Assessing Policy Options for Increasing the Use of Renewable Energy for Sustainable Development: Modelling Energy Scenarios for Ghana

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UN-Energy

ASSESSING POLICY OPTIONS FOR INCREASING THE USE OF RENEWABLE ENERGY FOR SUSTAINABLE DEVELOPMENT:

MODELLING ENERGY SCENARIOS FOR GHANA

A UN-ENERGY Demonstration Study

conducted by

Department of Economic and Social Affairs (DESA)
Food and Agriculture Organization (FAO)
International Atomic Energy Agency (IAEA)
United Nations Environment Programme (UNEP)
United Nations Industrial Development Organization (UNIDO)

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Preface

UN-Energy was created in 2004 as the United Nations' principal interagency mechanism in the field of energy. Its creation responds to a request in the Johannesburg Plan of Implementation, adopted by the 2002 World Summit on Sustainable Development, for a new collaborative mechanism between UN agencies, programmes and institutions.

UN-Energy has now grown to 20 members and published two reports: "The Energy Challenge for Achieving the Millennium Development Goals" for the September 2005 World Summit in New York and "Energy in the United Nations: An Overview of UN Energy Activities" for the May 2006 fourteenth session of the UN Commission on Sustainable Development (CSD-14).

This report is the third to be published by UN-Energy. It breaks new ground in being the first to present analytic results from interagency cooperation that, without UN-Energy, would simply not have happened. The study was carried out by five UN organizations and the Energy Commission of Ghana. It was led by the International Atomic Energy Agency (IAEA) and included the Department of Economic and Social Affairs (DESA), the Food and Agriculture Organization (FAO), the UN Environment Programme (UNEP) and the UN Industrial Development Organization (UNIDO).

The study analyzes alternative national policies to increase the share of renewables in the energy supply mix of Ghana. It was initiated by DESA in response to the Johannesburg Plan of Implementation's call to, "With a sense of urgency, substantially increase the global share of renewable energy sources". The study combines the IAEA models for analyzing national energy systems with data provided by the Energy Commission of Ghana, UNEP, FAO and UNIDO. It is a demonstration study, not a comprehensive analysis of policy options for Ghana. But it provides generic insights on policy options and describes one sort of joint assistance that UN organizations can offer to interested States.

A second such study is already underway for Sichuan province in China, and I look forward to UN-Energy serving as a continuing catalyst for new similar cooperation among UN organizations in the service of our Member States.

Mats Karlsson
Chair, UN-Energy
May, 2006

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Summary

The WSSD’s Johannesburg Plan of Implementation (JPOI) in Paragraph 20(e) calls on Governments and other stakeholders to, “With a sense of urgency, substantially increase the global share of renewable energy sources with the objective of increasing its contribution to total energy supply”. This paper reports initial results of a study of alternative national policies to increase the share of renewables in one country, Ghana. The study was initiated by the UN Department of Economic and Social Affairs (DESA), facilitated by UN-Energy and led by the International Atomic Energy Agency (IAEA). It uses data on biomass, solar, wind and micro hydropower resources from the Food and Agricultural Organization (FAO), the UN Environment Programme (UNEP) and the UN Industrial Development Organization (UNIDO), and it uses energy system analysis models from the IAEA. For specificity in the context of developing countries, it analyzes policy options as applied to the current energy system of Ghana. The quantitative characterization of the Ghanaian energy system was done with the direct participation of the Energy Commission of Ghana (ECG). The study, however, is intended to provide general insights on the relative effectiveness and costs of generic policy options to increase the share of renewables. It is not a comprehensive analysis of policy options for Ghana.

Based on ECG, FAO, UNEP and UNIDO data, the IAEA energy models were used to generate a baseline least-cost scenario of the Ghanaian energy system through 2030. This describes the development of the energy system that would minimize total discounted energy system costs based on the technology and resource costs input to the models. In this ‘base case’ scenario, the share of micro hydro, wind and solar power in the primary energy mix grows from nothing in 2005 to just 0.5% in 2030. In terms of electricity, their share grows over the same period from nothing to 4.4% (1,630 GWh) in generation and 11.6% (720 MW) in capacity.

Alternative scenarios were developed by adding constraints to the models to represent three different policy options to increase the share of renewables. The ‘Portfolio Standard / Renewable Energy Quota’ (REQ) scenario requires utilities to generate a certain percentage of their electricity from renewables, with the percentage starting at 2% (230 GWh) in 2010 and rising to 20% (7,340 GWh) in 2030. The ‘Public Benefit Fund’ (PBF) scenario creates a fund through a levy on electricity transmission. The fund is then used to partly finance renewable energy projects. The Clean Development Mechanism (CDM) scenario sells on the international market the certified emission reductions (CERs) generated by renewables.

Of the three scenarios, the REQ scenario leads to the largest share of renewables in electricity generation in 2030 (20% or 7,340 GWh). This is to be expected, given that the share of renewables is constrained to reach 20% in 2030 in this scenario, and the scenario calculated by the models is, by definition, the least-cost route to reaching that target. In the PBF scenario their share is 8.4% (3,090 GWh). In the CDM scenario it is 5.1% (1,860 GWh). Total investment costs are highest in the REQ scenario and lowest in the CDM scenario, but operating and maintenance costs are highest in the PBF scenario and lowest in the REQ scenario. The final factor to be considered in assessing the cost-effectiveness of the three options is who pays for the cost increases above the base case scenario. For the REQ scenario it is the Ghanaian utilities. For the PBF scenario it is mainly electricity consumers. For the CDM scenario it is principally foreign purchasers of CERs.

More generally, these results suggest that to meet the JPOI’s call to “substantially increase” the share of renewables, a combination of policy measures reinforcing each other may well be needed.

ASSESSING POLICY OPTIONS FOR INCREASING THE USE OF RENEWABLE ENERGY[1] FOR SUSTAINABLE DEVELOPMENT: MODELLING ENERGY SCENARIOS FOR GHANA

1 Introduction

The World Summit on Sustainable Development (WSSD) requested in its Johannesburg Plan of Implementation that a new collaborative mechanism between United Nations agencies, programmes and institutions be formed. In response, UN-Energy was created in 2004 as the principal interagency coordinating mechanism in the field of energy within the UN system. Its purpose is to help ensure coherence in the UN system's multi-disciplinary response to WSSD and to collectively engage non-UN stakeholders.

One of the joint activities agreed by UN-Energy is directly related to a major energy-related objective of WSSD, namely, "increasing the proportion of energy obtained from renewable energy sources". In this regard, UN-Energy agreed to conduct two case studies, Ghana and Sichuan Province in China. These case studies are designed to assess policy options that could be instrumental in fostering greater use of renewable energy, their effectiveness and their costs.

Ghana is particularly suitable for such a study. While its fossil fuel resources are very limited it has reasonable resources of renewable energy: biomass, wind, solar and micro hydro. These renewable resources could help to increase the available energy supply, reduce the country's energy import bill and enhance security of energy supply.

The IAEA's energy-environment planning and analysis tools were used for this case study to test the efficacy of various policy options in the context of a comprehensive national energy system. The specific tools used include MAED (Model for Analysis of Energy Demand) and MESSAGE (Model of Energy Supply Systems and their General Environmental Impacts). While the case studies have been led by the IAEA, other UN-Energy members – DESA, UNEP, FAO, UNIDO and the World Bank – have contributed input and assistance in their areas of expertise. The Government of Ghana contributed in a major way to the success for the study.

2 Prevailing Economic and Energy Situation in Ghana

Energy is an essential input for economic growth, and per capita use of energy is considered to be a key indicator of economic development. The Ghanaian economy grew at an average annual rate of 4.7% during the period 1984-94, and 4.4% during the period 1994-2004 (World Bank, 2005a). Despite this respectable growth compared to many sub-Saharan African countries, the per capita Gross Domestic Product (GDP) for the some 20 million inhabitants was only US$369 in the year 2004, which in terms of purchasing power parity (GDP_{ppp}/capita) was US$2,315 (World Bank, 2005b). Total energy use[2] in Ghana is 237 petajoule (PJ) which is equivalent to 12 gigajoule (GJ) per capita. The level of per capita commercial energy use is 4.5 GJ, which is less than one tenth of the world average.

The energy balance of Ghana for the year 2003 is listed in Table 1. (The year 2003 has been selected as the base year for the study for reasons of data availability.) In terms of energy demand, the household sector is the largest consumer of energy, followed by transport and industry.

As for energy supply, only one-third of Ghana's total energy supply is in the form of commercial energy, while the rest is traditional fuels which are low efficiency and mainly burned for cooking. In this report "traditional fuels" refers to wood, charcoal, crop residues and animal residues – which the consumer either pays for (charcoal, wood) or collects free of cost (crop residues, animal residues, branches of trees, etc.).

[1] In this report "renewable" includes wind, solar (thermal and photovoltaic), micro hydro and bio energy (traditional – fuelwood and modern - bio-diesel)
[2] Commercial and non-commercial (traditional biomass) energy

Out of total primary energy supply of 343.3 PJ in the year 2003, about one-third was imported. These imports included some 87% of commercial energy supplies, in the form of crude oil, petroleum products and electricity. The entire demand for oil and petroleum products was met through imports.

Table 1: Energy balance of Ghana in 2003 (PJ)

	Crude Oil	Hydro	Biomass [a]	Oil Products	Charcoal	Electricity	Total
Production	0.0	14.0	233.1	0.0	0.0	0.0	247.1
Imports	76.7	0.0	0.0	31.1	0.0	3.7	111.5
Exports	0.0	0.0	0.0	-13.2	0.0	-2.2	
Total Primary Supply	**76.7**	**14.0**	**233.1**	**17.9**	**0.0**	**1.5**	**343.3**
Petroleum Refineries	-57.0	0.0	0.0	54.5	0.0	0.0	
Electricity Plants	-19.7	-14.0	0.0	-0.1	0.0	21.4	
Charcoal Production	0.0	0.0	-127.8	0.0	39.6	0.0	
T&D Losses [b]	0.0	0.0	0.0	0.0	0.0	-3.1	
Total Transformation	**-76.7**	**-14.0**	**-127.8**	**54.4**	**39.6**	**18.2**	
Total Final Energy	**0.0**	**0.0**	**105.3**	**72.3**	**39.6**	**19.7**	**237.0**
Households	0.0	0.0	73.9	5.5	36.5	10.1	126.0
Commercial & Services	0.0	0.0	0.8	0.2	3.1	2.0	6.0
Agriculture & Fisheries	0.0	0.0	0.2	5.4	0.0	0.0	5.6
Industry	0.0	0.0	30.6	5.7	0.0	7.6	44.0
Transport	0.0	0.0	0.0	55.5	0.0	0.0	55.5

[a] Includes firewood, crop residues and animal residues. In the rest of the report, biomass includes charcoal also.
[b] Transmission and distribution losses.

