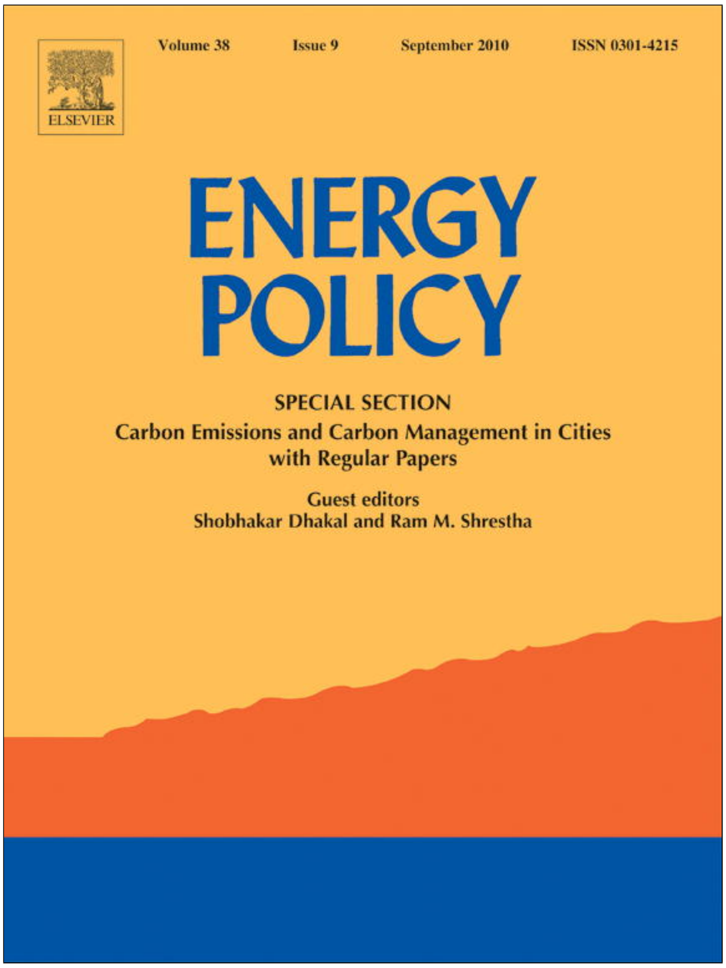
Volume 38
Issue 9
September 2010
ISSN 0301-4215
ELSEVIER
ENERGY POLICY
SPECIAL SECTION
Carbon Emissions and Carbon Management in Cities
with Regular Papers
Guest editors
Shobhakar Dhakal and Ram M. Shrestha

Energy Policy 38 (2010) 5123–5132

Contents lists available at ScienceDirect

Energy Policy

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

Evaluating the effectiveness of urban energy conservation and GHG mitigation measures: The case of Xiamen city, China

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ARTICLE INFO

Article history:
Received 23 February 2010
Accepted 21 April 2010
Available online 20 May 2010

Keywords:
GHG emissions
Policy measure
Scenario analysis

ABSTRACT

To assess the effectiveness of urban energy conservation and GHG mitigation measures, a detailed Long-range Energy Alternatives Planning (LEAP) model is developed and applied to analyze the future trends of energy demand and GHG emissions in Xiamen city. Two scenarios have been designed to describe the future energy strategies in relation to the development of Xiamen city. The 'Business as Usual' scenario assumes that the government will do nothing to influence the long-term trends of urban energy demand. An 'Integrated' scenario, on the other hand, is generated to assess the cumulative impact of a series of available reduction measures: clean energy substitution, industrial energy conservation, combined heat and power generation, energy conservation in building, motor vehicle control, and new and renewable energy development and utilization. The reduction potentials in energy consumption and GHG emissions are estimated for a time span of 2007–2020 under these different scenarios. The calculation results in Xiamen show that the clean energy substitution measure is the most effective in terms of energy saving and GHG emissions mitigation, while the industrial sector has the largest abatement potential.

1. Introduction

Energy consumption is the major contributor to the rising concentrations of greenhouse gases in the earth's atmosphere (IPCC, 2006, 2007), which in turn is resulting in climate change with significant negative impacts on both natural and socio-economic systems (Parks, 2009; Roger et al., 2008; Solomon et al., 2009). In addition, cities, with their high concentrations of both population and economic activities, have become the hot spots for energy demand and GHG emissions. Currently more than half of the world population lives in cities, and this population shift is increasing. Cities are estimated to account for about 75% of the global total GHG emissions (The-Climate-Group, 2009). In China, the 35 largest cities contain 18% of the population, and compose 40% of China's energy uses and CO_2 emissions (Dhakal, 2009). With the importance of energy-related GHG releases from cities, many governments and organizations are seeking measures to reduce these emissions, and cities are becoming the loci for innovative solutions (Bai, 2007a, 2007b; Grimm et al., 2008; Kennedy et al., 2009). A better understanding of the effectiveness of city-level measures will help devise a much needed integrated management framework, as well as to design and implement policies for addressing urban development, energy, and climate-change concerns collectively (Clinton et al., 2005; Kadian et al., 2007; Schmidt and Helme, 2005; WRI, 2005).

Policy changes are easier when the impacts of various measures can be properly quantified and analyzed (Dhakal, 2009; Yan and Crookes, 2009). Several energy-modeling approaches have been used to analyze the future trends of energy demand and GHG emissions and to develop GHG-reduction strategies; these can be categorized into three types: top-down, bottom-up, and hybrid models (Bohringer and Rutherford, 2009; Lin and Huang, 2009; Turton, 2008). Babiker developed a multi-regional general equilibrium model for climate policy analysis based on the MIT Emissions Prediction and Policy Analysis (EPPA) model (Babiker et al., 2009). Bollen performed an integrated assessment of the long-term conundrum of climate-change mitigation and the short-term challenge of reducing local air pollution using the MERGE model (Bollen et al., 2009). Strachan used the MARKAL model to discuss the iterative provision of modeling insights on long-term decarbonisation scenarios for UK energy policy makers (Strachan et al., 2009). MARKAL has also been applied to analyze energy systems and GHG reduction scenarios in many other works (Contaldi et al., 2007; Cosmi et al., 2009; Kannan and Strachan, 2009). Liu used the MESSAGE model to analyze the trends of new key power-generation technologies

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doi:10.1016/j.enpol.2010.04.042

and their contributions to GHG mitigation in China (Liu et al., 2009). The EPPA and MERGE models are widely-used top-down models and the MARKAL and MESSAGE belong to bottom-up. Top-down models examine the broader economy and incorporate feedback effects between different markets triggered by policy-induced changes in relative prices and incomes, but they typically do not provide technological details of energy production or conversion. Bottom-up models describe current and prospective technologies in detail, so they are well suited to the analysis of specific changes in technology or command-and-control policies such as efficiency standards (Bohringer and Rutherford, 2009).

