DRAFT

The Electric Power Sector in Cuba: Potential Ways to Increase Efficiency and Sustainability

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The author would like to thank his colleagues at USAID Micah Globerson and Luis Velazquez for their great support in the preparation of this paper, and Silvia Alvarado, Ignacio Rodriguez and Elizabeth P. Belt for providing comments. The author would also like to thank the International Resources Group (IRG) team of Evelyn Wright, Gary Goldstein, Pat Delaquil and Adam Chambers, who modeled the power sector of Cuba using MARKAL/TIMES. Working with the IRG team was a learning and pleasant experience. The persons mentioned above are not responsible for any errors in this paper.

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I. Summary

Cuba has succeeded in extending electricity services to a large proportion of the population — a noteworthy achievement. However, this was accomplished with little regard for economic, financial or environmental considerations. Generation based on liquid fuels, the predominant type in Cuba, is extremely costly when the true opportunity costs are taken into account. Additionally, the electric utility (Union Electrica or UE) sustains high technical losses of power and has low labor productivity in comparison with other countries. When Cuba lost fuel subsidies from the USSR, Venezuela came to the rescue. However, Venezuela's own fiscal accounts are now under significant pressure as a result of the sharp reduction in the price of crude oil. If the crude oil market continues to remain depressed, Venezuela may have no option but to reduce or end its support for Cuba, jeopardizing the island's precarious energy security situation. For the purposes of modeling the sector, we assumed that Venezuela will terminate its subsidies to Cuba by 2010.

Using the MARKAL/TIMES model, a low cost expansion plan for Cuba's power system was developed. Unfortunately, Cuba does not have a great potential for renewables, but wind power, photo-voltaic cells, small hydro and bagasse could play a greater role in generation than they do at present.[2] Under all scenarios, domestic or imported natural gas would become the predominant fuel. Combined cycle gas turbines (CCGT) would provide cheaper and cleaner power but would require an investment of $2.5 billion, and if the gas is imported, an additional investment would need to be made to build a regasification facility. The Cuban government has announced plans to build a gas regasification facility in Cienfuegos; estimated completion date is 2013.

Attracting these high levels of Foreign Direct Investment (FDI), particularly during the current global economic crisis, would require significant reforms designed to give comfort to potential investors. The necessary steps include: enacting an electricity sector law and establishing a Public Utility Commission (PUC); modeling the energy sector to better determine the least cost expansion path, including a more thorough analyses of the prospects for renewable energy; modifying tariffs gradually to reach full cost recovery; restructuring UE through unbundling and corporatization; promoting Independent Power Producer (IPP) arrangements; and developing operating contracts and/or concessions for existing assets.

The USG should consider supporting these efforts. Initial funding possibilities include technical assistance for modeling the sector to determine options for improving efficiency and environmental sustainability and training government officials in the economic

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[2] The potential role of bagasse depends on the fate of Cuba's sugar industry

regulation of utilities. The modeling and training would enhance the skills of Cuban professionals and would foster a dialogue with their peers in the USA. More cooperation between Cuba and the US could enhance energy security in both countries.

II. Development of Cuba's Power Sector

Introductory Comments

Since the beginning of the Cuban revolution, the electric power sector (referred to hereafter as the power sector) of Cuba has been developed with little regard for financial and economic considerations. This approach to the power sector has a long history in the communist bloc, as the sector was considered to have a preeminent political dimension. For example, Lenin said: "*Communism is Soviet power plus the electrification of the whole country*."[3] Many other quotes by Lenin make the same point.

Cuba's power consumption is about 1,300 kWh/capita. Table 1 presents data for Chile, Costa Rica, Cuba and the Dominican Republic. The table shows that Cuba has a slightly higher consumption of electricity than what would be expected for a country of its per capita income, and that it has a high electricity coverage ratio.[4]

Table 3.1 – Electricity Consumption per Capita and GDP per Capita				
Country	**GDP/capita**		**Electricity**	
	PPP (US$)	**Nominal** (US$)	**Coverage** (%)	**Consumption** (kWh/capita)
Chile	14,400	9,874	99	3,062
Costa Rica	13,500	5,525	99	1,730
Cuba	4,500	3,958	95	1,300
Dominican Rep	5,865	3,789	92	1,067

[3] Vladimir Ilyich Lenin,. Report on the Work of the Council of People's Commissars, Dec. 22 (1920), reproduced in Collected Works, vol. 31 (1966). Cited in The Columbia World of Quotations. 1996.
[4] The conclusion that Cuba has a higher consumption of electricity is based on a regression of the natural logarithm of electricity consumption as a function of the natural logarithm of GDP per capita (PPP basis).

While the power sector in Cuba is almost entirely controlled by the State (the only private participation is with the Independent Power Producer arrangements, or IPPs), in the hydrocarbon sector of Cuba, the situation is somewhat different, as there has been significant private participation in exploration and crude oil production beginning in the 1990s. This is the result of the very attractive Production Sharing Agreements (PSAs) offered in Cuba. At the same time, international trade in oil and derivatives, refining, distribution and pricing do not seem to follow financial and economic considerations. This lack of concern for financial and economic issues may result from the fact that both the Soviet Union and Venezuela have provided large subsidies to Cuba by supplying oil and derivatives at concessionary terms, and Cuban economic policy-makers do not seem to consider opportunity costs — at least in the energy sector.[5]

The power and hydrocarbon sectors are inextricably linked, as Cuba produces about 85% of its power using liquid fuels, a very high percentage when compared with other countries.[6] The total value of the modern energy sector of Cuba has been estimated at 14% of GDP, compared with an average of about 10% for the world. In 2007, domestic production of crude oil accounted for about 40% of total consumption and the rest was imported from Venezuela. From the total supply of fuel oil, about 50% is used for power generation and 50% for transport and other uses —consistent with the proportionate usage seen in other countries.

Table 3.2 – Liquid Fuel Supply 2007

Liquid Fuel Sources	**bbl/day**	**% of Total**
Domestic production	68,000	40%
Imports	102,000	60%
Total supply	**170,000**	**100%**
Liquid Fuel Uses		
Power generation	85,700	50%
Transport	84,300	50%
Total uses	**170,000**	**100%**

[5] Chapter Two by Jorge Piñon discusses the hydrocarbon sector in detail.
[6] In 2003, Cuba produced 93% of its power using liquid fuels, the fifth highest percentage in the world. The decline in that percentage is the result of new gas-fired facilities established under a Power Purchase Agreement (PPA).

Main Trends in the Cuban Power Sector

Until 1959, Cuba had four electric utilities, with additional power supplied by the large sugar mill industry. The four utilities were regulated by the Public Service Commission under the Ministry of Communications. Most of the boilers and turbine generators used to produce energy came from the U.S. or West Germany. After the revolution, the entire sector (generation, transmission and distribution) was nationalized and absorbed into a state-owned utility, Union Electrica, which is under the Ministry of Basic Industries.

The development of the sector since the revolution can be divided into three distinct periods:[7]

A. **The three decades between 1959 and 1989**, beginning with Castro's takeover and ending with the fall of the Soviet Union, saw rapid growth in Cuba's energy sector, facilitated by subsidized Soviet oil imports and other forms of financial support. The period included the country's largest buildup in energy generation infrastructure and highest rates of growth in consumption, based on oil and products imported from the Soviet Union at highly subsidized prices.

B. **The "periodo especial" followed from 1990 to 1997**, when domestic oil production accelerated and Cuba began to use fuel oil in the seven large generation plants. Unfortunately, domestic oil's high sulfur levels damaged the generation infrastructure severely.

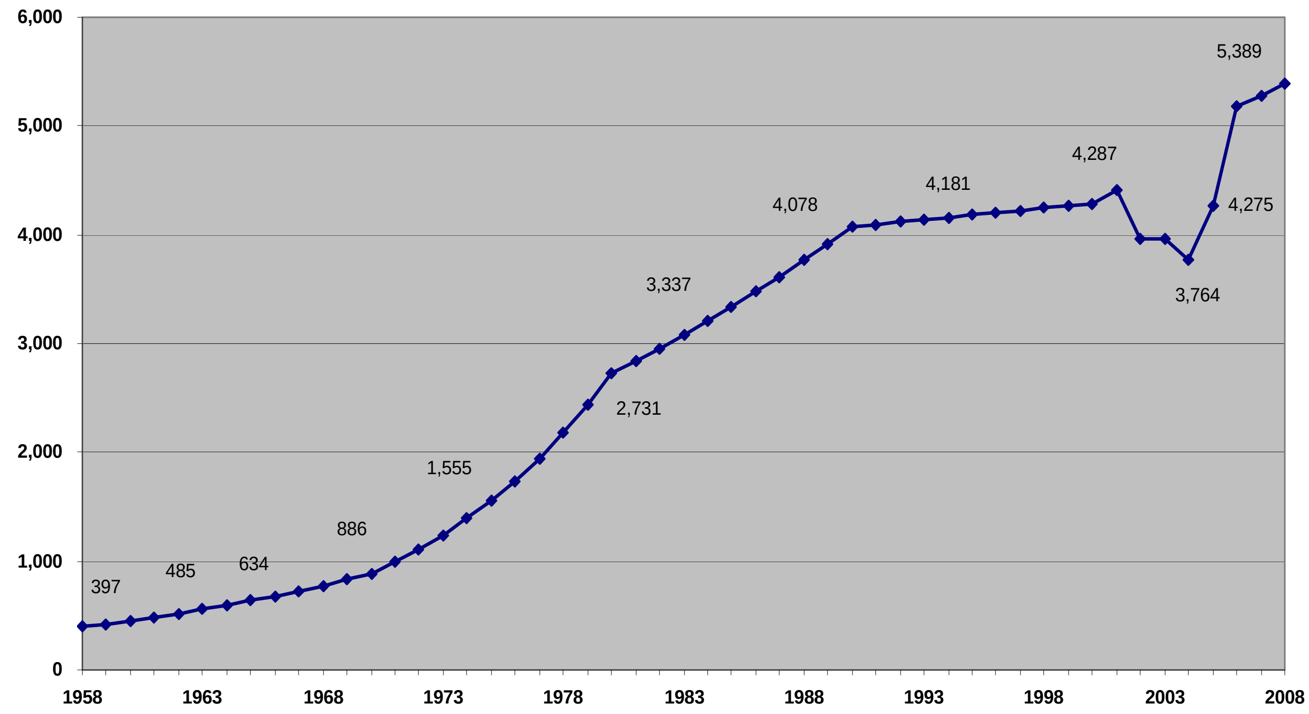
C. **The period 1998 to the present**, which is marked by Venezuelan support, the blackouts of 2004-05, the *Revolución Energética* of 2005-06, and the Independent Power Production (IPP) arrangement with Sherritt, based on combined cycle gas turbines (CCGT). While the sector is now significantly more stable than during the period of blackouts, the high proportion of generation that is based on liquid fuels results in extremely high costs and very high carbon emissions. The financial sustainability of the sector depends almost totally on the largesse of Venezuela. If support from Venezuela is reduced or ended, the sector would require extremely high fiscal subsidies.