The total installed electricity generation capacity of the country in 2003 was 1,903 MW of which 1,198 MW is hydropower. Actual generation was some 5,900 GWh, reflecting an average availability/capacity factor of about 35%. About 65% of all generation was from hydropower plants. Table 2 shows the generating plants in Ghana and their characteristics.

Table 2: Power sector in Ghana (2003)

Name of plant	Fuel	Installed capacity (MW)	Dependable capacity (MW)	Electricity Generation in 2003 (GWh)
Akosombo	Hydro	1,038	850	3,210
Kpong	Hydro	160	120	675
Tapco	Light crude oil [a]	330	330	1,328
Tico	Light crude oil [a]	220	220	668
Tema	Diesel	30	20	19
Barge	Natural gas [b]	125		0
Total		1,903	1,540	5,900

[a] Will convert to natural gas when available.
[b] This barge mounted power plant is not operational. It was built to use natural gas from the then drilled off-shore Tano field. However, an adequate quantity of gas was not discovered. The plant will start when imported gas is available in 2007.
Source: World Bank, 2005c.

3 Main Energy Institutions

The energy system in Ghana is essentially managed by the public sector. The Ministry of Energy is responsible for formulating and implementing energy and electricity policies. The Energy Commission advises the Government on energy policy and strategy. The Commission is also involved in indicative planning of energy and electricity system expansion, and licensing of energy sector operators. The Public Utilities Regulatory Commission (PURC) is a prime body for setting tariffs and framing customer service regulations.

The Volta River Authority (VRA), a state owned entity, is responsible for electricity generation and transmission in Ghana. VRA supplies electricity to large industrial and mining units and to two electricity distribution companies: (i) Electricity Company of Ghana Limited and (ii) Northern Electricity Department of VRA.

4 Key Energy Issues in Ghana

Three key issues will shape the future of Ghana's energy sector:

i unavailability or inaccessibility of modern energy sources to a large fraction of the population,

ii non-affordability of commercial fuels, and

iii high energy import dependence.

4.1 Accessibility and availability of modern energy

At present, about two-thirds (233.1 PJ) of the total primary energy supply is from traditional fuels, specifically biomass. In 2003, primary commercial energy supply in Ghana amounted to only 110 PJ. Thermal energy requirements (e.g., for cooking) are almost entirely met by traditional fuels, most of which are gathered by women and children. The time spent collecting such fuel could otherwise be used for productive economic activity or for education. Furthermore, burning of biomass in traditional cook stoves also results in indoor or local air pollution damaging to the health of the users, usually women.

The availability of modern energy in the country is very uneven. The rural areas of Ghana have especially poor access to commercial energy supplies. Less than 20% of the total rural population, and only 5% in the rural population of the northern part of the country, has access to electricity. Kerosene is the main fuel for lighting in rural areas.

The situation in urban areas is somewhat better, but some 30% of the urban population is still also without electricity. Those who do have access to electricity face availability problems due to frequent system breakdowns, especially in times of peak-load.

4.2 Affordability

Widespread poverty means that a large fraction of the rural population cannot afford to purchase modern commercial fuels even if these are available. The charcoal supply in the country is managed entirely by the private sector. Traders purchase charcoal prepared in rural areas and sell it in urban centres where it brings higher prices. In rural areas many cannot afford even charcoal.

Affordability is also hampering the national programme for rural electrification. Some pilot projects were initiated under this programme in the 1990s on the use of off-grid solar photovoltaic (PV) systems. A recent evaluation by the Energy Commission showed that most of the batteries had run down but had not been replaced because the rural community beneficiaries could not afford the replacement cost. Most of them had also reneged on their payment obligations into a revolving fund intended to sustain the system**.**

4.3 Import dependence

In 2003, net energy imports were 96.1 PJ in the form of crude oil, petroleum products and electricity. These imports comprised some 28% of total energy supplies and some 87% of commercial energy supplies. This high import dependence is a severe burden on the country's meagre foreign exchange earnings and a concern for security of energy supply. About one third of the export earnings of the country is spent on importing crude oil and petroleum products, which is equivalent to about 10% of the GDP (GSS, 2001).

5 Development of Future Energy Scenarios

5.1 Methodological approach

The IAEA's energy planning tools MAED and MESSAGE have been used for this study[3]. MAED uses a bottom-up approach to project future energy demand based on medium- to long-term scenarios of socio-economic, technological and demographic development. Energy demand is disaggregated into a large number of end-use categories corresponding to different goods and services. The influences of social, economic and technological driving factors are estimated and combined in each different category to present an overall picture of future energy demand growth under the assumptions of that scenario.

For energy demand analysis and projections, the end-use categories considered are: agriculture, construction, mining, manufacturing, transport, service, urban households and rural households. Based on densities of energy use, the end-use categories are re-organized into eight different groups that match the energy supply infrastructure, mainly in terms of centralised or decentralised supplies. These groupings are: electricity for urban areas, electricity for rural areas, electricity for very remote areas, electricity for industries, thermal uses in urban areas, thermal uses in rural areas, thermal uses in industries, and fuels for transportation and other uses.

MESSAGE has been used to develop four energy supply scenarios for Ghana. MESSAGE is an optimisation model and is used to get a least cost composition of energy sources under user defined constraints such as limits on new investments, market penetration rates for new technologies, fuel availability, trade, environmental emissions, etc. The MESSAGE model provides a flexible framework to model diverse energy supply systems.

Energy use and supply in rural and urban areas have been split into separate categories to analyse the different structures of energy supply-demand and suitability of supply technologies and fuels. The assumed allocation of electricity consumption in different sectors to these groups is shown in Table 3.

Table 3: Allocation of electricity use to different groups

	Electricity			
	Urban areas	Rural areas	Very remote areas	Industries
Agriculture	70%	30%		
Mining				100%
Construction				100%
Manufacturing				
Basic Materials				100%
Machinery & Equipment				100%
Consumer Goods		20%		80%
Transport				
Urban Households	100%			
Rural Households		99.8%	0.2%	
Service	89.9%	10%	0.1%	

5.2 Main Assumptions

5.2.1 Demographic development

The 2000 population and housing census put the national population of Ghana at 18.9 million. A regional summary of this census is listed as Table 4. Figure 1 shows the boundaries of the relevant census regions.

[3] Additional detail on the MAED and MESSAGE models is given in the appendix. A complete description of MAED is available in IAEA (2006). A comparable description of MESSAGE is in preparation.

The World Bank estimates that by 2000 the population of Ghana had increased to 20.4 million (World Bank, 2005b). Considering the rural-urban split in the year 2000 and inter-census growth of urban and rural areas, the estimated urban and rural populations in 2003 were 9.4 million and 11.0 million, respectively.

Table 4. Rural and urban[a] population in 2000, by region[b]

Region	Total Population (in thousands)	Population density (people per square kilometre)	Rural (%)	Urban (%)
All regions	18,912	79	56.2	43.8
1.Western	1,924	80	63.7	36.3
2. Central	1,594	162	62.5	37.5
3. Accra	2,906	895	12.3	87.7
4. Volta	1,635	80	73.0	27.0
5. Eastern	2,107	109	65.4	34.6
6. Ashanti	3,613	148	48.7	51.3
7. Brong-Ahafo	1,815	46	62.6	37.4
8. Northern	1,821	26	73.4	26.6
9. Upper east	920	104	84.3	15.7
10. Upper west	577	31	82.5	17.5

[a] Towns with populations of 5,000 and more.
[b] The regions are shown in Figure 1.
Source: GSS, 2001.

The population growth rate is slowing in Ghana. From an annual average of 2.7% during the period 1984-2000 (GSS, 2001), the present population growth rate has fallen slightly to 2.6% and is expected to drop to about 2.2% by 2030. This decline reflects the government's strategies to manage population growth at a level consonant with economic growth and social development targets.

As in most developing countries, the degree of urbanisation is expected to increase – from 46.3% in 2003 to 58.0% by 2030. Figure 2 shows the projected future urban and rural populations of Ghana**.**

5.2.2 Economic growth targets

The structure of the economy has undergone significant changes during the last 20 years. Figure 3 shows the historical and projected sectoral shares of GDP. The share of agriculture in GDP has declined from 49.2% in 1984 to 35.2% in 2003. In the same period, the share of the industrial[4] sector has increased from 10.6% to 24.7%. It has been assumed that this trend will continue in the future. According to this assumption, the share of agriculture will fall to 19.0% in 2030, and the share of the industrial sector will increase to 35.0%, while the share of the service sector[5] will grow to 46.0% in 2030 from a present 40.1%.

The World Bank projects 6.0% annual growth for Ghana during the period 2004-2008 (World Bank, 2005a). The government of Ghana is planning to stimulate rapid socio-economic development and aims to raise the annual economic growth rate from 6% to 8%, in order to achieve middle income country status by the year 2015 (NDPC, 2005). In the short to medium term the government's emphasis is on an agriculture-led economic growth strategy. Modernizing the agricultural sector is one of the main priorities established in the Growth and Poverty Reduction Strategy (GPRS II) being pursued in Ghana. However, the Government of Ghana believes that the road to economic growth lies ultimately in diversifying away from its coca-gold-timber base and adding an element of industrialization, technology development and higher productivity to the economy of Ghana (NDPC, 2005).

[4] The industrial sector includes manufacturing, mining and construction. During 1984-2003, the share of the manufacturing sector in total GDP increased from 6.4% to 8.5%.
[5] The service sector includes transport, storage, communication, wholesale and retail trade, restaurants and hotels, finance, insurance, real estate, business services, government services and community services.

Figure 1: Map of Ghana, by region

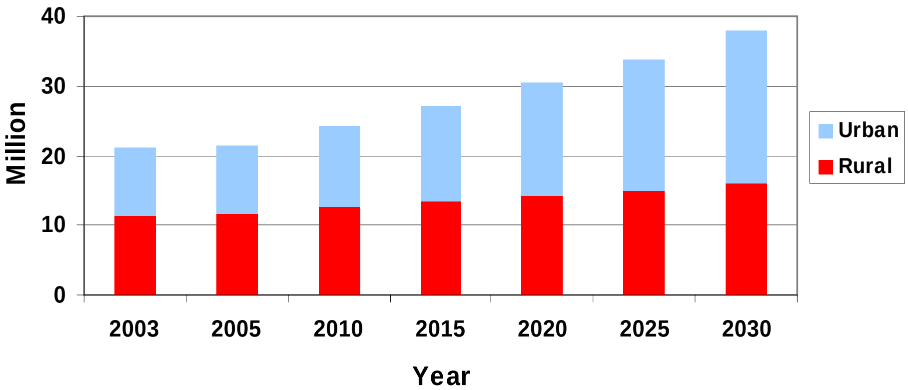

Figure 2: Urban and rural population scenarios

For a medium growth scenario, the target is to attain a per capita income of about US$1,000 by 2030, which requires an average annual economic growth rate of 6.1%. Under this assumption the size of the economy will grow from US$7.6 billion in 2003 to US$38 billion[6] by 2030. The targeted trends in growth of total GDP, in population and GDP per capita are shown in Figure 4.