The Long-range Energy Alternatives Planning system (LEAP) is a bottom-up scenario-based energy/environment modeling tool. With a flexible data structure, LEAP allows for an analysis rich in technological specifications and end-use details that allows the user many choices in setting parameters (SEI, 2006; UNFCCC, 2008). It is widely used to project energy supply and demand situations, in order to forecast future patterns, identify potential problems, and assess the likely impacts of energy policies on various areas at the local, national, and global scales. Huang and Lee used the LEAP model for estimating the future trends for energy-related carbon dioxide emissions, and then evaluated potential problems with the 2006 Greenhouse Gas (GHG) Reduction Bill for Taiwan (Huang and Lee, 2009). Cai employed the LEAP model to study the emissions reduction potential and mitigation opportunities in the major five emission sectors in China (Cai et al., 2008). Zhang used LEAP to evaluate the impact of several energy efficiency and environmental abatement policy initiatives in reducing the total energy requirements and external costs of electricity generation in China under various scenarios (Zhang et al., 2007). Kadian applied the LEAP system for modeling the total energy consumption and associated emissions from the household sector of Delhi (Kadian et al., 2007). However, there are few works using LEAP to comprehensively evaluate the efficiency of city-level policies and measures aimed at reducing energy demand and GHG emissions, which cover all urban sectors (Dhakal, 2004; Kadian, 2007; Kadian et al., 2007).

This study consists of five steps: (a) collecting information on local urban policies and measurements; (b) designing the corresponding scenarios; (c) constructing and applying the LEAP model to generate and analyze a reliable future trend of energy demands and GHG emissions in the Xiamen city area from 2007 to 2020, under several different scenarios; (d) assessing the effectiveness of various measures aimed at energy savings and GHG emission reductions; and finally (e) discussing implementation of current measures, future reduction measures, and implications for other cities. The results can provide valuable input for Xiamen's future energy planning and policy making, and it may provide some general insights on the effectiveness of urban-level energy conservation and GHG reduction for other cities as well.

2. Methodology

2.1. *The principles for calculating reduction potentials*

LEAP is a scenario/energy simulation model, which can provide a platform for structuring data, developing energy balances, projecting demand and supply scenarios, estimating associated emissions and evaluating alternative policies (Huang and Lee, 2009; SEI, 2006). With a powerful accounting ability, it can describe in detail how energy is consumed, converted, and produced in a given region or economy under a range of alternative assumptions for population, economic development, technology, price, etc. Furthermore, through comparing the results derived under different scenarios, the energy-saving potential and the CO_2 reduction potential under different scenarios in a specific target year or period can be obtained. In this study we focus on assessing the effectiveness of local control measures at the city scale. The calculation process, based on LEAP, consists of three parts: identification of energy consumption trends, estimation of greenhouse gas emissions, and estimation of energy savings potential. The analytical procedure in the LEAP model is described in Fig. 1. In this process, the baseline scenario (business as usual) and the integrated scenario are considered, which correspond to different control policies and measures, respectively. The total energy consumption and greenhouse gas emissions for both scenarios are calculated, and the potential energy savings and emission reductions are derived by comparing the results of the two scenarios.

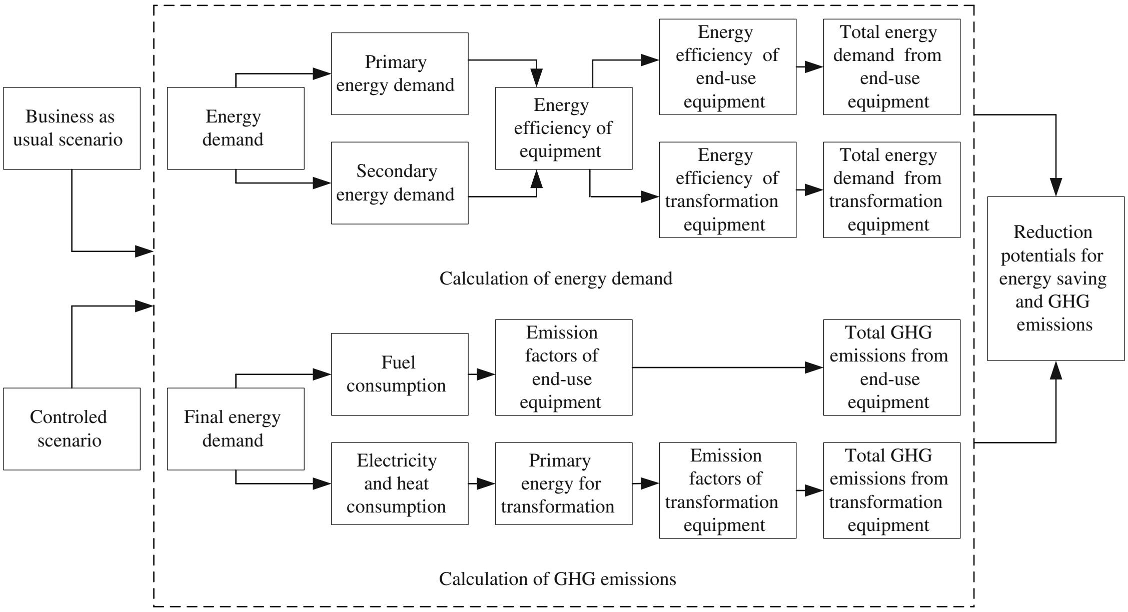

Fig. 1. Research processes based on the LEAP model.

2.2. Calculation of energy consumption

Total energy consumption includes total final energy demand and energy transformation, but since the calculation methods are different for demand versus transformation, these methods will be introduced separately.

