

The Primary Energy Use and Emissions of Housing Sector: The Changing Path of Taiwan

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Abstract-This paper analyses the changing path of primary energy use and emissions in Taiwan housing sector during 1982-2009. A key finding of the paper is that electricity was the major source of changing both in primary energy use and emission of the housing sector. During the study period, the annual logarithmic growth rate of the primary energy induced by electricity use in Taiwan housing sector was 6.45%. While the annual logarithmic growth rate of emissions from electricity used in housing sector was 7.82%. In which, about four-fifths of the growth rate came from electricity use, one-fifth came from emissions factor of electricity.

Keywords-primary energy use, greenhouse gases emissions, global warming potential, housing sector

I. INTRODUCTION

Building and climate change had been studied by United Nations Environment Programme (UNEP), International Energy Agency (IEA), World Business Council for Sustainable Development (WBCSD) recently. Results of the studies showed that the building emissions are an important sector of the society when we face the global warming [2-6]. Because of different countries are with different development paths, the shares of greenhouse gases (GHGs) emissions from building sector in whole society are quite different. The shares of building energy use of its respect society in OECD countries are about 25-40%. The shares of building energy use of its respect society in European countries are about 40-50%, which induced the major sources of the emissions of the society [2, 3].

In UK and Swedish, the shares of building energy use of its respect society are about half of the emissions, by which housing sector account for the major part the emissions [7-9]. In order to cut off the emissions of the building sector, the recent EC Directive on Energy Performance of Building (EPBD, Directive 2002/91/EC) requires member states to develop and introduce energy performance regulations by the year 2006. The common general framework for the energy performance of a building shall be expressed in a transparent manner and shall include an energy performance indicator and a numeric indicator of primary energy use, based on primary energy factors per energy carrier, which may be based on national or regional annual weighted averages [10-14].

The shares of building energy use to the whole society in developing countries, like China, India, Basil etc., are about 20-25%; which are lower than those in developed countries. According to Taiwan's Energy Balance Sheet [15], the shares of energy use and emissions in housing and service sector are about 18% and 28% of the society. Emissions come from

industry sector account for 50% in 2009, which was the major sector of Taiwan emissions. But in term of electricity, the final demand of the housing sector and service sector account for 50% of the society.

Electricity is the major energy use in housing sector, which is also a kind of secondary energy with high emission intensity. Observing the experiences of the development paths of the developed countries, building sector always become the key sources of the emissions; when a society shift from industry economy to service economy. Whenever economic growth and household income increase, the housing emissions become one of the major sources of the building sector. This is also the situation Taiwan faces now. Moreover understanding the historical processes of the primary energy use and emissions in Taiwan's housing sector will be helpful when Taiwan face the planning of the emissions reduction target in the near future.

In next section, the estimation method of primary energy use and emissions in housing sector will be introduced. In section 3, Taiwan energy balance sheet will be used to estimate the aggregated primary energy factor and emission factor of electricity 1982-2009 first. Then the primary energy use and emissions of the housing sector will be analysed. The characteristics of the housing energy use and emissions then were discussed. Finally, the conclusions were drawn.

II. METHODOLOGY

The types of energy use in Taiwan housing include liquefied petroleum gas (LPG), liquefied natural gas (LNG), electricity, and solar thermal. By multiply the primary energy factor and emission factor of the respect energy, the primary energy use and emissions in housing sector of Taiwan can be attained. In the following sub-section, how primary energy use and emission respect to each energy type can be summated will be formulated. The estimation method of primary energy use and emissions in housing sector, the primary energy factor and emission factor of electricity then will be introduced in sequence.

A. Primary Energy Use and Emissions in Housing Sector

Let $\hat{E}_{k,t}$ expressed as the primary energy use of energy type k in housing sector at year t; $f_{k,t}$ expressed as the primary energy factor and $Q_{k,t}$ expressed as the energy use of energy type k in housing sector at year t. The total primary energy use in housing sector at year t (\hat{E}_t) can be written as

$\hat{E}_t = \sum_k f_{k,t} Q_{k,t}$, where the subscript k denotes the energy types used in housing sector. Fig. 1 showed the relationship of the aggregation processes of primary energy use in housing sector. For example, to estimate the primary energy induced from electricity use in housing sector, we need to estimate the aggregated primary energy factor of electricity respect to the end user ($f_{\text{end-user}}$) before calculating processes were carried on.

