Changes of energy consumption and the CO_2 emissions structure in Vietnam from 1986 to 2005

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Studies on the future potential for CO_2 emissions reduction in Vietnam require the use of reliable information on economic development, energy consumption, and CO_2 emissions, topics that also tend to be incompletely monitored in other developing countries. In this paper, we apply the accounting principle for data reconciliation and a CGE (Computable General Equilibrium) model with calibrated parameters to estimate SAM (Social Accounting Matrix) and EIOT (Energy Input Output Table). They are used to analyze the economic, energy consumption, and CO_2 emission structures of Vietnam from 1986 to 2005. Our results on Vietnam over this period indicate that the GDP increases 3 times, energy consumption increases by more than 4 times, and CO_2 emissions increase by more than 6 times. Transport, utility, and industry are the main contributors to the increases in energy consumption and CO_2 emissions, while total services and agricultural activities remain as the main contributors to economic growth. To determine the main driver behind the change in CO_2 emissions, we decompose this change into changes of the population, GDP per capita, energy intensity, and carbon intensity over four consecutive sub-periods of 5 years. Energy intensity is the main driver behind the CO_2 emission changes in the first period (1986-1990) and GDP per capita becomes the dominant driver in the next three periods. Vietnamese policymakers may find these results instructive in their works to develop appropriate economic and energy development strategies. Our task for the future is to develop an dynamic model for providing historical data and understanding possibilities for future development policies in Asian countries.

Key Words : *data reconciliation, CGE model, parameter calibration, CO_2 emissions, energy structure*

1. INTRODUCTION

Since introducing the Doi Moi economic reforms in 1986, Vietnam has been opening its doors to the rest of the world step by step. Vietnam became a member of the ASEAN in 1995, joined APEC in 1998, and signed a bilateral trade agreement with the US in 2000. And more recently, it significantly enhanced its connections with the US, Japan, China, Korea, and other countries by acceding to the WTO in 2007[1)].

The increasing integration and trade liberalization of recent years bring Vietnam various opportunities not only for the expansion of its export market and inflows of foreign investment[1)], but also for enhancing productivity through specialization[2)] and improving the living standards of its people[3)]. Yet these open-door policies are also creating new pressures and potentially hindering the future development and industrialization of Vietnam[4)].

As it considers the various advantages and disadvantages of Doi Moi, the Vietnamese Government must also heed the energy consumption and CO_2 emission structures and constraints on natural resources amidst increasing economic development.

A major challenge, in studying the energy efficiency and CO_2 emissions reduction potential of Vietnam, is to cope with the scarcity of reliable disaggregated information on the economic structure, energy structure, and CO_2 emissions. There is generally no standardized methodology for establishing a reliable platform for disaggregating this type of information, both in Vietnam and in other developing countries lacking sufficient sources of statistical information.

To surmount this challenge here, we attempt to develop a methodology for estimating SAM and EIOT by reconciling data based on the accounting principle and a CGE model with calibration function. More specifically, we analyze changes in the industrial structure, energy structure, and CO_2 emissions in Vietnam over the 20-year period from 1986 to 2005. The databases applied cover population, employment, household consumption preference, industrial value added, GDP, production, and consumption. An understanding of the relationship among the industrial structure, energy structure, and CO_2 emissions will also help us better evaluate the energy efficiency potential under the Vietnamese development conditions.

The rest of this paper is divided into four sections. Section 2 reviews the historical economic changes, energy, and CO_2 emission structures with projections from previous studies. Section 3 presents our methodology for estimating the SAM and EIOT. Section 4 presents results on the industrial structure, energy structure, and CO_2 emissions, then analyzes the relationships among them in order to determine the main drivers behind the CO_2 emission changes. Section 5 closes with concluding remarks.

2. REVIEW OF HISTORICAL ENERGY CONSUMPTION AND CO_2 EMISSIONS IN VIETNAM

Most developed countries collect historical statistical data with which to characterize their economic growth, energy consumption, and CO_2 emissions in both the past and present, in order to predict the future developments in their societies. In today's globalizing world, Vietnam and other developing countries stand much to gain by collecting national statistics with the same rigor as their developed counterparts. Yet like other developing countries, Vietnam lacks sufficient baseline data with which to model past and current trends. This poses a serious problem for Vietnamese policymakers as they try to map out appropriate plans for future development. In this section we address this challenge by reviewing historical and future changes of Vietnam's economic structure, energy potential, and CO_2 emission structures.

(1) Historical changes in economic structure

Vietnam's economy was in a state of constant flux from 1977 to 2003[5]. This began with a sharp decline of the GDP, from 1977 to 1980, then followed with a rapid GDP recovery from 1980 to 1986 and another slowdown in the late eighties[5]. In 1986, the Vietnamese Government introduced Doi Moi, a policy of radical reform to promote economic development and trade liberalization. Since then the economic structure has been more closely interconnected with regional and even global forces, with a growing reliance on foreign direct investment (FDI)[3]. The collapse of the Soviet Union in 1989 incited a frantic search for changing ideas and development models in Vietnam from 1986 to 1990[5]. Vietnam's economy settled into a period of smoother progress from 1990 to 1996, then faltered and lost ground again from 1996 to 1999. Since 2000, the economy has been steadily growing[5]. In this paper we divide the period from 1986 to 2005 into four phases of five-years each and apply the economic changes in these phases to an analysis of the energy consumption structure and CO_2 emission structures.

