Cuba: A Country Profile on Sustainable Energy Development

CUBAENERGÍA
Centro de Gestión de la Información y Desarrollo de la Energía

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United Nations

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CUBA: A COUNTRY PROFILE ON SUSTAINABLE ENERGY DEVELOPMENT

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FOREWORD

This publication is the product of an international project led by the IAEA to develop and test a suitable approach for the comprehensive assessment of national energy systems within a sustainable development context. This country profile on Cuba is the result of an intensive effort conducted by Cuban experts, primarily from the Centro de Gestión de la Información y Desarrollo de la Energía (CUBAENERGÍA) with the collaboration of experts from energy related institutions in the country, jointly with the IAEA and the United Nations Department of Economic and Social Affairs (UNDESA).

The framework, approach and guidelines set forth in this study comprise one set of effective mechanisms for incorporating the concepts of sustainable development into practical implementation strategies. The assessment is specifically directed at one of the most important sectors affecting economic and social development — energy. It is part of an initiative, officially registered as a Partnership with the United Nations Commission on Sustainable Development, that contributes to Agenda 21, the Johannesburg Plan of Implementation and the goals and objectives of the United Nations Millennium Declaration. The study is, to a certain extent, a continuation and implementation at the national level of two worldwide studies exploring the ties between energy and sustainable development: the World Energy Assessment undertaken by the United Nations Development Programme (UNDP), UNDESA and the World Energy Council; and the Energy Indicators for Sustainable Development undertaken by the IAEA, the International Energy Agency, UNDESA, Eurostat and the European Environment Agency.

No study of a national energy system within the context of sustainable development can be final and definitive. To be useful, the assessment process must be adaptable over time to fit ever-changing conditions, priorities and national sustainable energy development criteria. This publication proposes one such approach for consideration and use in the assessment of energy systems by energy specialists and decision makers at the national level. It is hoped that other countries will use the experience and lessons learned from this study to develop an assessment of their own energy systems and to evaluate their progress towards nationally defined sustainable development goals and objectives. It is also hoped that users of this publication will contribute to refinements in the process by adding their own unique perspectives to what is presented herein.

The work of devising country profiles on sustainable energy development was initiated in 2002 by the IAEA, with the first country profile developed for Brazil and a second for South Africa. Work on this country profile, which represents the third such profile, started in 2003 with the creation of a joint partnership with participating Cuban organizations, UNDESA and the IAEA. Under this partnership, an ad hoc expert committee was created to direct the study and to monitor the progress of implementation. The Chairman of this committee was H.-H. Rogner (IAEA). Other members included D. Pérez (CUBAENERGÍA), K. Abdalla (UNDESA) and I. Vera (IAEA). The committee met with experts from the participating Cuban teams and from other Cuban organizations, including the National Institute of Economic Research, the Ministry of Science, Technology and Environment, the Agency for Nuclear Energy and Advanced Technologies, the Ministry of Basic Industry, the National Electric Union and Cubapetroleo, the Ministry of Economy and Planning, the National Institute of Hydraulic Resources, the National Office of Statistics, the Renewable Energy Technology Studies Centre, the Centre of Management of Prioritized Projects and Programmes, the Ministry of Sugar Industry, the Ministry of Transport, the Transport Research Centre and CUBASOLAR, a non-governmental organization, and also with representatives of international and regional organizations, including the United Nations Industrial Development Organization, the Latin American Energy Organization and the United Nations Economic Commission for Latin America and the Caribbean.

The IAEA and other participating organizations would like to express their gratitude to all of the experts involved in the preparation of this report. The IAEA officer responsible for this publication was I. Vera of the Department of Nuclear Energy.

EDITORIAL NOTE

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1. INTRODUCTION

F. TOTH, D. PÉREZ

Energy has been a central concern to humankind throughout its history. The adequate provision of energy services has become especially important for economic development since the industrial revolution. In recent decades, energy issues have been fundamental components of the conceptual and strategic discussions on sustainable development worldwide. This section introduces the project, Cuba: A Country Profile on Sustainable Energy Development, within its recent political context and starts with a concise overview of the energy related aspects of sustainable development programmes and declarations, followed by a short summary of events and documents explicitly devoted to energy matters (Section 1.1). Recent arguments in the debate on sustainability are presented in Section 1.2 in order to provide the conceptual background for the sustainability assessment of Cuba's energy system. The background, objectives and scope of the project are summarized in Section 1.3. Finally, in Section 1.4, a 'road map' to the report is provided, drawing the attention of different audiences to those sections of interest.

1.1. PRIMER ON SUSTAINABLE ENERGY DEVELOPMENT

1.1.1. Sustainable development (from Stockholm to Johannesburg)

The United Nations Conference on the Human Environment (UNCHE) held in Stockholm in 1972 was the first major United Nations conference entirely devoted to environmental issues. At that time, it was recognized that "the protection and improvement of the human environment is a major issue that affects the well-being of peoples and economic development throughout the world" [1.1]. The outcome of this conference, the Declaration of the UNCHE, known as the Stockholm Declaration, is dominated by the reciprocal concerns about the environmental implications of socioeconomic development and the repercussions of environmental degradation on the development prospects of present and future generations. It concludes with a commitment to respond to the worldwide problem of environmental deterioration, setting out the principles, guidelines and recommendations that should guide citizens, communities, and local and national governments in shaping their actions with "a more prudent care for their environmental consequences" [1.1].

The energy sector is not explicitly mentioned in the Stockholm Declaration, but several items hold messages for energy production and use. Principle 5 of the document declares that “non-renewable resources of the earth must be employed in such a way as to guard against the danger of their future exhaustion and to ensure that benefits from such employment are shared by all mankind”. This presages the (still unresolved) sustainability dilemma of using non-renewable resources and the equity element of sustainable development. Principle 6 addresses the environmental implications: “The discharge of … substances … in such quantities or concentrations as to exceed the capacity of the environment to render them harmless … must be halted in order to ensure that serious or irreversible damage is not inflicted upon ecosystems.” These are early indications of the critical load concept and the precautionary principle that have become key concerns in the environmental dimension of sustainable development.

Much has been accomplished over the past 35 years, but today the world recognizes that protection of the environment has to be linked to social and economic development to secure what has been termed ‘sustainable development’. The report entitled Our Common Future by the World Commission on Environment and Development [1.2] defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. The report further describes sustainable development “as a process of change in which the exploitation of resources, the direction of investment, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potentials to meet human needs and aspirations”.

The Commission’s report describes the challenges involved in meeting these goals and recognizes the importance of energy in sustainable development by devoting one of the six ‘challenges’ sections to this issue. Starting from the premise that development crucially depends on the long term availability of energy “in increasing quantities from sources that are dependable, safe, and environmentally sound” [1.2], the Commission defines four elements of sustainability for energy use: (i) sufficient growth of supplies to meet human needs, (ii) energy efficiency and measures advancing rational energy use, (iii) public health concerns and (iv) environmental protection (at all scales, from the biosphere to the local level). After investigating resource, economic, environmental and safety aspects of fossil fuels, nuclear energy, wood fuels and sources of renewable energy, and contemplating issues of energy efficiency and energy conservation, the Commission concluded that a “safe, environmentally sound, and economically viable energy pathway that will sustain human progress into the distant future is clearly imperative” [1.2] .

In 1992, the results of the United Nations Conference on Environment and Development were the adoption of the global programme entitled Agenda 21 and of the Rio Declaration on Environment and Development. Both identify actions to be taken to achieve the objectives of sustainable development. Neither document mentions energy issues explicitly. Principle 5 of the Rio Declaration asserts that eradicating poverty is an indispensable requirement for sustainable development and that the provision of energy services is a precondition for poverty eradication. Principle 8 calls for eliminating "unsustainable patterns of production and consumption" and has clear implications for energy production and use in developed countries with high energy intensities and in poverty stricken developing countries. Finally, Principle 15 stipulates the wide application of the precautionary approach that is often cited in the context of climate change, where CO_2 emissions from fossil fuels are considered a possible cause of potentially serious or irreversible environmental damage. Fifteen years later, this Principle was given particularly strong support by the Fourth Assessment Report of Working Group I of the Intergovernmental Panel on Climate Change [1.3], in particular:

> "Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 … The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land-use change ...
>
> "Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.
>
> "Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century."

The Millennium Summit in 2000 confirmed that progress towards sustainable development and poverty eradication has top priority for the global community. The Millennium Development Goals, derived from agreements and resolutions of relevant United Nations conferences in the post-Rio Declaration years, are rather ambitious. Some goals are only very remotely related to energy provision and use, e.g. Goals 4, 5 and 6 focus on human health concerns. Other goals have important indirect implications for energy development; access to electricity could foster universal primary education (Goal 2) in many regions of the world. Availability and affordability of commercial energy for cooking would drastically reduce the time and effort needed for fuelwood collection and thus promote gender equality and empowerment of women (Goal 3).

At the macropolicy level, Goal 7 calls for integrating the principles of sustainable development into country policies and mentions, among others, energy intensity and per capita carbon emissions as indicators for measuring progress. Ample opportunities exist to make progress on this goal and many economists suggest that eliminating subsidies that distort the energy sector in many countries could be a good start. Ironically, some energy related measures aimed at poverty alleviation would likely have a negative effect on the sustainability indicators related to energy intensity or emissions in the short term because they would increase energy use per unit of gross domestic product (GDP) (e.g. providing electricity to promote education, increased industrialization and urbanization) and per capita CO_2 emissions (replacing fuelwood with commercial fossil energy in households). However, once these investments in infrastructure and human capital (education, gender equality) start paying off, the energy and carbon intensity indicators should improve as well.

The World Summit on Sustainable Development (WSSD) that convened in Johannesburg in 2002 recognized that, although some progress has been made, major challenges must still be overcome to implement the vision of sustainable development. Paragraph 18 of the Johannesburg Declaration on Sustainable Development lists energy among 'essential' needs and suggests rapidly increasing the "access to such basic requirements as clean water, sanitation, adequate shelter, energy, health care, food security and the protection of biodiversity" [1.4]. Point 9 of the Johannesburg Plan of Implementation of the WSSD makes the direct link between access to reliable and affordable energy services and facilitating the Millennium Development Goals in general and eradicating poverty in particular. Actions to this end range from improving access to modern biomass technologies, efficiency improvements, cleaner use of liquid fossil fuels and advanced energy technologies to developing national energy policies and regulatory frameworks and enhancing international financial and technical assistance.

An important outcome of the WSSD that proved to be an effective implementation mechanism is the "non-negotiated partnership" in sustainable development. These partnerships supplement the commitments agreed to by governments through the intergovernmental process. The project presented in this report is an example of such a partnership.

1.1.2. Energy

Energy is generally recognized as a central issue in sustainable development. Several high level conferences and declarations have confirmed that the provision of adequate energy services at affordable costs, in a secure and environmentally benign manner, and in conformity with social and economic developmental needs is an essential element of sustainable development. Reliable energy services are the preconditions for investments that bring about economic development. They facilitate the learning and study that are crucial for developing human capital. They also promote equity by giving a chance for the less well off to study and thus provide a possible escape from poverty. Therefore, energy is vital for alleviating poverty, improving human welfare and raising living standards. However, the provision of energy services also raises other crucial sustainability concerns. The socially optimal depletion of non-renewable energy resources has been at the centre of the sustainability debate for decades. The environmental impacts of different energy forms and their repercussions on society (ranging from the damage imposed on socioeconomic and material assets to risks to human health) can undermine the sustainability of development.