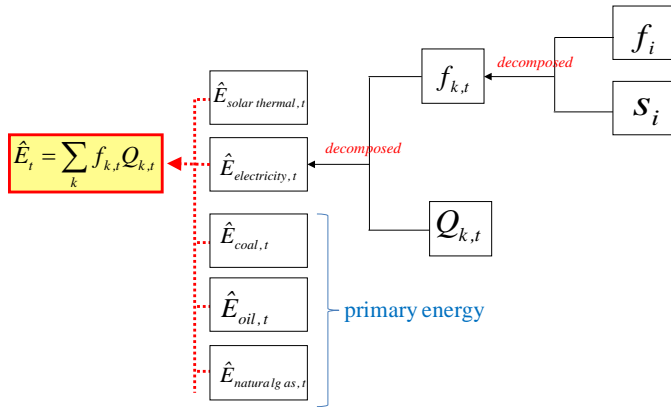


Fig. 1 the processes of estimation primary energy use in housing sector.

Respect to the estimation of the housing sector emissions, let $\hat{C}_{k,t}$ expressed as the emissions induced from the energy use of energy type k in housing sector at year t; $e_{k,t}$ expressed as the energy emission factor and $Q_{k,t}$ expressed as the energy use of energy type k in housing sector at year t; then the total emissions induced from energy use in housing sector at year t (\hat{C}_t) can be written as $\hat{C}_t = \sum_k e_{k,t} Q_{k,t}$.

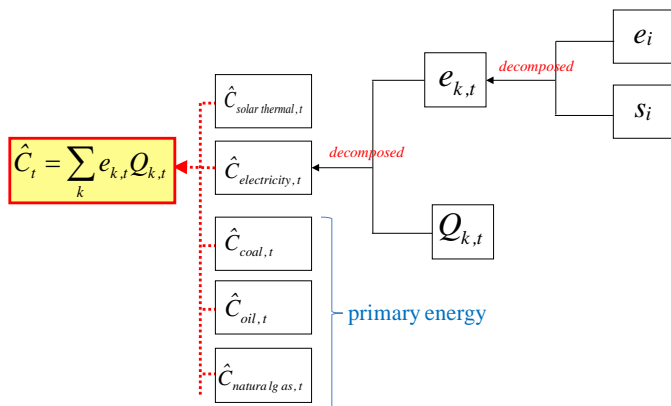


Fig. 2 the processes of estimation ghgs emissions in housing sector

Fig. 2 showed the estimation processes of the emissions induced from energy use of housing sector. When we try to estimate the emissions induced from electricity, the aggregated emission factor of electricity respect to the end user $e_{\text{end-user}}$ need be attained before electricity emissions calculating processes were carried on.

The logarithmic growth rate of primary energy use in housing sector from year 0 to year t, $r_{t,0}$, can be written as $r_{t,0} = \ln(\hat{E}_t / \hat{E}_0)$. The logarithmic growth rate of housing sector emission induced energy use from year 0 to year t, $\hat{r}_{t,0}$, can be written as $\hat{r}_{t,0} = \ln(\hat{C}_t / \hat{C}_0)$. The respect logarithmic growth rates described above are with addition property whenever the rate can be completely decomposed as multiplication relationship. Because electricity is a kind of secondary energy with high primary energy factor and emission factor, and always have different value at each year. So the primary energy factor and emission factor need be estimated before calculating primary energy and emission of each energy type used in housing sector.

B. The Primary Energy Factor of Electricity

The aggregated primary energy factor of electricity can be expressed as total heat value input divided by total electricity generation output. Let \dot{f} denotes the aggregated emission factor of electricity, the factor can be calculated by total heat value input (F) of the primary energy divide by the total output (E) of the electricity generation; $\dot{f} = F / E$.

