ANALYSIS OF THE FRANCIS TURBINE OPERATION USING COMPUTATIONAL FLUID DYNAMICS

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Universiti Malaysia Sarawak
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Approval Sheet

This project report attached hereto, entitle " Analysis of the Francis turbine operation using Computational Fluid Dynamics" prepared and submitted by SAMSUDIN BIN SULAIMAN in partial fulfillment of the requirements for the degree of Bachelor with honor of Mechanical and Manufacturing System Engineering is hereby accepted

Date: 28 June 1999.

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ANALYSIS OF THE FRANCIS TURBINE OPERATION USING COMPUTATIONAL FLUID DYNAMICS

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Tesis Dikemukakan Kepada
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Penganurahan Sarjana Muda Kejuruteraan
Dengan Kepujian (Kejuruteraan Mekanikal dan Sistem Pembuatan)
May 1999

To my wife, son , daughters and families

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ABSTRACT

The development of power generation have improved, in order to give optimum efficiency from energy sources such as hydroelectric power. Electricity being one of the important energy source is in great demand throughout the world energy consumption. The economic growth in Malaysia, alternative energy source such as hydro is utilized. This policy was then adopted by the implementation of few hydro electric generating plant such as the Batang Ai and the latest, the construction of the Bakun Hydro Project. This project will look into the investigation of performance of a Francis turbine without guide vane. In this study, Computational Fluid Dynamics code called *Phoenics* was used in analyzing the water flow in the turbine and also gave an in sight of the design of the turbine. The results were presented in graphical and simulations forms in order to compare and identify the factors influencing the turbine efficiency of the 108 MW Batang Ai Hydroelectric Power Station and the economics of using CFD in the analysis.

ABSTRAK

Kemajuan dalam penjanaan kuasa telah meningkat dimana ia perlu untuk memberi kecekapan optima seperti dalam penjanaan kuasa hidroelektrik. Selain daripada menjadi salah satu sumber tenaga, kuasa elektrik juga merupakan sumber yang terbanyak digunakan dalam penggunaan tenaga sedunia. Di Malaysia, perkembangan ekonomi yang pesat memerlukan sumber tenaga alternatif seperti tenaga hidro untuk dipertimbangkan penggunaannya. Polisi ini telah diserapkan dengan penggunaan kuasa hidro seperti di Batang Ai dan yang terkini, pembinaan Projek Kuasa Hidro Bakun. Projek ini akan membuat kajian mengenai prestasi turbin Francis tanpa *guide vane.* Kajian ini juga menggunakan simulasi komputer *Computational Fluid Dynamics* yang dipanggil *Phoenics* untuk menganalisa aliran air didalam turbin serta memberi satu gambaran dalam rekabentuk turbin tersebut. Keputusan kalian ini telah disampaikan dalam bentuk grafik dan simulasi untuk membezakan dan mengenal pasti faktor-faktor yang menpengaruhi kecekapan turbin air tersebut. Kecekapan turbin 108 MW Batang Ai telah dijadikan bahan kajian serta pandangan penggunaan CFD untuk membuat kajian dari segi ekonomi telah di kenal pasti.

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NOTATION

The following notations are employed

A	:	Cross sectional area (m^2)
b	:	Blade passage width (m)
B	:	Blockage factor
d	:	Diameter (m)
E	:	Energy supplied (kJ)
g	:	Gravitational acceleration (m/s^2)
H	:	Head (m)
m	:	Mass flow rate (kg/s)
N	:	Rotational speed (rpm)
N_s	:	Specific Speed
P	:	Power output (kW)
Q	:	Volume flow rate (m^3/s)
r	:	Radius (m)
T	:	Torque (Nm)
V	:	Velocity (m^3/s)
V_r	:	Radial component of velocity
V_f	:	Tangential component of velocity
w	:	Work per unit mass (kJ/kg)
W	:	Work done (kJ)

Greek symbols

α	:	Absolute flow angle (degrees)
β	:	Relative flow angle (degrees)
η	:	Efficiency
ω	:	Angular velocity (rad/s)
π	:	Pi, dimensionless parameter
ρ	:	Density of water (kg/m^3)
Σ	:	Summation