These trends are discussed in greater detail below, with particular emphasis on the most recent period.

[7] Cereijo, (2004).

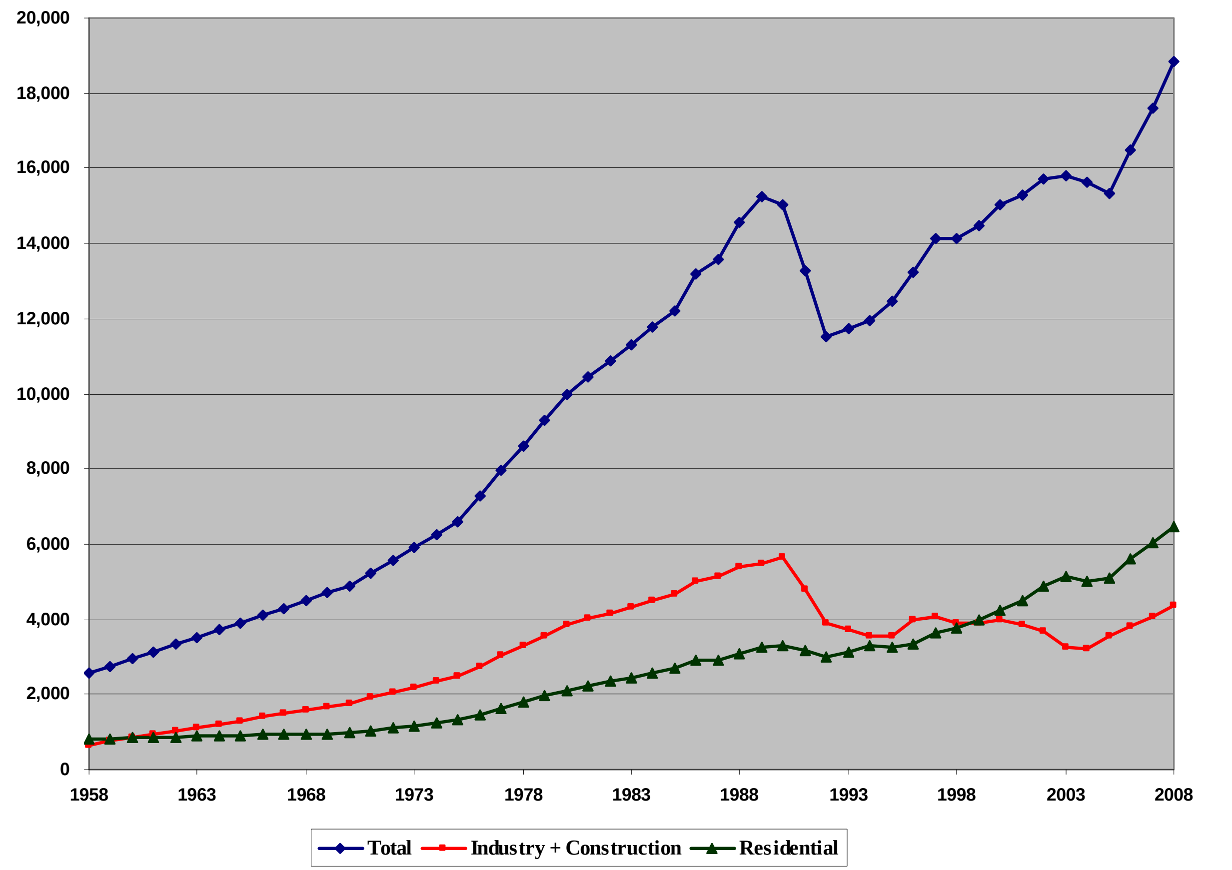
Power generation installed capacity increased from less than 400 MW in 1958 to about 4,000 MW in 1990, an annual compound rate of growth of almost 12%. During the same period, total electricity consumption grew from about 1,500 GWh to about 9,700 GWh, an annual rate of growth of 6% (see graph 1).

Graph 3.1 – Installed Generation Capacity (MW)



When Cuba lost Soviet assistance, which was estimated at US$ 5-7 billion per year, it suffered a sharp decline in GDP that was accompanied by a sharp decline in energy consumption per capita in the period 1990-95 (Graph 2). Most of the decline is accounted by a drop of consumption in "industry and construction" as other types of consumers, including households, did not curtail consumption.

Graph 3.2 – Electricity Consumption by Key Sector 1958-2008 (GWh)



By 2005-2006, power plant breakdowns hastened a new wave of severe blackouts, lasting up to 18 hours per day, and igniting civil unrest. After the blackouts of 2005-06, the Government of Cuba embarked on a program to reduce electricity consumption and to expand capacity to generate power in a program called the "*Energy Revolution*" or "*Revolución Energética*." This program, largely emphasizing energy conservation, was reasonably successful in reducing daily peak demand, but the results in terms of expanded capacity are mixed. The installation of about 1,200 MW of gensets is an extremely costly solution if fuel is valued at its international price. On the other hand, the gas-fired generation plants established under a Power Purchase Agreement (PPA) with a Canadian company, Sherritt, has been a highly positive development that significantly reduced both generation costs and carbon emissions.

The conservation component of the *revolución energética* involved removal of individuals' energy inefficient refrigerators, fans, and air conditioners, which were then replaced with energy efficient appliances and light bulbs. These upgrades were somewhat compulsory, and were incentivized in various ways, including the use of payment plans of up to ten years, with payments discounted directly from salaries.[8]

The production component of the *revolución energética* involved the installation of "grupos electrogenos," distributed generation. The distributed approach employed a couple thousand small generators scattered around nearly 70 percent of the island's 169 municipalities. The mini-generators, called "gensets," originated from South Korea, Germany, and Spain.[9] This investment began in 2005 and continues to provide a high-cost, low-efficiency 1.5 GW of additional energy output. Cuba also established a small wind farm (about 20 MW) and is reportedly also considering other renewable options, such as ethanol fuel from sugar cane.

The *grupos electrogenos* approach has special benefits for Cuba, as well as some significant costs. The distribution of generation itself offers some greater protection from hurricanes, which have been particularly frequent in recent years, averaging more than one a year over a 15 year period. Whereas the shutdown of a large generator would immediately impact a delicate energy system, individual failures of smaller generators will have a more negligible effect. Thus, the increased number of individual sources will reduce overall systemic risk of blackout. The smaller units were also simple to rapidly install and put into service, immediately resolving blackouts and thereby soothing public disquiet. Disadvantages of this approach include very high operating costs if Cuba values diesel oil and fuel at their opportunity costs, the challenge of providing maintenance and service to thousands of generator units, and the difficulty of efficiently dispatching such a numerous and scattered aggregation of generators. Additionally, it is probable that transmission stability problems could arise.

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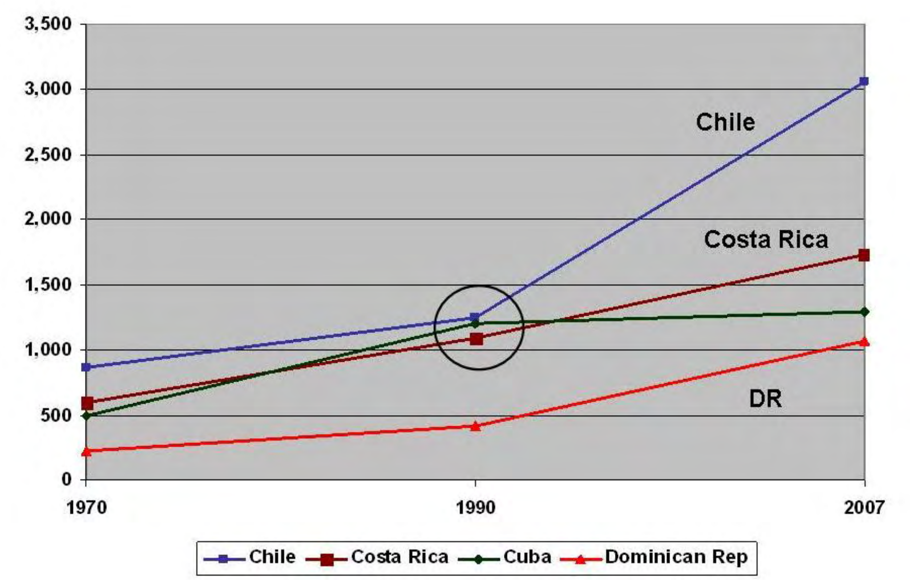
[8] Simon Romero, *In Cuba, a Politically Incorrect Love of the Frigidaire,* New York Times, Sept. 2, 2007.
[9] Cereijo, 28.

Graph 3.3 compares per capita electricity consumption rates in Chile, Costa Rica, Cuba and the Dominican Republic. It is interesting to note that while Costa Rica, Chile and Cuba had similar consumption per capita in 1990, consumption in Chile and Costa Rica today is significantly higher than in Cuba. It is also important to note that Chile, which relies mostly on private investment in the power sector, increased generation much faster than Costa Rica, where the private sector plays only a minor role in the power sector.