Respect to production modes of the electricity generation, the aggregated primary energy factor of electricity can be summated by the primary energy factor of each electricity generation modes with its own shares as weighting. Let subscript i denotes the electricity generation mode, the aggregated primary energy factor of electricity can be expressed as $\dot{f} = \sum_i \frac{F_i}{E_i} \frac{E_i}{E}$; where F_i / E_i represents the primary energy input per electricity output respect to generation mode i; and E_i / E represents the share of generation mode i respect to total electricity generation.

The actual delivered electrical energy (or Total Final Consumption, TFC) is the total electricity generation minus the own use of the generation plant and distribution losses. Let E_d denotes as the total final consumption of electricity, the primary energy factor of electricity respect to end user ($f_{\text{end-user}}$) can be expressed as

$$f_{\text{end-user}} = \dot{f} f_d; \quad (1)$$

where $f_d = E / E_d$ expressed as proportion of total electricity generation to total final consumption of electricity. Normally, the total electricity generation will larger than total final consumption of electricity whenever the own use of the generation plant and distribution losses were deduced from total electricity generation, so $f_d > 1$ and $f_{\text{end-user}} > \dot{f}$.

C. The Emission Factor of Electricity

The aggregated emission factor of electricity can be calculated as total emissions divided by total electricity generation output. Let e denotes the aggregated emission factor of electricity, the factor can be expressed by the GHGs emissions (C) divide by the output (E) of the electricity generation; $e = C / E$.

Respect to production modes of the electricity generation, the aggregated emission factor of electricity can be summated by the emission factor of the electricity generation modes with its own shares as weighting. The aggregated emission factor considering the electricity generation modes can be expressed

as $e = \sum_i \frac{C_i}{E_i} \frac{E_i}{E}$; where C_i / E_i represents the emissions

per electricity output respect to each generation mode i ; and E_i / E represents the share of generation mode i respect to total electricity generation. These showed that the aggregated emission factor of electricity can be decomposed as the emission coefficient respect to each generation mode and the share of its respect generation mode.

Because electricity generation from hydro power, nuclear power, new renewable energy (like solar photovoltaic and wind energy) have little fossil fuel input, the variation effect of fossil fuel input on primary energy factor and emission factor of aggregated electricity generation are rather stable. The major fuel input in thermal power and co-generation include coal (Bituminous coal-steam coal, sub-bituminous coal), oil (diesel oil, fuel oil), and natural gas (indigenous natural gas, imported LNG). And the effect of variation of fuel input share should be counted when we estimate the primary energy factor and emission factor of thermal power.

On macro-level, in order to simplify the aggregated emissions analysis, the emissions of hydro power, nuclear power, new-renewables are rather small and can be categorized as non-fossil fuel generation. Then the aggregated emission factor of electricity can be decomposed as two effects completely, the effect of emission coefficient of fossil fuel generation and the effect of the share of fossil fuel generation.

Let E denotes the total electricity generation; E_f denotes the fossil fuel generation of electricity. The emission factor of the fossil fuel generation (e_f) can be expressed as $e_f = C_f / E_f$, where C_f denotes as the total emissions of the fossil fuel generation. The share of fossil fuel generation can be expressed as $s_f = E_f / E$. The aggregated emission factor of electricity (e) can be expressed as $e = e_f s_f$. The aggregated emission factor of electricity of the end user ($e_{\text{end-user}}$) can be written as follow,

$$e_{\text{end-user}} = e f_d. \quad (2)$$

Also, because of $f_d > 1$, so $e_{\text{end-user}} > e$.

III. DATA AND ANALYSIS

In this section, the aggregated primary energy factor and emission energy factor of electricity respect to end user will be estimated first, then the primary energy use and emissions of housing sector will be calculated.