Subscripts

1	:	Runner outlet conditions
2	:	Runner inlet conditions
f	:	Reference to flow velocity
H	:	Hydraulic
O	:	Overall
r	:	Reference to relative velocity
s	:	Reference to specific speed
w	:	Reference to swirl velocity

CHAPTER 1
Introduction

1.0 Introduction

The world's energy sources comes in many forms. The natural energy source derive from mother nature are solar, wind, geothermal and etc. Human beings, animals and plants have lived in this planet for thousands of years and all of them depend on these resources of energy for survival. Human beings being the top of the living hierarchy need these energies the most, not only for survival but to develop their civilisation and prosper. The main application of this energy resources for them is to supply heat and since the invention of light, electricity. However, human being exceed other species in the race of development. Human development are also proportional to the energy usage. With the growing population and limited energy resources, human being need to make sure that the energy resources are always sufficient for the development of their civilisation. Realising the limitation of these resources, human being looked for alternatives or renewable energy source. They have developed many renewable energy sources to compensate the energy needed for their innovative technologies.

In addition to that, the technologies for the development of the existing power generation are also improving in order to give the optimum efficiency from the energy sources . With the invention of the internal combustion engine, development of turbines and other electrical devices, man have generated and extracted energy from oil , coal and natural gas. Due to the environmental concern, the world have utilised energies sources such as hydroelectric power. This hydroelectric power is ranked fourth after oil, coal and natural gas. In the energy usage, now, hydroelectric is the world's largest commercially available energy resources, which is

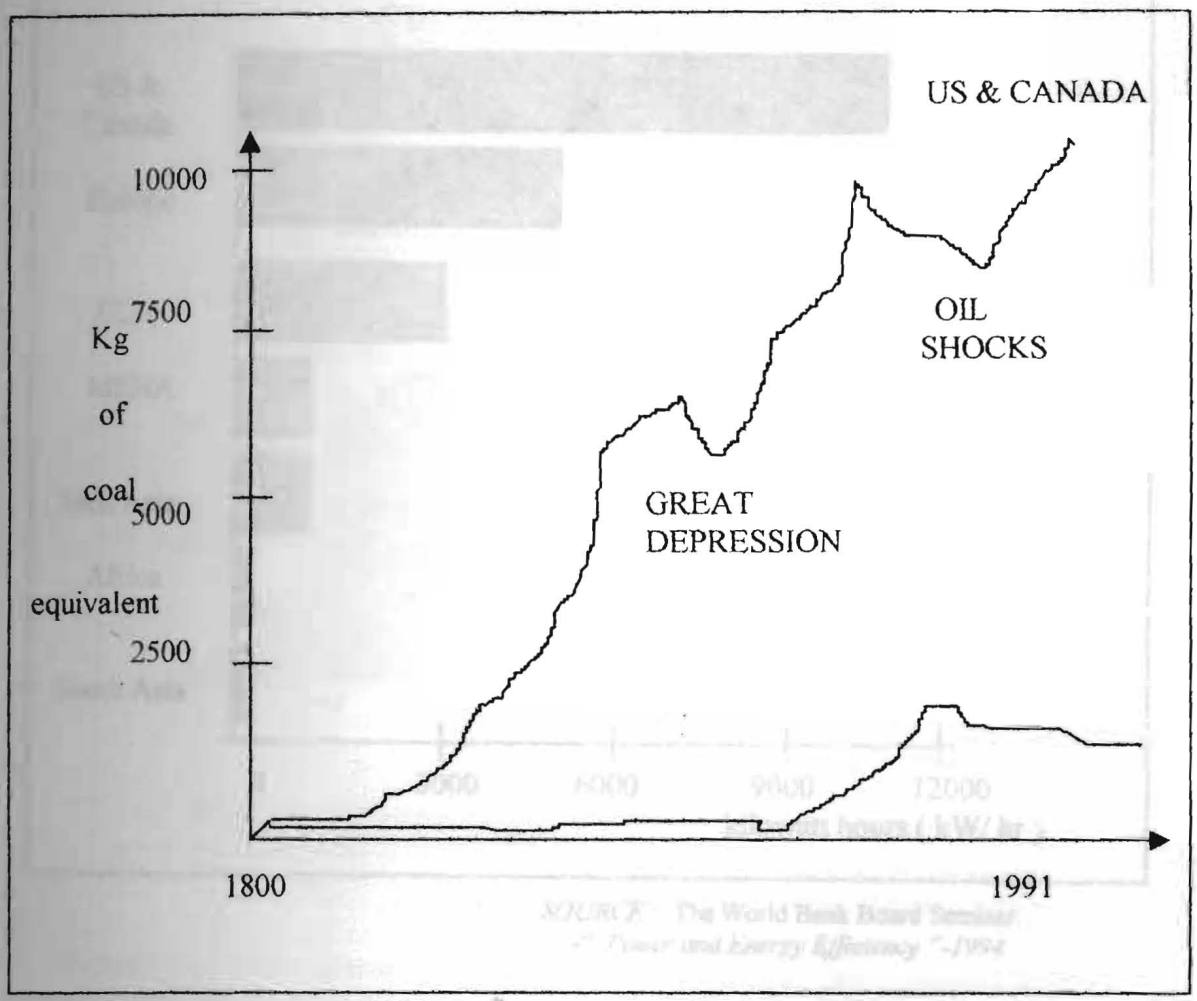
accounting for 67 % of the total primary energy consumption [1]. Further progress followed with the development of the water turbine for the generation of electricity.