Many current patterns of energy supply and use are unsustainable. About a third of the world's population relies on the use of non-commercial fuels that have negative impacts on health and the environment. Some 1.6 billion people have no access to electricity. Many regions of the world have no reliable and secure energy supplies, limiting economic development. The challenge is to design and implement sustainable energy development that will support these societies on the long term path of sustainable development.

In 1997, the United Nations General Assembly formally recognized the need for more sustainable energy use and, for the first time, an intergovernmental process was created to elaborate a common approach to the sustainable energy development agenda. The World Energy Assessment (WEA) [1.5] thoroughly analyses the relationships among energy, social issues, health and the environment; addresses issues of energy security, resource availability, end use efficiency, and renewable and advanced supply technologies; pays special attention to the fundamental problem of rural energy in developing countries and to the role of energy in economic prosperity; and depicts three energy scenarios for the 21st century. The study pays special attention to unsustainable features of the current energy system: problems related to equity (accessibility), reliability and affordability, and environmental impacts. The report concludes that sustainable energy policies should meet overall national sustainability goals and should:

— Rely on markets where they function properly and correct market failures by using suitable regulatory mechanisms where possible market failures (monopolies, externalities) and other obstacles (lack of technological knowledge, diverging interests of investors and users) exist;
— Complement measures of energy sector restructuring with regulations that encourage sustainable energy;[1]
— Provide incentives for mobilizing additional investments in sustainable energy and technological innovation in transition and developing countries by fostering reliable commercial legislation and regulation;
— Support technological leadership and capacity building in developing countries;
— Encourage enhanced international cooperation.

The development efforts of the international community and most developing countries have increasingly focused on poverty reduction in recent years. The World Bank has distinguished three main domains of poverty reduction strategies (promoting opportunity, facilitating empowerment, enhancing security) and identified a series of actions for implementation [1.6]. In the 'opportunity' domain, provision of energy services is among the key factors, with cascading effects in other areas — "improving poor people's access to energy or transport can increase their access and returns to education" [1.6]. Similarly, providing electricity is a core element of the strategy to get infrastructure and knowledge to poor areas.

In April 2001, the 9th session of the Commission on Sustainable Development (CSD-9) recognized the need for a movement towards sustainable patterns of production, distribution and use of energy. In establishing the multi-year programme of work of the CSD, the special session underscored that, in line with the objectives of Agenda 21, the CSD-9 should "contribute to a sustainable energy future for all". The IAEA and the International Energy Agency (IEA) presented a preliminary report on Indicators for Sustainable Energy Development as part of the deliberations of CSD-9 [1.7]. In 2005, the IAEA, in cooperation with the United Nations Department of Economic and Social Affairs (UNDESA), the IEA, the Statistical Office of the European Communities (Eurostat) and the European Environment Agency, published a multiagency report on guidelines and methodologies of Energy Indicators for Sustainable Development (EISD) [1.8]. Table 1.1 presents the

[1] The WEA defines sustainable energy as "energy produced and used in ways that support human development over the long term, in all its social, economic, and environmental dimensions" [1.5].

list of indicators included in that report. To the extent possible, these indicators are used in this study to characterize Cuba's past and present energy development and to assess alternative future scenarios and strategies.

Follow-up on energy for sustainable development at the international level took place during the 14th session of the United Nations Commission on Sustainable Development held in 2006 and continued during the 15th session of the Commission in 2007. The thematic cluster for the 2006/2007 cycle — energy for sustainable development, industrial development, air pollution/atmosphere and climate change — are deemed to be "unparalleled in their importance for achieving sustainable development goals" [1.9]. At its 14th session, the Commission confirmed that access to energy was critical to achieving sustainable development goals and the Millennium Development Goals, in particular the target on poverty reduction. Access to electricity at central points in rural and remote communities (schools, clinics and hospitals) is also important for achieving these goals. The Commission also underlined that, in addition to increasing energy efficiency, "a judicious mix of energy from all sources will be needed in order to meet the rising global energy demand" [1.9]. These issues were further elaborated at the 15th session of the Commission in 2007.

The project presented in this report draws heavily on the concepts, procedures, analytical frameworks and modelling tools of the above activities, especially those of the WEA and the Indicators for Sustainable Energy Development programme of the IAEA. In fact, it represents the first in-depth analysis of Cuba's energy system within a sustainable development framework.

1.2. THE ONGOING DEBATE: SUSTAINABILITY VERSUS DEVELOPMENT OR DEVELOPMENT VERSUS SUSTAINABILITY

1.2.1. Conceptual foundations and political debates

Numerous debates over the past 20 years have been desperately trying to make out the practical implications of the sustainability concept. Dozens of alternative definitions, hundreds of sustainability indicators, and numerous criteria and implementation strategies have been proposed. The reason why it is difficult to define precise criteria for sustainability is that doing so involves value judgements. What would one consider sustainable? For whom? By whom? In what context?

Considering the widely diverging views about sustainability even within individual economic sectors (What is sustainable agriculture or sustainable

TABLE 1.1. EISD [8]

Social				
Theme	Subtheme	Energy indicator		Components
Equity	Accessibility	SOC1	Share of households (or population) without electricity or commercial energy, or heavily dependent on non-commercial energy	Households (or population) without electricity or commercial energy, or heavily dependent on non-commercial energy Total number of households or population
	Affordability	SOC2	Share of household income spent on fuel and electricity	Household income spent on fuel and electricity Household income (total and poorest 20% of population)
	Disparities	SOC3	Household energy use for each income group and corresponding fuel mix	Energy use per household for each income group (quintiles) Household income for each income group (quintiles) Corresponding fuel mix for each income group (quintiles)
Health	Safety	SOC4	Accident fatalities per energy produced by fuel chain	Annual fatalities by fuel chain Annual energy produced
Economic				
Theme	Subtheme	Energy indicator		Components
Use and production patterns	Overall use	ECO1	Energy use per capita	Energy use (total primary energy supply, total final consumption and electricity use) Total population
	Overall productivity	ECO2	Energy use per unit of GDP	Energy use (total primary energy supply, total final consumption and electricity use) GDP

TABLE 1.1. EISD [8] (cont.)

Economic				
Theme	Subtheme	Energy indicator		Components
	Supply efficiency	ECO3	Efficiency of energy conversion and distribution	Losses in transformation systems, including losses in electricity generation, transmission and distribution
	Production	ECO4	Reserves to production ratio	Proven recoverable reserves Total energy production
		ECO5	Resources to production ratio	Total estimated resources Total energy production
	End use	ECO6	Industrial energy intensities	Energy use in industrial sector and by manufacturing branch Corresponding value added
		ECO7	Agricultural energy intensities	Energy use in agricultural sector Corresponding value added
		ECO8	Service/commercial energy intensities	Energy use in service/ commercial sector Corresponding value added
		ECO9	Household energy intensities	Energy use in households and by key end use Number of households, floor area, persons per household, appliance ownership
		ECO10	Transport energy intensities	Energy use in passenger travel and freight sectors and by mode Passenger·km travel and t·km freight and by mode

TABLE 1.1. EISD [8] (cont.)

Economic				
Theme	Subtheme	Energy indicator		Components
	Diversification (fuel mix)	ECO11	Fuel shares in energy and electricity	Primary energy supply and final consumption, electricity generation and generating capacity by fuel type Total primary energy supply, total final consumption, total electricity generation and total generating capacity
		ECO12	Non-carbon energy share in energy and electricity	Primary supply, electricity generation and generating capacity by non-carbon energy Total primary energy supply, total electricity generation and total generating capacity
		ECO13	Renewable energy share in energy and electricity	Primary energy supply, final consumption and electricity generation and generating capacity by renewable energy Total primary energy supply, total final consumption, total electricity generation and total generating capacity
	Prices	ECO14	End use energy prices by fuel and by sector	Energy prices (with and without tax/subsidy)
Security	Imports	ECO15	Net energy import dependency	Energy imports Total primary energy supply
	Strategic fuel stocks	ECO16	Stocks of critical fuels per corresponding fuel consumption	Stocks of critical fuel (e.g. oil, gas) Critical fuel consumption

TABLE 1.1. EISD [8] (cont.)

Environmental				
Theme	Subtheme	Energy indicator		Components
Atmosphere	Climate change	ENV1	Greenhouse gas (GHG) emissions from energy production and use per capita and per unit of GDP	GHG emissions from energy production and use Population and GDP
	Air quality	ENV2	Ambient concentrations of air pollutants in urban areas	Concentrations of pollutants in air
		ENV3	Air pollutant emissions from energy systems	Air pollutant emissions
Water	Water quality	ENV4	Contaminant discharges in liquid effluents from energy systems, including oil discharges	Contaminant discharges in liquid effluents
Land	Soil quality	ENV5	Soil area where acidification exceeds critical load	Affected soil area Critical load
	Forest	ENV6	Rate of deforestation attributed to energy use	Forest area at two different times Biomass utilization
	Solid waste generation and management	ENV7	Ratio of solid waste generation to units of energy produced	Amount of solid waste Energy produced
		ENV8	Ratio of solid waste properly disposed of to total generated solid waste	Amount of solid waste properly disposed of Total amount of solid waste
		ENV9	Ratio of solid radioactive waste to units of energy produced	Amount of radioactive waste (cumulative for a selected period of time) Energy produced
		ENV10	Ratio of solid radioactive waste awaiting disposal to total generated solid radioactive waste	Amount of radioactive waste awaiting disposal Total volume of radioactive waste

forestry?), it will take a long time and much debate before consensus may emerge about its more specific definition and practical implications. An important part of the problem is that the term is heavily loaded politically. It is widely used and often misused. This study is one attempt to discuss sustainability issues in a national context, to apply the EISD to describe the current situation of Cuba and to explore future development options for the national energy system.

As nations have been exploring strategies to reach sustainable development, it has become evident that the emphasis on what is needed depends on the country's level of development. Developing countries are more concerned with 'development', and in particular with economic and social development, since major priorities include improvements in income and standards of living while achieving full satisfaction of basic needs and high levels of employment. Developed countries, which have reached industrialization and high living standards, emphasize 'sustainability'; consequently their policies are formulated to stress the need to protect the environment. In a classic argument, developing countries see environmental restrictions as imposing constraints on their development that were not imposed on the developed countries as they went through the equivalent stages of the development process. Developed countries, in contrast, assert that the global character of environmental protection requires commitments from all countries and in particular those undergoing intense industrialization processes.

Recent debates and practical programmes have focused increasingly on the complementary characteristics of development and sustainability. Many unsustainable forms of resource use (fuelwood, water) and many practices harmful to human health and the environment (low quality fuel causing indoor air pollution and smog) are rooted in poverty, hence development would help alleviate poverty and simultaneously protect resources and nature. Further up the affluence ladder, there is ample evidence that societies pursuing environmentally benign development paths improve their overall welfare in ways that are superior to those following behind them on the environmental degradation–rehabilitation path. This is largely a function of affluence — having choices beyond survival and more income to spend on a higher quality of life.