A. Data Sources and Treatments

The electricity generation mix of Taiwan includes thermal power, cogeneration, nuclear power, hydro power, and new renewable energy, i.e. photovoltaic and wind energy. This paper used the constant unit heat values of the hydro power, nuclear power, new-renewables provide by Bureau of Energy, Taiwan (ROC) to calculate the primary energy input of electricity generation. The unit heat values of thermal power and CHP will reflect relationship to average efficiency of the electricity generation.

The aggregated primary energy factor of electricity can be estimated by multiply the primary energy factor of the generation modes with respect to its shares in whole electricity generation. Then by using Eq. 1, the aggregated primary energy factor of electricity of the end user can be attained. Combining the emission factors respect to each fuel type recommended in 2006 IPCC Guidelines for GHG Inventories [1], and the weighting of each greenhouse gases respect to 100 year horizon recommended by IPCC 2007 AR4 [16], one can calculate the total emissions of the electricity generation of the thermal power and CHP.

The aggregated emission factor of electricity can be derived by multiply the emission factors of the generation modes with respect to its share as weighting. This can be done by simplifying by multiplying the emission factor of the fossil fuel generation and the share of fossil fuel generation in whole electricity generation.

B. The Primary Energy Factor and Emission Factor of Electricity

Results of the estimation showed that the aggregated primary energy factor of electricity at 2009 was 2.64; and the proportion of total electricity generation to total final consumption at the year was 1.139, the demand side aggregated emission factor of electricity was 3.01 at 2009. Due to the fluctuation of fuel market international, the electricity generation mix in Taiwan had some strategy adjustments during 1982-2009. The shares of each fuel input in thermal power and CHP change too. So the aggregated primary energy factor and emission factor change a lot during the period.

Respect to emission factor of electricity, Table I showed that the mean value of the demand side aggregated primary energy factor ($f_{\text{end-user}}$) in 1982-2009 was 3.05, with range 2.88-3.17; the standard deviation was 0.06; the coefficient of variation (C.V.) was 2%. Results of the estimation showed that the emission factor of fossil fuel generation at 2009 was 0.842 kg-CO₂e/kWh; and the share of non-fossil fuel generation (include hydro power, nuclear power, new-renewables) was 21.52%; so the aggregated emission factor of electricity generation was about 0.661 kg-CO₂e/kWh. After adjustment by proportion of total electricity generation to total final

consumption of the year, the demand side aggregated emission factor of electricity at 2009, 0.753 kg-CO₂e/kWh, can be attained.

Results of the demand side aggregated emission factor ($e_{\text{end-user}}$) showed that the mean value among 1982-2009 was 0.631 kg-CO₂e/kWh, with range 0.360-0.778 kg-CO₂e/kWh; the standard deviation was 0.130; the coefficient of variation (C.V.) was 21%. Among 1982-2009, the highest emission factor of electricity for end user (0.778 kg-CO₂e/kWh at 2006) was about 2.2 time of the lowest one (0.360 kg-CO₂e/kWh at 1985).

TABLE I
THE PRIMARY ENERGY FACTOR AND EMISSION FACTOR OF
ELECTRICITY FOR END USER (1982-2009)

	Mean	Stedev	C.V.	Range
primary energy factor	3.05	0.06	2%	2.88 -3.17
emission factor (kg-CO ₂ e/kWh)	0.631	0.130	21%	0.360 -0.778

C. The Primary Energy Use of Housing Sector

Fig. 3 showed the accumulated composition of energy type consumption in housing sector before adjustment by primary energy factor of electricity respect to year 1995, 2000, 2005, and 2009. Results of the analysis showed that the share of electricity in whole energy use of housing sector was about 39.5% in 1982 before the demand side aggregated primary energy factor of electricity adjustment. The share increased to 65.3% after the demand side aggregated primary energy factor of electricity adjustment.

In Fig. 4, the accumulated composition of primary energy consumption in housing sector after adjustment by primary energy factor of electricity respect to year 1995, 2000, 2005, 2009 were showed. Respect to 2009, the share of electricity was 64.2% before adjustment; the share increased to 84.4% after the demand side aggregated primary energy factor of electricity adjustment.