Electricity is one of the most important energy. It is proven that, for any country, the rise electricity consumption per capita increases with the Growth Domestic Product (GDP). Figure 1.0 shows the relationship of electricity consumption and the GDP from 1800 to 1991. The chart shows that the energy consumption in the United States and Canada has risen steadily with the two tips. The Great Depression in 1929-1931 and the great oil shocks in the mid 70s and early 80s. [4].These are due to the significant increased of the standard of living in the period of 1800-1991.[4] Comparatively, the energy consumption in these countries in the 1850 is at the present energy consumption of Africa [4]. This is due to the fact that they are already industrialised during that time.

1.1 World energy Demand

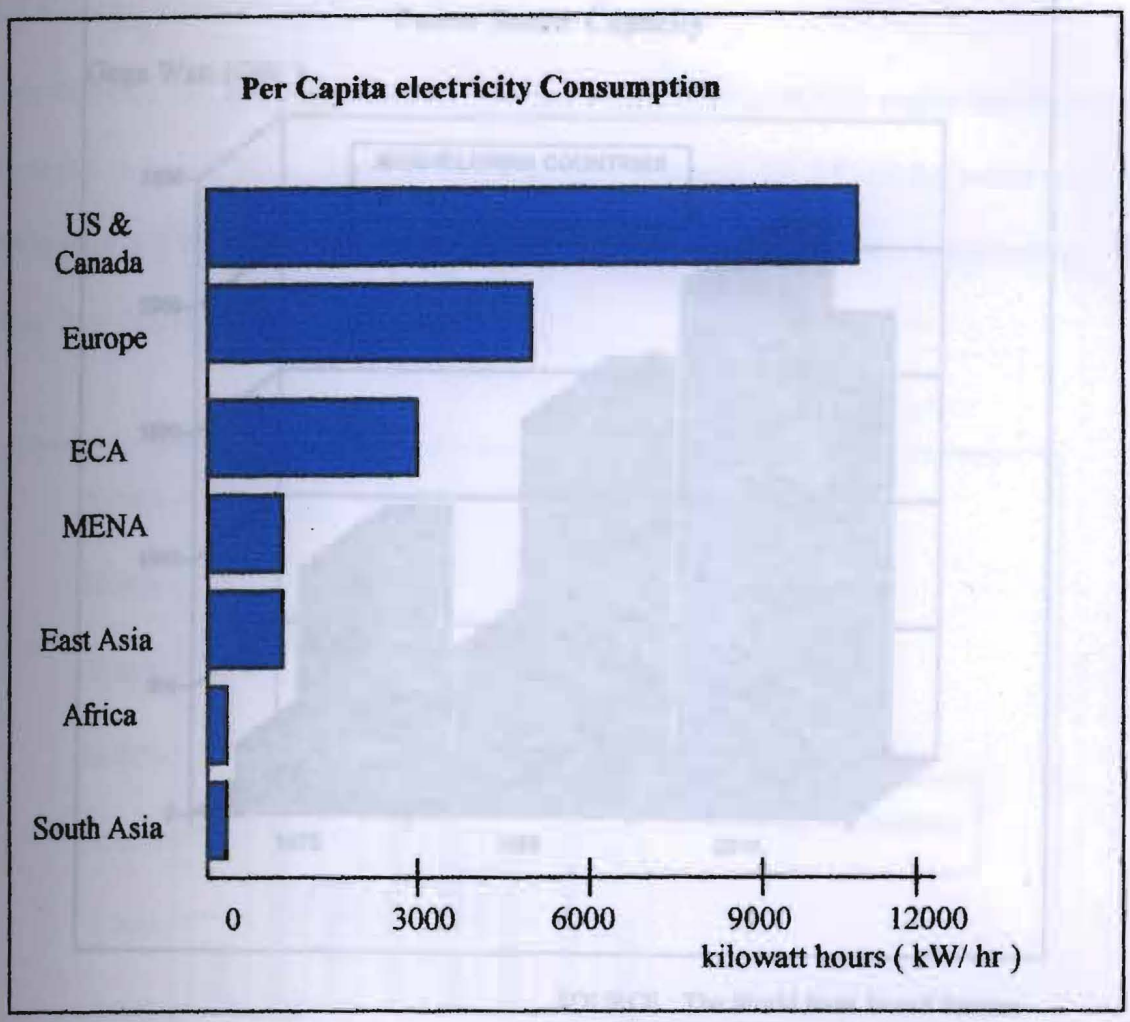
Nowadays, the major energy consumption is in the form electricity. Both the developed and the developing countries need this form of energy for development. This can be proven by the consumption per capita of electricity. For example, the rate of electricity consumption varies enormously from the developed countries such as United States and Canada compared to developing countries such as East Asia, Africa and South Asia [4] This is primarily due to energy consumption for industrialisation. Figure 1.1 shows comparisons of the energy consumption per capita.

The growing industrialisation of the many developing countries can also be reflected in their rapid energy consumption.