Sustainability is an intriguing concept for scholars and politicians alike. Serious efforts have been made to quantify and/or model the economic/non-economic balances that are struck in the process of charting a sustainable development course, taking into account national and regional differences. There is a general understanding that the term involves normative aspects and therefore defies 'objective' scientific treatment. The reason is that the sustainability notion goes beyond biophysical limits and the efficient allocation of scarce environmental resources. It involves choices about social, value and

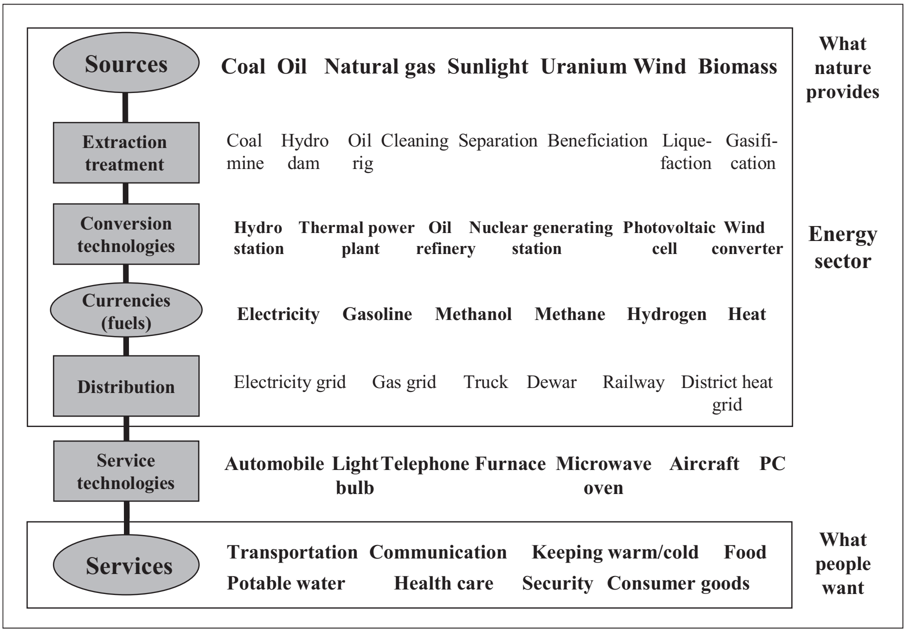

FIG. 1.1. Architecture of the energy system [1.11].

technological options made under circumstances characterized by severe uncertainties.

1.2.2. Prospects for sustainable development in the energy system

Section 1.1.2 presents several reasons why energy is at the heart of sustainable development. One additional reason is the pervasive nature of energy in societies; it is required for all production, use, service and investment activities, albeit in different forms and quantities. This is illustrated in Fig. 1.1 (see also Refs [1.5, 1.10]). Depending on their geographical (climate, location), social (values, customs, preferences) and economic (affluence, access to technologies) situation, people choose a set of goods and services to satisfy their needs, ranging from food to comfortable living conditions, from mobility to cultural needs, from survival to convenience or luxury. Energy services include cooking, lighting, air conditioning, communication or transportation while the corresponding technologies providing these services are stoves, light bulbs, air conditioning devices, entertainment devices, vehicles and other equipment. The manufacture of consumer goods and the provision of services, in turn, require another large array of tools and equipment (such as metal smelters, automobile and video assembly plants, medical instruments manufacturers), and their operation also requires energy. The hardwares used by final consumers and producers are termed service technologies in energy systems analysis. Such technologies perform the local conversion of final energy into useful energy required to provide the services (light, heat, mobility). In modern societies, a complex web of equipment and activities delivers final energy to the users, as depicted in Fig. 1.1.

The process starts at the locations (coal mines, hydropower dams, oil wells, windy areas, forests) of the energy sources (coal, oil, hydropower, wind, fuelwood). Depending on the nature of the source, some extraction and treatment operations are required to obtain what is called primary energy. Conversion sites (hydropower stations, thermal and nuclear power plants, oil refineries, coal gasification plants) apply a range of conversion technologies (turbines, cracking, chemical reactors) to turn energy sources (coal, oil, natural gas, uranium, sunlight, wind, biomass) incorporating primary energy into secondary energy.

Secondary energy takes different forms known as currencies (electricity, gasoline, hydrogen, heat) and is fed into distribution networks (electricity and gas grids, vehicles, heat grid pipes) that transmit it (and, in some cases, store it) from the conversion sites to the user. The final energy received by the user drives the service technologies in the process of local conversion into useful energy.

What is important to note is the difference between the 'energy sector' and the 'energy system'. Traditional energy sector industry operations focus on the delivery of fuels to the marketplace. The performance of end use technologies (efficiency, emissions, life cycle costs) is not part of their investment decisions. Energy system analysis includes all the technologies used for the production, conversion and distribution of fuels as well as the equipment and the processes of converting final energy into energy services. Energy related concerns (costs, efficiency, form, dependability, convenience) constitute only a subset of the many criteria considered by users and operators of the local conversion technologies. That is why highly efficient technologies often fail on the market, because consumers ignore them for economic (large investment), technical (frequency of maintenance needs), aesthetic (unattractive appearance), comfort (noise level), convenience (ease of operation) or religious (rules or taboos) reasons, or simply as a matter of taste.

Nevertheless, the framework provided in Fig. 1.1 is useful for illustrating the scope for sustainable energy development within the energy system and in energy–economy–society interactions. Steps in the long process from primary to useful energy are plagued by conversion and transmission losses, as measured by different efficiency indicators of the energy system. The range and the relative weight of energy sources are almost fixed in the short term but can be changed drastically in just a few decades. Consumer tastes and preferences may alter spontaneously or can be influenced by economic incentives (relative prices) and moral persuasion (ethical arguments), including environmental concerns.

Recent estimates of resources and reserves of non-renewable energy sources are supported by broad consensus (see Ref. [1.12]). Depending on one's stance with respect to their substitution by artificial capital (see Section 1.2.1), they can be extracted at faster or slower rates. Extraction technologies of non-renewable energy sources might become more efficient and this is likely to increase the total amount of primary energy gained from these sources. There is a larger scope for efficiency improvements in primary conversion, although different conversion technologies are in different phases of their technological life cycles and thus have different potentials for improvement. Conventional power plants and oil refineries rely on mature technologies with modest room for additional improvements in conversion efficiency. Solar heat and photovoltaic technologies, in contrast, are in an earlier phase and are rather far from the theoretical maximum of their conversion efficiencies. Further down the conversion pathway, there is more or less possibility of loss reduction (gas leakage, power transmission losses) depending on the energy form, distance, transmission technology and other factors. Finally, it is generally recognized that a large potential for reductions in energy use exists in efficiency improvements in local conversion technologies (from final to useful energy), in lifestyle changes (energy intensity of the goods and services consumed) and, partly as a result of the latter, in economic structural changes (energy intensity of producing the goods and services).

The message of the energy systems framework shown in Fig. 1.1 for sustainable energy development is twofold. First, the scope for efficiency improvements and corresponding resource savings and reduced environmental impacts increases as one proceeds from primary to secondary, final, and useful energy. Second, the relative weight of energy and efficiency concerns in the decisions declines along the same path: technical efficiency and economic costs carry significant weight in decisions on primary conversion and secondary transmission technologies, but the choice of final conversion technologies (typically integrated into production equipment and consumer goods) depends on numerous factors and thus is more difficult to influence on energy grounds.

1.2.3. The state of the sustainable development debate in Cuba

With the revolutionary Government coming to power in 1959, Cuba embarked on a new course with important social and economic goals. The

1970s and 1980s were characterized by strong economic and social development, although based on inefficient technologies (far from state of the art) that implied high energy use.

Cuba experienced a major economic crisis during the 1990s as a result of the termination of its favourable trade relationships with the countries of the Council for Mutual Economic Assistance (CMEA). As a result of this crisis, Cuba was forced to slash its energy imports, which affected the country's capability to satisfy its energy requirements. The search for energy solutions became the primary activity of national and territorial (State) institutions, and of many specialists, technicians and workers. The Government responded to the situation by elaborating and implementing the Development Programme of National Energy Sources (DPNES) in 1993 [1.13], which has been an important driving force for energy development and has led to improvements in development patterns and in the behaviour of society with respect to energy use.

The important reforms implemented in the wake of this crisis have resulted in a more sustainable path of economic development and a more reliable and self-sufficient energy system. The economic recovery that started in 1994 has been maintained, in large part owing to energy policies that have proved very successful. These policies have resulted in a major increase in the production of domestic crude oil and associated gas, considerable reduction in energy demand, reductions in electricity losses and improvements in some energy infrastructure. More rational energy use, more accurate estimates of the country's real expenditures on energy supply, more independent regulation of the energy sector and an increased emphasis on planning activities are ongoing tasks that Cuba is implementing to continue moving towards a more sustainable energy future.

In addition, Cuba has developed an important plan for sustainable development. In 1997, the National Environmental Strategy was approved and its implementation started in the main areas of the economy and services and in all the States and territories. The strategy establishes the principles that sustained the national environmental politics, characterizes the main environmental problems of the country and proposes the roads and instruments for its prevention, solution or mitigation to improving the protection of the environment and the rational use of the natural resources in linking with the economic and social development of the country.

In the same year, the National Assembly approved Law 81 on 'Environment' that reaffirmed national ownership of the natural resources and the environment [1.14]. In this law, the principles on which to base the management of the environment were formulated, and the institutional framework was defined, specifying the obligations, powers and functions of people and organizations in the conservation and rational use of the environment. In addition, the environmental policy and management instruments were regulated, the specific spheres of environmental conservation were established, and the actions pertinent to each case were identified.

Law 81 defines sustainable development as a “process of equitable and sustained raising of the quality of people’s life, by means of which is offered economic growth and social improvement, in harmony with the protection of the environment, so that the necessities of the current generations are satisfied, without putting at risk the satisfaction of the necessities of the future generations” [1.14].

In fulfilment of this law, legal bodies have been created and approved regarding biological security, a national system of protected areas, contraventions in matters concerning the environment, and management of the coastal zone and territorial waters. Also, the process of granting environmental licences was established for new projects or works or activities, the State Environmental Inspection organization was created and other legislation was issued that contributes to sustainable development, such as the laws governing mining, forestry and foreign investment.

Investments committed for environmental conservation constitute an essential element in the management of the environment in the country, oriented towards the mitigation and solution of the main environmental problems, related as much to the soils and forests as to the reduction of the pollution load and the construction of wastewater treatment systems and plants and water pipelines. These investments rose to 220 million pesos in 2004, equal to 7% of total investments in the country [1.15].

With the creation of the National Environmental Fund, which has as its purpose the total or partial financing of projects or activities aimed at environmental conservation and the rational use of the environment, a significant number of projects have been carried out since 2000. The Fund constitutes a new mechanism for the mobilization of resources destined for the environment, complementing but not substituting for the responsibilities of the Ministries that direct productive activities or services, with the environmental problems that they generate.

Other important aspects that are related to sustainable development are poverty eradication, health, culture, education, sports, equal rights for women, etc. Notable progress has been made in these areas in Cuba in the last decade.

Also, programmes and projects integral to development and urbanization have been carried out in mountainous, rural, local and territorial areas, contributing to sustainable development.

In different international forums, Cuba has contributed with initiatives and proposals for actions that contribute to sustainable development. The country's collaboration in the training of skilled personnel in different areas stands out, as well as assistance in the areas of health, education and sports to other countries.

1.3. RATIONALE AND OBJECTIVES OF THE STUDY

1.3.1. Background and justification

Sustainable development requires integrated economic development based on social responsibility and respect for the environment while keeping in mind the impact on future generations. Energy supply has a significant bearing on all the dimensions of sustainability: social, economic, environmental and institutional. Proper management of the energy sector in developing countries is indispensable for reducing poverty and advancing sustainability. There is a need among developing countries for a variety of tools and integrated evaluation methods that permit the formulation of comprehensive sustainable energy development strategies, as well as the monitoring of their successful implementation. Ideally, countries should be able to construct a profile of their own progress towards a sustainable energy future. A country profile for energy constitutes a vital road map for establishing priorities and optimizing allocation of limited resources.