The first of these phases, the Economic Renovation (Doi Moi 1986-1990) phase, was marked by decisive transformations from institutional performance to economic performance. The average per capita GDP over this period was 150USD[5]. Under the liberalizations of the domestic market in 1987, the government abolished the former rationing system for many commodities, introduced market-determined prices for nonessential goods, and reduced the differentials between state-controlled and free-market trades by modifying the dual price system. A year earlier, in 1986, the exhaustion of the state budget sent Vietnam reeling through a period of double- to triple-digit hyperinflation due to the exhaustion of the State budget[6]. Throughout this phase, however, Vietnam also scored major successes in reducing food imports and transforming itself into a net rice exporter[5].

The second of the phases, the More Opened Economy phase of 1990-1996, brought new developments in international economic relations. Starting from about 1989, Vietnam began to reorientate its geographic trading patterns, shifting from trade with the Soviet Union and East Europe to Japan, the EU, and China (1991), followed by the ASEAN countries (1995), and finally the United State (1995)[5]. After 1992, inflation slowed down to single digits and growth climbed above 8%, setting a favorable climate for economic stability and development[6]. Yet the GDP share of the State sector rose firmly over the same years, as was normal for a typical "socialism-oriented market economy". This inevitably led Vietnam into its next phase of economic slowdown[5].

The third phase, the Economic Slowdown of 1996-2000, naturally followed from the phase before it. The Asian crisis of 1997 pushed foreign investment in Vietnam sharply down and stymied growth in foreign trade (1997 only), leading to a steady deceleration of the economy up to 1999[5]. Compared to previous phase, the target growth rates for this phase were estimated at 9-10% for GDP, 4.5-5% for agriculture/forestry/fishery, 13-14% for industry, and 11-12% for services[6]. The GDP composition was highest for services, followed by industry and agriculture.

The last and most current phase was the Recovery phase starting from the year 2000. This was a period of macroeconomic instability with unpredictable fluctuations in prices. Inflation rose sharply from low levels in 2003 to almost 10% in 2004, possibly in response to factors such as rising global prices for petroleum, the avian flu pandemic, and the growth of the State's credit enterprise[5]. The Vietnamese government, meanwhile, sought to satisfy regional economic commitments by maximizing its list of goods in the 1-5% tariff range in 2003[7] and expanded its list of goods with zero tariffs in 2006[8]. Tariffs represented 15-20% of total tax revenue in this period, and tax revenues made up around 20% of the GDP and more than 90% of the State budget[9].

By the year 2005, the per capita GDP had almost quadrupled compared to 1987 and the economy had shifted from an agriculture-services-industry structure to an industry-services-agriculture structure, with drastic increases in the industrial and services output composition[10]. The trade structure continued to depend on tariff rates and the price controlling the import and export structure for each commodity. While liberalized trade may have reduce prices for imported goods, the degree to which consumers could substitute imports for domestic goods may not have been high enough to have an adverse output response in consumption[11].

(2) Energy consumption structure – Renewable energy (RE) potential

The analyses and data available on energy use are still insufficient to support studies for the formulation of national energy policies to stave off energy crisis[12]. In a review on power consumption in Vietnam from 1995 to 2005, the highest growth rates were recorded in the industrial sector (16.1%) and residential sector (14%). Electricity demand is forecasted to increase from 44,729GWh in 2005 to 381,163GWh in 2025 (average annual growth of 11.3%)[13]. If these numbers hold, the total power generation capacity will grow from 11,198MW in 2005 to 85,000MW by 2025[14], raising serious concerns about energy availability, CO_2 emissions, and environmental degradation. **Table 1** shows the electricity demand from 2001 to 2010, taken from the Vietnam Power Development Plan VI, a national vision towards 2020[15].

To ensure that the energy supply meets future demand, the Vietnamese government has issued a set of "Grid-Connected Renewable Energy Development policies" targeting 5% renewable energy (RE) use by 2020 in the national energy consumption structure. A fossil-fuel-based power generation of up to about 7.5cents/kWh is permissible under these policies.

Table 1 Electricity demand in Vietnam from 2000 to 2025[15]

	2000	2005	2010	2015	2020	2025
Total (bil. kWh)						
· Produced power	26.6	53	117.3	198.7	305.7	446
· Power for sale	22.4	45.6	101.1	172.3	267.3	394.4
Of which						
· Industry (%)	40.6	46.7	47.7	49.4	50.9	52.3
· Services (%)	4.8	4.7	6.4	6.4	6.7	7.2
· Households (%)	49	43.5	32.9	36.2	33.3	31.2
Consumption per capita (kWh/pers./year)	341	548	1,106	1,174	2,629	3,703
P_{max} (mil. kWh)	4.9	9.2	19.1	31.5	47.6	68.4

Notes: Data from 2010 to 2025 were projected by the Institute for Energy, Vietnam, in June 2006.

RE potentials are commonly classified in different categories based on their theoretical, technical, and economic potentials as alternatives to solve the above concerns.

First, there are 2,400 rivers of more than 10km length in Vietnam, which translates to an estimated hydro energy economic potential of 84TWh/yr, or almost double the electricity consumption recorded in 2005 (46TWh)[16]. Second, Vietnam's energy potential in term of hydro pump capacity is over 10,000MW. These hydro resources, however, are mainly located in the northern and southern areas of the country[16]. Third, Vietnam is preliminarily estimated to have the potential to produce 1,400MW of electricity for direct use, with more than 300 hot streams (from 30 to 148°C). Of this, the development of up to 400 MW geothermal capacity for electricity potential is feasible by the year 2020[16]. Fourth, biomass resources such as rice husk, paddy straw, bagasse (sugar cane, coffee husk, and coconut shell) and wood and plant residue have the potential to generate 1,000 to 1,600MW of electricity[16]. Fifth, solar radiation levels are generous in Vietnam (northern latitudes from 23° to 8°), ranging from 4 to 5.9kWh/m^2/day, with a uniform distribution throughout the year, in Southern and Central Vietnam, and from 2.4 to 5.6kWh/m^2/day in the North[16]. Lastly, Vietnam has about 31,000km^2 of land area available for wind development with current 865km^2 potential.