Graph 3.3 – Electricity Consumption (kWh/capita) – Country Comparison



III. Financial and Economic Aspects of Unión Eléctrica

Financial data on Unión Eléctrica (UE), the vertically-integrated utility providing power to most of the country, is not available.[10] Therefore, the financial analysis presented in this section should be considered a first approximation, and more research should be carried out to refine the numbers — an important task given the gravity of the energy sector in the Cuban economy in general and in the fiscal accounts in particular. Additionally, the dual monetary system imposes important conceptual difficulties, as it is very difficult to compare financial flows in US dollars with financial flows in pesos. In the paper, an exchange rate of one peso per one US$ is used but sensitivity analysis is carried out to determine the effects of different exchange rates. Furthermore, as most workers in Cuba are employed by the State or by state-owned enterprises (SOEs), the government essentially establishes wages throughout the economy and therefore it is very difficult to speculate about the opportunity cost of labor.[11]

Using information from multiple sources, financial statements for UE were developed and analyzed. This analysis must be considered a rough approximation of the actual financial situation.

The main parameters and assumptions used to estimate the 2008 cash flow include:

1. Total value of sales: US $2.8 billion.[12] Applying present rates to net sales (total sales minus losses and minus plant load) results in a figure of US $2 billion. The higher figure, which came from the analysis of Dr. Cereijo, was used in the analysis; if the lower figure were used, the results would be much more negative.
2. Number of workers: 33,950.
3. Total wage bill: CUP 266 million.
4. Total use of fuel for power generation: 28 million barrels (bbl).
5. Average cost of crude oil at international prices in 2008: $100/bbl.
6. Average cost of power generation fuel at international prices in 2008: $125/bbl
7. Estimated total value of assets: $6.8 billion.
8. Annualized capital cost (i = 10%; n = 20 years): $794 million.
9. Operations and maintenance costs: 1.5% of total asset value: $101 million.

[10] Financial records of Petroleos de Venezuela (PDVSA) are also not available.
[11] I am grateful to Dr. Jorge Sanguinetty who raised this issue in a conversation.
[12] Cereijo, M. (2008)

In 2008, the economic profit of UE was estimated at a loss of $1.9 billion, with an Earnings Before Interest, Taxes, Depreciation and Amortization (EBITDA) of approximately minus $1.1 billion. If Venezuelan fuel is discounted by 40%, EBITDA becomes positive, at around $329 million.[13] Following the sharp decline in oil prices in late 2008, UE's situation has improved. At crude oil prices of US$40/bbl,[14] and with the 40% fuel discount, EBITDA is forecasted at a positive $103 million. Many allege that Cuba does not pay anything at all for Venezuelan oil. If that is the case, the EBITDA for UE may exceed US$2.4 billion, even if Cuba pays international prices for the domestic oil that it purchases through private companies participating in the Production Sharing Agreements (PSAs).

Table 3.3 shows 2009 crude oil price forecasts from eight major institutions. The forecasted prices range from $43/bbl to $82/bbl. If the average price of crude oil reaches $60/bbl this year, which is roughly the average of the estimates, UE faces economic losses of $746 million (see Table 4). Even at the current level of around $40/bbl[15], economic losses are estimated at $184 million per annum and EBITDA would be $609 million, if Cuba were to pay the full international price.

[13] Officially, Cuba buys oil from Venezuela at a discount of 40%, and that is roughly the proportion of domestic oil that belongs to Cuba under the Production Sharing Agreement (PSAs).
[14] At the prices prevailing when the paper was written (first two months of 2009).
[15] Analysis was carried out in January-February 2009.

Table 3.3 Oil Price Forecasts 2009 (US$/bbl)[16]	
Institution	
Morgan Stanley	82
Barclays Bank	76
Analyst consensus (Reuters)	58
U.S. Dept. of Energy	51
CIBC World Markets	50
Goldman Sachs Group	45
JP Morgan Securities	43
Purchasingdata.com	43
Average	56

UE's results depend critically on the market price of crude oil. For most countries that base its power generation largely on liquid fuels, such as Cuba, a reduction of the price would be very good news. In the case of Cuba, however, a significantly lower price for crude oil may also lead to energy insecurity if low oil prices also result in a major reduction in Venezuelan subsidies. This highlights a critical vulnerability in the Cuban power sector: its dependence upon a stable relationship with its main foreign donor, Venezuela.

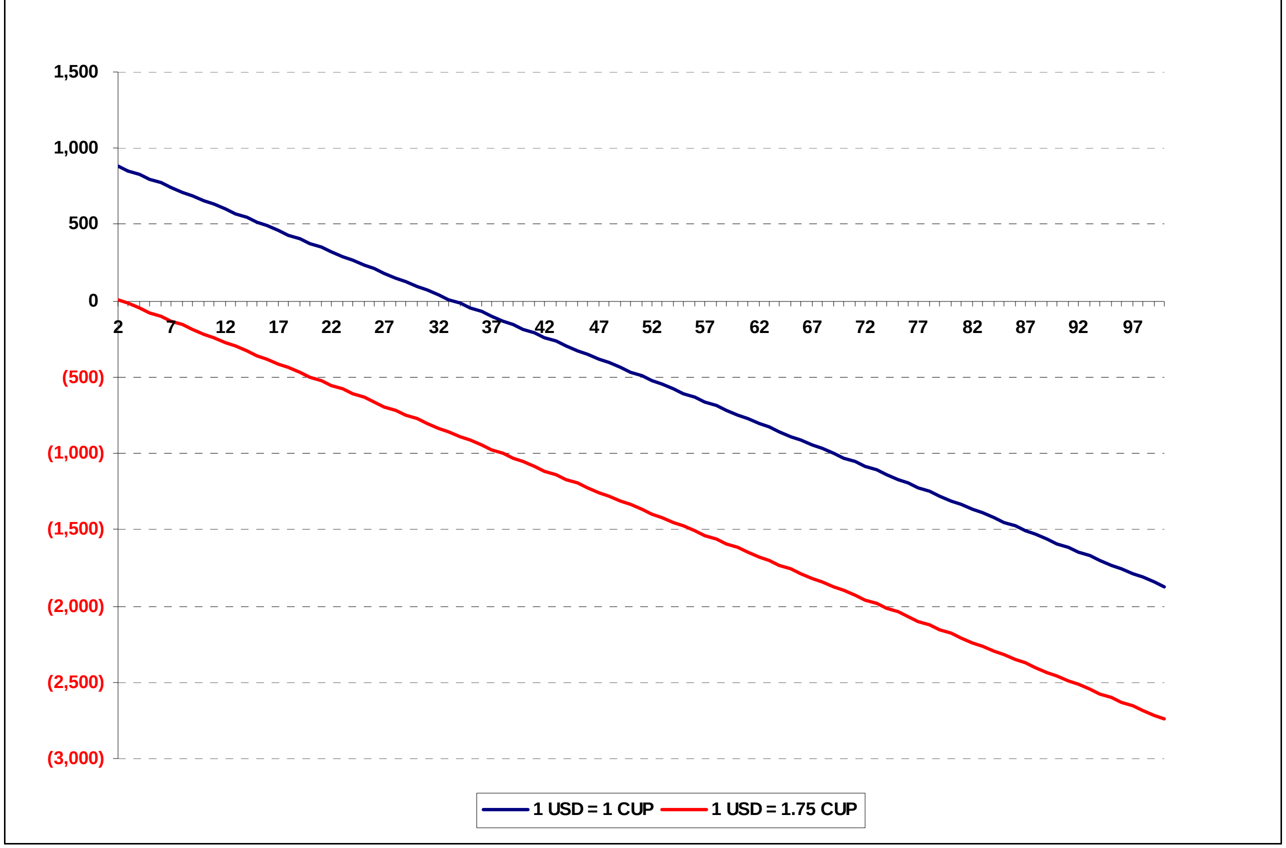
Economic profit and EBITDA were calculated over a range representing historical crude oil prices in 2007 and 2008, as well as current prices in 2009 (see table 4). Oil price forecasts fall throughout this range, but average near the middle at $56/bbl. Unfortunately, these calculations show Cuba as having an economic profit shortfall so long as prices exceed $33, which is an amount below the current international market price for crude. The effect of oil prices on economic profit is shown in Graph 3.4. Graph 3.4 also depicts the relationship between the economic profit and the price of crude oil under the assumption that the equilibrium exchange rate is 1.75CUP=US$1.0. At this rate of exchange, the break even price for crude oil is slightly above US$2.0.

[16] Purchasing.com http://www.purchasing.com/article/CA6628617 html

Table 3.4 - Unión Eléctrica – Estimated Financial Results 2008[17]						
	Units					
Crude Oil Price	$/brl	**30**[18]	**40**[19]	**60**	**87**[20]	**100**[21]
Fuel price (80% fuel oil, 20% diesel)	$/brl	55	65	85	112	125
Economic Profit	M $	97	(184)	(746)	(1,504)	(1,870)
EBITDA (fuel at international price)	M $	891	610	48	(710)	(1,076)
EBITDA (fuel discount 40%)	M $	1,508	1,340	1,003	548	329
EBITDA (fuel discount 100%)	M $	2,436	2,436	2,436	2,436	2,436

[17] This table assumes a uniform refining margin of $25 per barrel of oil in 2008 (Source: EIA).
[18] Crude oil price for UE's breakeven point is estimated somewhere in the range of $33.30/bbl.
[19] Average crude oil price in 2009 (2 months only).
[20] Average crude oil price in 2007.
[21] Average crude oil price in 2008.

Graph 3.4 – Economic Profit as a Function of Crude Oil Price



The data that underlie the graph are presented in Table 3.5, which estimates economic profit as a function of the fuel price and of the exchange rate. If the "correct exchange rate is 1.75 CUP=US$1.0 and if the price of oil were to be US$60/bbl (average forecast of seven institutions that is presented in Table 3), the economic losses of UE would be US$1.6 billion.