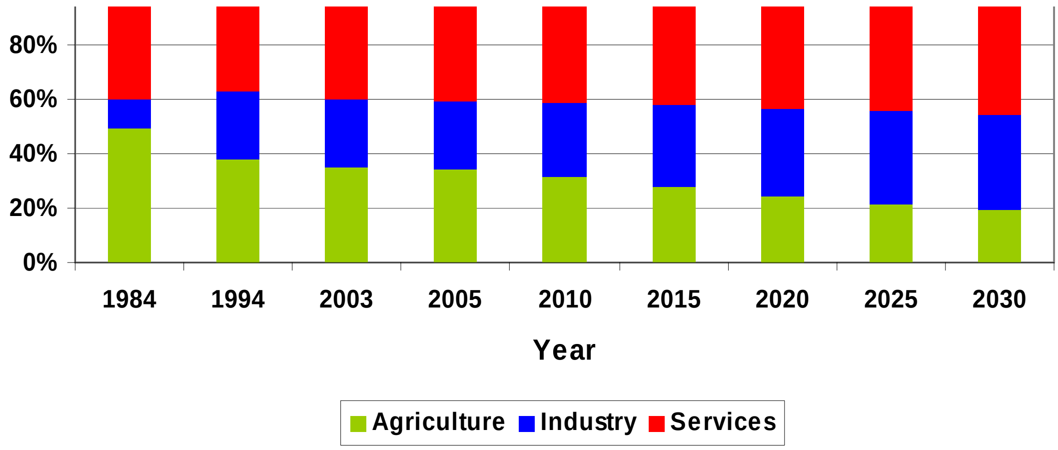

Figure 3: Historical and projected sectoral shares of GDP

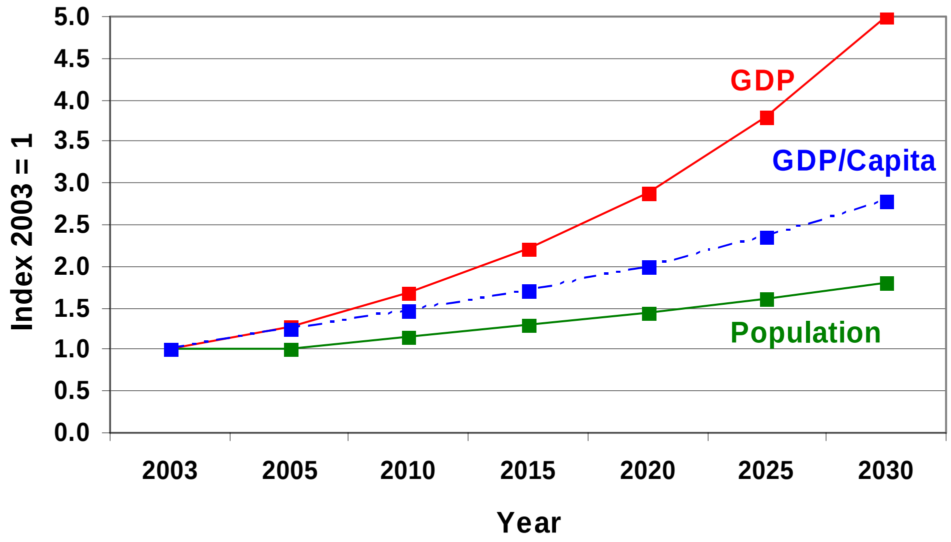

Figure 4: Population, GDP and GDP/Capita growth trends

5.2.3 Future potential for development of indigenous energy resources

5.2.3.1 Fossil fuels

Ghana's geology indicates the existence of some fossil fuel resources, but no discoveries of commercial oil or gas fields have been made so far. There are no coal resources in Ghana. In 1983, a national petroleum corporation was established to facilitate the exploration and development of the country's petroleum resources. Exploration work by various companies continues under agreements with the petroleum corporation of Ghana. In view of the unsuccessful exploratory efforts to date, no future contribution of indigenous oil and gas has been assumed in this study.

5.2.3.2 Hydropower

Ghana's first hydropower plant, Akosombo, was commissioned in 1965 and is still the largest power plant in the country. In 1982, the second hydropower plant, Kpong, was commissioned downstream of Akosmbo. These two hydropower plants produce more than half of Ghana's total electricity.

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[6] In constant 2003 prices.

Bui, the country's third hydropower plant, is in the final planning stage. There are four other large hydropower projects in feasibility and pre-feasibility stages. Their techno-economic data are listed in Table 5.

Table 5: Future hydro power projects of Ghana

Name of Plant/Site	River	Capacity (MW)	Generation (GWh)[a]	Overnight investment cost (US$/kW)	Fixed O&M cost **(US$/kW-yr)**	Levelised Generation Cost [b] US$/MWh
Bui	Black Volta	200	762	1,660	6.5	41.5
Hemang	Pra	93	237	1,860	11.5	72.5
Juale	Oti	87	237	3,300	12.0	157.5
Pwalugu	White Volta	48	61	3,600	16.0	173.3
Tanoso	Tano	56	n.a.	n.a.	n.a.	
Micro hydro				1,500	40.0	38.7

[a] Estimated annual firm generation.
[b] At 8% discount rate.
n.a. not available
Source: (ECG, 2005).

Ghana has an additional hydropower potential of 2,000 MW (AREED, 2004), of which 1,200 MW corresponds to large hydropower projects and the rest is in the form of small hydro power projects (SHP). About 40 sites have been identified for SHP (less than 10 MW).

5.2.3.3 Mini/Micro Hydro

There are a number of small rivers and streams in Ghana on which mini or micro hydro plants can be installed. A recent detailed study conducted in Ghana has identified some 68 sites for constructing mini or micro hydro power plants. The total capacity of these mini/micro hydro plants has been estimated as 25 MW (ECG, 2003a). An example for micro hydro is the Alavanyo-Abehensi project which was specifically modelled in this study. The techno-economic data for this project are listed in Table 6.

Table 6: Techno-economic data for Alavanyo-Abehensi project

Parameter	Unit	Value
Total potential of the site	kW	320
Proposed project	kW	2 x 30
Investment cost	US $/kW	1,666
Capacity utilisation	%	43.5
Levelised generation cost[1]	US $/MWh	37.8

[1] At 8% interest and discount rates.

5.2.3.4 Biomass

Annual consumption of wood in Ghana was 14 million cubic metres in 2001 (FAO, 2001), equivalent to 10 million tonnes[7], and is expected to rise to 20 million cubic metres in 2010 (FAO, 2001), an average annual growth rate of 4.0%. It is expected that the biomass will remain the main fuel for Ghana during the next 2-3 decades. Wood and charcoal are now dominant, but other biomass fuels include wastes from agricultural crops, the wood processing industry and animals.

The IEA has estimated that use of traditional energy in Ghana grew 2.1% in the period 2002-2003 (IEA, 2003). In keeping with the projections in FAO (2001) and these estimates of the IEA, it has been assumed that biomass production will increase at average annual growth rates of 2.8%, 2.2% and 1.8% during the periods 2003-2010, 2010-2020 and 2020-2030, respectively.

[7] One metric tonne wood = 1.4 cubic metre (http:/bioenergy.ornl.gov/papers/misc/energy_conv.html).

Ghana also has a suitable climate for plantation growth of Jatropha which can be used for producing bio-diesel, and the Government of Ghana has developed a plan for such production. Cost estimates for growing Jatropha and producing bio-diesel in Ghana were not available, but based on cost estimates of bio-diesel from Jatropha in India (CJP, 2005), it has been assumed that the production costs of bio-diesel from Jatropha will be about US$460 per tonne oil equivalent (toe), or some 8% higher than the price of imported normal diesel. It has been further assumed for this study that bio-diesel will be blended with normal diesel in the ratio of 1:10.

5.2.3.5 Solar

According to UNEP's SWERA (Solar and Wind Energy Resource Assessment) maps, the northern part of Ghana (see Figure 5) receives fairly good solar radiation in the range of 3.5-4.5 kWh/m^2/day. At this radiation rate, the total solar energy potential is enormous – some 35 EJ equivalent to about 100 times present energy consumption, even at a 10% recovery factor. This resource can be exploited to supply electricity to rural areas in the northern region where the solar potential is highest and the electrification rate is the lowest in the country. Solar energy can also be used for some thermal uses like water heating in industry, urban households and in the service sector.

As noted earlier, some solar photovoltaic (PV) systems were installed in the 1990s under a pilot project for rural electrification. The objective of these PV projects was to supply electricity to rural communities located 20 kilometres or more from the national grid, under terms similar to those served through grid. These installations however could not be kept operational due to lack of funding for replacement batteries.

5.2.3.6 Wind

As shown in SWERA maps for wind energy potential in Ghana, the strongest wind regime occurs along the Ghana/Togo border: 9.0-9.9 metres per second wind speed that can yield a wind power density of 600-800 Watt/m^2 in the mountains over an area of about 300-400 square kilometres. The total wind energy potential of this area has been estimated at around 300 MW capacity or 800 GWh electricity. Over a large area along the coast, high winds (6.2-7.1 metres per second at the height of 50 m) are also present; total potential there is around 3000 MW capacity or 7,300 GWh electricity. The SWERA map also indicates marginal or moderate wind power density (200-400 W/m^2) in other parts of the country (Figure 6). The estimated potential of scattered off-grid wind turbines is about 500-800 MW capacity or 1,100-1,700 GWh electricity. The wind potential at the Ghana/Togo border (Volta Region) and along the coast of the Gulf of Guinea is suitable for grid connected large wind farms while the scattered wind potential can be exploited through stand-alone wind turbines.

The government of Ghana is planning to exploit all available renewable energy resources (i.e. solar, wind, mini/micro hydro). Recently, the government has adopted a policy of seeking partnerships with companies, operators and others with the technical and financial capability to construct and operate stand alone or grid-connected renewable energy power plants. The Ministry of Energy intends to enter into power purchase agreements with such entities under mutually agreeable terms. The government will also consider what further assistance may be needed to implement such projects in rural areas to enhance economic and local industrial development. Qualifying facilities include: mini and micro hydropower plants, biomass co-generating power plants, and wind energy power plants.

For this study wind farms are considered as supplying electricity to the national electric grid, while isolated wind turbines, micro hydro and solar photovoltaic are assumed to supply off-grid electricity in rural areas. It has further been assumed that solar thermal systems will gradually penetrate to urban households and industry. The share of solar water heaters in urban areas will reach 10% by 2030.

5.2.4 Energy import options

5.2.4.1 Oil and oil products

Ghana imports crude oil and petroleum products to satisfy its needs. As there will be essentially no indigenous supply of oil in the near future, Ghana will continue to rely on imported oil.