(3) GHGs emissions in utilizing energy

In one analysis of the alternative renewable energy potential of Vietnam, Nguyen *et al.* used the MARKAL model to examine the impacts of wind power generation on the future choice of fuels and technologies in the power sector over the time frame from 2005 to 2025[13]. They found that even if wind energy remains too costly to compete with electricity produced by fossil fuel-based power plants, wind energy will only become a competitive alternative for CO_2 emission reduction when either a carbon tax or an emissions reduction target is imposed.

Without renewable energy, electricity energy generation from fossil fuels may account for 76.34%

of the total production of 7,389.6TWh over the specified period. Thus, the CO_2 emissions from fossil fuel are projected to increase from 60.7 mil. tons in 2010 to 352.3 mil. tons in 2030, at a growth rate of 14% per year, reaching an aggregate total of 3,825.3 mil. tons for the period 2010-2030[16]. With the contribution of renewable capacities, however, the share of electricity generation by coal fuel could be reduced by 5%. This would reduce the total cumulative CO_2, SO_2, and NO_x emissions by 8.2%, 3%, and 4%, respectively, in the same period[16].

In another study comparing the various energy options, the power output of selected renewable energy technologies (in this case, wind and solar energy) were evaluated together with financial and economic data in order to calculate the levelized cost per unit of electricity produced for each option[17]. A set of policy instruments was then developed to reap the benefits of renewable energy technologies based on this calculation, including instruments for setting renewable energy targets, providing subsidies and consumer credit, removing taxes and duties, and increasing consumer awareness[17]. The feasibility of these instruments must be evaluated while studying other types of renewable energy in the energy consumption structure of Vietnam.

One study applied a decomposition analysis approach to elucidate the dynamics of the energy and CO_2 intensities in the energy production systems of Vietnam and other Asian countries from 1984 to 1997, in comparison with the 1990 levels[18]. Results showed downward trends in both the energy intensity and CO_2 intensity effects from 1984 to 1995, followed by a drastic increase in the CO_2 intensity effect in the ensuing two years[18]. Fuel-switching was unremarkable from 1984 to 1995, but the final observations from 1996 1997 showed considerable fuel-switching towards more carbon-intensive fossil-based energy use[18]. This calls the reliability of the data into question. Later, the changes of embodied energy intensity in Vietnam from 1996 to 2000 were analyzed by structural decomposition and power series expansion approaches[19].

The share of the power sector in total CO_2 emissions of Vietnam decreased from 23% in 1990 to 13% in 1995, then returned to 23% by 2004[20]. This was lower than the corresponding figures from Japan (31%), Malaysia (31%), Thailand (19%), and various other countries in the same year[20]. Meanwhile, the share of thermal sources in the total electricity generation of Vietnam drastically dropped from 68% in 1980 to 38% in 1990, then climbed back up to 61% by 2004[20].

Among the factors contributing to the CO_2 emissions from power generation, CO_2 emissions and the GDP effect increased fivefold compared with 1980, the electricity intensity effect doubled, and the fuel intensity effect and generation mix effect both slowly decreased[20]. **Table 2** shows the CO_2 emissions trend and decomposition of factors in each period and the relative values in Vietnam from 1980 to 2004.

Table 2 Indices of CO_2 emissions and contributing factors in Vietnam from 1980 to 2004[20]

Period	CO_2 emissions index	Decomposition of factors			
		EIE	EGE	FIE	GSE
1980-1989 (1980 =1.0)	1.51	1.32	1.66	0.76	0.88
1990-1997 (1990 = 1.0)	1.68	1.26	1.75	0.92	0.83
1998-2004 (1998 = 1.0)	1.92	1.46	1.48	0.80	1.11

Notes: EIE = electricity intensity effect; EGE = economic growth effect; FIE = fuel intensity effect; GSE = generation structure effect.

Table 3 Main categories of energy sector GHG-emission-reduction options for Vietnam[21]

Categories	ALGAS studies (total accumulated CO_2 reductions)		UNEP studies (accumulated emissions 1994-2030)	
	CO_2 equivalent potential (Mt CO_2)	Cost per ton of CO_2 equivalent (US$)	CO_2 equivalent potential (Mt CO_2)	Cost per ton of CO_2 equivalent (US$)
Efficient air conditioners	49.9	-10.5	158	-4.4
Efficient refrigerators	84.5	-8.5	266	-3.6
Efficient electrical motors	67.2	-0.2	212	-3.0
Wind power	32.9	-4.6	104	-1.9
Efficient cooking	70.1	-4.2	212	-1.8
Fuels switching	1.6	46.4	0.014	21.2

The United Nations Environment Program (UNEP) study (based on the MARKAL model) and the Asian Least-cost GHG Abatement Strategy (ALGAS) (based on a system dynamic model) show that, with an annual growth rate of 7.7%, the elasticity of primary energy per GDP, CO_2 per primary energy, and CO_2 per GDP are 0.88, 1.24-1.4, and 1.09-1.24, respectively, for the 2020-2030 period in Vietnam[21].

Table 3 shows the main categories of energy sector GHG-emission-reduction options for Vietnam, together with the CO_2 equivalent potential and cost per ton of CO_2 equivalent by the ALGAS study and UNEP study. **Table 4** compares the Vietnam CO_2 emissions mix by sector between 1980 and 2005.