Cuba is a good candidate for demonstrating the feasibility and merits of constructing a country profile on sustainable energy development in a small island developing State (SIDS). Cuba, the largest of the SIDS, is characterized by relatively low average per capita income and per capita energy use. Cuba has a very limited mix of energy resource endowments. In the past, most of its energy requirements were satisfied by imports. However, after a major economic crisis in the 1990s, Cuba implemented a number of energy policies that have successfully increased domestic production of fossil fuels, allowing a considerable reduction in the share of imports. This study aims to provide a strong basis for decision makers in formulating energy policies consistent with sustainable development goals in the area of energy as part of the overall implementation of Agenda 21 and the Plan of Implementation of the WSSD at the national level in Cuba. Utilizing sustainable energy indicators and energy modelling techniques, current energy trends, options and goals are assessed and analysed with a view towards implementing policies to promote sustainable development in Cuba.

A major priority for Cuba is to satisfy the growing energy demand fuelled by population and economic growth using domestic resources, while continuing to address environmental priorities and other issues, such as energy affordability, accessibility, security and efficiency. The energy policies now being implemented and the formulation of future policies should be monitored and evaluated in light of both sustainable development needs and their effectiveness in ensuring efficient expansion of energy services.

This study aims to fill a need for more comprehensive energy policies at the national level for the advancement of sustainable development goals and in accordance with the outcome of the WSSD. The project is, to a large extent, a continuation and implementation at the national level of two CSD-9 undertakings: the WEA undertaken by the United Nations Development Programme (UNDP), UNDESA and the World Energy Council, and the Indicators for Sustainable Energy Development programme undertaken by the IAEA in cooperation with the IEA, UNDESA, Eurostat and the European Environment Agency.

1.3.2. Objectives

The primary objective of this study is to develop a country profile for Cuba in relation to sustainable energy development. It is one of the first attempts to produce a comprehensive, systematic and forward looking approach for the formulation of such a profile. The methodology can be replicated in other countries seeking to define a national plan for a sustainable energy future. A team of national and international experts has performed an overall assessment of the energy sector in Cuba using the proposed approach. This approach allows the assessment of different strategies Cuban policy makers might consider in formulating energy policies according to their priorities in pursuing different dimensions of sustainable development — social, economic, environmental and institutional. The final goal is to provide an assessment to foster progress towards a sustainable energy future.

The study demonstrates the practical application of this approach. It comprises quantitative and qualitative assessments of energy demand, supply and security; domestic resources; technology and trade; and scenarios of energy sector evolution under different policy assumptions to permit national decision makers to chart and monitor a course of sustainable energy development.

The report summarizes the analyses and findings and explores policy options useful to decision makers and energy and environmental specialists. The analysis provides a comprehensive assessment of the overall energy situation and the status of the major energy priority areas.

1.4. IMPLEMENTATION AND SCOPE

1.4.1. Conduct of the study

The project was completed over three years (2003–2006). Most of the research activities and analyses were conducted by experts from the Centre for Information Management and Energy Development (CUBAENERGÍA) in cooperation with other relevant Cuban organizations. Experts from CUBAENERGÍA were in charge of processing the statistics, implementing simulations for the energy system and providing the technical support necessary to build the country profile.

An ad hoc expert committee coordinated the overall effort. The committee consisted of members from Cuban energy, environmental and economic organizations and from international organizations. The Cuban experts were drawn from CUBAENERGÍA, the Ministry of Economy and Planning (MEP), the Ministry of Science, Technology and Environment (CITMA), the Agency for Nuclear Energy and Advanced Technologies, the Ministry of Basic Industry (MINBAS), the National Electric Union (UNE), Cubapetroleo S.A. (CUPET), the National Statistics Office, the Ministry of Transportation (MITRANS), the Ministry of Foreign Investment and Economic Cooperation, the National Institute of Hydraulic Resources, the Ministry of Sugar Industry (MINAZ), the National Institute of Economic Research, the Centre of Management of Prioritized Projects and Programmes and the Transport Research Institute (CETRA). The international experts were from the IAEA, UNDESA, UNDP-Cuba, the Organización Latinoamericana de Energía and the United Nations Economic Commission for Latin America and the Caribbean. The expert committee provided guidance for the final analysis and participated in the formulation of the approach followed in this study. The assumptions underlying this study as well as the recommendations, however, are the responsibility of the participating Cuban institutions and experts.

1.4.2. Road map

The study considers available data from the past 24 years in formulating the corresponding EISD for Cuba. Although data availability was a problem in some of the energy priority areas, valuable assessments of historic trends were performed. The effort includes an extensive energy supply and demand modelling investigation conducted with two IAEA simulation tools — MESSAGE (model for energy supply strategy alternatives and their general environmental impacts) and MAED (model for analysis of energy demand). Alternative paths have been developed for the period ending 2025.

To allow a better understanding of sustainable energy development, a complete review of the energy supply and demand situation in Cuba is presented. This approach not only provides a detailed overview of the energy system, but also allows quantification of the share of energy supply that may be considered socially and environmentally friendly. Such analysis reveals that, independent of the significant contribution from renewable energy sources, the country still relies on large amounts of fossil energy. Energy programmes implemented in the past several years have already demonstrated positive results in the increase in domestic fossil fuel exploration and production. A main objective is to try to satisfy energy requirements with an optimal balance of domestic renewable and fossil fuel resources, keeping energy imports at a minimum level. Increasing energy efficiency and reducing environmental impacts are also major priorities for Cuban policy makers.

The principal outcome of this extensive investigation of the energy sector is a better understanding of the energy system and of the sustainability features of different energy strategies, their benefits and shortcomings, and trade-offs, including the identification of ways to increase the share of renewable sources of energy in an economically feasible way.

This report presents a comprehensive appraisal of sustainable energy issues in Cuba's past, present and future. The assessment starts with a retrospective analysis of the Cuban energy sector and its implications for sustainable development. Past energy use and time series indicators as well as the social, economic, environmental and institutional dimensions of sustainable development are reviewed and priority issues for securing a sustainable energy future are identified in Section 2. The starting point for developing a national sustainable energy strategy is to take stock of the national energy resource endowment (Section 3). Cuba's conventional and unconventional energy reserves and resources are assessed, including oil, hydropower, biomass, agricultural residues and other renewable energy resources, as well as traditional versus modern applications of bioenergy and the potential use of fuelwood, charcoal and agricultural residues. Cuba has developed or adapted innovative and appropriate technologies that support sustainable energy strategies. These technologies are analysed in detail in Section 4.

Cuba's choices for promoting economic development have shaped its energy use in notable ways. This is demonstrated by the analysis of past energy use and its driving forces, such as changes in energy intensities, demographic factors and economic activity (Section 5). It is necessary to draw lessons from the past concerning the environmental impacts of energy production and use and apply them to guide strategies for the future. Environmental impacts are reviewed in Section 6. Particular attention is given to practices of the past related to unsustainable biomass use and deforestation. Emissions from energy systems are discussed in detail. Strategies are formulated to reduce negative environmental effects produced by energy systems.

Social and energy security concerns place additional demands on sustainable energy development. First, energy plays an important role in poverty eradication by allowing improvements in education, employment, health and sanitation (Section 7). Therefore, current problems of affordability, accessibility and disparity in energy use need to be alleviated through the adoption of appropriate strategies. Second, energy security risks in Cuba with respect to changes in the national and international markets for primary energy sources (strategic and economic security) and vulnerability to accidents, disruptions and attacks (physical security) need to be addressed (Section 8). Currently, security risks in Cuba are related to energy resources (limited domestic energy resources), economic factors (the lack of sufficient financial resources) and strategic factors (limited trade resulting from the economic blockade).

The value of the above 'lessons learned' from the past and the success of strategies formulated for the future crucially depend on the policies and measures available to decision makers and the effectiveness of their implementation. Therefore, major energy policies adopted by Cuba to increase domestic natural gas and oil use, improve energy efficiency and increase the use of renewable energy sources are reviewed in this report. Policy options are identified in major priority areas for Cuba, including fuel conservation and substitution, energy efficiency, financing, electricity conservation, renewables use, technology transfer, and international trade and cooperation (Section 9).

The main objective of the project is to assess possible paths towards sustainable energy development for Cuba. Drawing on the lessons learned from the evaluation of the relationships among socioeconomic development, energy use and environmental implications, a scenario analysis was conducted (Section 10). Building on the material presented in Sections 2–9, the future is explored by developing and using scenarios in two main steps and by producing two types of output. In the first step, an overall socioeconomic scenario is constructed on the basis of recent dynamics, existing assets (installed physical capital, available human capital), and generally agreed objectives and directions for medium term (15–20 years) strategic development. In the second step, energy modelling, the energy demand associated with the macrolevel scenario is calculated using MAED and other tools. Several options to satisfy the energy requirements are then explored using MESSAGE, resulting in several variants of energy strategies under the same socioeconomic scenario.

The main results of the study are summarized in Section 11. Special emphasis is given to the policy insights concerning national efforts to foster progress towards sustainable energy development.

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2. CURRENT ENERGY SITUATION

D. PÉREZ, I. BERDELLANS

The current energy situation in Cuba is that of a SIDS in the midst of a recovery from the dissolution of favourable trade agreements with the former Soviet Union for the import of crude oil and petroleum products. As with other SIDS, Cuba lacks sufficient proven indigenous fossil energy resources to support sustainable long term economic and social development. This situation, however, might change as a result of ongoing programmes in oil exploration in the Gulf of Mexico. In addition, the accelerated development of renewable sources is expected to make domestic energy supplies more accessible. Currently, the Cuban energy situation is characterized by a deficit in access to affordable energy services (especially in rural areas), the lack of finance for energy imports and energy infrastructure improvements and expansion as well as suboptimal institutional coordination. This section reviews the status of Cuba's energy system and how it developed. It is divided into four major sections: Section 2.1 outlines the organizational structure of the energy system; Section 2.2 presents the national energy balance; Section 2.3 assesses the country's energy status according to the economic, social, environmental and institutional dimensions of sustainable development; and Section 2.4 summarizes the major issues facing that system.

2.1. ORGANIZATIONAL STRUCTURE OF THE ENERGY SECTOR

The organizational structure of the energy sector in Cuba is different from that of other countries in that it lacks a Ministry of Energy. The MEP governs energy and economic policy and presides over the Advisory Council in Energy Matters, which is the body in charge of controlling the DPNES, promoting energy efficiency and renewable energy sources, and proposing laws and legislation to improve energy efficiency in the national economy.

The Advisory Council in Energy Matters includes representatives of the following bodies:

— MINBAS, which controls UNE and CUPET, the companies responsible for electricity and fossil fuel activities, respectively.

— MINAZ (which oversees the sugar mills that cogenerate electricity) enterprises providing energy services to this industry, sugar refineries, biogas plants and research centres.
— The National Institute of Hydraulic Resources, which deals with small, mini- and micro-hydropower plants and hydraulic development.
— The Ministry of Information Sciences and Communications, which includes the Electronic Components Complex comprising facilities that produce solar photovoltaic panels. The Ministry also includes several enterprises that commercialize renewable energy and energy efficiency technology. It also operates the Turiguanó wind farm.
— The Ministry of Steel and Mechanical Industry, which produces and commercializes hydraulic turbines and solar heaters.
— The Ministry of Agriculture, which manages forests, windmills for pumping water and biogas plants.
— MITRANS, which is in charge of transport development policy, although each ministry has its own section devoted to transport issues.
— CITMA and its institutions such as the Agency for Nuclear Energy and Advanced Technologies or CUBAENERGÍA, which provide scientific and technical support for the country's energy development. CITMA also coordinates the Renewable Energy Front, a specialized State instrument that coordinates and proposes policies on renewable energy and its use to the Government.
— Universities and research centres belonging to the Ministry of Higher Education, which support energy development in the country through research, education and staff training.
— The Ministry of Construction.
— The Ministry of the Interior.
— The Ministry of Armed Forces.
— The Ministry of Foreign Investment and Economic Cooperation.