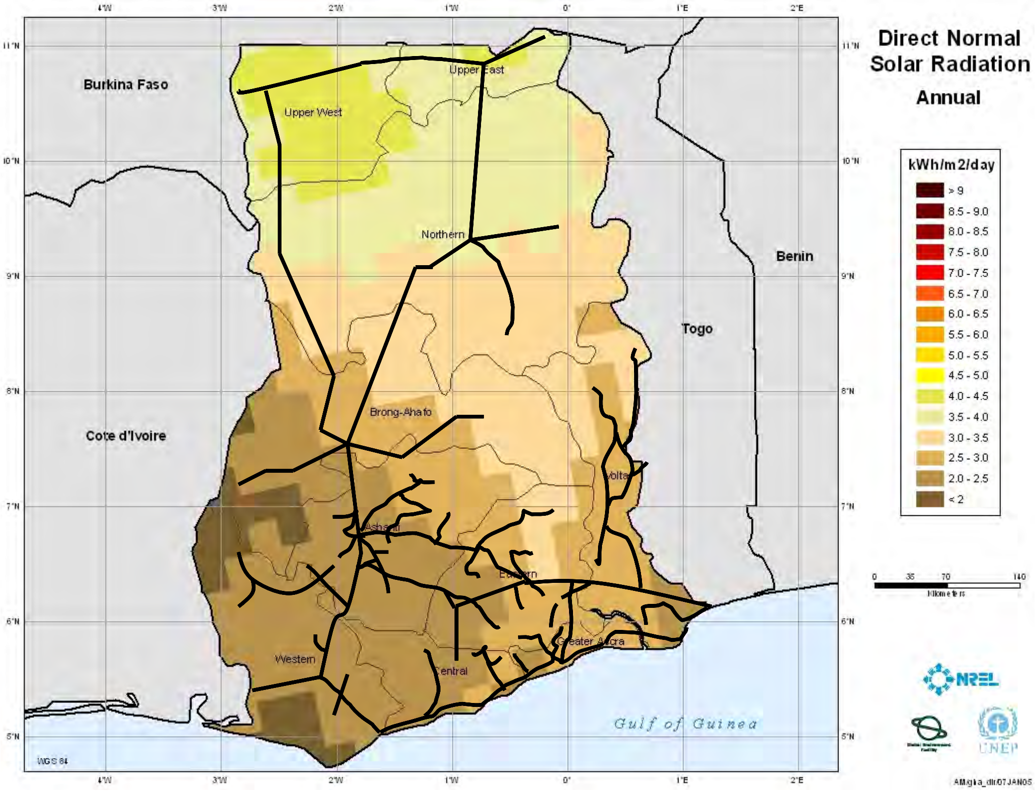

Figure 5: Annual direct normal radiation in Ghana and existing electricity transmission grid (Sources: UNEP/GEF and Ghana Energy Commission)

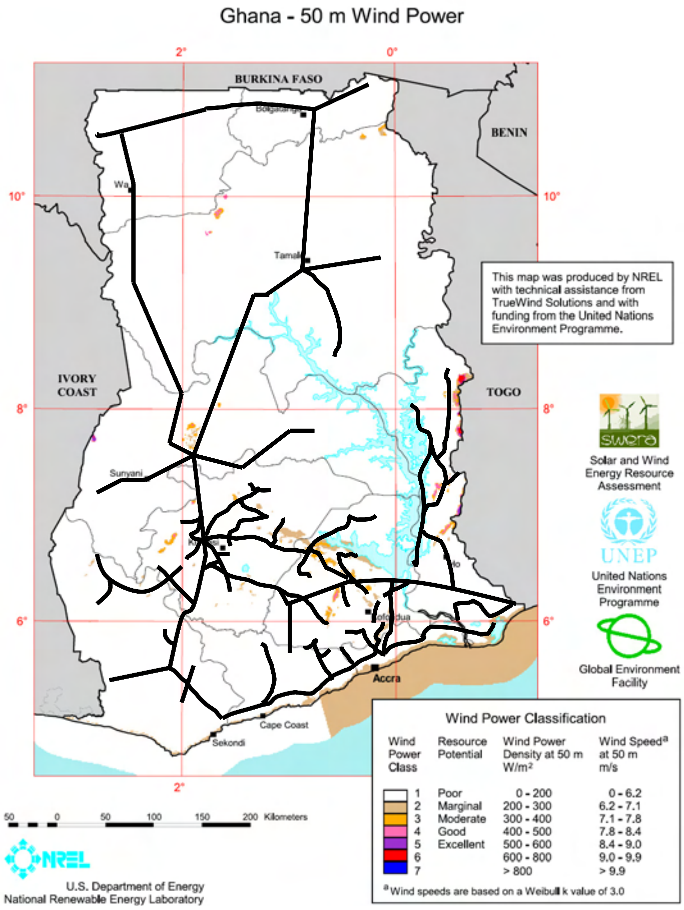

Figure 6: Wind power density in Ghana and existing electricity transmission grid (Sources: UNEP/GEF and Ghana Energy Commission)

5.2.4.2 Natural gas

The Escravos-Lagos pipeline (ELP) was commissioned in 1989, supplying natural gas to Nigeria's Egbin power plant and other industrial consumers in Lagos and Ogun States. ELP has the capacity to handle nearly 900 million cubic feet per day (MMCFT/D) of natural gas (950 TJ/day), but currently the majority of this capacity is not utilized. This pipeline is being extended under the West Africa Gas Pipeline Project (WAGP).

The WAGP will traverse 1,033 kilometres both on and offshore from Nigeria's Niger Delta region to its final planned terminus in Ghana. The first portion of the pipeline, which will deliver gas to the greater Lagos area (Alagbado), is already in existence. A 57-kilometre onshore portion of the WAGP will run from Alagbado to Seme beach in Lagos State. The WAGP will continue 560 kilometres offshore, measuring 18 inches in diameter with a daily capacity of 400 million cubic feet and proposed landfall spurs at Cotonou (Benin), Lome (Togo), Tema (Ghana), and Takoradi (Ghana). The route map of the proposed gas pipeline is shown in Figure 7. The initial capacity of the WAGP will be 200 MMCFT/D (211 TJ/day), with the potential to expand to 400 MMCFT/D (422 TJ/day) as demand grows.

The West African Gas Pipeline Company Limited (WAPCo), will build, own and operate the WAGP to transport gas from a location near the Lagos terminal to Takoradi (Ghana). The required investment of US$550-million for the pipeline will be financed by WAPCo's shareholders based on a gas purchase contract with 'foundation customers', namely VRA of Ghana, which will account for about 90% of the demand for gas to be supplied by the project initially, with CEB of Benin taking the remaining 10%. The gas supplies for Ghana are expected to start in 2007.

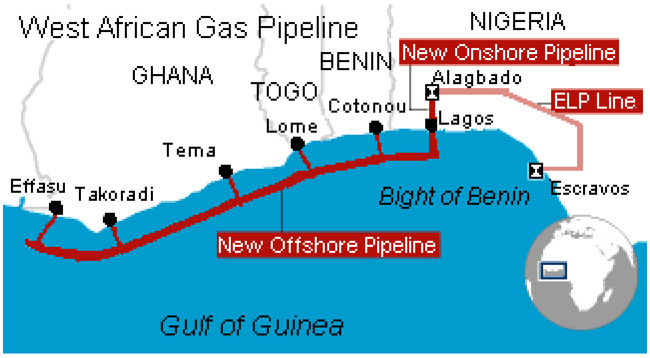

Figure 7: Route map of West Africa gas pipeline project

5.2.4.3 Coal

The import of steam coal for power generation is another option analysed in this study, which could be economically viable if coal power stations are installed on the coast. This is a new imported fuel and would help to diversify imports. However, additional investment in infrastructure would be needed for expansion of existing port warehousing and handling facilities in the second port at Takoradi as well as rehabilitation and extension of the existing railway lines from that port to the plant. For this study, minimum additional local port handling and landing charges of about US$5/tonne of coal (US$0.17/GJ) have been estimated (ECG, 2003b).

5.2.4.4 Electricity

The West African Power Pool (WAPP) is a regional project to connect the various transmission systems of its member countries to ensure that every country in the sub-region has access to sufficient quantities of least-cost power to fuel economic development and industrialization.

The WAPP can be divided into two non-restrictive zones. Zone A involves countries that are already interconnected and includes Nigeria, Niger, Benin, Burkina Faso, Ghana, Côte d'Ivoire and Togo. Zone B will have Mali, Guinea, Liberia, Sierra Leone, Guinea Bissau, Gambia and Senegal when these countries complete the interconnection.

The project to complete the interconnections is being carried out in phases. The first phase at an estimated cost of about US$151 million, consists of the following interconnections and the development of a West African Power Market:

- Ferkesedougou (Côte d'Ivoire) to Sikasse (Mali)
- Bolgatanga (Ghana) to Ouagadougou (Burkina Faso)
- Preatea-Tema (Ghana) to Lome (Togo)
- IkejaWest (Nigeria) to Sakete (Benin)

The World Bank has provided the government of Ghana with a US$40m facility, effective January 2006, to enable it to kick-start the first phase of the coastal West Africa Power Pool (WAPP) programme and to establish an Electricity Transmission Utility as an autonomous transmission system operator within WAPP (ECG, 2005).

5.2.5 *Power generation system*

Table 7 gives the assumed techno-economic data of existing and expected future power plants in Ghana. (Data for existing and future hydropower plants are reported in Tables 2 and 5). The cost assumptions for future power plants have been taken as the average of estimates reported for various countries in a recent study by the OECD/NEA/IEA (OECD, 2005).

Table 7: Techno-economic data for existing and future power plants

Name	Overnight investment cost (US$/kW)	Fixed O&M cost (US$/kWyr)	Variable O&M cost (US$/MWh)	Construction time (Years)	Efficiency (%)	Levelised Generation Cost [b] US$/MWh
Tapco	[a]	17	2.3	[a]	40.4	76.8[c]
Tico	[a]	13	2.3	[a]	26.9	110.6[c]
Thema	[a]	8	1.1	[a]		125.6[c]
Barge	[a]	10	1.1	[a]		61.9[c]
CCGT[e]	550	12	2.1	3	50	42.7
CT[f]	400	10	1.1	3	30	59.6
Coal steam	1,050	25	3.1	4	36	39.7
Wind farm (Volta)	1,250	25	-	2	-	54.7[d]
Wind farm (Coast)	1,250	25	-	2	-	58.6[d]
Wind rural	1,250	25	-	2	-	65.7[d]
Solar PV	4,000	10	-	2	-	187.6
Nuclear	1,680	59	0.4	5	33	40.2
T&D[g]	1,000	9			90	10.7

[a] Existing plants.

[b] 8% discount rate.

[c] Assuming whole investment has been paid. Fuel of Tapco and Tico is light crude oil. For barge, levelised generation cost based on natural gas.

[d] The plant factors for wind farm (Volta region), wind farm (coast) and 'wind rural' are 30%, 28% and 25% depending upon respective wind regimes.

[e] Combined cycles gas turbine.

[f] Combustion turbine.