Table 3.5 – Economic Profit as a Function of Crude Oil Prices and Exchange Rates					
Sensitivity Analysis for Exchange Rates, Crude Oil and Fuel Prices	**Fuel price (80% fuel oil, 20% diesel)**	**Exchange Rates (CUP/US $1)**			
		1	**1.5**	**1.75**	**2**
Sales Revenue (million US$)		2,803	2,015	1,790	1,621
Net Economic Profit (π) when Crude Oil Price ($/bbl) is					
2	27	883	204	10	(136)
5	30	799	120	(74)	(220)
10	35	658	(21)	(215)	(360)
15	40	518	(161)	(355)	(501)
20	45	378	(302)	(496)	(641)
25	50	237	(442)	(636)	(782)
30	55	97	(583)	(777)	(922)
40	65	(184)	(864)	(1,058)	(1,203)
60	85	(746)	(1,425)	(1,619)	(1,765)
87	112	(1,504)	(2,184)	(2,378)	(2,523)
100	125	(1,870)	(2,549)	(2,743)	(2,889)

UE is an inefficient enterprise by international standards, with very low labor productivity, high technical losses and over-reliance upon liquid fuels. Table 3.6 summarizes key indicators for UE and compares the Cuban power sector to those of Chile, Costa Rica and the Dominican Republic.[22] Employees per 1,000 connections at UE number 9.0, compared to 5.1 in the Dominican Republic, 3.8 in Costa Rica and 0.7 in Chile. Losses, which are mostly technical as there is almost no energy theft in Cuba, are 143% higher than in Chile and 88% higher than in Costa Rica. Losses in the Dominican Republic, a country characterized by massive energy theft, are

[22] Source: The World Bank – Benchmarking Data in the LAC Region 1995-2005. Data for number of employees in Chile seems too low.

much higher than in Cuba.[23] In 2003, Cuba ranked number 5 in the world in terms of percentage of total energy derived from liquid fuels. This excessive dependence results in very high unit generation costs, as fuel accounts for 70-80% of total generation costs. Table 6 shows unit electricity costs as a function of crude oil prices. Even if losses were eliminated, costs per kWh would be about $0.33 (crude oil at $140/bbl) — a cost level that would make almost any economic activity uncompetitive in international markets.

Table 3.6 – Productivity and Efficiency[24]

Indicators	Chile	Costa Rica	Dominican Republic	Cuba
Total number of connections	4,861,913	1,236,847	914,279	3,923,650
Total number of residential connections	4,486,053	1,080,591	844,613	3,773,720
Total electricity sold per year (MWh)	29,000,000	11,800,000	3,719,640	13,892,760
Electricity sold per connection (MWh/yr)	6.5	10.9	4.4	3.7
Total losses (in %)	6.5	8.4	42.5	15.8
Total Employees	3,136	4,155	4,317	33,949
Employees per 1000 residential customers	0.7	3.8	5.1	9.0

Table 3.7 - Unit Costs of Electricity – Sensitivity Analysis to Crude Oil Prices (2008) [25]

Crude Oil Price	$/bbl	**30**	**40**	**60**	**87**	**100**
Fuel price (80% fuel oil, 20% diesel)	$/bbl	55	65	85	112	125
Cost per kWh sold	$/kWh	0.1943	0.2145	0.2549	0.3093	0.3356

[23] Energy theft in Cuba is penalized with exorbitant fines and even prison.
[24] Source: The World Bank – Benchmarking Data in the LAC Region 1995-2005.
[25] This table assumes a uniform refining margin of $25 per barrel of oil in 2008 (Source: EIA).

Cost per kWh generated	$/kWh	0.1532	0.1691	0.2009	0.2439	0.2646

At present crude oil prices, fuel accounts for more than 60% of total electricity costs (Table 8). While increases in labor productivity and reductions in losses can reduce costs per kWh, major reductions are not possible unless fuel costs are reduced through greater plant efficiency and by moving to other less costly sources of generation, including renewables.

TABLE 3.8 – UNIT PERCENTAGE COSTS					
Unit crude oil costs		**30**	**40**	**60**	**87**
Costs					
Labor	%	9.8%	8.9%	7.5%	6.2%
Fuel	%	57.1%	61.1%	67.3%	73.0%
O&M	%	3.7%	3.4%	2.9%	2.4%
Annualized capital	%	29.3%	26.6%	22.4%	18.4%
Total costs (fuel 100%)	%	**100.0%**	**100.0%**	**100.0%**	**100.0%**

In order to determine the effect of different exchange rates on the financial and economic results of UE, sensitivity analysis was carried out and is summarized in Tables 9 and 10. As would be expected, higher exchange rates make the situation worse.

Table 3.9 – Effect of Exchange Rates on 2008 Economic Profit [26]						
Description	**Sales Revenue**		**Total (US $)**			
	Local (CUP)	**Foreign (US $)**				
Exchange Rate (CUP/$1)			**1.0**	**1.5**	**2.0**	**3.0**

[26] Average Crude Oil Price = $100/bbl – Refining Margin = $25/bbl

Sales Revenue	**2,365**	**438**	**2,803**	**2,015**	**1,621**	**1,227**
Expenditures						
Labor	266	0	266	177	133	89
Fuel	0	3,511	3,511	3,511	3,511	3,511
Annualized capital		794	794	794	794	794
O&M	61	41	101	81	71	61
Total expenditures	**327**	**4,346**	**4,673**	**4,564**	**4,509**	**4,455**
Economic Profit	**2,038**	**(3,908)**	**(1,870)**	**(2,549)**	**(2,889)**	**(3,228)**
Cash Flow			**(1,076)**	**(1,755)**	**(2,095)**	**(2,434)**

Table 3.10 – Breakeven Rates for Equilibrium as a Function of Exchange Rates[27]				
Rate of Exchange (CUP/$1)	**1.0**	**1.5**	**2.0**	**3.0**
Total Sales Revenue (US $ million)	2,803	2,015	1,621	1,227
Net Energy Sold (GWh)	13,925	13,925	13,925	13,925
Total costs (US $ million)	3,549	3,440	3,386	3,331
Unit Sales Revenue ($/kWh)	0.201	0.145	0.116	0.088
Breakeven rate ($/kWh)	**0.255**	**0.247**	**0.243**	**0.239**
Economic Profit ($ million)	0	0	0	0

[27] This table assumes a uniform refining margin of $25 per barrel of oil in 2008 (Source: EIA)

IV. Results of Modeling the Cuban Power Sector[28]

The Cuban power sector will require extensive investment to reduce high operating costs and to meet growing demand in the coming years. As discussed in previous sections, power generation currently relies primarily on a set of aging heavy fuel oil plants, whose condition has been compromised by the burning of heavy, sour domestic crude. These plants have been recently supplemented by natural gas plants financed through international joint venture and by more than one Gigawatt (GW) in new small gensets. Going forward, the system is subject to a large number of uncertainties.

Some of these uncertainties are faced by all countries, including the rate of economic growth and international fuel prices. Other uncertainties, such as the rate and nature of market liberalization, openness to and availability of foreign investment, and changes in the structure of energy demand are particular to the Cuban situation. Decisions about investment in new generation capacity will involve weighing several interlocking factors, including: capital versus operating costs, future fuel cost risk, future demand growth, demand-side versus supply-side investment, availability of domestic and foreign investment capital, and environmental considerations.

Cuba also faces uncertainty with respect to the ability and willingness of Venezuela to subsidize Cuba. If the subsidies were to end or to be reduced, Cuba would find it difficult to generate the fiscal resources necessary to continue to operate the power system at present levels of generation and tariffs.

A MARKAL/TIMES model was developed and used to analyze future capacity investment decisions designed to increase the efficiency of the power system. The MARKAL/TIMES energy systems analysis toolbox is well suited to examine these interlocking uncertainties through a systematic approach. MARKAL/TIMES represents all energy producing and consuming sectors in an integrated and highly transparent framework at a user-specified level of end use, technology, and pollutant detail. This modeling paradigm has been in use for more than 30 years at more than 200 institutions worldwide. The model has become one of the leading energy systems modeling frameworks currently in use for several major international and global applications, and in dozens of developed and developing countries for national strategic planning.

[28] This Section is based on a report prepared by the international Resources Group (IRG). Lead researcher was Evelyn Wright. Similarly to Section III of this paper, this analysis was hindered by the lack of reliable data. Annex 1 summarizes the characteristics of the MARKAL/TIMES model.

In the interests of simplicity and short model construction time, the Cuba MARKAL/TIMES model development and analysis effort focused on the supply and power sectors only, representing electricity demand growth in a simple summary fashion. This Section summarizes the results of running the MARKAL/TIMES model.

The goal of the analysis was to identify cost-effective power sector investment options under various scenarios of electricity demand growth, oil and gas production, and other key energy system variables over the period 2007-2025. The key uncertainties were divided into two scenario sets or "storylines". The first is a business-as-usual (BAU) case which assumes continued moderate electricity load, limited foreign investment in the oil and gas sector, and hence, limited production growth. The second (HI) case assumes rapid economic and electricity demand growth, high foreign investment, rapid increase in domestic fuel production, and transition to market pricing of electricity. Within each scenario set, sensitivity analyses were conducted on key variables, including higher gas prices, lower oil prices, restrictions on the feasible rate of new power plant and LNG import infrastructure investment, and high bagasse availability due to a revitalized sugar/ethanol industry. The scenarios are summarized in Table 11.