Energy demand can be calculated by the following expression:

$$ED_k = \sum_i \sum_j AL_{k,j,i} \times EI_{k,j,i} \tag{1}$$

where ED is the total energy demand, AL is the activity level, EI is the energy intensity, i is the sector, j is the device/vehicle, and k is the fuel type. Differing equipment compositions in different scenarios will result in various AL and EI, thereby reflecting the changes in energy demand.

Net energy consumption for transformation can be expressed as follows:

$$ET_m = \sum_n \sum_t ETP_{n,t} \times (e_{m,n,t} - 1) \tag{2}$$

where ET is the net energy consumption for transformation, ETP is the energy transformation product, m is the type of primary energy, n is the equipment, t is the type of secondary energy, and $e_{m,n,t}$ is the energy consumption of fuel type m to produce unit secondary fuel type t in equipment n. Differing equipment compositions in different scenarios will result in various ETP and $e_{m,n,t}$, which then reflect the changes in energy demand.

2.3. Model adjustment

China's statistical method employs the energy equivalent value (energy equivalent value means how much standard coal or oil is need to burn in order to produce unit electricity under the current technological situation.) during the calculation of the import electricity at the national, provincial, and urban levels (Guan, 2009), while the LEAP model employs the energy calorific value during the calculation of the import electricity. We have made the following adjustment to the model to incorporate the differences.

Total energy consumption is calculated as follows:

$$TEC = \sum_k ED_k + \sum_m ET_m + EI \times (e_{electricty} - 0.086) \tag{3}$$

where TEC is the regional energy consumption, ED is the total energy demand, ET is the total energy transformation, EI is the import electricity, and $e_{electricity}$ is the energy consumption of standard oil per kWh of electricity.

2.4. Calculation of GHG emissions

As energy consumption includes both energy demand and energy transformation, the GHG emissions also have two parts: emissions from energy demand and emissions from transformation.

The GHG emissions from energy demand can be calculated as follows:

$$ED\,Emission = \sum_i \sum_j \sum_k AL_{k,j,i} \times EI_{k,j,i} \times EF_{k,j,i} \tag{4}$$

where $ED\,Emission$ is the GHG emissions, $EF_{k,j,i}$ is the GHG emission factor from fuel type k through equipment j from sector i, and $EF_{k,j,i}$ is drawn from statistics, the LEAP technical database and previous research.

The GHG emissions from energy transformation are calculated as follows:

$$ET\,Emission = \sum_m \sum_n \sum_t ETP_{n,t} \times e_{m,n,t} \times EF_{m,n,t} \tag{5}$$

where $ET\,Emission$ is the GHG emissions, ETP is the energy transformation product, $EF_{m,n,t}$ is the emissions factor of producing unit secondary fuel type t from fuel type m through equipment n, and $EF_{m,n,t}$ is drawn from statistics, the LEAP technical database and national standards. The calorific values and emission factors data used in this study are given in Table 1.

Table 1
Calorific values and emission factors of fuels.

Fuel type	Calorific value[a]	GHG emission rate[b] (tC/TJ)
Coal	20,934 kJ/kg	98.2
Crude oil	41,868 kJ/kg	73.28
Gasoline	43,124 kJ/kg	69.2
Diesel	42,705 kJ/kg	74.0
Fuel oil	41,868 kJ/kg	77.3
LPG	47,472 kJ/kg	63.0
Natural gas	35.588 kJ/m^3	56.8

[a] Calorific values are from 'General calculation principles for total production energy consumption (GB/T-2589-2008)' (in Chinese).

[b] Emission factors are extracted from the Technology and Environmental Database (TED) in LEAP. Referring to the Kyoto Protocol, GHG includes Carbon dioxide, nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride and other major GHGs.

3. Case study

3.1. Study area and data use

Xiamen is a coastal sub-provincial city in southeastern Fujian province, P.R. China (longitude 118°04′04″E, latitude 24°26′46″N). It is one of China's earliest Special Economic Zones, designated in the 1980s. It covers an area of 1 652 km^2 with a total population of 2.43 million in 2007. Xiamen has experienced rapid economic development since 1980. Its regional GDP reached 138.785 billion yuan in 2007, up from 1.72 billion yuan (comparable GDP value) in 1980, with an average annual increase of 17.66%. The urbanization ratio also rapidly increased, from 35% in 1980 to 68.2% in 2007. The rapid economic growth and urbanization have resulted in rising energy consumption in Xiamen city, and its total electricity consumption reached 11.88788 billion kWh in 2007, up from 235.89 million kWh in 1980. To achieve energy savings and emission reduction targets, Xiamen city has adopted a series of countermeasures and polices. In 2009, it became one of the first ten pilot cities of the 'COOLCHINA-2009 civil low-carbon action pilot project'. This makes Xiamen city a particularly interesting case for the analysis of energy savings and emission reduction potentials.

The data used in this study are from three sources: the Statistical Yearbook of Xiamen, the comprehensive urban planning and special sector planning documents, and the government departmental survey data. The basic social and economic data were obtained from the Statistical Yearbook of the Xiamen Special Economic Zone (SYXSEZ, 1999–2008). Xiamen city's 11th 5-year plan, the Master plan of Xiamen (2004–2020), the Comprehensive Transportation Plan of Xiamen (2006–2020), and the Xiamen Transportation, Postal Service and Telecommunications Annual Report (1999–2008) were also important data sources. In addition, energy consumption data for electricity, coal, gasoline, diesel, fuel oil, LPG, natural gas, and crude oil were obtained from the Xiamen Development and Reform Commission, the Economic Development Bureau of Xiamen, the Fujian Electronic Power Company Limited, the Xiamen Municipal Works and Municipal Gardens Administration Bureau, the Xiamen Statistical Bureau, the Xiamen Transportation Bureau, the Urban Planning Bureau of Xiamen and the Xiamen Vehicles Administration Center.

3.2. Model structure and basic assumptions

The LEAP-Xiamen model developed in this paper considers both the energy consumption sector and the energy transformation sector, covering all the primary and secondary energies used in Xiamen. The time span of the analysis was 2007–2020, with 2007 as the baseline year. The model scenarios were designed to include the following six aspects reflecting Xiamen's relevant policies, planning and management measures: clean energy substitution, industrial energy conservation, combined heat and power generation, energy conservation in buildings, motor vehicle control, and new and renewable energy utilization.