In order to examine the changing paths of energy use among 1982-2009, the energy use of housing sector each year were plotted respect to each year. Fig. 5 showed the energy

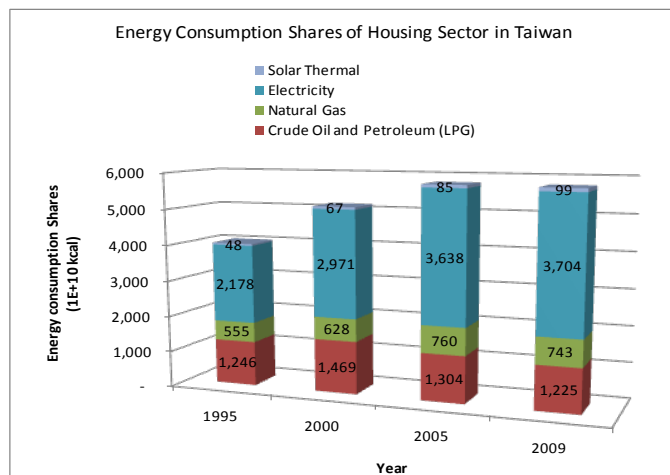


Fig. 3 the composition of energy consumption in housing sector before adjustment by primary energy factor of electricity (1995, 2000, 2005, 2009)

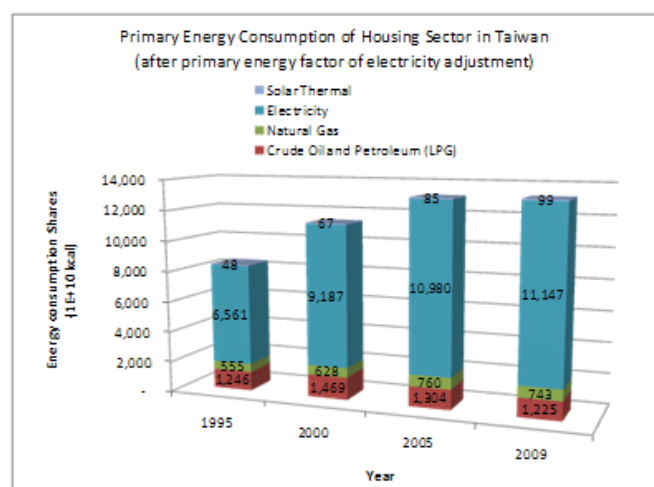


Fig. 4 the composition of energy consumption in housing sector after adjustment by primary energy factor of electricity (1995, 2000, 2005, 2009)

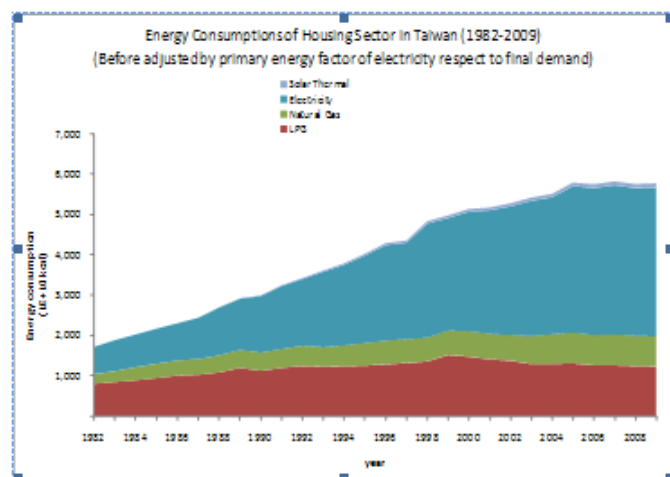


Fig. 5 the energy use of housing sector respect to each energy type without primary energy factor of electricity adjustment (1982-2009)

use of housing sector respect each energy type without primary energy factor of electricity adjustment. After primary energy factor of electricity adjustment, the primary energy use of housing sector respect each energy type were drawn in Fig. 6.