Table 4 CO_2 emissions mix by sector in Vietnam[22]

	1980	2005
Total (Mt of CO_2)	**14**	**80**
Power (%)	24	24
Industry (%)	36	37
Transport (%)	14	25
Other (%)	26	14

The changes in per capita GDP, population growth, and transportation energy intensity are determined as the main drivers behind the growth in the transport sector CO_2 emissions in most Asian countries, including Vietnam[22].

3. DATA ESTIMATION

(1) Overview of the data estimation method

To analyze the economy, energy consumption, and CO_2 emissions, we need SAM and EIOT. In this paper, the Vietnamese SAM and EIOT have to be estimated, as the statistics have not been published by the Vietnamese Government. This section describes how we estimate the data.

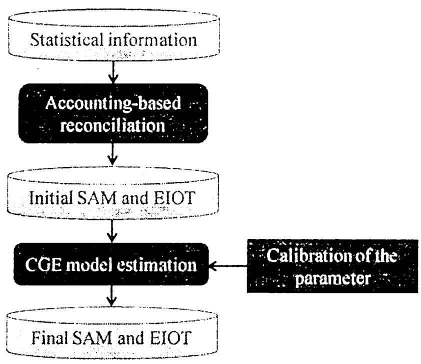

Fig. 1 Overview of the data estimation

Fig. 1 gives an overview of our method. The SAM and EIOT are estimated in two steps: (1) data reconciliation with the accounting principle and (2) data estimation with a CGE model. The first step aims to form an initial SAM and EIOT consistent with the statistical information, however it does not take economic theoretical information into account. Therefore the next step applies a CGE model based on the general equilibrium theory, thus providing the final results for the SAM and EIOT.

The following sections describe the steps pictured here.

(2) Data reconciliation with the accounting principle

a) Overview of the data reconciliation with the accounting principle

In this step we reconcile energy and economic information and estimated time-series SAM and EIOT. The reconciliation methods discussed earlier by Fujimori and Matsuoka (2008[24], 2009a[25], and 2009b[26]), are applied. The data are reconciled by a mathematical programming, described as non-linear. The minimizing function has the summation of three kinds of discrepancies:

(1) discrepancy between unknown variables and observations (statistical information).

(2) discrepancy between the ratio of unknown variables and the ratio from external information; for example, input-output coefficients.

(3) time-series discrepancy, as determined using the HP-filter as a time-series discrepancy function (Hodrick, 1997)[27].

Two types of constraint are used in this programming; namely, (1) the balance between the input and output and (2) the relationship among the price, value and volume. A more detailed explanation of the method has been published by Fujimori and Matsuoka (2008[24], 2009a[25] and 2009b[26]).

b) Data sources

Table 5 List of statistics[29)30)31)32)33)34)35)36)37)38)39)40)40)]

Name of statistic	Publisher	Published year	Data coverage
Global Trade Analysis Project	Purdue University Dimaranan	2006, 2009	2001-2004
Balance of Payments	IMF	2007	1950-2006
Commodity Trade Statistics Database	UN	2006	1962-2005
Industrial Demand-Supply Balance Database at the 4-digit level of ISIC code (Rev2)	UNIDO	2006a	1980-2004
Industrial Demand-Supply Balance Database at the 4-digit level of ISIC code (Rev3)	UNIDO	2006b	1980-2004
Industrial Statistics Database at the 4-digit level of ISIC code (Rev2)	UNIDO	2006c	1980-2004
Industrial Statistics Database at the 4-digit level of ISIC code (Rev3)	UNIDO	2006d	1980-2004
National Accounts Database	UN	2008	1971-2005
World Development Indicators	World Bank	2008	1960-2005
Globalstat	Enerdata	2008	1960-2003
Energy Balance of non-OECD countries	IEA	2009	1971-2008
Energy Statistics	EIA(USA)	2007	1980-2005
The Vietnamese International Merchadise Trade for 20 years Renovation (1986-2005)	TRD(VNM)	2006	1986-2005
Statistical Yearbook of Vietnam 2008	SY2008(VNM)	2009	1995-2008
Vietnamese Industry in 20 years of Renovation and Development	IND(VNM)	2006	1985-2004
Input-Output Tables 1989, 1996, 2000, 2005	IOT(VNM)		1989, 1996, 2000, 2005

Table 5 lists the statistical data applied to this reconciliation. Generally, developing countries have not collected and published sufficient statistical information. Fortunately, however, Vietnam Industrial Statistics and IO tables are available. We therefore use these data and other information obtained from international organizations.

(3) Data estimation with CGE model

a) Model structure

In the estimation of the initial SAM and EIOT in the previous step, there is no assurance that the results are consistent with the economic theory. This is to be expected, as the economic theory is disregarded in the first-step reconciliation. By economic theory, we refer for example, to the notion that production behavior can be explained by a CES (Constant Elasticity of Substitution) production function. In principle, the final data from the SAM and EIOT should be consistent with this theoretical information. In the next step we apply a CGE model based on the general equilibrium theory.

First, the parameters of the CGE model are calibrated to prepare for the use of the model. Without calibrated parameters, the model would be incapable of reproducing historical observations. This section describes the model structure and the next section presents the calibration method.

The CGE model here is based on the model developed by Lofgren (2002), with several modifications[23]. **Fig. 2** shows the structure of the model. **Table 6** shows the sector classifications and their aggregations in analysis.