Four end-use sectors are included in the model: the household sector, the industrial sector, the transport sector, and the commerce sector. Each sector includes corresponding sub-sectors, end-use sectors, energy-using devices, and fuel types. The energy conversion system comprises three sectors: transmission and distribution, electricity generation, and combined heat and power generation. Electricity generation consist of thermal power, hydropower, LNG combustion power, solar power, and garbage incineration.

The key assumption variables in the LEAP-Xiamen model, such as population, population growth, number of households, family size, regional gross domestic product (GDP), and GDP growth rate, are listed in Table 2. In addition, we assume Xiamen's economic growth rate will be sustained at a constant level during the scenario period (2007–2020), similar to what it has been in the past two decades.

3.3. Scenario design

Scenarios are self-consistent story lines of how a future energy system might evolve over time under a particular set of conditions (Kadian et al., 2007). The scenarios in LEAP are generated to encompass any factor that is anticipated to change over time. In order to analyze possible effects of series policies for energy savings and emissions mitigation, two scenarios were set up: the business as usual (BAU) scenario and the integrated (INT) scenario. The key assumption in the BAU scenario is that no measures will be implemented during the scenario period to reduce energy demand or GHG emissions in Xiamen city. Hence the BAU scenario provides a reference vision of how energy demand and GHG emissions in Xiamen would evolve if the Xiamen government does nothing to influence long-term trends.

In the INT scenario, a series of policies and measures aimed at reducing total energy demand and GHG emissions in Xiamen city were assumed to have been implemented. These measures include those already implemented in Xiamen before 2007, those going to be implemented according to government's plan and those that are highly likely to be adopted because of successful implementation elsewhere. The INT scenario were developed in the LEAP-Xiamen model under different sets of options—the clean energy substitution (CES) measure, the industrial energy conservation (IEC) measure, the combined heat and power generation (CHP) measure, the energy conservation in buildings (ECB) measure, the motor vehicle control (MVC) measure, and the new and renewable energy utilization (NRE) measure. The set of conditions is detailed in the respective measures, and the policy options and assumptions in the different measures, are given in Tables 3 and 4.

Table 2
The basic assumptions for key variables for the LEAP-Xiamen model.

Key variables	2007[a]	2010	2015	2020
Population[b] (millions)	2.43	2.61	2.95	3.33
Population growth rate[c] (%)	2.46	2.46	2.46	2.46
Size of households[d] (Persons)	3	3	3	3
Number of households[e] (millions)	0.81	0.87	0.98	1.11
GDP (billions of yuan)[f]	138.785	213.67	376.57	606.46
Growth rate of GDP[g] (%)	15.47	12	10	10

[a] The key variables are from the Xiamen Special Economic Zone 2008, except for size of household.

[b] The population used in this paper is the resident population.

[c] Population growth rate includes natural growth rate and mechanical growth rate; 2.46 was the average annual population growth rate during 1998–2007.

[d] The household size is set to 3 people for simplicity.

[e] The total resident population divided by the household size is the number of households.

[f] The GDP of Xiamen increases by the growth rate.

[g] The GDP growth rates for different time periods are assigned based on the 11th Five-Year Development Program for Xiamen and the 2004–2020's integrated planning for Xiamen.

4. Results and discussion

4.1. Energy consumption

Based on the assumptions of socio-economic development in Xiamen and the various parameters for scenarios in the LEAP-Xiamen model, the total energy consumption for the BAU and INT scenarios during the period 2007–2020 are shown in Fig. 2. The total energy consumption under the BAU scenario increases from 5.92 million tons of oil equivalents in 2007 to 21.65 million tons of oil equivalents in 2020, with an annual growth rate of 10.5%. Under the INT scenario, the energy consumption in 2020 is 18.41 million tons of oil equivalents, with a 9.13% annual growth rate. The series of energy-saving and emission-reduction policies and measures have the effect of suppressing the growth of total energy consumption by 1.35% annually.

According to the energy intensity calculated in Table 5, the energy consumption intensity was 0.4268 toe/10,000 yuan in 2007, and it will reach 0.3569 toe/10,000 yuan and 0.3035 toe/10,000 yuan in 2020 for the BAU and INT scenarios, respectively. The energy intensity decreases annually by 1.37% in the BAU scenario, by 2.59% in the INT scenario. In the BAU scenario, the drop in energy intensity is caused mainly by scientific and technological progress and by increases in production efficiency. In the INT scenario, the series of energy-saving and emission-reduction policies and measures is the most important method of decreasing the energy intensity. The end point difference in energy efficiency, between the two scenarios, would be about 1.22%.

4.2. GHG emissions

GHG emissions under both the BAU and the INT scenarios during the period 2007–2020 are displayed in Fig. 3. The GHG emissions under both scenarios are in line with total energy consumption trends. Greenhouse gas emissions in 2007 were 17.3 million tons CO_2 eq., and under the BAU scenario it would increase to 60.3 million tons CO_2 eq. in 2020, with an average annual increase rate of 10.08%. Under the INT scenario, the emissions would increase to 41.4 million tons CO_2 eq. in 2020, with a significantly lower annual increase rate of 6.94%. Comparing these numbers with Fig. 2, in the baseline scenario, the energy consumption and greenhouse gas emissions all maintain about a 10% growth rate in Xiamen. In the INT

Table 3
Policy options and assumptions for the INT scenario[a].