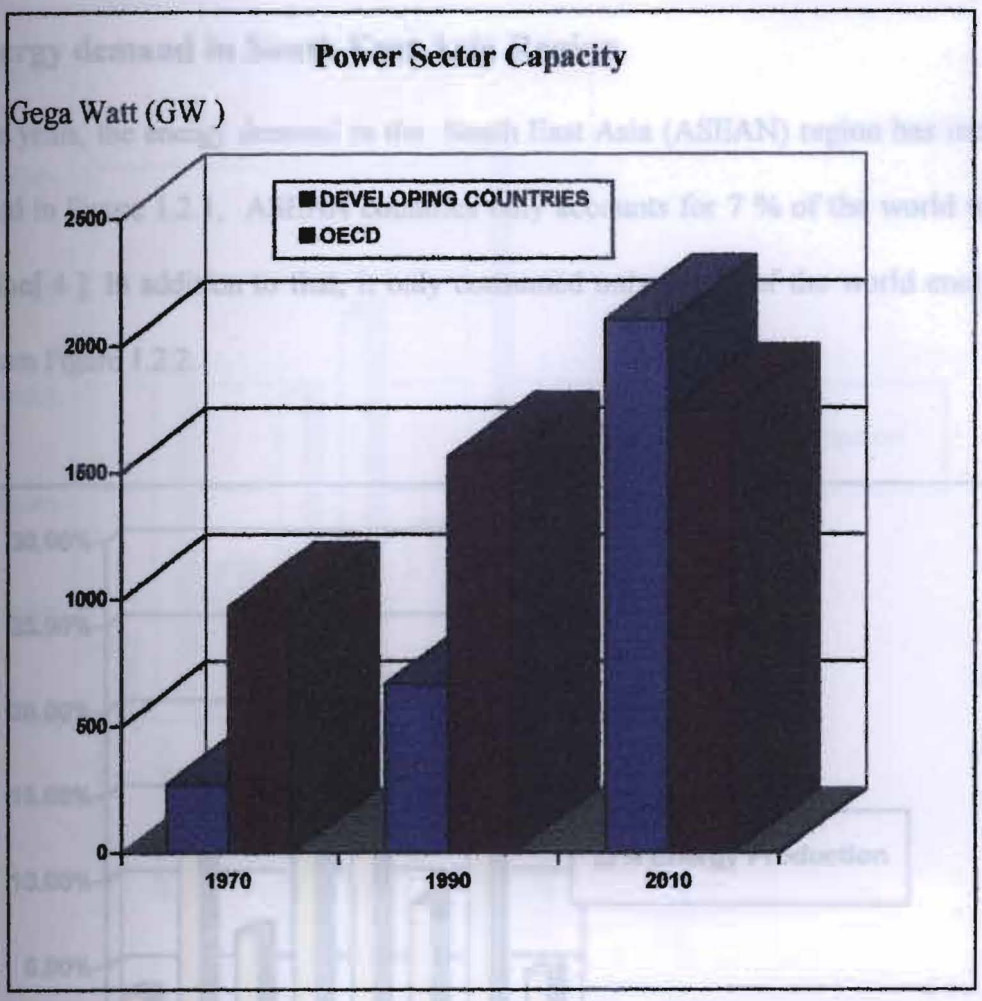
SOURCE: World Bank Board Seminar
- " *Power and Energy Efficiency*"-1994

Figure 1.0 Energy Consumption Per Capita over two centuries



SOURCE : The World Bank Board Seminar