The MEP is also in charge of State energy inspections throughout the country.

The energy sector also includes the joint ventures with Energas and GENPOWER, independent power producers that contribute to electricity generation on the Isla de la Juventud, and the participation of bodies within the Government, including the Industry and Energy Commission within the Parliament (or National Assembly of People's Power), representing the legislative power, and the Executive Power (or Council of State), comprising a number of ministries, including several energy related structures within the MEP.

An important element of the country's energy sector is the skilled human resources and the scientific and technological capability that has been created in the energy field, including training of staff able to support a nuclear power programme. The organization of research and development activities in national research programmes, such as the programme on sustainable energy development, as well as territorial or State programmes and those concerning the different branches of industry also contribute to such capacity building.

National seminars on energy aimed at supporting decision makers have been held every year since 2001, with the participation of many decision makers and energy specialists. The broader debate on current and future energy trends and their impacts has resulted in the integration of institutions and specialists in energy activities within the country.

2.2. ENERGY BALANCE: RETROSPECTIVE AND GENERAL OVERVIEW

Between 1959 and 1989, Cuba experienced economic development with increasing social equity as a result of favourable trade relations with the countries of the CMEA. In the early 1990s, with the dissolution of the CMEA, Cuba was faced with an economic crisis that affected the whole society. It was necessary to carry out reforms and economic adjustments in an effort to maintain basic services for the population, such as education, health, culture, sports and social security.[2]

During the crisis, industrial and agricultural production decreased abruptly and drastically, as did per capita energy use. Economic recovery began in 1994. Significant elements of this recovery include increased production of domestic crude oil and associated gas, improved energy efficiency as a result of dedicated programmes, modernization of thermoelectric power plants, a decrease in total electricity losses during transmission and distribution, investments in infrastructure for fuel transport, increased fuel diversification resulting from fuel substitution programmes, and a reduction in the dependency on energy imports. There has been growth in the transport sector and especially in the commercial and services sector, for which growth in tourism is the driving force. Recovery in the industrial sector has been slow. The sugar industry, as of 2006, has still not fully recovered.

[2] See Section 5 for details on Cuba's economic development.

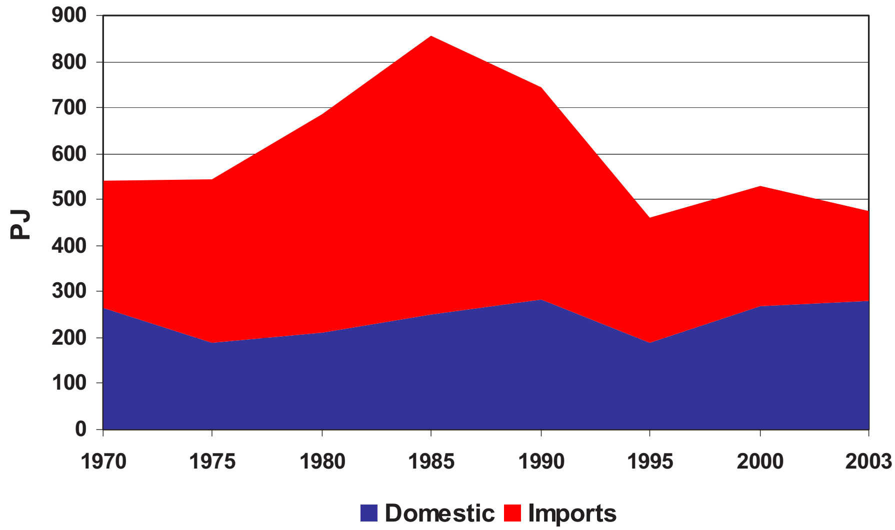

FIG. 2.1. TPES. Source: Authors' elaboration from Refs [2.1–2.9].

2.2.1. Primary energy supply

Growing in line with the country's social and economic development, Cuba's total primary energy supply (TPES) increased 61% from 1970 to 1989 at an annual rate of about 2.5%. During the 1990s, with the country in a critical economic situation, TPES underwent important changes, falling 38% between 1990 and 1995. By 2000, TPES had increased 15% from the lowest level experienced in 1995. However, after 2001, TPES decreased and in 2003 was still 44% lower than the peak value observed in 1985 (Table 2.1 and Fig. 2.1).

The rapid decrease of the TPES during the economic collapse period resulted mainly from a drastic drop in energy imports due to the lack of hard currency[3] necessary to buy fuels on the world market at non-preferential prices. Oil imports decreased dramatically even after 1995 and by 2003 were 67% lower than the 1985 values. Coal imports dropped by 50% between 1990 and 1995. Decreases in domestic fuels were also observed in the same period for sugarcane biomass (55%), gas (49%) and hydropower (18%). The decrease in biomass resulted from the closure of sugarcane production facilities and a reduction in harvesting areas during the crisis, which limited the availability of

[3] Hard currency refers to currency that is commonly accepted for major commodities trading (e.g. US dollars).

TABLE 2.1. TPES (TJ)
(Authors' elaboration from Refs [2.1–2.9])

Domestic	1970	1975	1980	1985	1990	1995	2000	2002	2003
Gas	59	639	658	255	1 245	639	21 217	21 609	24 318
Oil[a]	7 127	10 142	12 257	38 867	30 055	65 890	120 746	162 525	164 850
Hydropower	408	281	437	244	409	335	401	479	575
Sugarcane biomass	246 661	160 959	182 621	195 797	238 350	106 231	115 100	93 275	77 599
Fuelwood	11 933	16 171	15 291	13 780	14 545	15 059	12 681	11 660	10 824
Total domestic	**266 189**	**188 193**	**211 264**	**248 943**	**284 604**	**188 154**	**270 146**	**289 549**	**278 166**
					Imports				
Coal[b]	2 834	2 757	3 159	4 204	5 125	2 582	727	878	938
Oil[c]	271 020	351 866	470 817	604 700	453 859	270 737	260 578	194 836	197 135
Total imports	**273 854**	**354 623**	**473 976**	**608 903**	**458 984**	**273 320**	**261 305**	**195 713**	**198 073**
					Total: Domestic + imports				
Coal	2 834	2 757	3 159	4 204	5 125	2 582	727	878	938
Gas	59	639	658	255	1245	639	21 217	21 609	24 318
Oil	278 147	362 009	483 074	643 567	483 915	336 628	381 324	35 361	361 985
Hydropower	408	281	437	244	409	335	401	479	575
Sugarcane biomass	246 661	160 959	182 621	195 797	238 350	106 231	115 100	93 275	77 599
Fuelwood	11 933	16 171	15 291	13 780	14 545	15 059	12 681	11 660	10 824
Total dom. + imp.	**540 042**	**542 816**	**685 240**	**857 846**	**743 588**	**461 474**	**531 450**	**485 262**	**476 238**

TABLE 2.1. TPES (TJ) (cont.)
(Authors' elaboration from Refs [2.1–2.9])

	Share (%)								
Coal	0.5	0.5	0.5	0.5	0.7	0.6	0.1	0.2	0.2
Gas	0.0	0.1	0.1	0.0	0.2	0.1	4.0	4.5	5.1
Oil	51.5	66.7	70.5	75.0	65.1	72.9	71.8	73.6	76.0
Hydropower	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1
Sugarcane biomass	45.7	29.7	26.7	22.8	32.1	23.0	21.7	19.2	16.3
Fuelwood	2.2	3.0	2.2	1.6	2.0	3.3	2.4	2.4	2.3

[a] Refers to crude oil production.
[b] Imported coal is for non-energy use (metallurgical industry) and includes small quantities of coke from coal.
[c] Includes crude oil and petroleum products.

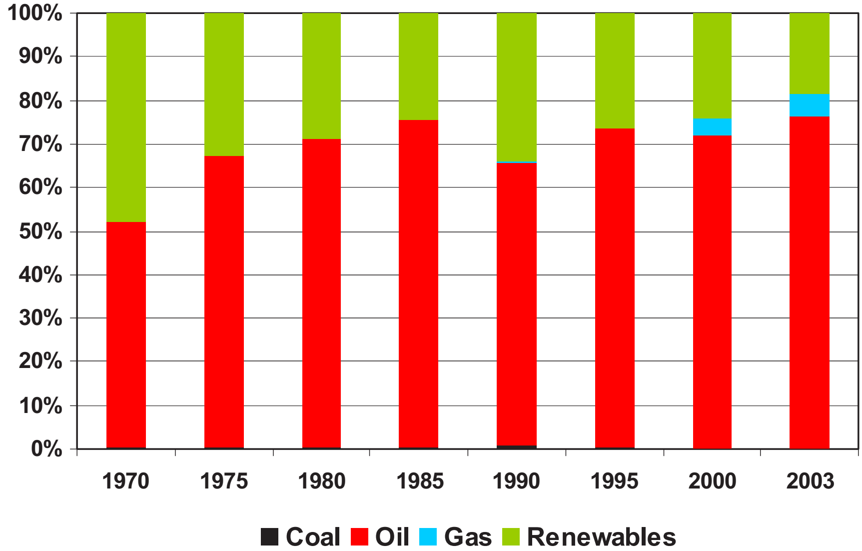

FIG. 2.2. Fuel shares in the TPES. Source: Authors' elaboration from Refs [2.1–2.9].

the corresponding sugarcane biomass (bagasse). The decrease in gas production resulted from the reduction in demand due partially to the closure of industries during this period. The hydropower reduction was a consequence of limitations imposed by the 'annual regulation regime of work' of the water reservoir for the main hydropower plant, which also serves as water supply for the population and agricultural activities of the region.

Up to 1998, the TPES in Cuba had been dominated essentially by two fuels: oil and biomass. Biomass in Cuba includes mainly bagasse from sugarcane, sugarcane crop residues and fuelwood. Only since 1999 has gas started to play a considerable role. Figure 2.2 shows the fuel shares in the TPES. The share of oil, the dominant fuel, grew significantly from 52% in 1970 to 75% in 1985. This increase was compensated by an equivalent reduction in the biomass share, with the exception of the period around 1990, when there was a significant increase in sugarcane production and therefore a rise in the biomass share. Also, the lack of affordable commercial fuels caused an increase in the use of fuelwood during the crisis period, leading to the non-sustainable use of forest resources. Subsequent improvements in the fuel supply, increased generation of electricity and measures adopted to restrict or prevent the use of forest resources led to a decrease in fuelwood use to the current sustainable level (reforestation compensates for deforestation caused by wood use for energy purposes).[4] By 2003, the oil share had returned to around 76%, biomass to 16% and gas had reached about 5% of the TPES.

Even with the sustained growth achieved in recent years, the TPES has not returned to the levels reached before the crisis. This situation reflects positive results being achieved by the implementation of effective measures for the reduction of energy intensities, the introduction of more efficient equipment and the management of energy and electricity demand that allowed fuel conservation.

These activities are part of the DPNES [2.10] approved by Parliament in 1993. The main objectives of this programme are to:

— Increase the use of domestic crude oil and associated gas in electricity generation as a substitute for imported fuel oil;
— Achieve higher efficiency in the use of bagasse and other crop residues of the sugar industry, allowing this industry to provide itself with its energy requirements and to increase the electricity delivered to the National Electric System (NES);
— Extend the use of hydropower, waste based (industrial, agricultural and urban) energy sources, solar energy, wind energy and biogas.