Table 6 Sector classifications and aggregations

AGR	Agriculture	AGR
COA	Coal mining	Total mining (MINE)
OIL	Oil mining	MINE
GAS	Gas mining	MINE
OMN	Mineral mining and other quarrying	MINE
FPR	Food products	Light industry (LightIND)
TEX	Textiles and Apparel and leather	LightIND
LUM	Wood products	LightIND
PPP	Paper. Papor products and Pulp	Heavy industry (HeavyIND)
CRP	Chemical, Plastic. and Rubber products	HeavyIND
NMM	Mineral products nec	HeavyIND
I_S	Iron and Steel	Basic metal (BasicMET)
NFM	Non-ferrous products	BasicMET
MCH	Machinery	Total machinery (TotalMCH)
TRN	Transport equipment	TotalMCH
OMF	Other manufacturing	TotalMCH
ELY	Electricity	Utility (UTIL)
P_C	Petroleum and Coal refinery	UTIL
GDT	Gas manufacturing distribution	UTIL
WTR	Water	UTIL
CNS	Construction	CNS
TRS	Transport and communications	TRS
TRD	Trade and Wholesale and retail	Total services (TotalSER)
FIR	Finance, Insurance, Real estate, etc.	TotalSER
CSS	Community, Social Services nes	TotalSER
HURB	Urban households	HURB

There are four blocks: production, income distribution, final consumption, and market.

The first block, production, represents the structure of the production functions. We apply a CES function for production activities with three nested CES functions, namely, (1) value added and intermediate inputs, (2) capital and labor, and (3) intermediate inputs goods. The last branch (3) is defined as a Leontief type function ($\sigma=+\infty$).

The use of a Leontief type function is open to discussion, as the technology inevitably changes over a long-run period such as two decades. We understand this issue, but also recognize that the production function would be extremely difficult to identify if another assumption were introduced. We therefore apply the Leontief type function in this analysis and set this issue aside as a later step for our work on this methodology.

Second, incomes are distributed to three institutional sectors; namely, enterprises, government, and households. The government takes in income by collecting tax.

Third, institutions consume goods as final consumption. Government expenditure and capital formation are defined as a constant coefficient function. The LES (Linear Expenditure System) function is used for household consumption.

Lastly, the CES function is applied to the import of goods and the CET function is applied to the export of goods. A goods-consumption-and-supply equilibrium is achieved for each market.

Most of the parameters are calibrated by using initially estimated SAM and EIOT. In the analysis of the relationships between energy consumption and economic growth, however, the production behavior

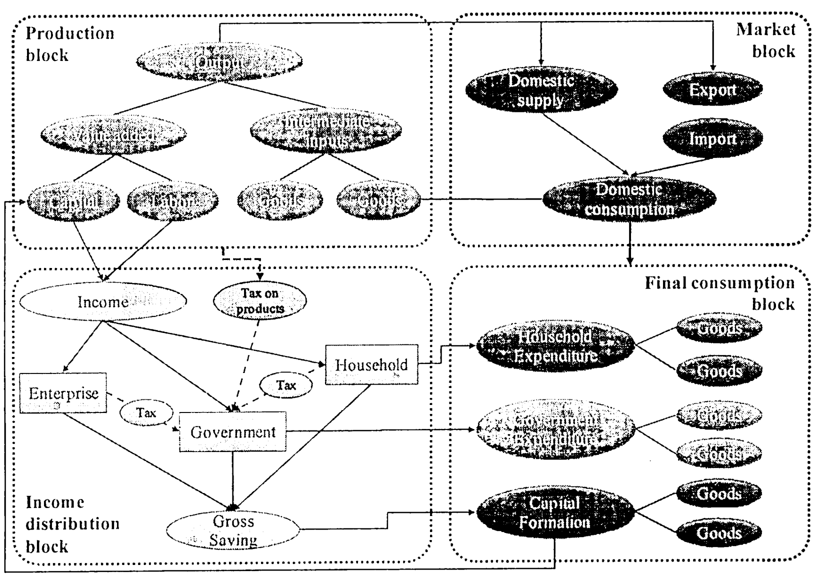

Fig. 2 CGE model structure

plays an especially important role. The parameters applied in the production function are therefore calibrated using time-series data. Ultimately we aim to develop a dynamic CGE model that accounts for the mechanism of capital stock and capital formation. Here, however, we only apply a static model. The next section describes the calibration method.

b) Calibration of the parameters in production functions

As explained in the previous section, a CES function is applied production behavior. This CES function can be written as follows.

$$Q_{0t,j} = \alpha_j \cdot \left(\delta_j \cdot Q_{1t,j}{}^{-\rho_j} + (1-\delta_j) \cdot Q_{2t,j}{}^{-\rho_j}\right)^{-\frac{1}{\rho_j}} \quad (1)$$

Where:

α, δ, ρ are an efficiency parameter, share parameter, and exponent parameter for sector j, respectively, as calculated by substitution elasticity.

$Q_{0t,j}$ is the output for sector j at year t, and $Q_{1t,j}$ and $Q_{2t,j}$ are inputs of factors and intermediate inputs for sector j at year t. The maximizing profit condition with the budget constraint can be expressed as the following equation.

$$\frac{Q_{1t,j}}{Q_{2t,j}} = \left(\frac{\delta_j}{1-\delta_j} \cdot \frac{P_{2t,j}}{P_{1t,j}}\right)^{\frac{1}{1+\rho_j}} \quad (2)$$

Where: $P_{1\,t,j}$ and $P_{2\,t,j}$ are the prices of factor inputs and intermediate inputs.