[g] Transmission and distribution.

Sources: Based on data from ECG (2005), OECD (2005) and EIA (2004).

5.2.6 *Fuel price assumptions*

The price of imported crude oil has been taken as US$45/bbl ($7.8/GJ) in constant 2003 prices, and the prices of petroleum products have been linked to crude oil price projections according to specific proportions determined on the basis of Rotterdam product price data during the last 15 years (BP, 2005). A sensitivity analysis has also been carried out with a crude oil price of US$70/bbl ($12.3/GJ) in constant 2003 prices.

The price of imported electricity has been taken as US$0.066/kWh which is the currently prevailing price. The imported coal price has been assumed as US$45/tonne (US$1.54/GJ) plus local port handling and landing charges of US$5/tonne (US$0.17/GJ) of coal (ECG, 2003b).

The price of WAGP imported natural gas will be determined on the basis of a base price indexed to oil prices, plus transportation charges, delivery fee, etc. (ECG, 2005). This import price is still under negotiation, but is not expected exceed US$4.5/MMBTU (US$4.3/GJ) when the pipeline becomes operational in 2007.

6 Scenario Results

6.1 Future energy demand

Based on the assumed population and economic growth rates, the overall final energy demand is projected to increase 3.3 times over the study period 2003-2030, with an average annual growth rate of 4.5% (Table 8). Final energy use is estimated to increase from 11.6 GJ per person in 2003 to 20.6 GJ per person in the year 2030. Because of assumed changes in the structure of the economy and assumed technological improvements, the energy intensity of GDP is expected to fall from 31.0 MJ/US$ in year 2003 to 19.8 MJ/US$ in year 2030.

Table 8: Final energy demand

	2003	2005	2010	2015	2020	2025	2030
Total Energy (PJ)	**237.0**	**249.9**	**295.6**	**372.1**	**482.9**	**624.0**	**780.1**
Share by sector (%)							
Agriculture	2.3	2.4	2.5	2.5	2.3	2.2	2.0
Construction	0.3	0.3	0.3	0.3	0.3	0.2	0.2
Mining	1.3	1.2	1.3	1.2	1.1	1.0	0.7
Manufacturing	17.0	19.0	25.1	30.7	34.4	36.0	36.9
Transport	23.4	23.4	23.3	23.1	23.2	24.0	24.9
Urban Household	18.4	17.5	16.5	15.5	15.1	14.9	14.8
Rural Household	34.8	33.6	28.0	23.3	19.7	17.2	15.3
Services	2.5	2.6	3.0	3.4	3.9	4.5	5.2
Share by fuel (%)							
Oil Products	30.6	30.1	36.6	41.4	44.6	46.5	49.7
Gas [a]	0.0	0.0	0.0	0.3	0.6	0.9	1.3
Electricity	8.3	10.3	12.5	13.8	14.4	14.9	15.3
Biomass [b]	44.4	43.7	35.0	30.0	28.0	27.2	24.4
Charcoal	16.7	15.8	15.9	14.5	12.4	10.6	9.2
Solar	0.0	0.0	0.0	0.01	0.02	0.03	0.04

[a] Natural gas import is expected to start in 2007 but will be allocated only to power generation in that year.
[b] Biomass includes firewood, crop residues and animal residues.

6.2 Primary energy supply

A baseline energy supply scenario (Base Case) was developed using the MESSAGE model. Total primary energy supply in this scenario increases from 343 PJ in 2003 to 552 PJ in 2015 and to 1,108 PJ in 2030, with an overall average annual growth rate of 4.4% during the period (Figure 8 and Table 9). Among the renewable options, solar thermal, micro hydro and off-grid wind turbines succeed in getting shares in the Base Case least-cost energy supply mix of Ghana. Their total contribution to primary energy supply increases from nothing in the base year (2003) to 1 PJ (0.2% in total energy supply) in 2015 and to 6 PJ by 2030 (0.5% in total primary energy). The grid-connected wind farms, solar photovoltaic technologies and bio-diesel could not compete with other energy sources in the Base Case, except that small scale solar photovoltaic systems compete with small diesel generator sets in very remote areas where the cost of diesel transportation is extremely high. Biomass remains the largest single contributor to the total primary energy supply, but its share decreases from 68% in 2003 to 38% in 2030.

As for electricity generation, the contribution of renewable energy technologies reaches 1.6 TWh in the year 2030 (Table 10) which is 4.4% of the total electricity generation in that year. This renewable electricity is generated from micro hydro and off-grid wind turbines, and solar photovoltaic systems in remote areas. The entire estimated potential of micro hydro and about 85% of the scattered off-grid wind power potential is exploited in the Base Case (Table 11 and Figure 9).

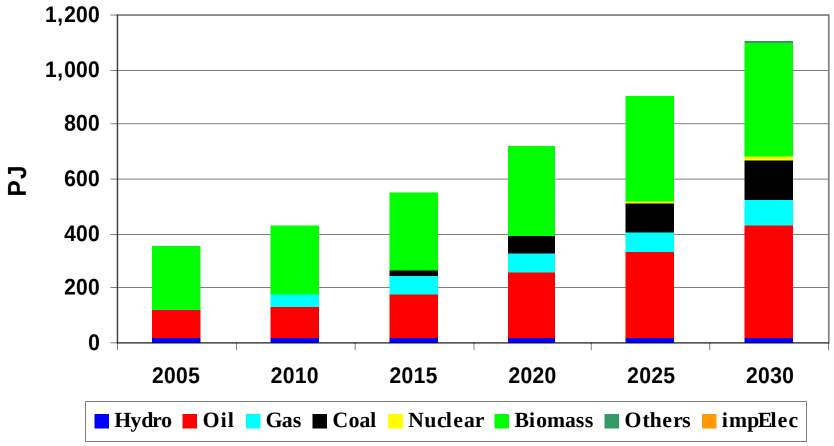

Figure 8: Primary energy supply for base case

Table 9: Primary energy supply for base case (PJ)

	Hydro	Oil	Imported Electricity	Gas	Coal	Nuclear	Biomass	Other Renewables[a]	Total
2003	14	95	2	0	0	0	233	0	343
2005	20	97	2	0	0	0	237	0	356
2010	20	113	0	44	0	0	255	0	432
2015	20	159	0	65	21	0	286	1	552
2020	22	235	0	69	63	0	329	2	720
2025	22	310	0	74	105	8	382	4	905
2030	22	406	0	97	147	8	422	6	1,108

[a] Includes micro hydro, wind, and solar.

Table 10: Electricity generation mix for base case (TWh)

	Oil	Gas	Coal	Nuclear	Large Hydro	Micro Hydro	Wind	Solar	Imports	Total
2005	2.0	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.6	8.0
2010	0.0	5.9	0.0	0.0	5.5	0.04	0.02	0.001	0.0	11.4
2015	0.0	8.0	2.1	0.0	5.5	0.07	0.13	0.002	0.0	15.8
2020	0.0	8.4	6.3	0.0	6.2	0.11	0.39	0.002	0.03	21.4
2025	0.0	8.5	10.5	2.2	6.2	0.11	0.86	0.003	0.0	28.5
2030	0.0	11.9	14.7	2.2	6.2	0.11	1.52	0.003	0.0	36.7

Table 11: Electricity generation capacity in base case (MW)

	Hydro	CCGT	CT	Diesel	Coal	Nuclear	Micro Hydro	Wind (grid)	Wind (off grid)	Solar	Total
2005	1,198	330	345	35	0	0	0	0	0	0	1,908
2010	1,198	930	345	36	0	0	10	0	11	0.5	2,530
2015	1,198	930	345	36	300	0	15	0	61	0.7	2,885
2020	1,398	930	455	6	900	0	25	0	176	1.0	3,891
2025	1,398	930	386	6	1,500	300	25	0	394	1.3	4,940
2030	1,398	1,584	110	5	2,100	300	25	0	694	1.6	6,217

CCGT = combined cycle gas turbine
CT= combustion turbines

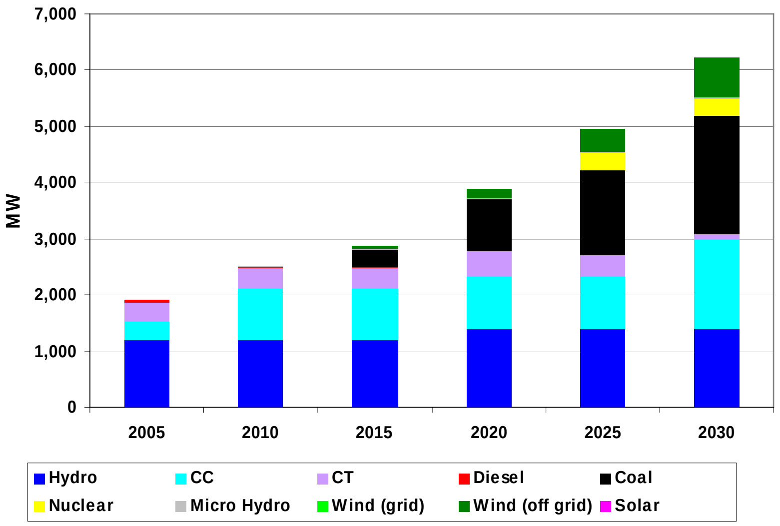

Figure 9: Development of electricity generation capacity

Any increase in oil prices from the reference price of US$45/bbl (US$7.8/GJ) (constant 2003 prices) has little impact on Ghana's electricity generation mix as oil-based generation will be phased out with the completion of the WAGP[8]. However, an increase in crude oil prices could make bio-diesel competitive with normal diesel used in the transport sector.

6.3 Policies and measures to promote renewable energy sources

As noted above, under the assumed cost conditions of the Base Case (see Tables 5&6), solar photovoltaic, grid connected wind farms and bio-diesel do not compete with other energy supply options on a least-cost basis. To promote these and other renewable energy options, several policy measures have been analysed in alternative scenarios. These include:

i Portfolio Standard / Renewable Energy Quota Scenario (REQ). In this scenario a minimum share obligation of renewable energy is imposed on electric utilities, starting from 2010. The share of renewable technologies in total electricity generation has been assumed at 2% for 2010, progressively rising to 20% in 2030.

ii Public Benefit Fund (PBF). In this scenario a fund is created through a levy on electricity transmission, which can be used for partly funding investments in renewable energy technologies – up to one-third of the needed investment for wind and solar technologies for any enterprise. A flat rate levy of US$1 per MWh on electricity transmission has been assumed throughout the study period.

iii CDM Scenario. This scenario analyses the possibility of deploying renewable energy technologies as CDM (Clean Development Mechanism) projects under the Kyoto Protocol. A price of US$15/tonne of CO_2 avoided has been assumed.