This programme was divided into two phases, demarcated by results and not by periods of time. The first phase focuses mainly on (a) increase in the production and use of domestic crude oil and associated gas, (b) increases in energy efficiency and (c) the contribution of sugarcane biomass to the country's energy mix. These actions combined were expected to add an additional 29 308 TJ (or 700 000 t of oil equivalent (toe)) of domestic fuel annually. The second phase was planned for when sufficient financial resources would be available for energy infrastructure development. Several components of the second phase are currently under implementation. It is expected that the total contribution of these actions will result in the following energy supply structure: sugar industry 45%, domestic crude oil and associated gas 40% and other energy sources 15%.

As a result of this programme, it was possible to increase domestic production of crude oil nearly sixfold and that of associated gas more than 19-fold between 1990 and 2003. These production increases were used to fuel almost all electricity generation in the country as well as the energy requirements of the cement and nickel industries; they also enabled the reduction in the use of naphtha in the city gas supply [2.9]. Stepped up domestic oil and gas

[4] See Section 7 for details concerning household energy use.

availability allowed the increase in electricity generation observed since 1994. Important investments were made in infrastructure to transport crude oil and associated gas.

The sugarcane industry, however, has not yet recovered. There has been a steady reduction in the use of sugarcane biomass owing to the limited availability of sugarcane, mainly as a result of the low sugar prices on the world market, and a lack of financial resources and fertilizers, which resulted in a significant drop in land productivity.

A restructuring process in the sugar sector, postponed because of its social implications, was finally implemented in 2002. Nearly half (45.5%) of the 156 sugar mills in the country were closed, and half the area devoted to sugarcane cultivation was used for other crops to substitute for food imports and for timber-yielding trees. After professional retraining and/or reorientation, 25% of the sector's labour force was assigned to other productive activities. The restructuring process has not yet been completed.

2.2.2. Energy imports

The principal energy imports of Cuba have been crude oil and petroleum products. Cuba also imports small quantities of coal for use in the metallurgical industry. Cuba's net overall energy import dependency relative to the TPES is shown in Fig. 2.3. Overall, net imports increased steadily from 1970, reaching 71% of the TPES in 1985. During this period, crude oil and petroleum products were imported from the former Soviet Union at preferential prices. Net imports dropped between 1985 and 1995 to 59% of the TPES and continued to decline through 2003 when they reached 42%. The net energy import dependency could have been even lower in recent years had the sugar industry not continued to be depressed and made more bagasse available for energy purposes.

2.2.3. Final energy use

Table 2.2 shows the simplified balance[5] of final energy use in Cuba in 2002. The data are presented following the structure used in the MAED. MAED is an analytical tool of the IAEA which has been used to model Cuban energy demand [2.11]. The manufacturing sector accounts for 52% of the final energy use, the transport sector 20%, the household sector 12% and the services sector 10%. The final energy use of the remaining sectors (agriculture,

[5] Detailed data on the final energy balance are not available.

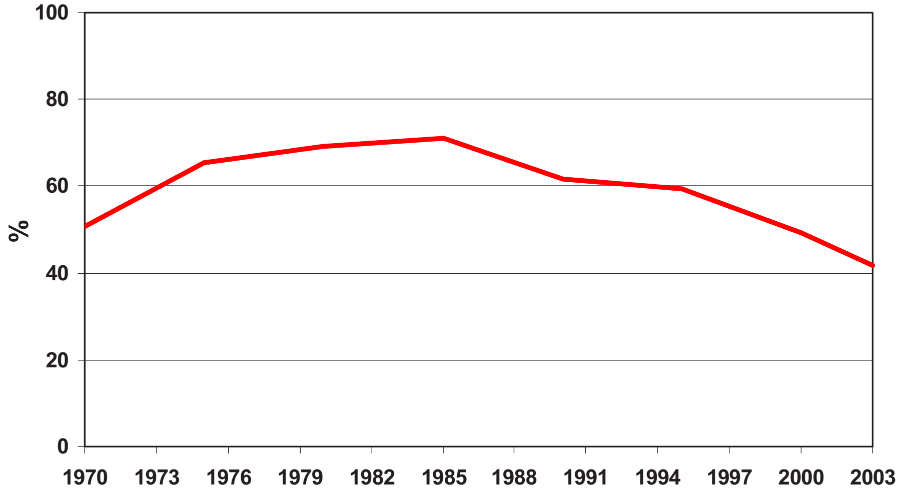

FIG. 2.3. Net energy imports in the TPES. Source: Authors' elaboration from Refs [2.1–2.9].

construction, mining) is very small, altogether 7%. By fuel, 62% of final energy is provided by fossil fuels, of which motor fuel accounts for 40%, electricity represents 17% and biomass 21% (see Table 2.3).

The structure of the final energy mix has been mainly affected by the penetration of crude oil as a final fuel and changes in the shares of electricity and biomass. Since 1990, the use of crude oil allowed a reduction in the share of petroleum products. Crude oil is used in Cuba as a final energy fuel in the cement and other industries. The electricity share has increased almost continuously at the expense of decreases in the share of sugarcane biomass[6] (Table 2.3). In absolute terms, between 1970 and 1990, final energy use increased by 34%; it subsequently decreased and in 2003 it was 56% below the 1990 level. From 2000 to 2003, a substantial reduction in sugarcane biomass, fuelwood and charcoal use occurred as a result of the expanded availability of electricity, crude oil and petroleum products. However, in absolute terms, the contribution of fossil fuels decreased by 10% and renewables by 45% and only

[6] The decrease in biomass use is due to the reduction of sugarcane production. With the restructuring of the industrial sector in 2002, the use of biomass is expected to be even smaller in the future, and any increase will depend on a rise in productivity and efficiency in the sugar industry.

TABLE 2.2. BALANCE OF FINAL ENERGY USE IN 2002 (TJ)
(Authors' elaboration from Ref. [2.8])

Economic sector	Fossil fuel				Electricity	Total commercial	Non-commercial	Total
	Fossil (substitutable)	Motor fuel	Coke	Total				
Manufacturing	66 579.9		515.0	67 094.9	13 774.6	80 869.4	59 406.5	**140 275.9**
Agriculture	3 979.0			3 979.0	707.6	4 686.6	1 653.8	6 340.4
Construction	1 998.5			1 998.5	230.3	2 228.8	28.3	2 257.1
Mining		9 234.0		9 234.0		9 234.0		9 234.0
Transport		55 076.3		55 076.3	7.0	55 083.3		**55 083.3**
Household	13 159.1			13 159.1	17 710.2	30 869.3	1 886.2	**32 755.4**
Services	12 083.7			12 083.7	9 388.1	21 471.8	4 962.7	**26 434.5**
Total	**97 800.2**	**64 310.3**	**515.0**	**162 625.6**	**41 817.8**	**204 443.2**	**67 937.4**	**272 380.7**

TABLE 2.3. SHARES OF FINAL ENERGY USE BY ENERGY TYPE (%)
(Authors' elaboration from Refs [2.1–2.9, 2.12])

	1970	1975	1980	1985	1990	1995	2000	2002	2003
Crude oil	0.0	0.0	0.0	0.0	0.9	3.9	5.2	8.0	11.1
Petroleum products	46.6	60.7	61.3	60.6	53.6	50.4	49.1	49.8	49.4
Gas	0.5	0.6	0.7	0.6	0.7	1.3	1.1	1.3	1.4
Electricity	3.3	4.8	6.4	7.2	7.4	10.5	13.2	16.3	17.4
Biomass	49.6	33.9	31.6	31.6	37.4	34.0	31.4	24.7	20.7
Total (PJ)	**432.5**	**417.1**	**482.0**	**493.3**	**581.7**	**314.5**	**319.4**	**272.2**	**257.8**

TABLE 2.4. FINAL ENERGY USE SHARES BY SECTOR (%)
(Authors' elaboration from Refs [2.1–2.9, 2.12])

	1970	1975	1980	1985	1990	1995	2000	2002	2003
Manufacturing	71.5	60.0	59.5	59.0	63.0	65.4	59.9	58.2	53.8
Construction	2.1	3.1	3.3	3.9	3.8	2.9	2.7	2.4	2.3
Agriculture	2.4	3.7	3.8	4.3	4.1	5.0	4.1	3.5	3.9
Transport	6.6	9.1	10.3	11.3	9.0	8.8	8.4	9.3	8.0
Services	10.2	14.7	13.4	10.5	11.2	7.4	13.7	14.1	16.9
Household	7.2	9.4	9.7	11.0	8.9	10.6	11.2	12.5	15.2
Total (PJ)	**432.5**	**417.1**	**482.0**	**493.3**	**581.7**	**314.5**	**319.4**	**272.4**	**257.8**

electricity increased by 6% between 2000 and 2003. Total final energy use during these years was reduced by 19%.

Regarding the economic sectors, the shares of the services and household sectors in final energy use have increased since 1990 as a result of the structural changes that have taken place in the national economy (Table 2.4), namely, a reduction in energy use in the manufacturing and agricultural sectors. Although industrial energy demand continues to dominate final energy use, these trends reflect the growing role of the services and household sectors in the Cuban economy, despite the fact that these sectors are not major energy users. The industrial sector in Cuba includes energy intensive industries such as steel, nickel, cement, etc.

2.2.4. Electricity generation: Use and installed capacity

Electricity generation by fuel shows that crude oil and petroleum products increased their share from 80% in 1970 to 85.5% by 2003 (Table 2.5 and Fig. 2.4), but since 1991 electricity generation using petroleum products has been dramatically replaced by the direct use of crude oil. This replacement allows the use of available domestic crude oil and eliminates the need for imports of petroleum products for electricity generation. Biomass reduced its contribution from 18% to 4.6% from 1970 to 2003. Associated gas, which began to be used in 1998, accounted for 7% of the electricity generation in the country in 2003. The contributions of hydropower and wind energy are very small, with the two combined representing only about 1%. The installed capacity of sugarcane cogeneration represents 16.7% of the total installed capacity in the country. However, it produces only 4.6% of the electricity because of low

TABLE 2.5. ELECTRICITY GENERATION BY FUEL (%)
(Authors' elaboration from Refs [2.1–2.9])

	1970	1975	1980	1985	1990	1995	2000	2002	2003
Crude oil	0	0	0	0	0	3451	6 297	9 759	11 613
Petroleum products	3693	5410	8353	10 317	12 586	7567	5 557	2 811	934
Gas	0	0	0	0	0	0	1 217	1 098	1 444
Biomass	881	756	954	1 131	1 449	690	944	939	720
Hydro + wind	91	63	97	54	91	74	89	112	132
Total (GW·h)	**4665**	**6229**	**9404**	**11 502**	**14 126**	**11 782**	**14 104**	**14 719**	**14 843**
					Share (%)				
Crude oil	0.0	0.0	0.0	0.0	0.0	29.3	44.6	66.3	78.2
Petroleum products	79.2	86.8	88.8	89.7	89.1	64.2	39.4	19.1	6.3
Gas	0.0	0.0	0.0	0.0	0.0	0.0	8.6	7.5	9.7
Biomass	18.9	12.1	10.1	9.8	10.3	5.9	6.7	6.4	4.9
Hydro + wind + solar	2.0	1.0	1.0	0.5	0.6	0.6	0.6	0.8	0.9