The three parameters α_j, δ_j, and ρ_j are estimated using econometric methodology. The initially estimated SAM and price variables, such as the deflators and energy prices, serve as the observations.

c) Calibration results

Equation (2) is converted into equation (3). The linear regression can be applied to equation (3). The results of the regression are shown in **Table 7**, with the values R^2, DW (Durbin-Watson), a_1, a_2, and t-values. R^2 is low in many sectors, and DW is much smaller than 2 even in the sectors with a high R^2. This means that the errors in the equation correlate serially in all sectors. We also find that a_1, the variable for substitution elasticity (defined as $a_1>0$), is negative in some sectors.

$$\log\frac{Q_{1t,j}}{Q_{2t,j}} = \frac{1}{1+\rho_j}\log\left(\frac{P_{2t,j}}{P_{1t,j}}\right) + \frac{1}{1+\rho_j}\log\left(\frac{\delta_j}{1-\delta_j}\right)$$
$$= a1_j \log\left(\frac{P_{2t,j}}{P_{1t,j}}\right) + a2_j \quad (3)$$

The analysis here is lightly modified to account for above occasions. To begin with, the model assumes that if there is no correlation between the independent variable and dependent variable, the substitution elasticity should be zero. This is because the production activity does not decide the volume of the factor or intermediate inputs based on the relative price when a correlation is absent. Two criteria are used for the evaluation here: (1) $R^2>0.1$ and (2) $a_1>0$.

Table 7 Results of the regression

Sectors	a_1	(t)	a_2	(t)	R^2	DW
AGR	-0.496	(-16.687)	1.045	(22.594)	0.116	0.432
COA	1.216	(27.065)	0.230	(14.194)	0.592	0.354
OIL	1.239	(138.165)	1.080	(75.280)	0.699	1.002
GAS	1.325	(415.145)	1.623	(222.527)	0.879	0.081
OMN	1.096	(96.960)	-0.832	(-51.734)	0.764	0.547
FPR	1.604	(87.444)	-1.010	(-36.079)	0.587	0.916
TEX	2.999	(97.794)	-1.746	(-22.423)	0.250	0.236
LUM	-1.438	(-34.989)	-1.174	(-17.450)	0.137	0.360
PPP	0.800	(58.064)	-0.856	(-46.560)	0.515	0.566
CRP	0.656	(25.199)	-0.771	(-24.620)	0.215	0.512
P_C	-0.593	(-2.196)	-0.561	(-2.862)	0.023	0.215
NMM	0.446	(12.453)	-0.595	(-17.761)	0.159	0.585
I_S	0.300	(16.217)	-1.981	(-33.848)	0.118	0.437
NFM	0.860	(17.931)	-1.699	(-11.897)	0.049	0.086
MCH	2.136	(102.747)	-1.034	(-32.754)	0.548	0.754
TRN	2.040	(74.069)	-0.368	(-18.317)	0.742	0.958
OMF	2.298	(59.799)	-0.951	(-15.472)	0.243	0.721
ELY	0.981	(6.173)	-0.062	(-0.683)	0.370	0.296
WTR	1.314	(28.257)	0.807	(33.070)	0.579	0.088
CNS	-0.034	(-0.891)	-1.074	(-18.583)	0.000	0.968
TRD	1.170	(39.583)	1.279	(24.931)	0.173	0.263
TRS	-0.322	(-5.090)	0.667	(11.723)	0.026	1.166
FIR	1.233	(47.479)	1.015	(28.837)	0.345	0.508
CSS	1.776	(62.553)	1.222	(26.395)	0.398	0.401

Next, as the second modification, the auto-regression model is applied for the sectors that pass these two criteria. The results of the auto-regression model are shown in **Table 8**. The valid criteria are not satisfied in the sectors with blank rows. Here we find that the auto-regression model clearly improves DW. The sign condition of the parameters and t-values are valid. R^2 here appears to be a concern however, as this variable is still small in some sectors.

Table 8 Results of the autoregression model

Sectors	a_1	(t)	a_2	(t)	R^2	DW
AGR						
COA	0.906	(8.072)	0.185	(21.172)	0.333	1.897
OIL	1.300	(29.491)	1.119	(31.469)	0.834	0.929
GAS						
OMN	1.034	(38.805)	-0.857	(-77.039)	0.161	1.136
FPR	1.320	(37.920)	-1.049	(-41.515)	0.599	1.236
TEX						
LUM						
PPP	1.271	(41.625)	-0.789	(-64.719)	0.182	1.622
CRP	0.337	(5.622)	-0.836	(-41.004)	0.421	1.477
P_C						
NMM	0.990	(10.938)	-0.474	(-17.022)	0.685	2.090
I_S	0.692	(14.848)	-1.624	(-46.993)	0.294	1.350
NFM						
MCH	1.530	(38.550)	-1.033	(-43.715)	0.319	1.810
TRN	1.830	(38.853)	-0.384	(-22.236)	0.411	1.814
OMF	0.740	(9.892)	-1.105	(-24.309)	0.874	1.744
ELY	0.821	(3.984)	-0.450	(-8.729)	0.884	2.012
WTR						
CNS						
TRD						
TRS						
FIR	0.586	(9.111)	0.918	(39.591)	0.272	1.407
CSS	0.860	(12.389)	1.138	(48.197)	0.297	1.643

4. ANALYTICAL RESULTS

This section on analytical results focuses on changes in the energy consumption structure and CO_2 emissions by sector. But before doing so, it analyzes the change of the population and GDP structures in order to clarify the economic development trend and the contribution of each sector to this growth. The relationships among population, GDP, energy consumption, and CO_2 emissions are determined based on these results in order to identify the main drivers behind the CO_2 emission changes over this 20-year period compared with the base year of 1986. More importantly, the change of industrial value added, GDP per capita, carbon intensity, and energy intensity are calculated to determine how the abovementioned factors affect CO_2 emissions in Vietnam over this period, both on the macro level and on sector-by-sector levels, in order to determine the main drivers behind CO_2 emission changes in each economic activity.