TABLE 3.11 – SCENARIO SETS AND SENSITIVITY CASES		
Set	**Description**	**Sensitivity cases**
BAU	o Moderate electricity demand growth in line with recent trends o Slow growth in oil and gas production in line with recent trends	o Higher gas prices o Lower oil prices o Limited rate of new investment o No LNG import available o Higher bagasse availability
HI	o Rapid economic growth o High foreign investment o Accelerated oil and gas production growth	o Higher gas prices o Lower oil prices o Limited rate of new investment

	o Transition to market electricity prices	o No LNG import available o Higher bagasse availability

The key results were found to be surprisingly robust across these multidimensional hypotheticals. Natural gas was found to be the cost effective fuel, even in cases where natural gas prices were increased 40% above AEO2009 projected levels and oil prices were decreased 40% below AEO2009 levels. The model found it to be most cost effective to replace the existing heavy fuel oil power plants with new natural gas combined cycle plants as quickly as possible, due to the low efficiencies, low availabilities, and high maintenance costs of the existing plants. Sensitivity analysis found this conclusion to be robust even when assumed maintenance costs were reduced by half.[29]

Given these results, the key uncertainty is access to natural gas through domestic production and imported LNG. Generic assumptions from the U.S. Energy Information Administration were used to characterize LNG import costs. Under these assumptions, importing LNG was found to be cost effective in every scenario, suggesting that further examination of site specific LNG infrastructure costs is an important area for future study. Restricting LNG imports substantially increased system costs in every scenario. When LNG import was denied as a model option, wind and sugarcane bagasse resources were utilized, although they played a marginal role in the non-restricted scenarios.

A second key uncertainty is how rapidly the replacement of the existing plants can feasibly be conducted. In the HI growth case, the unconstrained system built nearly 3 GW of gas combined cycle generation in the 2012-2014 period, at a cost of $2.5 billion. This rate of construction and investment may be unrealistic due to both economic and physical construction constraints. Various restrictions on the speed of this replacement were imposed, and were found to be a primary determinant of system costs and electricity prices.

Current electricity tariffs are subsidized, at an estimated average of $0.13 per kWh, or somewhat over half of current costs, assuming an exchange rate of approximately 1.75 CUP/US$. A variety of scenarios endogenizing demand response to price liberalization were explored. The effect was found to be primarily on medium-term demand. Once the system has completed the replacement of existing

[29] Future analysis should also look more closely at the economic and financial viability of coal. The GOC recently announced a plan to establish a gas regasification facility in the Port of Cienfuegos. If this investment were to be made, then gas would become the most viable alternative.

plants, subsidies are no longer needed to maintain electricity prices at or below current levels until the final periods of the modeling horizon.

In the BAU scenario, because of limited domestic gas production growth, the system is very sensitive to changes in external conditions. A 40% increase in gas prices increased system cost by 15%, and an inability to import LNG increased system cost by 50%. With LNG restricted, the system maintained the more efficient existing heavy fuel oil plants and built a combination of new heavy fuel oil steam, wind, and bagasse. When the rate of new investment was constrained below the 2.5 GW built in 2012-2014 in the unconstrained scenario, existing heavy fuel oil plants continued to operate for some time as the slower turnover took place.

Fuel expenditures sharply increased in 2010, as Venezuelan oil subsidies were assumed to expire. Switching to natural gas fired plants enabled a precipitous drop in fuel costs, even in the high gas price case. Limiting access to imported LNG greatly increased fuel costs as reliance on petroleum-fired generation was extended. However, a revitalized sugar-bagasse-to-energy industry mitigated this effect by eliminating the need for imported petroleum by 2020.

In the HI scenario, system costs were also sensitive to increases in gas prices and restrictions on the rate of investment in new power plants, but the effect was less pronounced than in the BAU case. When electricity subsidies were removed, demand growth moderated, but only slightly. The effect was most pronounced when replacement of the existing plants was slowed by investment constraints. Once the transition was completed, relatively low market prices led to only minor adjustments in demand. Only restricting new investment or denying LNG imports significantly increased prices beyond this level. Unlike in the BAU scenario, rapidly expanding domestic gas production enabled system reliance on gas even in the absence of LNG imports, with a minor role for wind and bagasse. However, higher costs led to a downward adjustment of demand in response to market prices, suggesting that end use energy efficiency potential and cost are important variables for further analysis.

As in BAU, the switch to natural gas in the HI scenario enabled a substantial drop in fuel costs. However, higher demand growth left the system vulnerable to increases in natural gas prices, which substantially increased generation costs. Greater domestic production of natural gas than in BAU allowed the system to obtain the majority of its fuel from domestic sources, decreasing energy security concerns.

In both scenarios, replacement of the existing plants led to a sharp drop in CO_2 emissions. However, by 2025, steady generation growth brought emissions nearly back to near 2007 levels (in the BAU case) or above (in the HI case). Only in the renewables-heavy, LNG restricted BAU scenario were CO2 emissions flat across the time horizon. Scenarios with CO2 emissions prices or caps were not examined in this analysis, but such an analysis could identify opportunities for emissions reductions.

The analysis suggests that key areas for further study are 1) the cost and potential for future access to natural gas through domestic production and LNG import; 2) the feasible rate of power plant replacement; 3) the potential for price-responsive demand adjustment through end-use energy efficiency; and 4) the feasibility of coal generation..

The potential for **renewables** in Cuba is somewhat limited but more research is needed. Some of the conclusions of the IRG report on the potential for renewables are outlined below.

Hydropower: The total hydropower resource in Cuba has been estimated at 650 MW.[30] [31]However, much of the currently unutilized potential is in protected or naturally sensitive areas that may not be candidates for development. The remaining resource appears suited for small facilities in areas that are mountainous or have seasonal characteristics. Thus, we assumed that these resources could continue to be exploited primarily for off-grid electricity supply to rural schools, medical centers, and small villages rather than for the grid-connected demand considered in this study. Therefore, new hydropower installations were not included in the set of new power plant options.

Solar PV: Cuba clearly has excellent solar resources, and the use of solar photovoltaic generation is limited by capital cost rather than resource base. Present photovoltaic applications are largely for off-grid uses. We developed solar PV capacity factors for Cuba from the RETSCREEN database.[32] Concentrated solar was investigated but not regarded as a realistic grid-connected option due to radiation and atmospheric clarity limitations.

Wind: Cuba's wind potential has been very preliminarily estimated at 400 MW[33]. Wind capacity factors and transmission costs are highly site dependent. Hence, making general estimations in the absence of a detailed site inventory can be treated as an approximation. A detailed high-resolution wind energy resource map for Cuba was created at the United States Department of

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[30] The International Solar Energy Society – Sustainable Energy Policy Concepts (SEPCO). *Country Case Study – Cuba*. (2005). http://www.ises.org/sepconew/Pages/CountryCaseStudyCu/2 html

[31] Perez, D., Lopez, I., and Berdellans, I. Evaluation of Energy Policy in Cuba Using ISED. *Natural Resources Forum* **29**: 298-307, 2005.

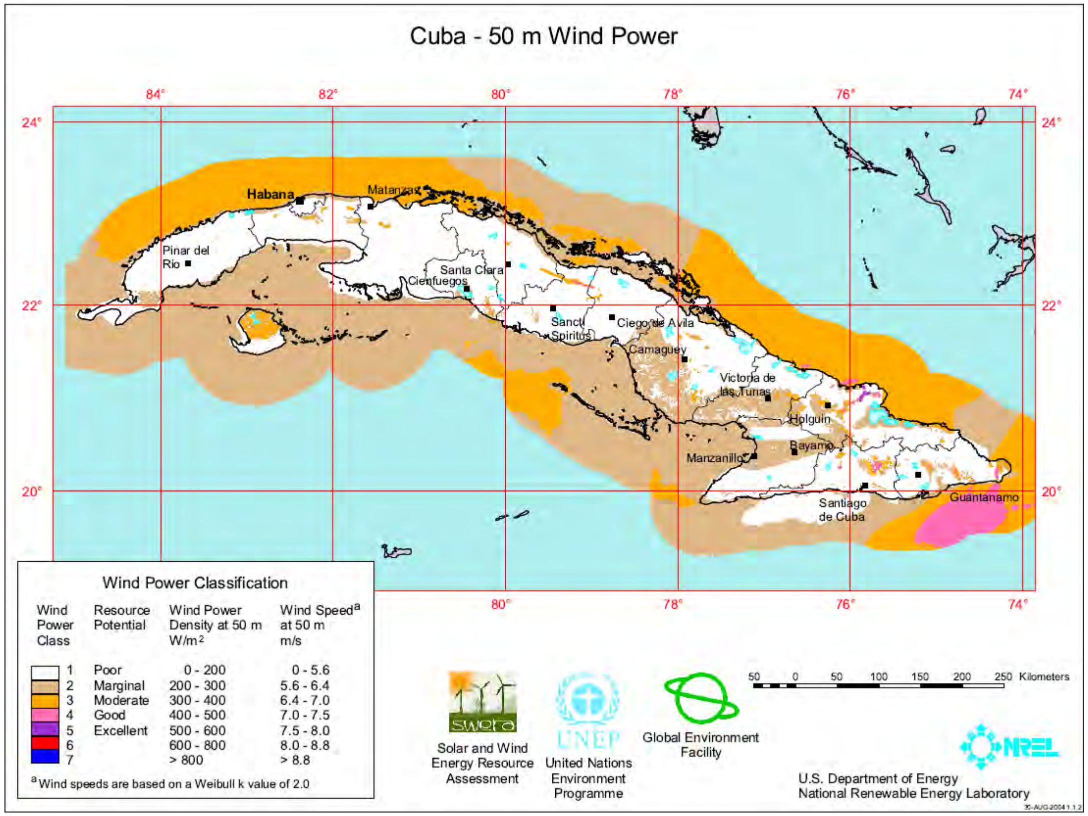
[32] http://www retscreen.net/ang/home.php

[33] Perez, D., Lopez, I., and Berdellans, I. Evaluation of Energy Policy in Cuba Using ISED. *Natural Resources Forum* **29**: 298-307, 2005.

Energy's National Renewable Energy Laboratory (NREL) as part of the Solar and Wind Energy Resource Assessment (SWERA) project for the United Nations Environment Programme.. The wind mapping activity covered approximately 110,000 km2 of land area and, including offshore areas, more than 150,000 km2, and used a combination of analytical, numerical, and empirical methods using Geographic Information System (GIS) mapping tools and data sets. This activity highlighted the major wind resource areas and providing a wind resource estimate consistent with available measurement data. The report estimated the total wind electric potential for Cuba at 2,550 MW for class 4 and 5 wind areas. [34]

The national wind resource map shown below indicates mostly moderate resources with the largest area with good winds being off shore from Guantanamo. Mountain ridges are likely to have small localized good to excellent wind resources.