Measures	Assumptions	Policy options
CES measure	All cooking fuel will be completely replaced by natural gas. Some of the industrial coal, diesel, and fuel oil will be replaced by natural gas, which will account for 70%, 60%, and 40%, respectively. LPG and LNG buses will be substituted for conventional buses, for 5% and 20% of the fleet, respectively. LPG and LNG taxis will be substituted for conventional taxis, for 10% and 20% of the fleet, respectively. An LNG power plant will be constructed in the future.	Several measures and policies have already been promulgated for saving energy and reducing GHG emissions. They are as follows: Decision on Development of the Recycling Economy issued by the Standing Committee of Xiamen People's Congress[b]; Xiamen Municipal Government's Views on the Strengthening of Energy Conservation[c]; Xiamen's '11th 5-Year' Action Plan Action Pan of Key Energy-Saving Projects[d]; Xiamen's Energy Consumption Evaluation System for per unit GDP[e]; Xiamen's Energy Conservation Regulations[f]. In addition, the Xiamen city government has promulgated a series of plans: Xiamen's Master Plan in 2004–2020[g]; Xiamen's Comprehensive Transportation Plan for 2006–2020[h]; Xiamen's Outline Plan for Building an Eco-city[i]
IEC measure	Several measures will be implemented in order to improve the efficiency of industrial energy use, such as adjusting the industrial structure (replacing energy-intensive enterprises with low energy consumption's), cascade utilization of energy, and recycling waste heat. The energy consumption per unit of product will be reduced 15% by 2020.	
CHP measure	In order to improve the efficiency of energy use and reduce the amount of fuel oil (comparing with projected total), several CHP plants will be built in a near future, and the amount of fuel oil will be reduced by 500,000 tons by 2020.	
ECB measure	Energy conservation in buildings includes households, commercial buildings and large public buildings. Saving electricity is the key measure; 80% of households will purchase efficient electrical appliances by 2020. The energy intensity of commercial buildings and large public buildings will decrease.	
MVC measure	The total number and growth in ownership rate of motor vehicles will be controlled compulsorily, and the number of private cars per 100 households will be controlled to 30 maximum. Developing public transportation systems, especially Bus Rapid Transit (BRT), is another significant measure. The BRT contribution rate to passenger capacity in public transports will reach 30% by 2020.	
NRE measure	New and renewable energy sources, such as solar energy, hydropower, biomass energy and wind energy, etc., will be developed. The contribution rate of new and renewable energy will reach 3% of total energy consumption by 2020.	

[a] The INT scenario includes 6 measures, according to the measures, policies, and plans which have been promulgated so far. The 6 measures' quantitative data were derived mainly from the Energy Planning in Xiamen's Outline Plan for Building an Eco-city.

[b] The regulation was issued in 2005, but the implementation details of the regulation were only issued in 2007.

[c] The policy was promulgated in 2007.

[d] The measure was put forward by the Xiamen Municipal Energy Saving Office in 2007.

[e] The policy was promulgated in 2008.

[f] The regulation was issued in 2008.

[g] The plan was designed by Urban Planning Bureau of Xiamen in 2004.

[h] The plan was designed by Urban Planning Bureau of Xiamen in 2006.

[i] The plan was designed in 2004 by the School of Environment, Beijing Normal University.

scenario, the energy consumption average annual growth rate would be 9.13%, while the GHG emissions would have an average annual growth rate of 6.94%, due to the introduction of clean energy and subsequent energy structure changes. This result may indicate that the policy measures have a more significant effect on GHG emission reduction than on total energy use reduction.

The per capita GHG emissions under different scenarios are shown in Table 6. The per capita greenhouse gas emissions were 6.95 tons CO_2 eq. in 2007, and under the BAU scenario would be 17.66 tons CO_2 eq. in 2020, with an average annual growth rate of 7.44%. Under the INT scenario, this would reach 12.12 tons CO_2 eq. in 2020, with an average annual growth rate of 4.37% during the same period. This suggests a significant per capita emissions mitigation effect from the policy measures adopted under the INT scenario. According to the Maplecroft Climate Change Risk Report (Maplecroft, 2009), China's per capita greenhouse gas emissions were 4.6 tons in 2009, while they were 20.58 and 19.58 tons, respectively, for Australia and the USA. Our results suggest that Xiamen's per capita greenhouse gas emissions are higher than the national average, and while this figure is still significantly lower than the level in either the USA or Australia, if no measures taken, the per capita GHG emissions in Xiamen will reach a level comparable to those two countries in the future.

Table 7 illustrates the GHG emission intensity under the BAU and INT scenarios. In BAU scenario, Xiamen only reduces GHG emissions per GDP by 20% in 2020 compared with 2007 level. However, GHG emissions will be reduced by 45% by 2020 from the emission level in 2007 in INT scenario. During the Copenhagen Climate Conference, Chinese government promised to reduce the GHG emissions per GDP by 40–45% in 2020 compared with the 2005 level (Qiu, 2009). The results show that the effects of measures and policies undertaken in INT scenario will achieve the national emission reduction targets.

4.3. Reduction potential of energy consumption and GHG emissions

4.3.1. Reduction potential of energy consumption

The reduction potential of total energy consumption and the contribution rate of each measure and consumption sectors are listed in Table 8. The results show that the energy-saving potential in the Xiamen area will gradually increase, with the implementation of a series of policies and measures for energy consumption reduction. Among all the measures, the contribution of the clean energy substitution (CES) measure would have the largest share, accounting for about 50% from 2007 to 2020, followed by the industrial energy conservation (IEC) measure and the energy conservation in building (ECB) measure. The motor vehicle control (MVC) measure and combined heat and power generation (CHP) measure contributions are less significant. In terms of energy consumption by sector, the contribution rate of the industrial sector is dominant, albeit decreasing over time, followed by the transportation and business sectors, with the contribution rate of the household sector relatively small.

4.3.2. Reduction potential of GHG emissions

Table 9 lists the mitigation potential of GHG emissions and the contribution rates of each measure and consumption sectors. The calculation results show that the reduction potential of GHG emissions under the INT scenario, compared with BAU scenario,

Table 4
The major parameters used in the LEAP-Xiamen model.