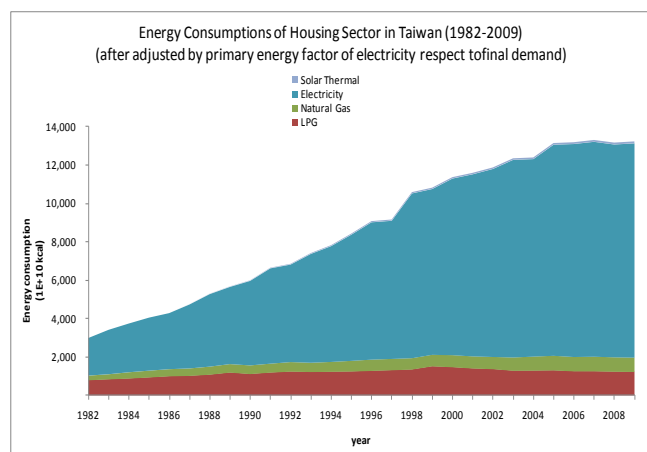


Fig. 6 the energy use of housing sector respect to each energy type after primary energy factor of electricity adjustment (1982-2009)

Table II showed that the annual logarithmic growth rate of the electricity use among 1982-2009 was 6.29% before the demand side aggregated primary energy factor adjustment; the cumulated logarithmic growth rate of the electricity use in these twenty eight years was 169.79%. The electricity use in 2009 was of 5.46 times of which in 1982 ($\ln(5.46) = 169.79\%$).

TABLE II
THE ANNUAL LOGARITHMIC GROWTH RATE OF PRIMARY ENERGY USE AND EMISSIONS IN HOUSING SECTOR (1982-2009)

		Annual logarithmic growth rate	Proportion of emission in 2009 to which in 1982
electricity use & primary energy factor adjustment	before	6.29%	5.46
	after	6.45%	5.70
primary energy factor of electricity		0.16%	1.04
emission factor of electricity		1.53%	1.51
emission from electricity		7.82%	8.25

After primary energy factor of electricity adjustment, the annual logarithmic growth rate of the primary energy use of housing sector among 1982-2009 was 6.45%; which can be breakdown into 6.29% came from the growth of electricity use, and 0.16% came from primary energy factor of electricity. The cumulated logarithmic growth rate of electricity use in these twenty eight years was 174.09%. Finally, the primary energy use of electricity in 2009 was 5.70 times of which in 1982.

D. The Emissions of Housing Sector

Fig. 7 showed the accumulated composition of energy type emissions in housing sector respect to year 1995, 2000, 2005, and 2009. Fig. 3 showed the compositions of the emissions of each energy type of housing sector. Results of the analysis showed that the share of emissions from electricity dominant the whole emissions of the housing sector. The share of the emissions of the electricity in housing sector was about 59.6% in 1982; and increased to 86.6% in 2009.

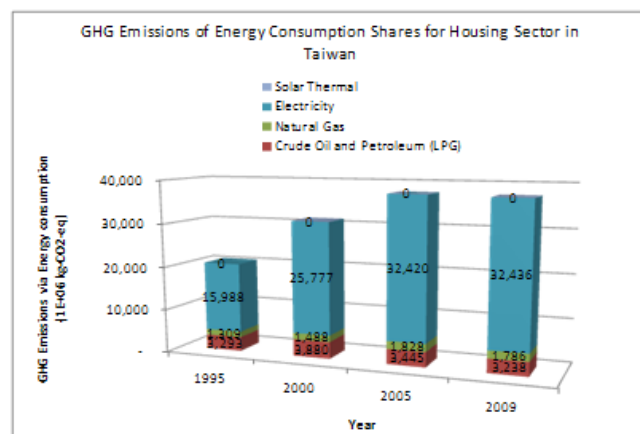


Fig. 7 the accumulated composition of energy type emissions in housing sector (1995, 2000, 2005, 2009)

Fig. 8 showed the emissions of housing sector respect each energy type. Among 1982-2009, the cumulated logarithmic growth rate of the emissions induced by electricity use of housing sector was 210.99%; the annual logarithmic growth rate was 7.81%.