[34] Technical Report - Cuba Wind Energy Resource Mapping Activity, Solar and Wind Energy Resource Assessment (SWERA),21 August, 2006, found at http://swera.unep.net/index.php?id=userinfo&file=cubawindreport_243.pdf



Biomass: Estimates of the sugar cane bagasse resource in Cuba were derived from work by Alonso-Pippo [35] that examines the history, methods, costs, and future prospects of Cuba's attempts to develop the energy potential of sugarcane. The paper shows that sugarcane production in Cuba was historically over 70 million tons per year (tpy) until the early 1990s when production dropped dramatically to about 35 million tpy and has continued a slow decline to about 25 million tpy.

[35] Walfrido Alonso-Pippo, Carlos A. Luengo, John Koehlinger, Pietro Garzone, and Giacinto Cornacchia Sugarcane energy use: The Cuban case. *Energy Policy* **36**:2163– 2181, 2008.

From the 1990s to the present, the Cuban sugarcane industry's average sugarcane yield has declined from 57.5 ton/ha to 22.4 ton/ha in 2005, a 39% decrease. At the same time, the total amount of cultivable land in Cuba used for sugarcane cultivation has declined from 21% of Cuba's cultivable land to barely 5%. While Alonso-Pippo cites many reasons for the decline of Cuba's sugarcane industry and for the resistance of the industry to recover in spite of government efforts to improve it, there is significant room for expanding cane production if sufficient investment and improved incentives were employed. Following consultation with Jorge Piñon, two sugarcane yield scenarios are proposed for resource potentials, one representing the current sugar industry and one representing a revitalized sugar-ethanol-bagasse industry (Table 12).

Table 3.12 – Sugarcane Production in Two Scenarios (million tpy)							
Scenario	**2007**	**2010**	**201 3**	**2016**	**2019**	**2022**	**2025**
Low bagasse	25.0	25.0	25.0	25.0	25.0	25.0	25.0
High bagasse	25.0	30.8	36.7	42.5	48.3	54.2	60.0

The amount of bagasse that remains at the mills after grinding and crushing of the sugarcane represents only about 15% of the weight of the sugar cane on a dry basis[18]. The heat content of sugarcane bagasse is 15.6 GJ per dry ton. The potential energy available from Cuba's bagasse resource is given in the table below for each of the three scenarios.

Table 3.13 – Bagasse Energy Potential in Two Scenarios							
Scenario	**2007**	**2010**	**2013**	**2016**	**2019**	**2022**	**2025**
Low bagasse	58.5	58.5	58.5	58.5	58.5	58.5	58.5
High bagasse	58.5	72.2	85.8	99.5	113.1	126.8	140.4

Electricity production from bagasse at sugar/ethanol mills was based on the operation of a 7,000 ton/day sugar mill producing either sugar or ethanol. The length of the crushing season is 3,800 hr/yr. The amount of surplus electricity that can be cogenerated is based on efficiency improvements to reduce steam use in the sugar factory, the addition of a distillery, and the addition of a 33MW cogeneration plant based on a condensing-extraction steam turbine. The plant generates 92 GWh per year of surplus power, which is about a 32% capacity factor. The capital investment cost for the sugar factory steam reductions, the distillery, and the 33MW cogeneration plant are shown in the table below, along with the operating and maintenance costs.

Table 3.14 – Technology Characterization for Bagasse Plant	
Capital and Operating Costs	
Capital Investment, Million US$	
Steam saving from sugar factory	3.3
Distillery	6.4
Cogeneration capacity (33MW)	50.4
Total investment	60.1
O&M Costs	
Fixed, US$/kWh	0.031
Variable, US$/kWh	0.015

V. Potential Ways to Increase Efficiency and Sustainability of the Power Sector

By definition, no major changes would be required to achieve the "business as usual" (BAU) scenario. To achieve the high growth and high investment scenario (HI) different policy measures would have to be implemented, including the rationalization of the tariff regime. Equally importantly, a more favorable environment for foreign investment would have to be established; this is a particular challenge, as the general environment for Foreign Direct Investment (FDI) is being affected negatively by the global financial crisis. This section discuses the measures that should be implemented to achieve the HI scenario, including attracting investment of US$2.5 billion for generation using CCGTs plus the resources necessary to expand domestic gas production or to establish a regasification plant to handle imported Liquefied Natural Gas (LNG).

In promoting the policies necessary to achieve HI, Cuba could benefit from the experience of countries in Latin America, Asia, Eastern Europe and Central Asia.[36] Before discussing the potential measures that Cuba should consider, some caveats are in order. These are:

- The purpose of these recommendations is not to be prescriptive but rather to highlight some of the main issues that would have to be faced if a Cuban government makes the decision to reform its power sector. While this section makes frequent use of the verbs "should" and "would," these terms have been used merely for the purpose of simplification. What is meant is that authorities in Cuba should consider adopting the proposed measures.

- Tariff adjustment, protection of vulnerable groups and private participation policies must be formulated in the context of national policies dealing with those subjects. In other words, the power sector reforms can only succeed if they are coordinated with the policies guiding reforms in other sectors

- Decisions on how to reform the power sector are extremely important, as an adequate power supply is a necessary condition for rapid economic growth. These decisions must be made autonomously by local authorities vested with such decision-

[36] Some of these lessons are discussed in three papers by the author of this Chapter. These papers are: Telecom and Power Sector Reforms in Latin America – Lessons Learned (2000), Power Sector Reforms in Market and Transition Economies – Lessons for Cuba (2006), and Cuba: Reforming the Power, Telecommunications and Water Sectors During a Transition (2007).

making responsibility, but international experts can provide valuable advice, as the experiences of other countries can inform the direction taken by Cuba.

- While lessons from other countries can be valuable, models should not be imported in their entirety, but rather must be adapted to the local conditions.

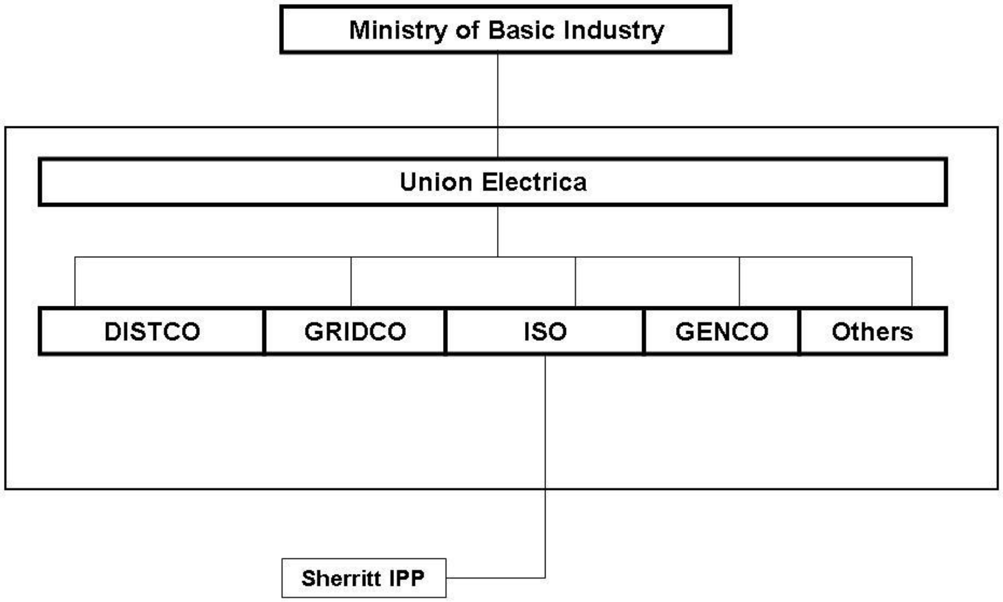
- Most importantly, this section assumes the Cuban government has made the decision to improve the environment for foreign investment in the power sector. While not absolutely necessary, USG support could make the transition to cleaner and cheaper energy faster and easier. In this context, the recommendations of the recently completed report by a Staff Member of the SCFR are particularly relevant. [37]

The structure of the Cuban power sector is shown in Chart 1. UE is under the Ministry of Basic Industry. It is a vertically and horizontally integrated utility that controls the entire sector, with the exception of the Independent Power Producer (IPP) arrangement with Energas/Sherritt. [38] This is normally referred to in the literature as "Model 2", or single buyer model, in contrast with "Model 1", where a fully integrated utility that owns all assets necessary to provide power to final users.

Chart 3.1: Present Structure of the Power Sector

[37] Changing Cuba Policy—In The United States National Interest, Staff Trip Report to The Committee on Foreign Relations, United States Senate, February 23, 2009.An extract of the Trip Report is provided in Annex 2.