-" *Power and Energy Efficiency* "-*1994*

Figure 1.1 Consumption of Electricity Per Capita



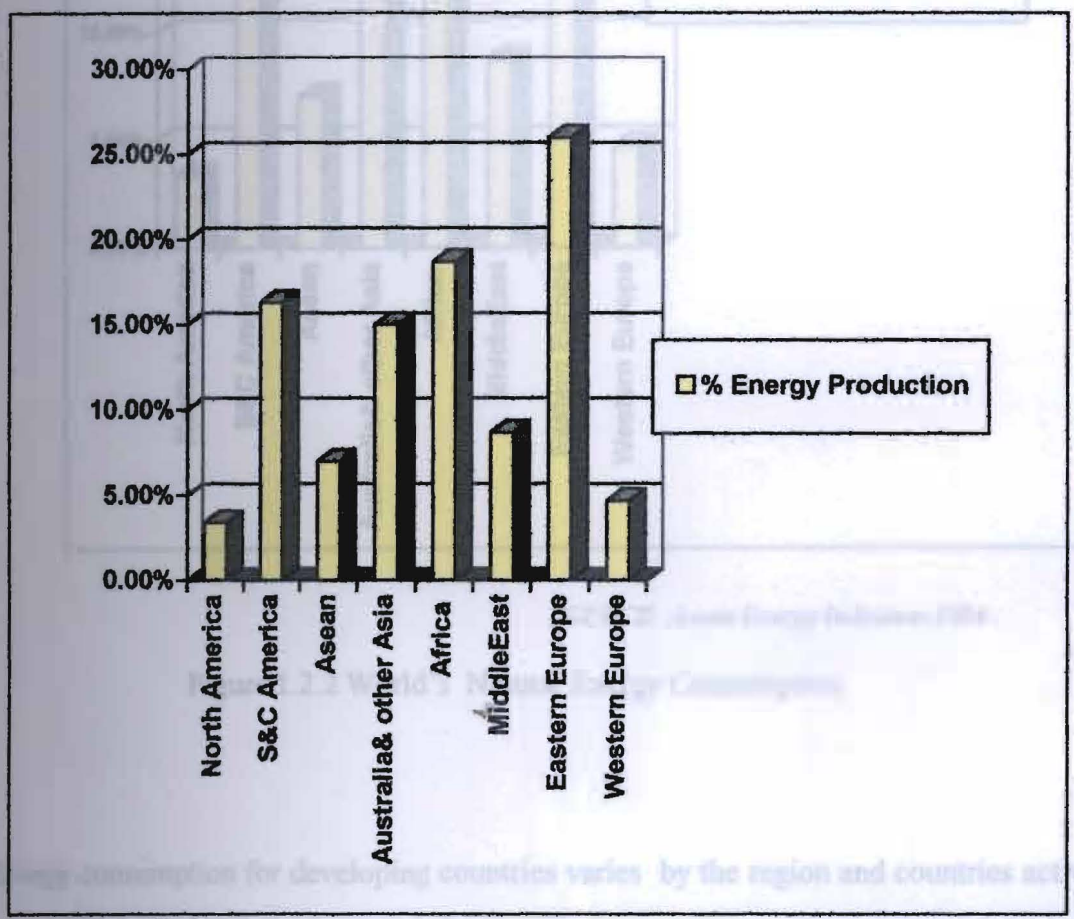
SOURCE : The World Bank Board Seminar
-"*Power and Energy Efficiency*"-1994