Sector	Scenario fuel/technology		CUR	BAU			INT			
			2007	2010	2015	2020	2010	2015	2020	Measures
Household	Electrical appliances	Existing[a] (%)	80	80	80	80	80	70	50	ECB
		Efficient (%)	20	20	20	20	20	30	50	
	Cooking fuel	LPG (%)	100	100	100	100	40	0	0	CES
		Natural gas (%)	0	0	0	0	60	100	100	
Industry	Electricity	Intensity (kWh/yuan[b])	0.1096	0.1070	0.1096	0.1027	0.0984	0.1041	0.0957	IEC
	Coal	Industrial coal (%)	100	100	100	100	50	40	30	CES
		Natural gas (%)	0	0	0	0	50	60	70	
	Diesel	Diesel (%)	100	100	100	100	40	24	14.4	CES
		Natural gas (%)	0	0	0	0	60	76	85.6	
	LPG	LPG (%)	100	100	100	100	30	15	15	CES
		Natural gas (%)	0	0	0	0	70	85	85	
	Fuel oil	Fuel oil (%)	100	100	100	100	80	64	51.2	CES
		Natural gas (%)	0	0	0	0	20	36	48.8	
	Gasoline	Gasoline (g/yuan)	5.4512	5.1306	5.4512	4.6614	4.1921	4.8229	4.0147	IEC
Transport	Bus	Existing bus (%)	100	100	100	100	62.91	50.73	43.60	MVC/CES
		BRT (%)	0	0	0	0	24.21	30.54	33.13	MVC
		CNG bus (%)	0	0	0	0	6.78	13.77	18.56	CES
		LPG bus (%)	0	0	0	0	6.10	4.96	4.71	
	Taxi	Gasoline (%)	100	100	100	100	80.77	75.83	72.27	CES
		CNG (%)	0	0	0	0	6.41	13.43	18.49	
		LPG (%)	0	0	0	0	12.82	10.74	9.24	
	Car	Growth rate (%)	15.7	15.7	12	10	9.36	7.15	5.31	MVC
	Motorcycle	Growth rate (%)	15.7	15.7	12	10	9.36	7.15	5.31	MVC
	Passenger ship	Capacity (M person-time)	19.42	19.60	19.87	20.13	19.60	19.87	20.13	MVC
	Truck	Growth rate (%)	15.7	15.7	12	10	9.36	7.15	5.31	MVC
Commercial	Electricity	Intensity (kWh/yuan[b])	0.0363	0.0336	0.0299	0.0261	0.0320	0.0266	0.0211	ECB
	Oil	Intensity (g/yuan)	1.0855	1.0855	1.0855	1.0855	1.0217	0.9235	0.8348	ECB
Transformation	Power plant[c]	Coal (MW)	1200	1990	2807	2850	1200	1200	1200	NRE/CES
		Hydropower (MW)	10	10	10	10	13	14	16	NRE
		LNG (MW)	0	0	0	0	780	1560	1560	CES
		Solar (MW)	0	0	0	0	7	22	63	NRE
		Waste (MW)	0	0	0	0	0	20	20	NRE
	CHP[d]	Coal (MW)	50	450	840	870	90	120	150	CHP
		Natural gas (MW)	0	0	0	0	360	720	720	CHP/CES

[a] Existing appliances specially refer to the ordinary appliances comparing with the efficient appliances.
[b] kWh/yuan is electricity consumption per unit of GDP. It means how much electricity to be consumed per unit GDP product.
[c] Due to constraints in the model structural design, electricity generation includes hydropower, thermal power, LNG gas-fired power plants, solar power and biomass power generation in LEAP-Xiamen model, but not combined heat and power generation.
[d] The combined heat and power generation includes coal-fired combined heat and power plants and gas (LNG) combined heat and power plants.

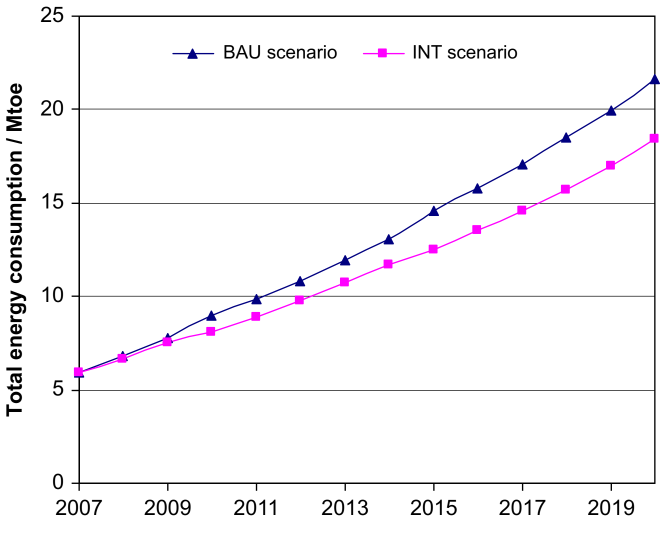

Fig. 2. Energy consumption forecasts for the BAU and INT scenarios, 2007–2020.

Table 5
Energy intensity forecast for different scenarios (toe/10,000 yuan).

Year	2007	2010	2015	2020
BAU scenario	0.4268	0.4202	0.3878	0.3569
INT scenario	0.4268	0.3799	0.3325	0.3035

will increase year by year. This indicates that the energy-saving and emission-reduction effects will be amplified with the implementation of a series of policies and measures planned for Xiamen. In the measures, the greatest contribution of GHG emissions reduction is the CES measure, which promises a contribution rate of more than 70%; the CHP measure also has an important contribution, while other measures contribute significantly less. The CES measure contributes the most because it is affected by almost all of the specific policies and measures, which cover domestic, industrial, transportation and commerce sectors. The IEC and ECB measures focus mainly on limited electricity-saving efforts, and therefore have limited emission-reduction potential. In terms of consumption sectors, the industrial sector is the largest contributor of GHG emissions reduction potential, as it is affected by most of the reduction methods within the CES, CHP, and IEC measures.

GHG emissions are mitigated mainly by energy consumption reduction and energy structure changes. The results show that the contribution of adjusting the energy structure remains at about 72%, indicating that the structural change has the greatest mitigation potential. The structural changes of energy use in both scenarios are shown in Fig. 4. Under the BAU scenario, electricity, coal, and oil would account for the vast majority of energy use. Under the INT scenario, the proportion of clean energy use would increase from 0.1% in 2007 to 45.97% in 2020, if all the measures can be implemented successfully. In the INT scenario, the energy use structure will gradually become environmentally friendly in Xiamen, with rapid growth in the use of alternative clean energy.