(1) Economic structure

The industrial value added increases drastically, effectively tripling from 13,030USD in 1986 to 46,730USD in 2005 (as illustrated in **Fig. 3**). The two main contributors are total services (contributes steadily at the same rate of about 40%) and agriculture (decreases from 35% to 20%). The contributions from the mining and quarrying, light industry, and total machinery increase softly, while those of the transport, construction, basic metal, and utility show little change.

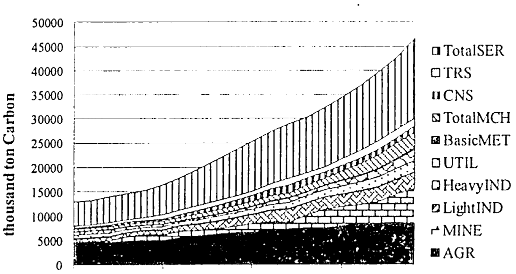

Fig. 3 GDP change by sector

(2) Energy consumption

The total energy consumption of Vietnam begins to increase from 1986-1987, then loses ground from 1988 to 1990, eventually returning to the 1986 level of around 4,700kTOE. After this two-year retraction, the energy consumption begins a rapid ascent, climbing from 4,974kTOE in 1990 to 22,668kTOE in 2005.

Increases in all sectors contribute to this growth in energy consumption. The main contributors are transport, utility, industry, residential, basic metal, and total services, making up 20%, 22%, 25%, 12%, 9%, and 6% of the total consumption, respectively, in 2005. The energy consumption of machinery, agriculture, mining, and construction is still very small compared to the other consumption sources during this period (see **Fig. 4**).

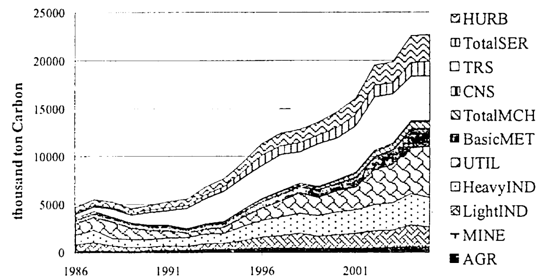

Fig. 4 Energy consumption change by sector

(3) CO_2 emissions

The CO_2 emissions of each sector follow the same trend as energy consumption, climbing more than six-fold from 4,086 (in 1986) to 16,378 thous. tons of carbon (in 2005). The change in percentage contribution to CO_2 emissions by sector is also very close to the percentage change of energy consumption, increasing rapidly from 1990 onward (see **Fig.5**).

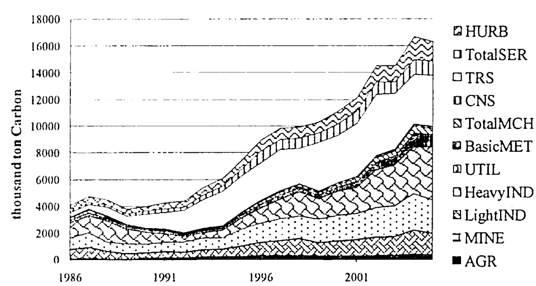

Fig. 5 CO_2 emissions by sector

(4) Main drivers of CO_2 emissions in Vietnam from 1986 to 2005

An accurate analysis of the CO_2 emission reduction potential requires an understanding of the main drivers behind the CO_2 emission changes. **Fig. 6** shows the changes of the population, GDP, energy consumption, and CO_2 emissions in the other years of the period, compared to the base year of 1986. The population increases much more slowly than the GDP, energy consumption, and CO_2 emissions. The gaps among these parameters increases rapidly, especially from 1995 onward, marking the start of rapid development in Vietnam.

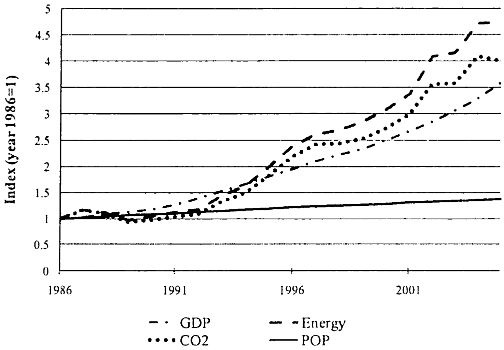

Fig. 6 Changes of population, GDP, energy consumption, and CO_2 emissions

CO_2 emissions are decomposed into economic activity (GDP), energy intensity, and carbon intensity, in order to determine the main drivers behind them (see equation 4). The GDP, meanwhile, is decomposed into population and GDP per capita. Equation 5 shows the change of CO_2 emissions on this basis.

$$CO_2 = Pop * \frac{GDP}{Pop} * \frac{EC}{GDP} * \frac{CO_2}{EC} \quad (4)$$

$$\Delta CO_2 = \Delta Pop + \Delta\left(\frac{GDP}{Pop}\right) + \Delta\left(\frac{EC}{GDP}\right) + \Delta\left(\frac{CO_2}{EC}\right) \quad (5)$$

Where:
CO_2: CO_2 emissions
Pop: total population
GDP: Gross Domestic Production
EC: total energy consumption
$\frac{GDP}{Pop}$: GDP per capita
$\frac{EC}{GDP}$: energy intensity
$\frac{CO_2}{EC}$: carbon intensity

Fig. 7 shows the contribution of decomposed factors affecting the CO_2 emission changes over each 5-year period from 1986 to 2005. Our macro economic analysis identifies the energy intensity as the main driver behind the decrease of CO_2 emissions in the first period, 1986-1990, when energy consumption is decreasing. The other three factors contribute in almost the same proportions during this period. This can be explained by the hyperinflation in 1986, together with the shock from the Soviet Union collapse in 1989[5].