Under each of these policy measures, the contribution of renewable energy technologies increases compared to the base case. The electricity generating capacity based on renewable technologies in the REQ scenario is 304 MW in 2015, rising to 3,035 MW, or an impressive 40% of total generating capacity, in 2030. The corresponding shares for PBF and CDM scenarios are 20.0% and 13.1% respectively (Figure 10). The share of renewables in electricity generation reaches 8.4% and 5.1% in PBF and CDM scenarios, respectively, by 2030, compared to a renewable share in generation of 4.4% for the base case in that year (Figure 11).

[8] Stand-alone diesel generation (back-up in hotels, hospitals or some remote areas) will continue and thus is affected by international oil market prices.

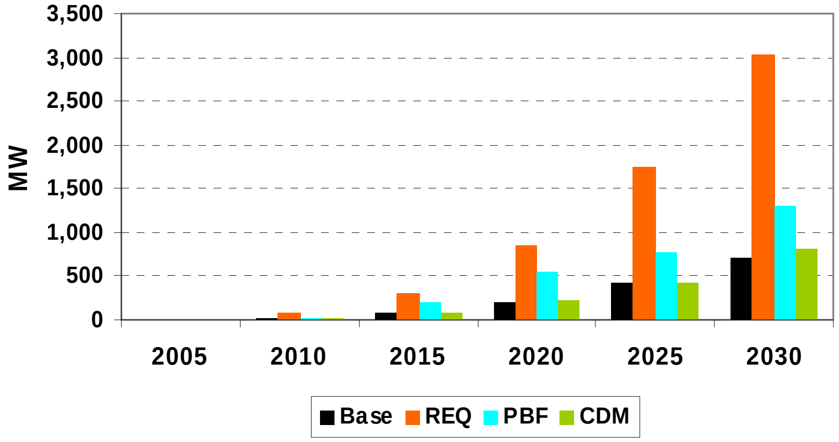

Figure 10: Electricity generating capacity by renewable technologies under different scenarios

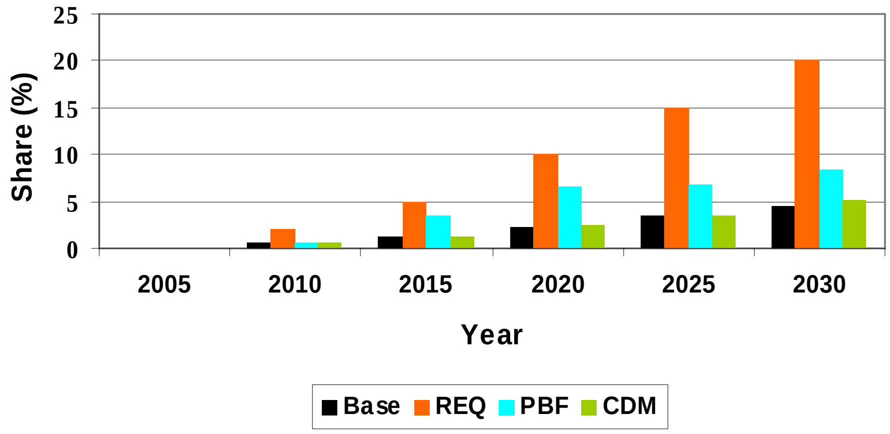

Figure 11: Share of renewable energy sources in electricity generation under different scenarios

Figure 12 compares the total investments in generating capacity under the four cases for the 25-year period 2005-2030. REQ requires the largest investments as it must deploy sub-economic renewable technology generating units to meet the required minimum renewable share in the total generation. For PBF and CDM scenarios, investments are also higher compared to the Base Case but the extra funds are raised at least in part either from internal sources by a levy on grid electricity, or from external sources by selling Certified Emission Reductions (CER) associated with the avoided CO_2.

Despite the difference in investment costs among the scenarios (some 47% higher than the Base Case for REQ, 7% higher in PBF and 2% higher in CDM) the average cost of total generation is almost same in the four cases since the higher investments for renewable technologies are largely off-set by lower operating costs, and because the contribution of these technologies to total output is rather small (Figures 12-14).

In the PBF scenario, at a levy rate of US$1/MWh, the total amount generated for the Public Benefit Fund over the 25 year period, to be used for supporting renewable technologies, is US$407 million. Figure 15 shows the annual amount of the levy collected in the PBF scenario. Figure 16 shows the possibilities for renewable electricity generation corresponding to different levels of levy rates

Under the CDM scenario, the total amount of carbon credits generated over the 25-year period is 1.4 million tonnes (Mt), at a price of US$15/tonne (US$/t) of CO_2. A sensitivity analysis of the CER price (see Figure 17) shows that the total amount of CERs is less sensitive to a price range of US$10-15/t of CO_2 and more sensitive to higher price differences. For example, if the price of CER is assumed to be US$20/t of CO_2, the total amount of CER generated would be about 2 Mt of CO_2.

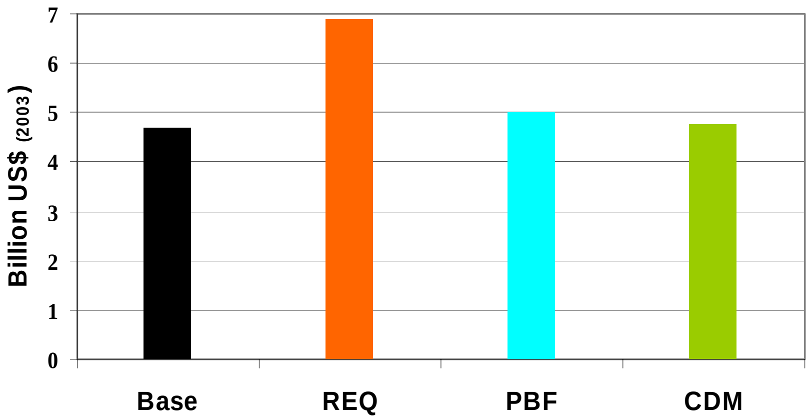

Figure 12: Total investments required for electricity generating capacity (2005-2030)

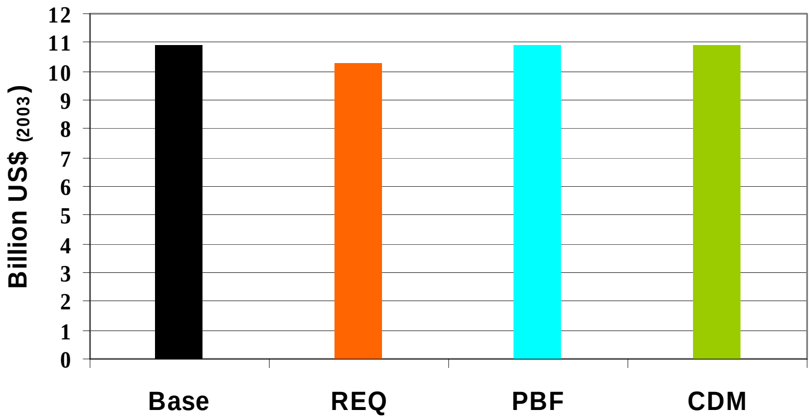

Figure 13: Total O&M costs (including fuel costs) for electricity generation (2005-2030)

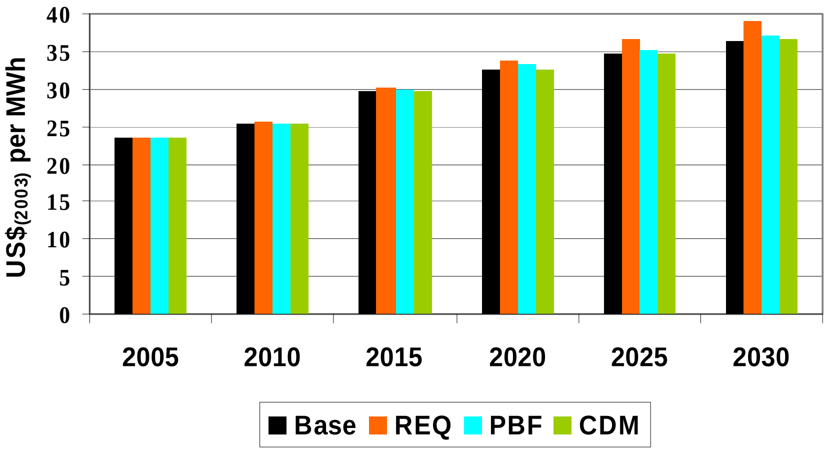

Figure 14: Average cost of electricity generation

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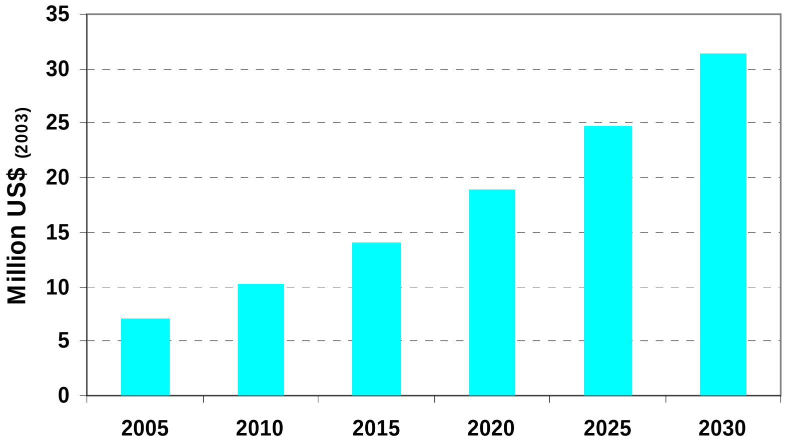

Figure 15: Annual levy on electricity transmission for Public Benefit Fund

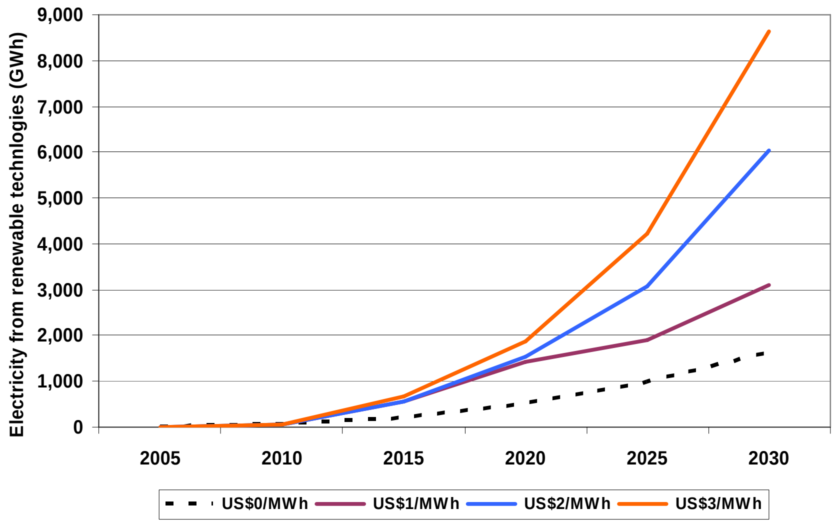

Figure 16: Impact of levy rate on renewable electricity generation in PBF scenario