Figure 1.1.1 Power consumption of The Developing Countries compared to the countries of the Organisation for Co-Operation and Development (OECD)

From Figure 1.1.1, it infers that the efficiency gain in the developing countries comes from the installation on the more efficient design. As forecast in 2010, for developing countries, a small rise in the demand initiate a massive increase in the demand for electricity due to the large population.

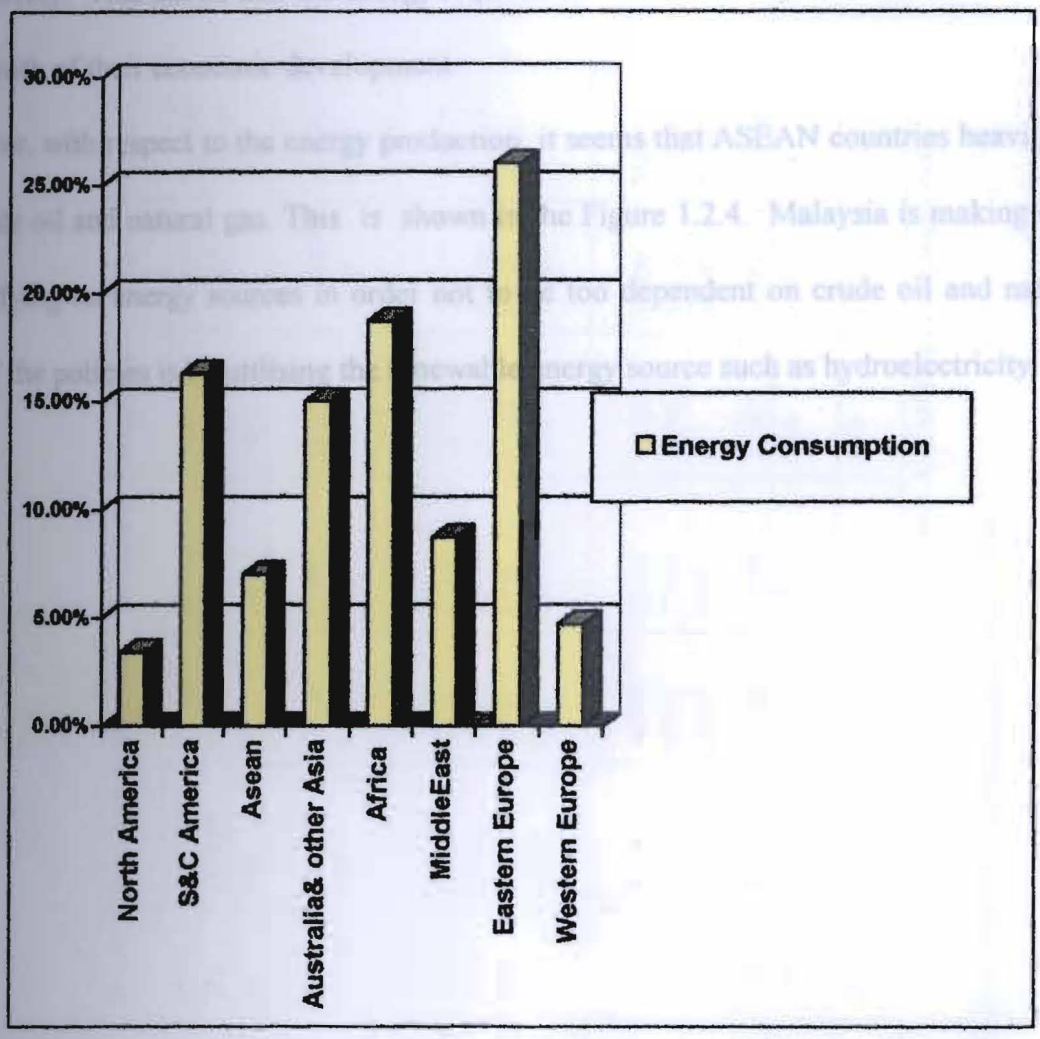
1.2 Energy demand in South East Asia Region