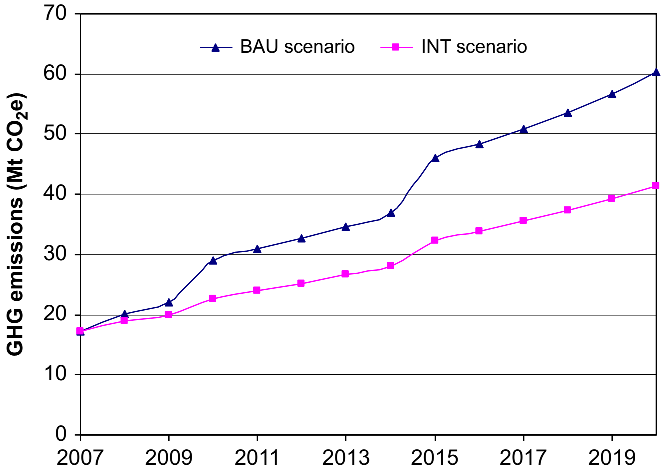

Fig. 3. GHG emissions forecast for the BAU and INT scenarios, 2007–2020.

Table 6
GHG emissions per capita under two scenarios (t CO_2 eq./person).

Year	2007	2010	2015	2020
BAU scenario	6.95	10.83	15.24	17.66
INT scenario	6.95	8.48	10.68	12.12

Note: CO_2 eq. is CO_2 equivalent. Referring to the Kyoto Protocol, nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride, and other major GHGs are converted into CO_2 in the calculation.

Table 7
GHG emission intensity under two scenarios (t CO_2 eq./10,000 yuan).

Year	2007	2010	2015	2020
BAU scenario	1.2465	1.3572	1.2242	0.9942
INT scenario	1.2465	1.0624	0.8577	0.6827

4.4. *Implementation of control measures*

In the clean energy substitution (CES) measure, the alternative energy method for households is rather easy to implement, as the piped LPG can be easily replaced by natural gas. In fact, it has been implemented gradually throughout 2009. The implementation of alternative energy measures in the transportation sector has some uncertainties, as the substitution of CNG buses and CNG taxis has fewer precedent cases in China. Considering that the substitution shares are only about 18%, however, it might not be too difficult to achieve. Natural gas substitution in the industrial sector might be the most challenging, though, as it is constrained by the cost of equipment replacement. Incentive policies from the government might be necessary to promote the substitution. In terms of energy transformation, an LNG plant is under construction by the government. Contrasting the calculation results with the actual situation, there are some obstacles to reaching 45.97% of clean energy use by 2020.

As for the motor vehicle control (MVC) measure, motorcycles and government vehicles will be controlled well through the government's strict regulations. The current BRT system (58.8 km) constructed in September 2008 performs well, and the passenger carrying capacity has achieved the desired purpose. The follow-on project (56.2 km) is under construction now. Controlling the number of private cars will be the most difficult measure to achieve in the MVC measure. As a pillar industry of the national economy, the automobile industry is encouraged to continue developing, and it is often beyond the control of local governments. In fact, the measures already implemented to control private car use, e.g. increasing vehicle purchase tax, do not seem to be working well.

As for the new and renewable energy utilization (NRE) measure, the largest potential for Xiamen lies in solar and wind power resources. Xiamen's annual sunshine time is 2233.5 h, and annual radiation amounts to 5200 MJ/m with a sunshine ratio of 51%. And the effective power-generating speed of the wind averages 1400–2800 h/year, with coastal wind power density reaching 170 W/m^2. With the reduction in development costs and the government incentives for implementation, the potential for wind power development is promising.

Table 8
Reduction potential of total energy consumption for the INT scenario compared with the BAU scenario and the contribution rate of each measure and consumption sectors.

Year	2010	2015	2020
Abatement potential of total energy consumption for the INT scenario compared with the BAU scenario			
Reduction value of total energy consumption (Mtoe/year)	0.86	2.08	3.24
Contribution rate of reduction potentials of total energy consumption (%)			
CES	66.83	57.04	40.75
IEC	7.76	14.65	23.97
CHP	13.56	11.23	7.24
ECB	7.48	14.19	23.29
MVC	5.96	8.40	11.47
NRE	0.30	0.84	1.02
Contribution rate of each sector (%)			
Household sector	1.88	4.50	5.25
Industrial sector	71.40	60.60	58.46
Transport sector	9.57	15.04	15.11
Commercial sector	17.15	19.86	21.18

Table 9
Reduction potential of GHG emissions under the INT scenario, compared with the BAU scenario, showing the contribution rates of each measure and consumption sectors.

Year	2010	2015	2020
Abatement potential of GHG emissions under the INT scenario compared with the BAU scenario			
CO_2 emission reduction value (Mt CO_2 eq./year)	6.3	13.8	18.9
The contribution rate for CO_2 emission reduction (%)			
CES	82.97	79.79	77.80
IEC	1.49	2.76	4.47
CHP	11.84	10.89	7.83
ECB	0.33	0.67	1.21
MVC	2.48	3.82	5.79
NRE	0.90	2.06	2.91
Contribution rate of each sector (%)			
Household sector	3.99	3.82	3.47
Industrial sector	84.18	83.53	82.92
Transport sector	7.13	8.96	8.88
Commercial sector	4.70	3.70	4.74
Contribution rates of structural mitigation and non-structural mitigation (%)			
Structural mitigation[a]	74.60	72.46	68.25
Non-structural mitigation[b]	25.40	27.54	31.75

[a] Structural mitigation means GHG emission reduction caused by optimization of the energy use structure.

[b] Non-structural mitigation is the emission reduction caused by measures other than structural mitigation, such as low-carbon technologies' applications, green-oriented life style, etc.