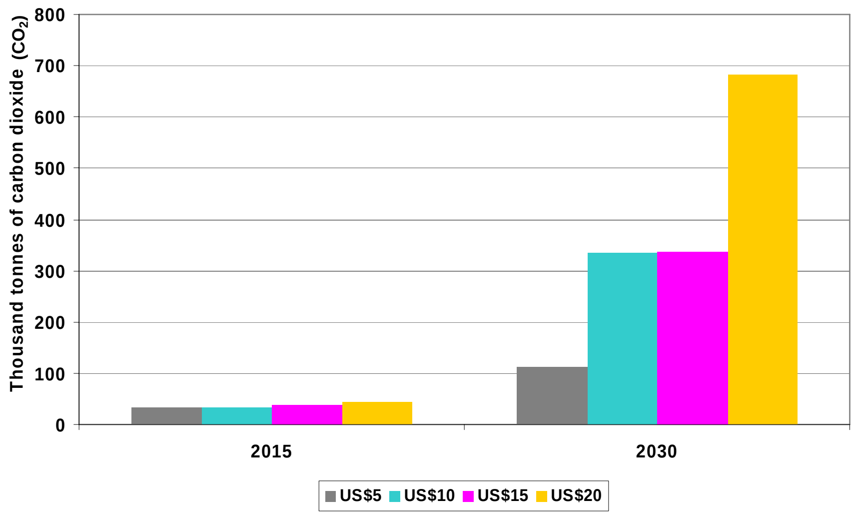

Figure 17: Annual amount of CER generated by CDM projects

Figure 18 shows the accumulation of CER over time, while Figures 19 and 20 show the average annual and total cumulative revenues corresponding to different CER prices. At a price of US$15/t of CO_2, total revenues from CER sales are US$21.6 million over the 25 year period.

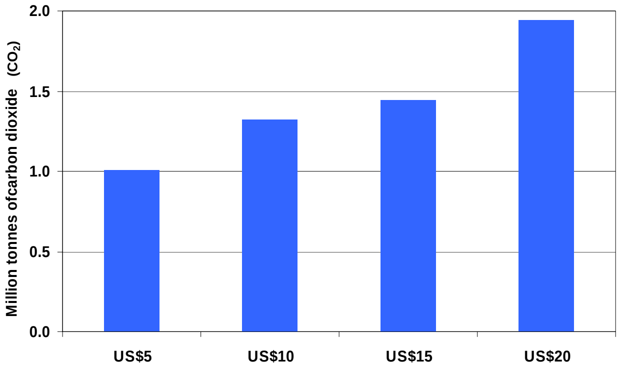

Figure 18: Total amount of CER over 25 year period of study in CDM scenario

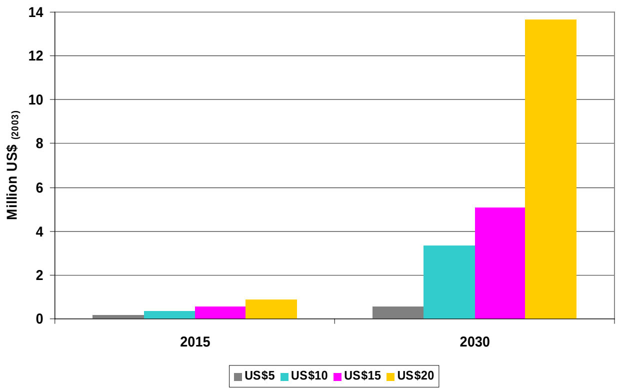

Figure 19: Annual average revenue from sale of CER in CDM scenario

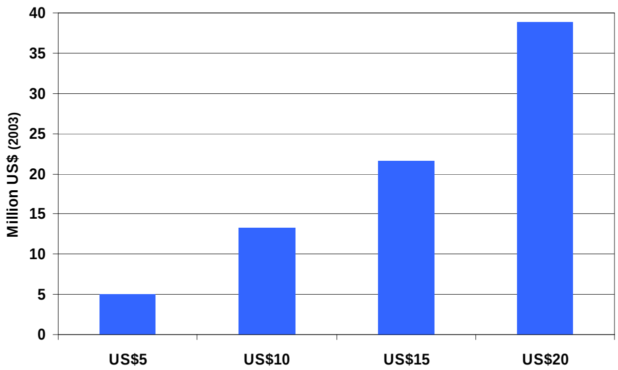

Figure 20: Total revenue from sale of CER during 2005-2030 in CDM scenario

7 Energy Issues Revisited

7.1 Accessibility and availability

In all the scenarios, accessibility and availability of energy is enhanced. Over the study period, per capita total primary energy and electricity supplies increase by 1.7 and 2.2 times, respectively (Figure 21). The electrification rate in urban areas rises from 74% in 2003 to 88% in 2015 and 100% in 2030. In rural areas this rate rises from 18% at present to 32% in 2015 and 80% in 2030. To whatever extent renewable energy successfully penetrates rural areas as a result of any of the policies considered herein, it would help to improve the energy situation in those areas.

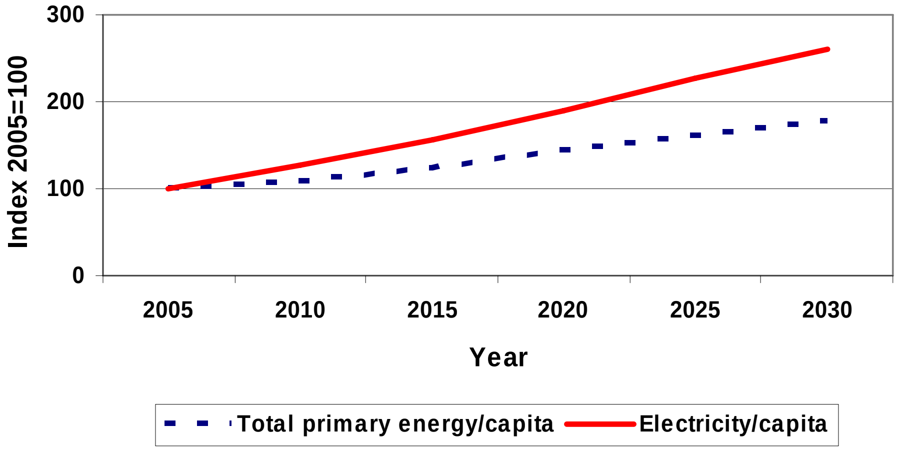

Figure 21: Growth trend of per capita commercial energy and electricity supplies

7.2 Affordability

Although the absolute values of the marginal costs in the different scenarios vary, their trends are similar. There is a sharp decline in the marginal costs of electricity supply in the year 2010 in all scenarios, due to anticipated conversion of existing power plants from light crude oil to natural gas.

In the alternative scenarios (REQ, PBF and CDM), indigenous energy supplies have a higher share compared to the Base Case. Development of local renewable energy supply industries would also generate additional employment opportunities and potentially raise the income of people, further enhancing the level of affordability.

Figure 22 compares the projected trend of the marginal cost of electricity with that for GDP/capita. By 2030, average per capita income increases by about 2.5 times whereas the electricity prices fall by some 73-81% in real terms, thereby improving considerably the affordability of energy for both rural and urban populations.

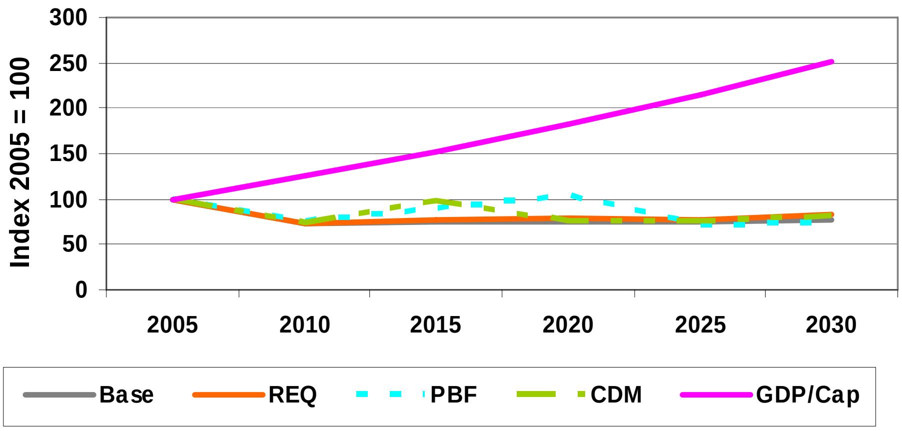

Figure 22: Trend of marginal cost of electricity supply

7.3 Import dependence

Energy import dependence increases in all scenarios from about 28% in 2005 to 56-59% in 2030, virtually all for growing quantities of fossil fuel, of which there is no indigenous supply. But in all scenarios energy supplies are more diversified compared to the past. And import dependence is somewhat lower in the REQ, PBF and CDM scenarios than in the Base Case, as the renewable energy technologies gain a greater market share (Figure 23).

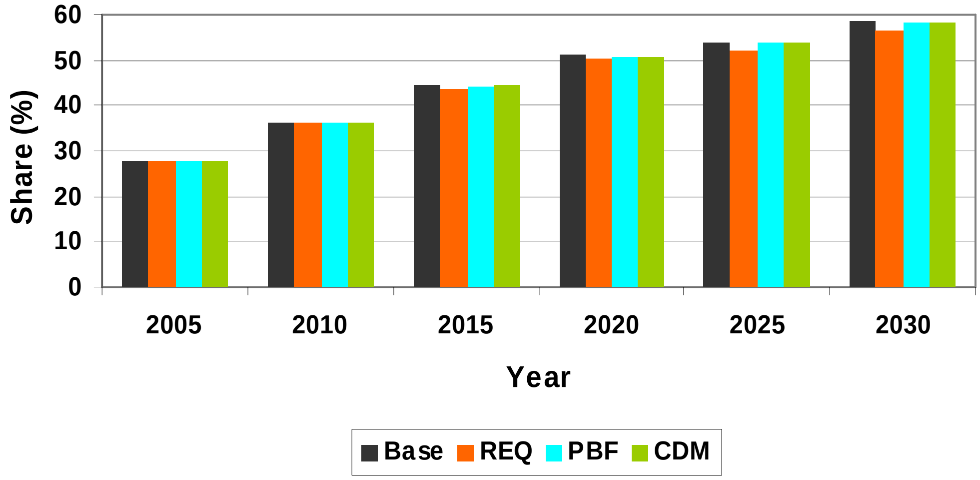

Figure 23: Share of imported energy in total primary energy supply

8 Concluding Remarks

As in other countries under prevailing economic conditions, the role of renewable energy technologies in the future energy supply of Ghana will be limited. Some supporting policy measures are needed to promote these technologies if further market penetration is to be realised. In this respect, the government's energy policy objectives under GPRS II already include diversifying the national energy mix by implementing programmes to support renewable energy sources including micro hydro, wind, and solar PV.