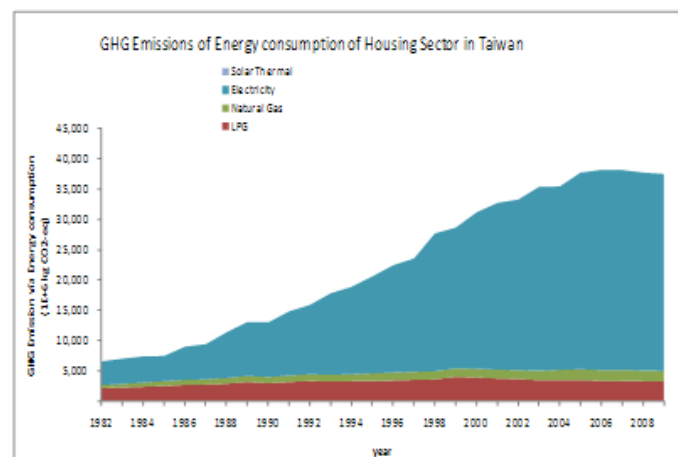


Fig. 8 the accumulated emissions of energy use of housing sector (1982-2009)

Table II also showed that the annual logarithmic growth rate of emissions in housing sector was 7.82% among 1982-2009. The sources of annual logarithmic growth rates of the emissions of housing sector can be breakdown into 6.29% came from the growth of electricity use, and 1.53% came from the growth of emission factor of electricity. Finally, the emissions from electricity in 2009 were 8.25 times of which in 1982. In which, about four-fifths of the growth rate came from

electricity use, one-fifth came from emissions factor of electricity.

IV. CONCLUSIONS

The paper used data of Taiwan energy balance sheet, the emission factor of each fuel recommended in 2006 IPCC Guidelines for GHG Inventories, and the weighting of each greenhouse gases respect to 100 year horizon recommended by IPCC 2007 AR4 to explore the characteristics of primary energy use and emissions of Taiwan housing sector. Results of the research are as follows,

- The share of electricity in whole energy use of housing sector before and after primary energy factor of electricity adjustment were 39.5% and 65.3% respect in 1982.
- The share of electricity in whole energy use of housing sector before and after primary energy factor of electricity adjustment were 64.2% and 84.4% respect in 2009. The share of the emissions induced by the electricity of the housing sector was 59.6% in 1982; and increased to 86.6% in 2009.
- The results of the analysis showed that the electricity was the major source of primary energy use and emission both in the housing sector.
- During 1982-2009, the annual logarithmic growth rate of the primary energy induced by electricity use in Taiwan housing sector was 6.45%. While the annual logarithmic growth rate of emissions from electricity used in housing sector was 7.82%. By which, about four-fifths of the growth rate came from electricity use, one-fifth came from emissions factor of electricity.
- During 1982-2009, the primary energy use of electricity of housing sector in 2009 was 5.70 times of which in 1982. Among 1982-2009, the emission induced by electricity use of housing sector in 2009 was 8.25 times of which in 1982.

The growth rate of housing demand always fast in preliminary stage of the economic development. Latter, the growth rate of housing demand will slow down, but energy intensity of the housing increase because the amenity of the living space upgrade if the development continues. According empirical analysis of Taiwan's housing sector showed in this paper, the growth rate of the emissions during study period majorly came from electricity use. This showed that the building energy efficiency strategies, include passive design, envelope design, high energy efficient equipment, and life style adjustment will be all important in the future.

On the other hand, although the growth rate of the emissions during study period were one-fifth came from emissions factor of electricity. But the emission factor of electricity for end user double from 1985 to 2007 also showed

its large influent on the sector's emissions. This means that if the emission mitigation policy is definitely clear, the use of renewable energy will be another important issue we need to face. Although we still face the dilemma of the high renewable technologies cost now in the society. As a result, in order to lower the target emissions of the society, the strategies of passive design and energy efficiency in housing design, the life style adjustment, and the lower emission factor of electricity will be all keys of the low-carbon society.

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