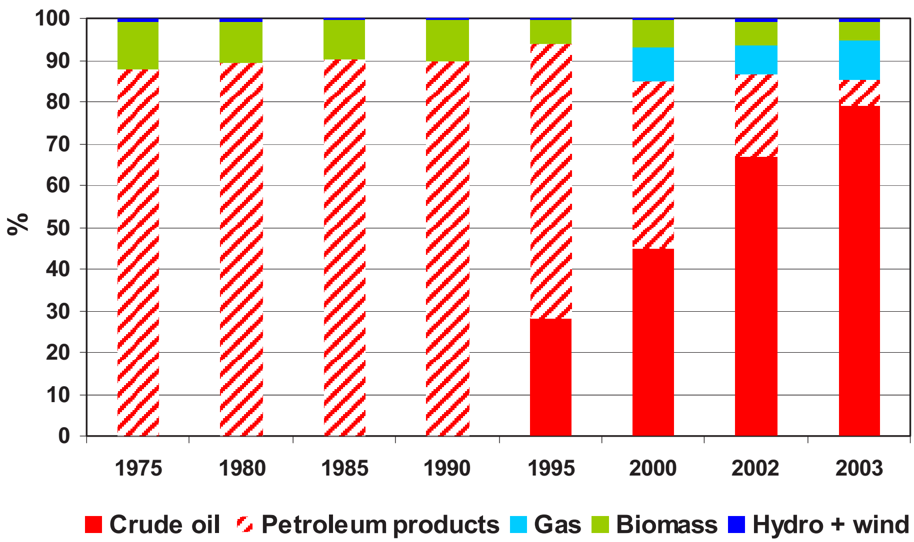

FIG. 2.4. Electricity generation by fuel. Source: Authors' elaboration from Refs [2.1–2.9].

efficiencies and because operation is restricted by the sugarcane harvest season (around 120 days per year).

There was a rapid increase in electricity use (10.5% per year) in the 1970s, due, in particular, to industrial development. In the 1980s, electricity demand increased at a lower yearly average rate of 4%, a slowdown primarily caused by increased household demand and lower industrial expansion compared with the 1970s. However, in the 1990s the crisis affected all sectors, reducing the use of electricity across the board, although to a greater extent in the services and industrial sectors. Many economic activities were suspended and industries closed, mainly because of the lack of fuels and electricity, although some closures were the result of a lack of hard currency needed to import the necessary raw materials. Blackouts were a normal practice and were planned on a daily basis. However, attempts were made to minimize the impact on the population, and by 1995, electricity use in households had already returned to the level of 1990 (Table 2.6).

From 1994 onwards, with the beginning of the economic recovery, electricity use in the services and household sectors grew at a higher pace than in the industrial sector. Since 2000, electricity use in the industrial sector has followed a decreasing trend but continued to grow again in the services and household sectors. On average, in the period 1994–2003, electricity use grew by 3.8% per year (Table 2.6). However, since 1997 the electricity conservation programme has kept the average maximum electricity peak demand at 2150 MW and growth rates have been below 2% per year.

TABLE 2.6. ELECTRICITY USE BY SECTOR (GW·h) [2.1–2.9]

	1970	1975	1980	1985	1990	1995	2000	2002	2003
Industry	1866	2617	4055	4897	5 969	3733	4 220	4 087	3 473
Services	1145	1590	2402	2345	2 674	2126	3 277	3 299	3 835
Household	972	2117	2117	2682	3 306	3274	4247	4 919	5 123
Total	**3983**	**6324**	**8574**	**9924**	**11 949**	**9133**	**11 744**	**12 305**	**12 431**
					Share (%)				
Industry	46.8	41.4	47.3	49.3	50.0	40.9	35.9	33.2	27.9
Services	28.7	25.1	28.0	23.6	22.4	23.3	27.9	26.8	30.9
Household	24.4	33.5	24.7	27.0	27.7	35.8	36.2	40.0	41.2

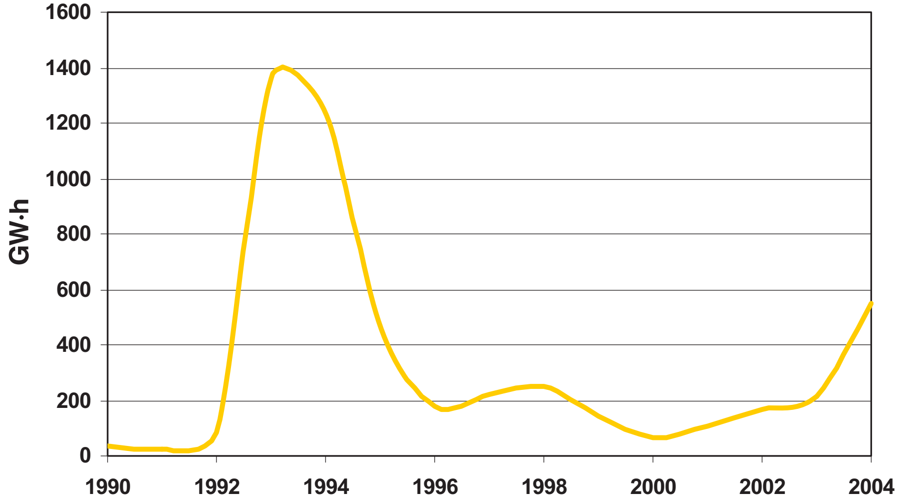

FIG. 2.5. Electricity not served. Source: Ref. [2.13].

During the crisis period from 1992 to 1996, the 'electricity not served'[7] reached very high levels, peaking in 1993 at twelve times the 1990 value, mainly because of the lack of fuel. This level was drastically reduced by 1996 but, owing to damage in different electric power plants, the electricity not served increased again in 2003 and 2004. Although it was five times higher in 2004 than in 1990, it only constituted 4% of the electricity demand of the country in that year (Fig. 2.5).

Cuba's installed electricity generating capacity has grown rapidly to meet the increased demand resulting from economic and social development. Between 1970 and 1990, on average, 160 MW capacity was installed per year. The generating capacity continued to grow thereafter, although at a much lower rate. Regarding generating technology, the greatest growth has been in conventional thermal power plants and cogeneration in the sugar industry, although since 1998 gas turbines and combined cycles using associated gas have begun to play a significant role (Table 2.7). At the end of 2003, the installed capacity was 3965 MW, 98% of which was connected to the NES, with isolated power systems and plants making up the rest. By 2003, 68% of the electric generating capacity was based on crude oil.

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[7] Electricity not served refers to the overall amount of electricity demanded that could not be supplied by the electric power system.

TABLE 2.7. INSTALLED CAPACITY (MW) [2.1–2.9]

	1970	1975	1980	1985	1990	1995	2000	2002	2003
Crude oil	0.0	0.0	0.0	0.0	0.0	1335.0	1784.0	2836.0	2676.5
Petroleum products	840.7	1104.6	2164.7	2563.8	3203.7	1723.4	1435.2	333.8	333.8
Gas	0.0	0.0	0.0	0.0	0.0	0.0	160.0	160.0	235.0
Biomass	n.a.*	527.9	520.7	620.2	825.4	876.5	849.9	571.9	662.3
Hydro + wind	44.8	44.8	46.0	45.0	48.8	56.2	57.4	57.9	57.4
Total	**885.5**	**1677.3**	**2731.4**	**3229.0**	**4077.9**	**3991.1**	**4286.5**	**3959.6**	**3965.0**
					Share (%)				
Crude oil	0.0	0.0	0.0	0.0	0.0	33.4	41.6	71.6	67.5
Petroleum products	94.9	65.9	79.3	79.4	78.6	43.2	33.5	8.4	8.4
Gas	0.0	0.0	0.0	0.0	0.0	0.0	3.7	4.0	5.9
Biomass	n.a.*	31.5	19.1	19.2	20.2	22.0	19.8	14.4	16.7
Hydro + wind	5.1	2.7	1.7	1.4	1.2	1.4	1.3	1.5	1.4

* Data not available.

During the restructuring process of MINAZ in 2001–2002, significant cogeneration capacities were retired totalling 278 MW. However, with the introduction of combined cycle technology plants and the increased overall efficiency in the operation of existing power plants, power generation increased 5% in 2003 compared with 2000 (Table 2.7).

Total electricity losses in 1996 grew to 23.2% of generated electricity, as a result of inadequate maintenance, lack of investment in the distribution network and 'theft' of electricity. Starting in 1997, measures to reduce transmission losses were initiated, such as monitoring of the transmission system or the installation of new electric meters to control distribution losses. By 2003, these measures brought the level of total electricity losses down to the same level as those in 1990, i.e. 17.5%.

2.2.5. Investments and financial constraints

Investment in the Cuban energy sector has been primarily used to modernize thermal power plants, to improve electric transmission lines, to expand drilling and extraction of crude oil and associated gas, and to improve fuel transport infrastructure via oil and gas pipelines or by sea transport. From 1996 to 2002, average investments in the energy sector were about 298 million pesos per year, which, in 2002, represented almost 13% of the total annual investments in the country for that year [2.14].

More than 500 km of oil and gas pipelines were built between 1998 and 2002. Harbour facilities and a supertanker station, including an oil treatment facility to improve quality, were also constructed to supply crude oil to the thermal power plants located in the western and eastern parts of the country, i.e. areas far from the production sites.

The main short and medium term limitations inhibiting development of the Cuban energy sector are the scarcity of hard currency for normal operations and the lack of finance needed to undertake new investments, maintenance work, modernization, grid extensions, etc.

The limited availability of hard currency affects the scheduling of hydrocarbon imports and thus causes supply disruptions and ‘brown outs’ which at times have seriously adverse impacts on all activities throughout the economy. Emergency response measures have been created to facilitate fuel allocation at short notice, thus minimizing hardships. However, these measures do not allow the optimization of imports, storage, refining, distribution, etc.

The lack of financial resources is the main problem hindering the investment process in Cuba and affects the energy sector in particular. Although private sector foreign investments have emerged in recent years, they are insufficient to meet the needs of the energy sector. Private investment is concentrated in specific areas and an expansion would require the revision of the regulatory framework.

The crisis in the 1990s caused a serious fuel (oil products) shortage, which significantly affected the household sector. Measures were taken to remedy this situation, including an increase in electricity supply. Also, a programme aimed at extending the supply of city gas in Havana was initiated. The extension of liquefied petroleum gas (LPG) supply increased access to this fuel in Havana and in Santiago de Cuba province. Fuel supply to households, however, is still limited, mainly in rural areas of the country. Here, the supply of alcohol and kerosene is insufficient. In 2005, a comprehensive programme was launched which was targeted at increasing the utilization of electricity in households, especially for cooking.

2.2.6. Resources and security of supply

Analysis of the energy resource situation in Cuba[8] shows that fossil fuels will maintain their significant contribution to the national energy balance, mainly because of the use of domestic oil and associated gas. The Cuban oil and gas industry has been one of the most dynamic industries within the Cuban economy in the last decade, making important progress in prospecting and extraction, as well as in the development of infrastructure for fuel transport. The discovery of important light crude oil and natural gas reserves in the Cuban Economic Exclusion Zone (EEZ) of the Gulf of Mexico is expected.

Because of the biomass potential in sugarcane, which can be used in cogeneration, the sugar industry continues to be a strategic part of the development of domestic energy sources. After the economic crisis of the 1990s, the share of biomass in the country's energy mix has declined. Efforts are now under way to increase energy efficiency in the sugarcane industry and cogeneration is expected to increase with the installation of higher efficiency boilers and new turbogenerators in operating sugar mills.