The analysis of various policy measures in this study shows that each one can help to increase the contribution of renewable energy technologies in Ghana's future energy supply mix, though with varying efficacy and different economic impacts. Soft-measures like the Public Benefit Fund and CDM have economic advantages in that higher investments for renewable energy technologies are partly financed by either internally generated funds or earnings from CO_2 credits. Hard measures, like a regulatory requirement for a minimum market share for renewables (Portfolio Standard / Renewable Energy Quota), can be more effective but generate inefficiencies and impose an economic burden on suppliers. A combination of these three measures plus some other policy options may well be the best approach for increasing the contribution of renewable energy technologies in future energy supplies, in line with one of the objectives of WSSD – "increasing the proportion of energy obtained from renewable energy sources".

This study has also shown the suitability of the IAEA's energy models for analyzing the role of various energy technologies in meeting future energy needs, and for evaluating the effectiveness of various policy measures.

9 For Readers Interested in Undertaking Similar Studies with UN Support

9.1 Energy resource data and information on DESA, FAO, UNEP, UNIDO and UN-Energy

Information on wind and solar resources is available through UNEP (www.unep.org/), particularly the Solar and Wind Energy Resource Assessment clearinghouse at http://swera.unep.net/swera/index.php.

Information on biomass resources and bioenergy options is available through FAO (www.fao.org/).

Information on rural energy projects is available through UNIDO (www.unido.org/) and its Initiative on Rural Energy for Productive Use (www.unido.org/doc/24839).

Information on DESA's Division for Sustainable Development, including activities to follow up the World Summit on Sustainable Development and Johannesburg Plan of Implementation, is available at www.un.org/esa/sustdev/.

Information on UN-Energy is available at http://esa.un.org/un-energy/.

9.2 IAEA energy models

The MAED and MESSAGE energy models used in this study are two of the analytic tools that the IAEA maintains, disseminates to its interested Member States, and sometimes applies directly, as in the study reported here. More generally, the IAEA's Planning and Economic Studies Section (PESS) offers assistance to Member States, particularly from developing regions, to strengthen their energy planning and analysis capabilities. Assistance can include:

- transferring modern planning methods, tools and databanks,
- training for model set-up and application, and
- interpreting, synthesizing and applying model outputs to policy formulation.

The five main energy models that the IAEA makes available are:

- MAED: Model for Analysis of Energy Demand (see Appendix)
- WASP: Wien Automatic System Planning Package
- FINPLAN: Model for Financial Analysis of Electric Sector Expansion Plans
- MESSAGE: Model of Energy Supply Systems and their General Environmental Impacts (see Appendix)
- SIMPACTS: Simplified Approach for Estimating Impacts of Electricity Generation

The two principal mechanisms for IAEA assistance are Technical Cooperation projects and regional and national workshops and training courses.

Technical Cooperation (TC) projects are the main mechanism for IAEA assistance to Member States. They are implemented, upon the request of a Member State government, through the Agency's Technical Cooperation Programme. Each TC project is tailored to a country's specific needs. Typical projects include assessments of future energy and electricity needs, technical, economic and environmental evaluations of all energy supply options, and the formulation of medium- to long-term energy strategies. Projects build local capabilities by transferring the IAEA's models and databases and by extensive training and guidance in national planning studies.

PESS regularly arranges regional and national workshops and training courses on the IAEA's energy models. These include topical and specialized lectures, group discussions and work sessions. Each Workshop or Training Course focuses on one model and is designed to provide an understanding of the methodology and to train participants to collect and compile input data, operate the model, interpret its results and synthesize policy recommendations.

Further information is available at www.iaea.org/OurWork/ST/NE/Pess/index.shtml.

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APPENDIX

The MAED and MESSAGE models

A.1. Model for Assessment of Energy Demand (MAED)

MAED evaluates future energy demand based on medium- to long-term scenarios of socio-economic, technological and demographic developments. The model relates systematically the specific energy demand for producing various goods and services identified in the model, to the corresponding social, economic and technological factors that affect this demand. Energy demand is disaggregated into a large number of end-use categories; each one corresponding to a given service or to the production of a certain good. The nature and level of the demand for goods and services are a function of several determining factors; including population growth, number of inhabitants per dwelling, number of electrical appliances used in households, peoples' mobility and preferences for transportation modes, national priorities for the development of certain industries or economic sectors, the evolution of the efficiency of certain types of equipment, market penetration of new technologies or energy forms, etc. The expected future trends for these determining factors, which constitute "scenarios", are exogenously introduced.

An understanding of these determining factors permits the evaluation of the various categories of energy demand for each economic sector considered. The total energy demand for each end-use category is aggregated into three main "energy consumer" sectors: household/service; industry, including agriculture, mining, construction and manufacturing; and the transportation sector. The model provides a systematic accounting framework for evaluating the effect on energy demand of a change in economics or in the standard of living of the population.

The starting point for using MAED is the reconstruction of base year energy consumption patterns within the model. This requires compiling and reconciling necessary data from different sources, deriving and calculating various input parameters and adjusting them to establish a base year energy balance. This helps to calibrate the model to the specific situation of the country.

The next step is developing future scenarios, specific to a country's situation and objectives. The scenarios can be sub-divided into two sub-scenarios:

- one related to the socio-economic system describing the fundamental characteristics of the social and economic evolution of the country;
- the second related to the technological factors affecting the calculation of energy demand, for example, the efficiency and market penetration potential of each alternative energy form.

The key to plausible and useful scenarios is internal consistency of assumptions, especially for social, economic and technological evolution. A good understanding of the dynamic interplay among various driving forces or determining factors is necessary. The model output, i.e. future energy demand, is just a reflection of these scenario assumptions. The evaluation of output and the modification of initial assumptions is the basic process by which reasonable results are derived.

The model focuses exclusively on energy demand, and even more specifically on demand for specified energy services. When various energy forms, i.e. electricity, fossil fuels, etc., are competing for a given end-use category of energy demand, this demand is calculated first in terms of useful energy and then converted into final energy, taking into account market penetration and the efficiency of each alternative energy source, both specified as scenario parameters. Non-substitutable energy uses such as motor fuels for cars, electricity for specific uses (electrolysis, lighting, etc.) are calculated directly in terms of final energy.

Demand for fossil fuels is therefore not broken down in terms of coal, gas or oil, because this energy supply mix largely depends on the technological possibilities of supply and relative prices of these fuels, aspects that are outside the scope of the MAED analysis. The substitution of fossil fuels by alternative "new" energy forms (i.e. solar, district heat, etc.) is nevertheless estimated, due to the importance of the structural changes in energy demand that these energy forms may introduce in the future. Since these substitutions will be essentially determined by policy decisions, they are to be taken into account at the stage of formulating and writing the scenarios of development.

A.2. Model for Energy Supply Systems and their General Environmental Impacts (MESSAGE)

MESSAGE is designed to formulate and evaluate alternative energy supply strategies consonant with user-defined constraints on new investment limits, market penetration rates for new technologies, fuel availability and trade, environmental emissions, etc. It was originally developed at the International Institute for Applied Systems Analysis (IIASA). The IAEA acquired the latest version of the model and added a user-interface to facilitate its applications. The underlying principle of the model is the optimisation of an objective function under a set of constraints.

The backbone of MESSAGE is the technical description of the modelled system. This includes the definition of the categories of energy forms considered (e.g., primary energy, final energy, useful energy), the energy forms (commodities) actually used (e.g., coal or district heat), as well as energy services (e.g., useful space heat provided by energy). Technologies are defined by their inputs and outputs, their efficiency, and the degree of variability if more than one input or output exists, e.g., the possible production patterns of a refinery or a pass-out-turbine.

These energy carriers and technologies are combined to construct so-called energy chains, where the energy flows from supply to demand. The definitional limitations on supplying energy carriers are that they can belong to any category except useful energy, they have to be chosen in light of the actual problem, and limits on availability inside the region or area and on import possibilities have to be specified. The technical system provides the basic set of constraints to the model, together with demand, that is exogenous to the model. Demand must be met by the energy flowing from domestic resources and from imports through the modelled energy chain(s).

The model takes into account existing installations, their vintage and their retirement at the end of their useful life. During the optimisation process, this determines the need to construct new capacity of various technologies. Knowing new capacity requirements permits the user to assess the effects of system growth on the economy.

The investment requirements can be distributed over the construction time of the plant and can be subdivided into different categories to reflect more accurately the requirements from significant industrial and commercial sectors. The requirements for basic materials and for non-energy inputs during construction and operation of a plant can also be accounted for, by tracing their flow from the relevant originating industries either in monetary terms or in physical units.

For some energy carriers assuring timely availability entails considerable cost and management effort. Electricity has to be provided by the utility at exactly the same time it is consumed. MESSAGE simulates this situation by subdividing each year into an optional number of so-called "load regions." The parts of the year can be aggregated into one load region according to different criteria, for example, sorted according to power requirements or aggregation of typical consumption patterns (summer/winter, day/night). The latter (semi-ordered) load representation creates the opportunity to model energy storage as the transfer of energy (e.g., from night to day, or from summer to winter). Including a load curve further improves the representation of power requirements and the utilization of different types of power plants.

Environmental aspects can be analysed by keeping track of, and if necessary limiting, the amounts of pollutants emitted by various technologies at each step of the energy chains. This helps to evaluate the impact of environmental regulations on energy system development.

The most powerful feature of MESSAGE is that it provides the opportunity to define constraints between all types of technology-related variables. The user could, *inter alia*, limit one technology in relation to some other technologies (e.g., a maximum share of wind energy that can be handled in an electricity network), give exogenous limits on sets of technologies (e.g., a common limit on all technologies emitting SO_2, that would be defined in millions tonnes of SO_2), or define additional constraints between production and installed capacity (e.g., ensure take-or-pay clauses in international gas contracts forcing customers to consume or pay for a minimum share of their contracted level during summer months). The model is extremely flexible and can also be used to analyse energy and electricity markets and climate change issues.

UN-Energy Membership

The following agencies, programmes and organizations constitute the membership of UN-Energy:

Economic Commission for Africa (ECA)

Economic Commission for Europe (ECE)

Economic Commission for Latin America and the Caribbean (ECLAC)

Economic and Social Commission for Asia and the Pacific (ESCAP)

Economic and Social Commission for Western Asia (ESCWA)

The Food and Agriculture Organization (FAO)

The International Atomic Energy Agency (IAEA)

United Nations Human Settlements Programme (HABITAT)

United Nations Conference on Trade and Development (UNCTAD)

United Nations Development Programme (UNDP)

United Nations Educational, Scientific and Cultural Organization (UNESCO)

United Nations Environment Programme (UNEP)

United Nations Framework Convention on Climate Change (UNFCCC)

United Nations Industrial Development Organization (UNIDO)

United Nations International Research and Training Institute for the Advancement of Women (INSTRAW)

World Health Organization (WHO)

World Meteorological Organization (WMO)

The World Bank Group (WBG)

Department of Economic and Social Affairs (DESA)

Chief Executives Board Secretariat