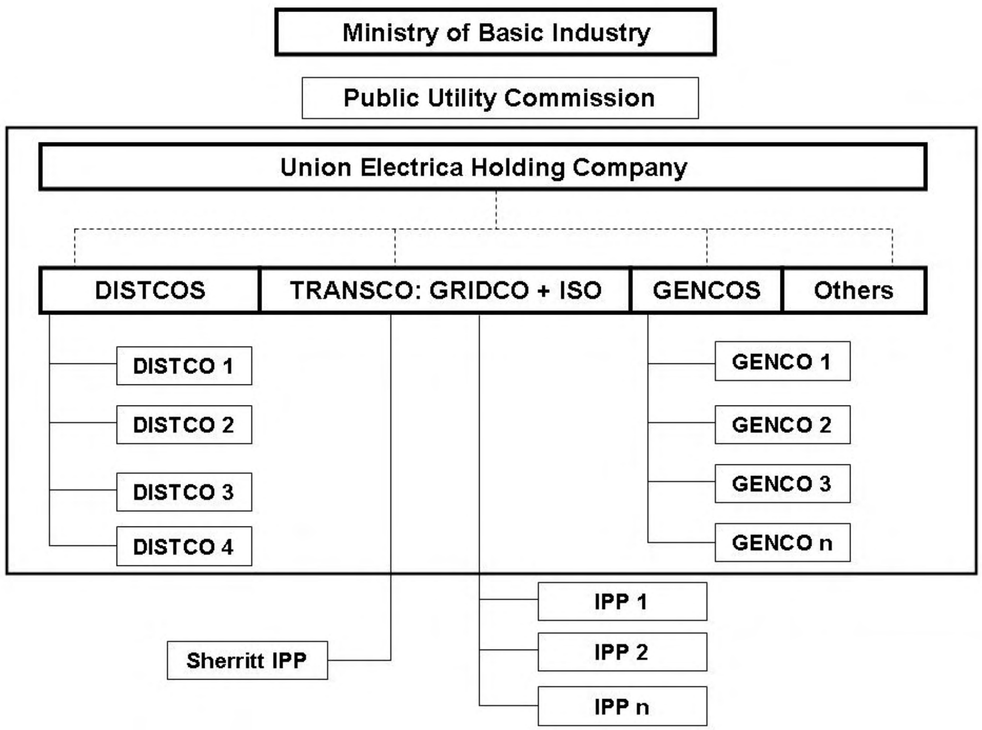
[38] DISTCO refers to the distribution assets; GRIDCO to the high voltage transmission network; ISO to the system operator; GENCO to the power generation assets; and "others" refer to support activities, mainly construction personnel and other assets.



Most of the literature on power sector reform advocates that countries with a sufficiently large market (rule of thumb posits that competition is possible in markets above 1,000 MW of installed capacity") should move to a fully competitive power system. These are usually referred to models 3, 4 and 5. The author of this Chapter has advocated in other papers on the Cuba power sector that Cuba should eventually move to a competitive model, which is what predominates in Latin America. But the author also concluded that reaching that stage would take three to five years[39]. The rest of this section identifies the different measures that the GOC should consider to strengthen the present power sector model (Model 2 in the literature on power sector reform) in order to encourage FDI for generation. The proposed future structure necessary to achieve the high growth and high foreign investment scenario (HI) is shown in Chart 2.

[39] Belt, *op cit.*

Chart 3.2: Structure to Achieve the High Growth High Investment (HI)



Some of the steps that should be implemented to achieve HI include:

A. Enact an electricity sector law and establish the Public Utility Commission (PUC)
B. Model the energy sector
C. Modify tariffs

D. Restructure UE
E. Develop IPPs
F. Develop operating contracts and/or concessions for existing assets.

A. Establish PUC

The electricity sector law ("the law") should establish that the Ministry of Basic Industries would concentrate its efforts in the power sector on the formulation of strategy and policies and the PUC should be in charge of regulating the sector. A basic lesson learned by Latin American countries that reformed their power sectors was that it is easier to develop the legal/regulatory framework than to develop adequate institutions. The institutions include the relevant ministries in charge of policy-formulation and the regulatory agencies. The latter must be independent from the former as well as accountable for its actions.

Independence and autonomy of the regulator includes (Smith, 1997):

- Regulator established by law.
- Arms length relationship with operators, consumers and other private interests;
- Arms length relationship with political authorities;
- Financial independence, with funding from a fee charged the regulated companies and the ability to pay competitive salaries;
- Professional criteria for appointment of commissioner(s);
- Fixed, staggered terms and removal only for well defined cause; and
- The executive and legislative branches of government involved in selection.

Independence, however, has to be accompanied by accountability. This requires (1) strong provisions prohibiting conflicts of interest; (2) established rules and procedures for appeal and overturning decisions of the regulator; (3) public availability of budget and scrutiny (usually) by Parliament; (4) external audits; (5) permitting removal for just cause; and (6) open hearings with participation by the regulated industries and the consumers.

The staff of the PUC will require training on the job as well as abroad. Good possibilities for training abroad include the Public Utilities Research Center of the University of Florida (PURC), the Kennedy School of Government at Harvard (specifically the course *Infrastructure in a Market Economy*) and the Institute for Public Private Partnerships (IP3). The regulator can also be supported by foreign consultants who would also provide on the job training. Additionally, partnerships under the National Association of Regulatory Utility Commissions (NARUC) with a US state regulator could be a powerful instrument for enhancing the skills of the staff of the Cuban regulator. Presently, USAID is supporting a partnership between the regulator on Nicaragua and the regulator of Texas and the results have been positive.

B. Model the Energy Sector

Section IV (*Results of Modeling the Power Sector*) presents the results of running MARKAL/TIMES. This effort relied on secondary data and estimates and can only be considered a first approximation. A more thorough modeling of the energy sector as a whole (power, transport, industry and households) and real and more accurate data could help determine more accurately the optimum path for restructuring the power system. Some additional studies would include:

- A more thorough analysis of the prospects for renewable energy.
- The cost and potential for future access to natural gas through domestic production and LNG import.
- Pre-feasibility study of a potential degasification plant and/or the domestic gas transmission.
- Modeling the transmission network to determine the optimal location of power plants, including the CCGTs.
- Determination of the feasible rate of power plant replacement.
- Potential for price-responsive demand adjustment through end-use energy efficiency.

C. Modify Tariffs

Based on the new costs and the increases in efficiency, a new tariff schedule should be developed. The preliminary analysis shows that if the sector is transformed from liquid fuels to gas and renewables, there may not be a need for major tariff increases. Any tariff changes should be established by the PUC and a system designed to adjust prices to reflect changes in costs should be established.

D. Restructure UE.

The GOC should consider unbundling UE by implementing a functional separation under a holding company. This is represented graphically in Chart 2. The **distribution** assets could be separated into three or four separate companies. Table 14 shows the possible division of those assets. A more thorough analysis of the different load centers and of the transmission network would need to be developed.

Table 3.14 – Possible Electricity Distribution Markets		
Market Areas	**Provinces**	**Estimated number of customers (millions) and % market participation**
3 Distribution Areas	Provincia de La Habana	1.1 (33.3%)
	Provincias Centrales	1.2 (36.4%)
	Provincias de Oriente	1.0 (30.3%)
	Total	**3.3 (100%)**
4 Distribution Areas	Provincia de La Habana	1.1 (33.3%)
	Provincias Centrales 1	0.7 (21.0%)
	Provincias Centrales 2	0.8 (22.8%)
	Provincias de Oriente	0.8 (22.9%)
	Total	**3.3 (100%)**

Sally Hunt (2002, pp302-303) recommends that the dispatch center (ISO) and the transmission network (GRIDCO) should be combined and corporatized into a TRANSCO. Main reasons given by Hunt are that doing so provides a better business model and that coordination can be improved. Transmission and system operations were combined effectively in a number of markets, including England and Wales, Spain and Scandinavia. Some argue against this recommendation because of the concentration of market power in one institution.

The GOC should consider establishing 7-8 GENCOS with the generation assets of UE. Additionally, a company could be established with the personnel and assets that carry out construction.

E. Develop Independent Power Producer (IPP) contracts

Using the results of the planning model, a transparent system should be developed for life-of-plant contracts. Some of the key issues in the design of IPPs are:

- Should the technology be specified?
- Should the contracts be non-dispatchable, i.e not under the control of the system operator?
- Should the profits be earned on the fixed assets, or on the variable costs, or on a combination of both?

F. Develop operating contracts and/or concessions for existing assets.

Cuba has demonstrated that it is ready to permit significant private participation in infrastructure. Besides the IPP (Energas/Sherritt), Cuba privatized a majority of the telecommunications company and developed concessions for the water utilities in Havana and Varadero (with Aguas de Barcelona and Aguas de Valencia). Cuba should also consider introducing operating contracts (incentive-based management contracts) and/or concessions for some of the state-owned GENCOS and DISTCOS.

USG support for the potential reforms of the power sector is severely constrained by existing legislation. If legislation is modified or a waiver is granted, the USG could support technical assistance for modeling the sector (using MARKALTIMES, possibly) to determine the possibilities to improve efficiency and environmental sustainability; and training government officials on economic regulation of utilities. Training possibilities include:

- Course on regulation at the Public Utilities Research Center at the University of Florida (PURC). This course takes place twice a year, in June and January.
- Course on private infrastructure at the Kennedy School of Government, Harvard University. This course is offered every summer.
- Courses on the design of IPPs and rate design at the Institute for Public Private Partnerships (IP3), which are offered several times each year.

Annex 1

MARKAL/TIMES[40]

MARKAL is the acronym for MARKet Allocation, while TIMES — which is the next generation version of MARKAL — stands for The Integrated MARKAL/EFOM System. MARKAL/TIMES is a technology-rich energy modeling framework with a transparent architecture (with respect to both data and well-understood methodology). It is a full-sector model, meaning that it encompasses not just power generation but also upstream fuel production and all forms of energy consumption in all demand sectors of an economy. MARKAL/TIMES models are constructed for specific geographical boundaries that can range from global, multi-region models, to single and multi-region national models as well as sub-regional models down to the municipal and even village level.

A MARKAL/TIMES model typically represents the energy economy by means of a Reference Energy System, a “network” that links resource supplies, energy conversion and processing technologies, and end-use demands and the devices that meet them, tracking the flows of energy and associated emissions, as depicted in Figure 1 below. The model finds the least-cost path through the network to meet all end-use demands, subject to constraints that enforce network integrity as well as any user-imposed (policy) constraints.

[40] Prepared by Gary Goldstein, Pat Delaqui and Evelyn Wright, International Resources Group (IRG), 2008.