Over the years, the energy demand in the South East Asia (ASEAN) region has increased. As illustrated in Figure 1.2.1, ASEAN countries only accounts for 7 % of the world total energy production[4]. In addition to that, it only consumed only 3.4 % of the world energy. This is based from Figure 1.2.2.



SOURCE: Asean Energy Indicator-1994

Figure 1.2.1ASEAN in the world's Natural Energy Production



SOURCE: Asean Energy Indicator-1994

Figure 1.2.2 World's Natural Energy Consumption

Energy consumption for developing countries varies by the region and countries activities. The large surge of economic growth was expected in the early nineties for Malaysia and Singapore [4]. As shown by the table 1.2.3, Malaysia and Singapore share the largest energy consumption of 0.98 ton of oil equivalent (toe)/person and 0.96 ton of oil equivalent (toe)/person

respectively. This shows that the energy requirement of the country in South East Asia reflects the growth of their economic development.

However, with respect to the energy production, it seems that ASEAN countries heavily depend on crude oil and natural gas. This is shown in the Figure 1.2.4. Malaysia is making efforts in diversifying its energy sources in order not to be too dependent on crude oil and natural gas. One of the policies is by utilising the renewable energy source such as hydroelectricity.

	Brunei	Indonesia	Malaysia	Philippines	Singapore	Thailand	Asean
1. Area (sq. km)	6000	1905000	330000	300000	1000	513000	3055000
2. Population (Thousand)	285	193100	19500	67030	2930	59400	342245
3. Population Density (person/sq. km.)	48	101	59	223	2930	116	112
4. Gross Domestic Product (at current prices)	4100	174600	72300	63900	68900	143300	527100
Value (million US $)	14386	904	3708	953	23515	2412	1540
Per Capita GDP (US$)							
5. Sectoral GDP Components (at current Prices)	1746	68986	30385	20384	23771	54024	188277
Industrial (million US $)	2012	61586	25371	25496	36724	69756	212215
Residential/Commercial (million US $)	210	12397	5018	3770	8.268	10318	39381
Transport (million US $)	131	30380	11527	14250	138	19202	
Agriculture (million US $)							
6. External Trade							
Exports f.o.b	2162	40100	56700	13433	96500	43800	75628
Imports f.o.b	3142	32000	60851	22804	102400	54616	252695
7. Primary Energy Production (ktoe)	17984	152981	65642	3596	0	18197	258400
8. Final Energy Consumption (ktoe)	548	46899	19188	10628	32587	32587	112.940
9. Per Capita Final Energy Consumption (toe/person)	1.92	0.24	.98	.16	0.96	0.55	.33
10. Electricity Share in Final Energy Consumption %	20.3	7.9	15.3	20.4	57.6	16.2	14.0

Source: ASEAN Energy Indicators-1994

Table 1.2.3 ASEAN Energy- Economy Indicators-1994