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Energy and greenhouse gas emissions review for Macao

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ABSTRACT

Although Macao is one of the individual members of the Kyoto Protocol, a holistic picture to draw its energy consumption and GHG emissions has been lacking. A comprehensive review of energy consumption as well as GHG emissions is presented in this study for Macao since the handover of sovereignty to China. The results show that the Macao's energy consumption and its related GHG emissions were 32,700 Terajoules (Tj) and 3.70E+06 t CO_2 e. in 2010, increased by 31.10% and 100.34% over those of 2000, respectively. The results also indicate that electricity is the biggest contributor to GHG emissions, and induced a large amount of GHG emissions in other places. Energy intensity and per capita GHG emission also witnessed growth from 2000 to 2010. In terms of sectors of the economy, the service industry, commerce, restaurants and hotels, transportation and households are the leading four energy users and GHG emission inducers. Our analysis also suggests that decision-makers should take indirect emissions from energy consumption into consideration to support Macao's energy, climate and sustainability initiatives.

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Contents

1. Introduction . . . 23
2. Methodology and data sources . . . 25
   2.1. Fuel energy consumption . . . 25
   2.2. Electricity consumption . . . 25
   2.3. GHG emissions from sectoral energy consumption . . . 25
3. Review of Macao's energy consumption 2000–2010 . . . 26
   3.1. Fuel energy consumption . . . 26
   3.2. Electricity consumption . . . 26
   3.3. Sectoral energy consumption . . . 27
   3.4. Total energy consumption and per capita energy consumption . . . 27
4. Results . . . 28
   4.1. The GHG emissions of fuel energy consumption . . . 28
   4.2. The GHG emissions of electricity consumption . . . 28
   4.3. GHG emissions from sectoral energy consumption . . . 29
   4.4. Total and per capita emissions . . . 29
5. Discussion . . . 30
6. Concluding remarks . . . 31
Acknowledgement . . . 31
References . . . 31

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1. Introduction

Cities are characterized by compact settlements and modern lifestyles [1]. As centers of population, manufacturing, commerce, construction and service industries, cities' prosperity and development demand large amounts of energy. International Energy Agency [2] estimated that cities account for 67% of energy consumption worldwide, a figure which is expected to rise, given that cities will host 60% of world's population by 2030. In China, cities are responsible for 75% of total energy consumption and 84% of commercial energy consumption [3]. As the trend of urbanization continues, cities are expected to consume more energy [4–6].

A price has to be paid, however, for the benefits of city life. People living in the cities have witnessed environmental degradation directly related to extensive consumption of energy, from major sources such as fossil fuels. Besides air pollutants which are harmful to people's health, urban energy consumption releases large amount of greenhouse gases (GHG) into atmosphere, which have significantly impacted global climate [7,8]. It is recognized that GHG emissions from cities dominate global anthropogenic GHG emissions, mainly driven by energy consumption [9,10]. According to The-Climate-Group [11], cities have already contributed 75% of the current global GHG emissions. Within China, cities emitted 85% of energy-related CO_2 emissions in 2006 [2]. As the rapid urbanization is still ongoing, energy and GHG emissions issues will continue to be the greatest challenges to cities' development and sustainability. Consequently, cities are assumed to take major responsibility for energy conservation and GHG emissions reduction. To achieve this goal, it is crucial to take actions to implement urban energy strategies and emission mitigation policies.

Considering the great importance of energy-related GHG emissions from cities, many efforts have been made in both political and academic fields to reduce cities' energy-related emissions. As cities become focal points for GHG mitigation, international organizations, such as Cities for Climate Change Protection, the C40 Cities Climate Leadership Group, ICLEI–Local Governments and the Climate Summit for Mayors, are seeking strategies which might promote both development and sustainability [12,13]. In addition, a number of researchers have already developed methodologies to calculate some cities' energy-related GHG emissions [3–6,9,14–24], which have helped policy makers to implement efficient energy policy to curb city's GHG emissions. However, because cities' characteristics and economic structures are so different from one to another, it is impossible that one specific city's energy and emission reduction strategies would be suitable in all situations [5]. In order to effectively guide one specific city's energy and GHG mitigation plans, a comprehensive study of this individual city's energy consumption and its related GHG emissions is needed.

Macao, one of the two special administrative regions of the People's Republic of China, is located in the Pearl River Delta, with an area of 29.7 km^2 and with a population of 544.6 thousand, as one of the most densely populated regions in the world [25]. The climate in Macao is typical humid subtropical, with a mean air temperature of 22.7 °C, average relative humidity between 75% and 90%, and average annual rainfall of 2120 mm [26]. Macao is one of the most important gaming centers across the world. With more than 400 years of development, the service industry such as gaming industry and the associated hospitality services have now become the backbone of Macao's economy. Benefitting from the boom in casinos, Macao has been experiencing spectacular economic growth since the handover of sovereignty to China on December 20th, 1999. Macao's gross domestic product (GDP) increased from 71.1 billion Patacas (MOP) in 2000 to 214.9 billion MOP in 2010 [25], equaling 33.5 billion US dollars and 75.0 billion US dollars, respectively. The annualized GDP per capita in Macao also increased from 20,568 US dollars in 2000 to 49,199 US dollars at the end of 2010 [25], which was even higher than that of Hong Kong [27]. The fast pace of Macao's economic growth resulted in a rapid increase in energy use (and thus GHG emissions). Although there have been several studies analyzing Macao's energy-related GHG emissions [28–31], they are limited to reflect overall GHG emissions from Macao's energy consumption. First, these studies only take into account only one or a few energy products, which do not reflect the complete scope of Macao's energy consumption. Second, almost all of these studies only focus on direct emissions and do not include indirect emissions. In addition, as a special administrative region, calculation of Macao's GHG emissions is an indispensable part of the whole nation's emission reduction action. However, a comprehensive and detailed analysis of energy consumption and its related GHG emissions in a time series is still lacking. As the economy as well as the population is expected to continue to grow in the near future [31], Macao has to face greater pressure on energy security and GHG abatement. As a consequence, evaluation and investigation of Macao's energy consumption and its related GHG emissions is vital for developing Macao's energy and GHG reduction plans.

Therefore, this paper aims to draw a full picture of energy consumption and estimate related GHG emissions from 2000 to 2010 in Macao, using the latest data. This paper also outlines the underlying factors that have an effect on Macao's energy consumption and GHG emissions. To our knowledge, this is the first review on energy consumption as well as comprehensive accounting for energy-related GHG emissions for Macao. The results presented in this study could be used as a reference to understand energy consumption and its related GHG emissions for cities. The rest of this paper is organized as follows: Section 2 describes the methodology and data sources used in this paper;

Table 1
GHG emission factors of different fuel types.

Fuel energy	Direct emission factors				Indirect emission factors[c]
	CO_2[a] Unit: kg/Tj	CH_4[a]	N_2O[a]	GWP[b] Unit: t CO_2 e./Tj	GWP Unit: t CO_2 e./Tj
Gasoline	69,300	3	0.6	69.5	10.7
Kerosene	71,900	3	0.6	72.1	12.7
Gas oil and diesel	74,100	3	0.6	74.3	10.7
Fuel oil	77,400	3	0.6	77.6	10.1
Liquefied petroleum gas	631,00	1	0.1	63.2	11.0
Traditional fuels	112,000	1	1.5	112.3	77.9
Natural gas	56,100	1	0.1	56.2	20.9

[a] *Source*: IPCC [32].
[b] *Source*: GHG emission factors are calculated by using GWP in this paper, based on the emission factors given by IPCC [32].
[c] *Source*: Derived from Lai [40].

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