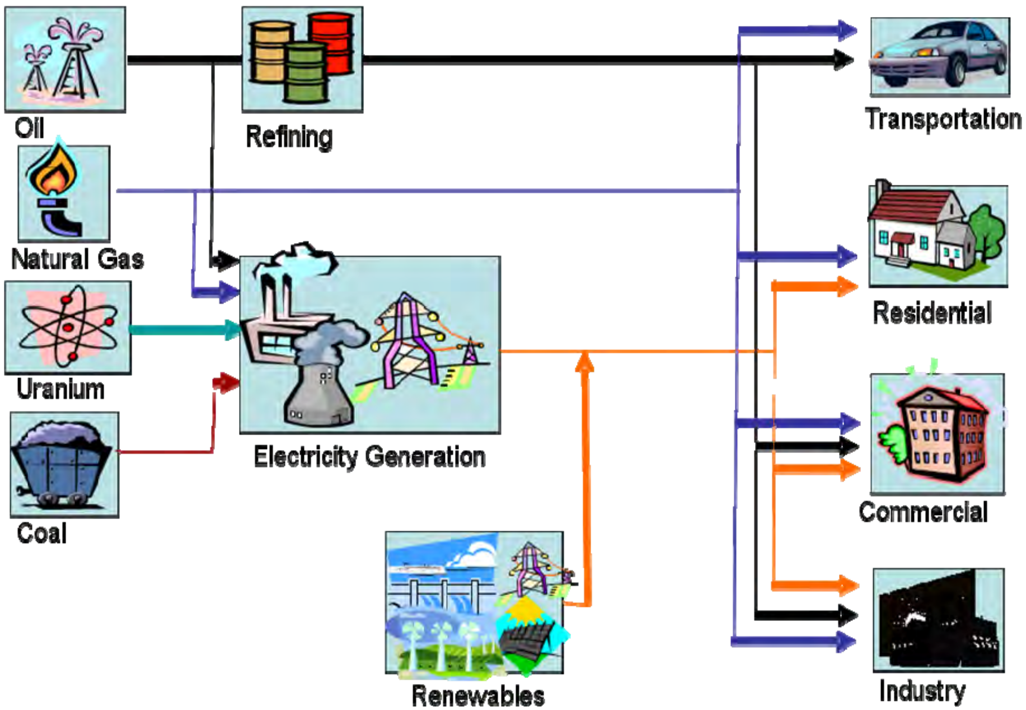


Figure A.1 -- MARKAL/TIMES Energy System Structure

The MARKAL/TIMES model accepts industrial, commercial, residential, and transportation demands for energy services over the next several decades, and determines where the sources of energy will originate – whether domestic or imported – based on the available technologies that transform primary energy into final energy that is used by end-use devices to meet the demands for energy services. The components are tied together by means of a Reference Energy System (RES), as depicted above, which establishes the network of energy flows and technology options encompassing the energy system. The characteristics of each technology (resource supply, process, conversion and end-use) include the investment cost, operating and maintenance costs, service life, efficiency, availability and emissions.

The MARKAL/TIMES model then simultaneously identifies the least-cost mix of energy carriers and existing and new technologies that will satisfy the energy service demands and meet all the constraints imposed on the energy system. Common constraints include limitations on the rate of fuel switching or the penetration of new technologies, caps on various emissions (SO2, NOX, CO2, mercury, etc.), minimum requirements for renewable energy, etc.

MARKAL/TIMES models also have the ability to allow the actual energy service demands to respond to price pressures by means of own-price elasticities. They also allow for learning-based cost reductions as new technologies get taken-up by the energy system. In addition, MARKAL/TIMES models are used for tracking material flows, factoring in lumpy investments, and the development of hedging strategies by employing probability functions.

Once a model is established, its base year is calibrated to actual data from the energy system being modeled, and a Reference scenario is established that is often based on “official” projections that constitute a business-as-usual future. Then a series of Policy scenarios can be investigated with the model to explore their impact in comparison to the Reference scenario.

Policy scenarios that can be analyzed with the model include measures to improve energy security, cut emissions, promote energy efficiency, reduce new technology costs, impose a cap-and-trade program, institute incentives or impose taxes. The value of the model is that the impacts of these policy scenarios can be compared in terms of the different technologies used, the different fuels consumed, the change in energy system cost, emission levels, etc.

Worldwide, MARKAL/TIMES is used by some 200 institutions in over 60 countries. Because of its flexibility, the model has been applied for local energy planning (at the municipality/utility/state and even African village level), and for policy analysis at the regional, national and even global level.

Some of the most prevalent uses of MARKAL/TIMES (along with some recent examples) include:

- energy security;
- identifying least-cost energy systems and investment strategies;[41,42]

[41] EC New Energy Externalities Development for Sustainability (NEEDS), www needs-project.org. Follow-on projects include projects aims to evaluate the Renewable Energy Standards directives for the EU27 (http://www.res2020.eu/, and Risk of Energy Availability) and Common Corridors for Europe Supply Security (EACCESS), which is a techno-economic + environmental evaluation of global energy supply options for the EU in the context of long term sustainability and energy security.
[42] Enhanced Economic Modeling Capacity for Kazakhstan, http://www.sofreco.com/projets/c886/Reports.htm, Task 6.

- identifying cost-effective responses to restrictions on environmental emissions and wastes under the conditions of sustained development;[43]
- evaluating new energy markets, technologies and priorities for R&D;
- evaluating the effects of regulations, taxes, and subsidies;
- UNFCCC assessments and National Communication Action Plans;[44,45,46]
- evaluation of options for a low-carbon future;[47,48]
- examining rural energy use transition from traditional, highly polluting, energy forms;[49]
- determine the costs and benefits of Renewable Portfolio Standards;[50]
- looking at integrated local energy and waste management planning;
- Greenhouse Gas (GHG) baseline determination, mitigation project evaluation and estimate of the value of carbon rights;[51,52,53] and

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[43] The Future of Natural Gas vs. Coal Consumption in Beijing, Guangdong and Shanghai: An assessment utilizing MARKAL, BinBin Jiang, Program Coordinator, http://pesd.stanford.edu/news/chinagasreport/, September 2007.

[44] *Second National Communication of Italy for the United Nation Framework Convention on Climate Change*, G.C. Tosato, M. Contaldi, and D. Gaudioso, prepared by ENEA for the Ministry of the Environment, 1999. Available from the Italian Ministry of the Environment, SIAR, Via Cristoforo Colombo 44, *I-00100 Roma; also www.unfccc.de.*

[45] *The Third National Communication of the Republic of Latvia Under the UNFCCC*, Ministry of Environment Protection and Regional Development, 2001, http://www.varam.gov.lv/vide/publik/Epub.htm.

[46] Loulou, R., et al, *Integrated Analysis of Options for GHG Emission Reduction with MARKAL*, Prepared for the Canadian National Climate Change Implementation Process, June 3, 2000.

[47] *Options for a Low Carbon – Phase 2*, prepared by AEA Technology Plc. for the UK Department of Trade and Industry, 2002, http://www.dti.gov.uk/energy/whitepaper/phase2.pdf.

[48] *Final Report on DTI-DEFRA Scenarios and Sensitivities using the UK MARKAL and MARKAL-Macro Energy System Models*, 2007, http://www.ukerc.ac.uk/ResearchProgrammes/EnergySystemsandModelling/ESM.aspx.

[49] *An Energy Model for a Low Income Rural African Village*, Program on Energy and Sustainable Development, Stanford University, June 2003, http://iis-db.stanford.edu/viewpub.lhtml?pid=20219&cntr=cesp

[50] *Including New and Renewable Technologies in Economy-level Energy Models*, Asia-Pacific Economic Cooperation, September 2002, APEC#202-RE-01.011, ISBN: 0-9726293-0-0.

[51] *Models to Asses the Implications of the Kyoto Protocol on the Energy System and Economy of Colombia*, Cadena Angela, HEC, School of Economy and Social Sciences, University of Geneva, Switzerland, 2000.

[52] USAID providing support to Panama, El Salvador and Honduras under CONCAUSA Plan of Action on Climate Change; and Bolivia to study the economic impact of reforestation for GHG mitigation.

[53] An analysis of the proposed Lieberman-Warner US Climate Security Act conducted on behalf of the Natural Resources Defense Council (NRDC), http://www nrdc.org/media/2008/080513.asp.

- determining the value of regional and international cooperation.[54,55,56]

Annex 2

RELEVANT QUOTES FROM CHANGING CUBA POLICY—IN THE UNITED STATES NATIONAL INTEREST

STAFF TRIP REPORT TO THE COMMITTEE ON FOREIGN RELATIONS UNITED STATES SENATE

ONE HUNDRED ELEVENTH CONGRESS
FIRST SESSION, FEBRUARY 23, 2009

Investments in alternative energy
Energy security has vaulted to the top of both the U.S. and Cuban political agendas amid concerns about supply interruptions and rising prices, sparking a renewed search for viable alternative fuels. For the USG, an important element of an effective energy strategy from both cost and environmental perspectives lies in forging technological and open trading relationships in the Western Hemisphere.

For the GOC, upgrading the island's decaying energy infrastructure and promoting alternative energy sources are national security priorities referred to as the ''energy revolution.'' GOC officials indicated to staff that they are particularly interested in wind power, while other renewable energy projects are receiving support from the United Nations Development Program, which maintains an office in Havana and finances, among other projects, household solar photovoltaics and hydro power for use in rural areas. In addition, the GOC is encouraging foreign investment to develop its oil fields,
with probable hydrocarbon reserves of five billion barrels, according to estimates by the United States Geological Survey—significant for Cuban energy consumption and comparable to the oil reserves of Ecuador.

[54] Northeast States for Coordinated Air Use Management, New England MARKAL Model, ongoing, http://www nescaum.org/projects/ne-markal/index.html.
[55] "Energy Policy and Systems Analysis Project," 8-country (3.5 year) capability building undertaking sponsored by AusAID under Phase III of the ASEAN-Australia Economic Cooperation Programme, http://www.epsapforum.com/.
[56] USAID is support the Athens Forum process for Southeast Europe by promoting capacity building in eight countries of the region to look at the potential for and implications of increased access to natural gas, energy efficiency and accelerated economic growth.

In staff's meetings, GOC officials particularly welcomed U.S. participation in renewable energy development. If restrictions were lifted, U.S. technology could help ensure environmentally-sustainable development of Cuba's energy sector. Most importantly, cooperation in this area would be consistent with long-term U.S. interests in energy security and efficiency in the region.

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