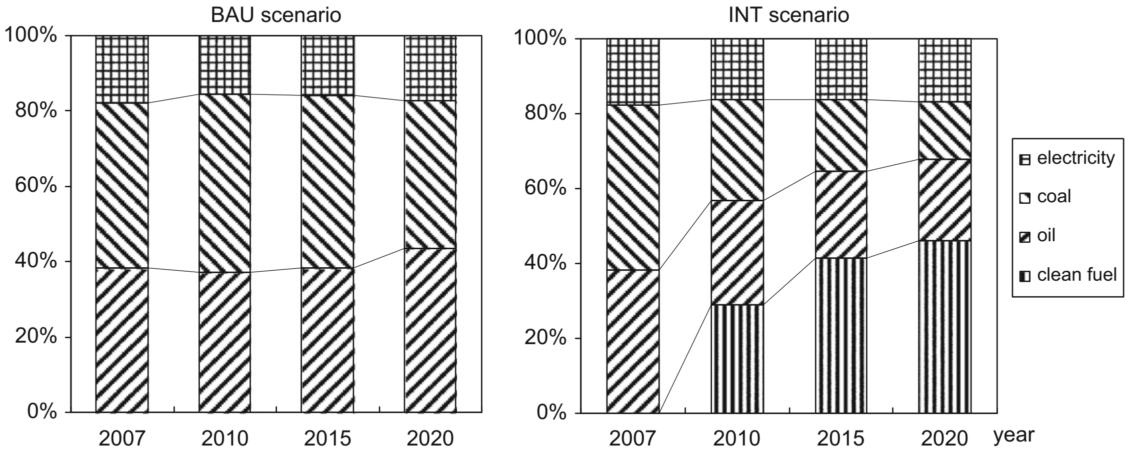

Fig. 4. Structure of energy use for the BAU and INT scenarios. *Note*: Coal includes primary coal, refined coal and coke; Oil includes gasoline, diesel, kerosene, heavy oil, crude oil and LPG; Clean energy includes natural gas, LNG, solar, wind and biomass.

In the energy conservation in building (ECB) measure, household electricity savings measures can be easily implemented because the cost of electricity-efficient appliances continues to decline. However, the saving potentials in the commercial sector are limited, as currently implemented measures, such as increasing electricity rates, do not work well. As the Xiamen city government has issued a number of specific and quantitative indicators to limit enterprises in order to save energy, the industrial energy conservation (IEC) measure is likely to be carried out well. The combined heat and power generation (CHP) measure is also implementable, for the thermal power plants planned are currently under construction.

In all, the main difficulties in implementation lie in the CES measure, the MVC measure and the ECB measure. All these are focused on fields hard for local government to directly control, or constrained by implementation investment costs or specific implementation experiences. The NRE and CHP measures, on the other hand, are relatively easy to implement because of the mature performance conditions.

4.5. *Recommendations*

Based on above analyses and findings, some other measures are recommended for future Xiamen's energy conservation and GHG reduction. From the perspective of the whole city, recycling economy should be developed to promote enterprises' reduction of energy consumption, waste reduction and waste recycling utilization. For energy supply sector, development of solar and wind energy should be reinforced as Xiamen having abundant those resources. For urban transport sector, planning and layout of road traffic should be improved, and vehicle emission standards should be raised. For civil construction sector, energy efficiency standards and regulations should be further developed and improved. For industry sector, energy-saving and low-carbon enterprises can be fostered by of eco-industrial park construction, and new enterprise energy efficiency standards and energy monitoring system should be built. Moreover, financial policies should play special energy-saving funds, subsidies, financial incentives to promote enterprise transformation. It should raise awareness and capacity building of residents to support energy conservation and GHG reduction.

Most Chinese cities currently experiences rapid urbanization, economic growth, and the accelerated changes in technology, life style, and societal transformation. Therefore, improvement in energy efficiency and promotion of clean and renewable energy development might play the most important role in energy conservation and GHG reduction. The key energy saving areas lie in industry, transportation, and construction, which can achieved mainly through application of new technology, construction of relevant laws, regulations and standards, and formulation fiscal policies etc.

5. Conclusions

In this paper, the computing principle based on the LEAP model for urban energy saving and emission reduction is first introduced. A detailed model, namely LEAP-Xiamen, was developed to estimate the reduction potential for energy consumption and GHG emissions in Xiamen for a time frame of 2007–2020. Two scenarios, with (INT) and without (BAU) new policy measures, were designed to represent different development pathways of Xiamen's energy future, reflecting Xiamen's current and planned policy measures. Scenario analysis results show that different modes of economic development and policy implementation have significant impacts on energy consumption and GHG emissions. Overall, with the expected continued rapid development of Xiamen's economy in the period 2007–2020, total energy demand and greenhouse gas emissions will maintain relatively high, continuing to grow. However, our results indicate that local policy measures can have a significant effect on energy conservation and GHG mitigation:

(1) In the BAU scenario, the average annual growth rate of energy consumption is 10.5% in Xiamen; energy intensity (energy consumption per GDP) will decrease annually by 1.37%; and greenhouse gas emissions will increase an average annual of 10.08%. In the INT scenario, however, the energy consumption, energy intensity and GHG emissions will increase by 9.13%, decrease by 2.59%, and increase by 6.94%, respectively.

(2) According to the analysis of energy consumption in Xiamen city, the INT measures will save 0.86 million tons of oil equivalents in 2010, 2.08 Mtoe by 2015, and 3.24 Mtoe by 2020. In terms of measure-specific contributions, the clean energy substitution measure (CES) will be the most effective, followed by the combined heat and power generation (CHP), industrial energy conservation (IEC), energy conservation in building (ECB), motor vehicle control (MVC), and renewable energy utilization (NRE) measures. The industrial sector has the greatest energy-saving potential in Xiamen, followed by the commercial, transportation, and household sectors.

(3) In terms of GHG-emission mitigation, the INT measures will reduce 6.3 Mt CO_2 eq. emissions in 2010, 13.8 Mt CO_2 eq. by 2015, and 18.9 Mt CO_2 eq. by 2020. Among all the policy measures, CES will contribute the most, followed by CHP, MVC, IEC, ECB, and NRE. For reducing consumption, the greatest potential for reducing emissions lies in the industrial sector, followed by the transportation, commercial, and household sectors. Energy structure change has the great reduction potential.

(4) Comprehensive consideration of both energy conservation and emissions mitigation shows that the CES measure will have the most significant results for Xiamen, and that the industrial sector has the greatest potential. In addition, the optimization of energy use in Xiamen is the best long-term strategy for reducing emissions. As for implementation, local government control, investment costs, and implementation experiences are the main issues in implementing the CES, MVC, and ECB measures.

Acknowledgements

The authors gratefully acknowledge funding by the Chinese Ministry of Science and Technology and the Chinese Academy of Sciences through the following Research Programs: 2009DFB90120, KZCX2-YW-450. And the helpful comments of two anonymous referees are gratefully acknowledged.

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