revised form 1 November 2017; Accepted 4 November 2017

Nomenclature

BC	British Columbia
GHG	greenhouse gas
GDP	gross domestic product
CO_2	carbon dioxide
PJ	petajoule
HVAC	heating, ventilation and air conditioning
U.S.	United States
U.K.	United Kingdom
CANSIM	Canadian socio-economic information management
CHP	combined heat and power
NGL	natural gas liquids
NG	natural gas
NFL	Newfoundland and Labrador
NS	Nova Scotia
NB	New Brunswick
PEI	Prince Edward Island

these five sectors emitted 473.4 million tonnes (CO_2 equivalent) of GHGs in 2012 [12], of a total 699 million tonnes (CO_2 equivalent) that year [10]. The total fossil fuel production was 16,459 PJ in 2012; the major forms of fossil fuels are crude oil (47.6%) and natural gas (38.7%). Coal and natural gas liquids contributed 9.6% and 4.0%, respectively, of the fossil fuel supply in 2012. As energy consumption increases, GHG emissions from fossil fuel production have also increased and went up by 10% between 2005 and 2012 [10]. Net GHG emissions increased by 36%, 29%, and 8% in the transportation, commercial/institutional, and industrial sectors, respectively, between 2005 and 2009 [13].

In December 2015, Canada committed to the Paris Agreement, which included a commitment to restrict the global average temperature increase to below 2 °C over pre-industrial levels. This is a significant challenge in and of itself, and its complexity is compounded by Canada's massive economic growth, which is projected to be approximately 32% higher in 2020 than it was in 2005 [14]. In order to meet these commitments by the target dates, Canada must consider the rational use of energy in a timely manner, especially as the energy sector is a key part of Canada's economy. Energy use in Canada has become more efficient over time, but energy consumption has simultaneously increased. Hence, it is necessary to understand energy flow from primary fuel to end use in different sectors.

Canada is composed of 13 regions: 10 provinces and 3 territories. A map of Canada with its regions is shown in Fig. 1. Each region has an independent and unique energy system that is explored in this paper. Table 1 compares the population and GDP for each region in 2012. Ontario and Quebec are the most populous provinces in Canada with 38.6% and 23.3% of the national population, respectively. Ontario and Quebec are also the most economically active with 39% and 17% of the 2012 national GDP, respectively. The eastern provinces Newfoundland and Labrador (NFL), Prince Edward Island (PEI), Nova Scotia (NS), and New Brunswick (NB) make up Atlantic Canada. The combined population and GDP of the Atlantic provinces contributed 6.8% and 5.7% to the Canadian total in 2012, respectively. The western provinces British Columbia (BC), Alberta, and Saskatchewan have the largest GDP/

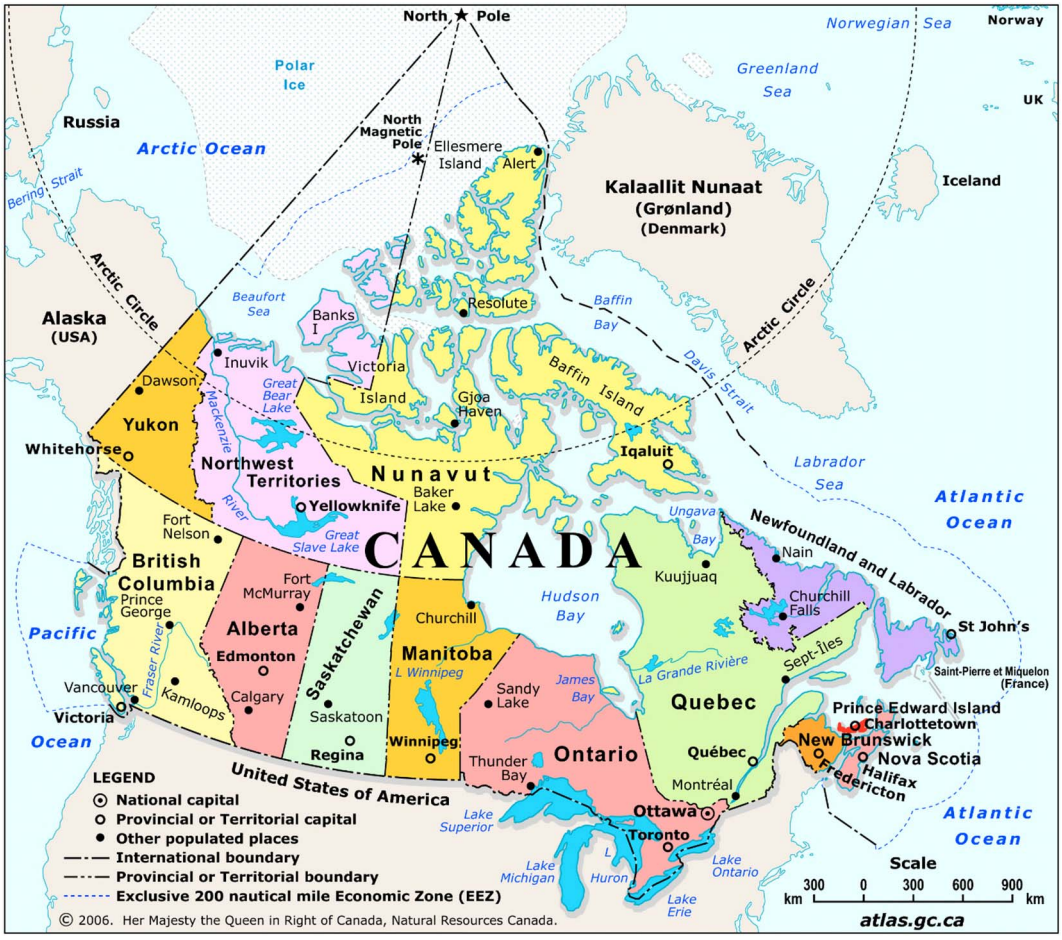

Fig. 1. Provincial and territorial map of Canada (contains information licensed under the Open Government License – Canada) [17].