In the second period, 1991-1995, the main driver behind the increase in CO_2 emissions switches to GDP per capita, though the contribution of energy consumption remains high. Over the next two periods. 1996-2000 and 2001-2005, the GDP per capita remains the main driver behind the CO_2 emission changes, while the contribution of carbon intensity slightly rises and the contribution of industrial value slightly falls.

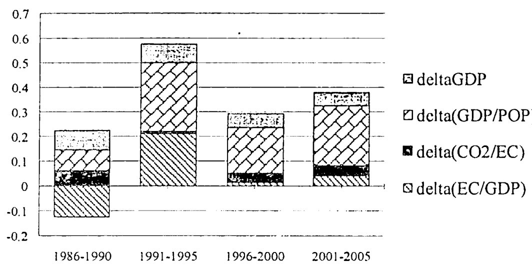

Fig. 7 CO_2 emission changes by decomposed factors

This paper also closely analyzes the transport, utility, and industry sectors, three main contributors to energy consumption and CO_2 emission changes.

The main driver in the transport sector is energy intensity, except during the period from 1996 to 2000 (see **Fig. 8**), when foreign investment and foreign trade sharply fall in the aftermath Asian crisis (1997)[5]. The energy intensity decreases gradually from 2001 to 2005, possibly as a consequence of the rises in global petroleum prices and the outbreak of the avian flu[5].

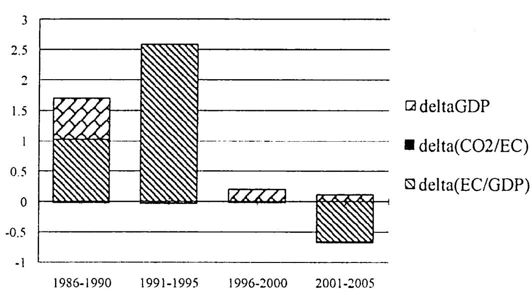

Fig. 8 CO_2 emission changes by decomposed factors in the transport sector

In terms of utility (aggregated from sectors as given in **Table 6**), the main driver from 1991 to 1995 is energy intensity. From 1996 to 2005 the main driver switches to GDP (see **Fig. 9**), but energy intensity remains a very strong contributor to income from the utility sector, a major contributor to the CO_2 emission changes.

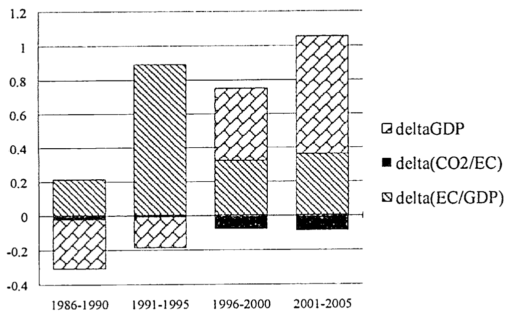

Fig. 9 CO_2 emission changes by decomposed factors in the utility sector

Heavy industry (HeavyIND) and light industry (LightIND) are aggregated from sectors as given in **Table 6**. GDP persists as the main driver for heavy industry throughout the whole study period (see **Fig. 10**), just as it does for light industry during all periods except the plateau period from 1986 to 1990 (see **Fig. 11**). CO_2 emissions from light industry from 1986 to 1990 are strongly affected by the energy intensity.

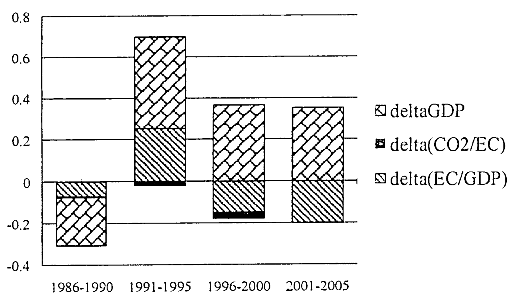

Fig. 10 CO_2 emission changes by decomposed factors in the heavy industry sector

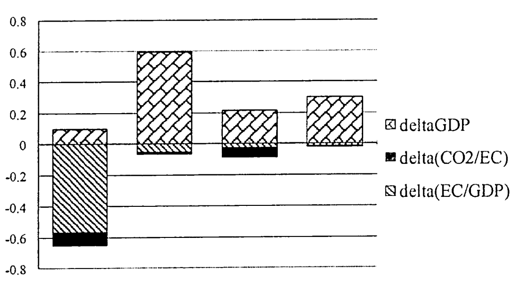

Fig. 11 CO_2 emission changes by decomposed factors in the light industry sector

Generally, for all sectors analyzed in this paper, the reasons for the change in the main drivers behind the CO_2 emission changes are still very difficult to understand, especially on a sector-by-sector basis.

5. CONCLUSIONS

We have developed a data estimation method to provide information on past trends and the relationship among economic development, energy structure, and CO_2 emission changes for use as background data in further studies. The accounting principle and CGE model are applied with the calibration of parameters in production functions.

In applying this methodology to the case of Vietnam, we come up with results discrepant from those presented in the review of historical energy consumption and CO_2 emissions of Section 2. Specifically, we find that the transport and utility sectors are the biggest energy consumers and sources of CO_2 emissions over the study period; followed by industry, residential, basic metal, and total services.

Rapid development growth in Vietnam has led to uncontrolled consumption of energy and sharply rising levels of CO_2 emissions, especially since 1995. With this methodology, Vietnamese policymakers can garner a new understanding of the influences of economic development on energy consumption and CO_2 emissions and apply that understanding to the formulation of appropriate economic and energy development strategies.

This paper relies on only a static model with no dynamic relationship between capital stock and savings. Our task for the future will be to develop a dynamic model with improvements to help us provide better historical information and more fully understand the prospects of future development policies in Asian countries.

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