Distilleries have been used for obtaining alcohol from molasses; the alcohol is used mainly for rum production and to preheat kerosene stoves in households. Tests for its use as a fuel for vehicles in mixtures of 25% in gasoline and 8% in diesel have also been carried out. In the future, the use of ethanol from sugarcane in the fuel mix in all motorized vehicles will be expanded.

The hydropower potential in Cuba is low and whether or not it will be exploited will be determined mainly by technical and economic studies and corresponding evaluations of environmental impact.

Solar radiation in Cuba is high, but at present its exploitation is very low. Photovoltaic systems were favoured by social programmes aimed at electrifying schools and meeting other social objectives in isolated mountainous areas. If Cuba is to provide electricity to 100% of the population in the country, photovoltaic applications will have to play a significant role. Solar thermal energy should increase its share in the public sector; it is already being used in tourism, an industry that pays for electricity in hard currency.

Wind energy has considerable potential for market penetration and there is an ongoing plan to install 100 MW by 2008. In the future, depending on confirmation by measurements of the current preliminary potential (700–1200 MW), its development could be expanded with the participation of different industries.

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[8] Details on Cuban energy resources are provided in Section 3.

In addition, the development of biodiesel production from two plants, *Jatropha curcas* and *Ricinus communis*, is being evaluated for direct use as motor fuel. This fuel can be mixed with diesel and can be used as a substitute for other diesel additives.

Urban solid wastes represent an option for obtaining methane. Currently, biogas production is limited and only very few wastes are being used. There are possibilities for expanding the use of wastes, particularly those from the sugar industry and distilleries.

Forest biomass is another resource that is not yet used to produce energy in a practical manner. A 3–4 MW pilot gas plant project for the gasification of forest biomass is expected to be completed on the Isla de la Juventud.

Recent problems concerning the security of the national energy supply include the following:

— A shortage of hard currency to finance the purchase of imported fuels, new investments and the implementation of programmes for the rational use of energy.
— High dependency on imported fuels.
— Electricity generation is heavily dependent on oil and gas (95%). The high sulphur content of domestic crude oil has adverse effects, both environmentally and operationally (decreases in the availability and efficiency of thermal power plants, increases in unplanned downtimes because of breakdowns, shorter operating times between maintenance cycles and increases in the resources needed for maintenance, among others).
— Problems related to fuel transport, particularly coastal transport, which have sometimes caused temporary shortages of energy and interruptions in energy services resulting from rainstorms and tropical hurricanes.
— The extension of transmission lines throughout the country; because of the country's geographical position, the lines are susceptible to damage from tropical storms and hurricanes.

2.2.7. Energy system status: Economic, social and environmental dimensions

This section examines some of the most important factors that have shaped Cuba's energy system and policies according to the economic, social and environmental dimensions of sustainable energy development, using as a framework the EISD devised for such purposes by the IAEA (see Table 1.1).

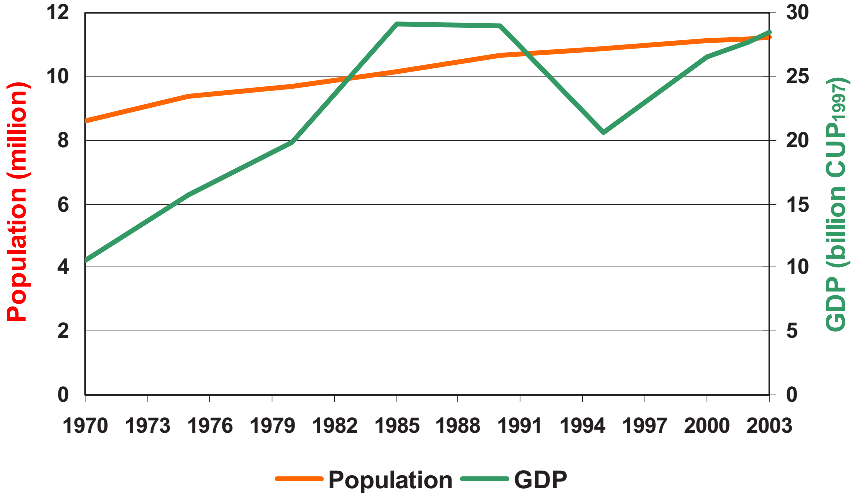

FIG. 2.6. Population and GDP. Source: Refs [2.1–2.9].

2.2.8. Economic dimension

The drastic changes that affected the Cuban energy system were driven mainly by economic changes brought about by the crisis that hit the country in the early 1990s. Other driving forces included urbanization processes, the decrease in demographic growth rates, the development of both the education and health systems, and the increase in life expectancy.

2.2.8.1. Activity effects

Population and GDP

The Cuban population has doubled in the past 50 years. The annual growth rates per thousand inhabitants were at or above 10 until 1990. The crisis of the 1990s, combined with higher levels of education, improved medical care, sexual education programmes, migration, etc., led to a decrease to the very low value of 2.7 in 2003 (Fig. 2.6).

From 1970 to 1990, the GDP at 1997 constant prices[9] increased 2.7 times. However, during the crisis, activity levels decreased and GDP fell by 33% from

[9] Exchange rate 2005: 1 peso = US $0.9259.

1990 to 1993. The economic recovery that began in 1994 put a stop to the decline of the previous years, and between 1995 and 2003 the average annual GDP growth rate was 4.1%. Nonetheless, GDP in 2003 was still 2% lower than in 1990 (Fig. 2.7).

Energy use per capita

The effects of economic and social activities on energy use are reflected in a variety of ways, including the per capita use of different types of energy. Table 2.8 and Fig. 2.7 present Cuba's per capita energy use for the period 1970–2003. Figure 2.7 also includes the corresponding per capita GDP.

The economic and social development of the 1970s and 1980s led to a sustained increase in per capita electricity use rates, which were 2.4 times higher in 1990 than in 1970. The TPES per capita increased only moderately until 1985 (1.3 times) and then followed a decreasing trend. Biomass use per capita (which includes fuelwood and bagasse from sugarcane) was highest in 1975 and then progressively decreased up to 2003 with only a temporary increase around the 1990–1995 crisis period. By 2003, the use of biomass per capita had decreased five times with respect to 1970 levels (Fig. 2.7).

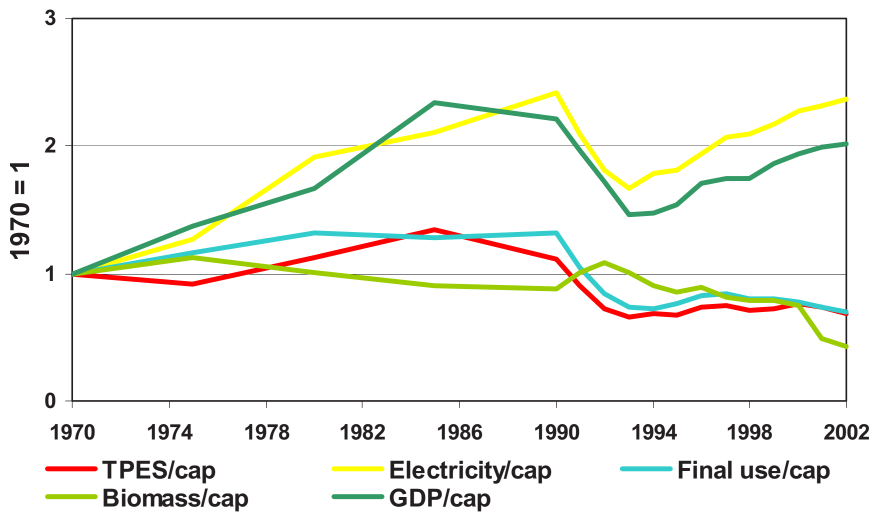

FIG. 2.7. Indices of energy use and GDP per capita. Source: Authors' elaboration from Refs [2.1–2.9].

TABLE 2.8. ENERGY USE PER CAPITA
(Authors' elaboration from Refs [2.1–2.9])

	1970	1975	1980	1985	1990	1995	2000	2002	2003
TPES (GJ/cap)	62.8	58.0	70.7	84.5	69.7	42.5	47.7	43.3	42.4
Final energy use (GJ/cap)	50.3	44.5	49.7	48.6	54.6	29.0	28.7	24.3	23.0
Electricity (kW·h/cap)	463.0	589.1	884.5	977.5	1120.8	841.0	1052.5	1097.0	1106.1
Household energy (GJ/cap)	3.6	4.2	4.8	5.4	4.9	2.9	3.2	3.0	3.5
Household electricity (kW·h/cap)	113.0	139.9	215.2	264.2	310.1	301.5	379.0	436.9	456.2

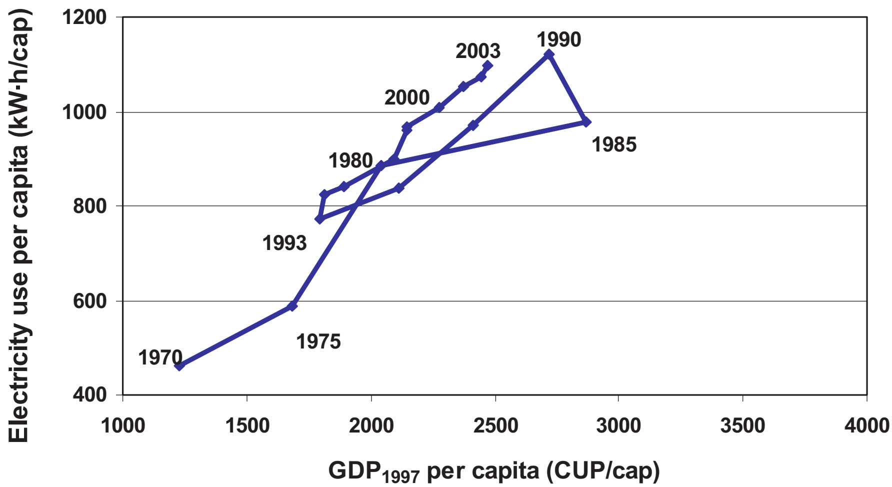

FIG. 2.8. Electricity use per capita versus GDP per capita. Source: Authors' elaboration from Refs [2.1–2.9].

In general, owing to the crisis in the 1990s, per capita energy use (TPES, final and electricity) fell between 1990 and 1993. The lack of fuels during this period was compensated in part by an increase in the use of fuelwood (Fig. 2.7).

The result of economic and energy efficiency programmes implemented in Cuba since 1995 can be observed in the slight decreases in final energy use per capita during recent years (Table 2.8). In 2003, final energy use per capita was still 2.2 times lower than in 1970.

Figure 2.8 shows the relation between per capita GDP and per capita electricity use. The effect of the 1990 crisis is reflected in these indicators during 1990–1994. In general, per capita electricity use increased through the 1980s while the per capita GDP was increasing. However, by 1990 a reverse trend was observed in both indicators which lasted until 1994. Then, with the economic recovery, both indicators experienced an increasing trend, but by 2003 per capita electricity use and the per capita GDP still remained lower than the 1990 level.

The energy intensity (TPES per unit of GDP) decreased from 1970 to 1992 for a number of reasons (Fig. 2.9). First, during the 1970s and 1980s, GDP grew more rapidly than the TPES. Despite being inherently energy intensive, the accelerated expansion of the industrial sector resulted in higher rates value added than industrial energy demand. Later, in the 1990s, at the beginning of the crisis, energy intensity continued its decline – now due to a faster reduction in the TPES than the drop in GDP. Between 1990 and 1994, the TPES dropped by 38% because energy imports were reduced by 45% and domestic primary

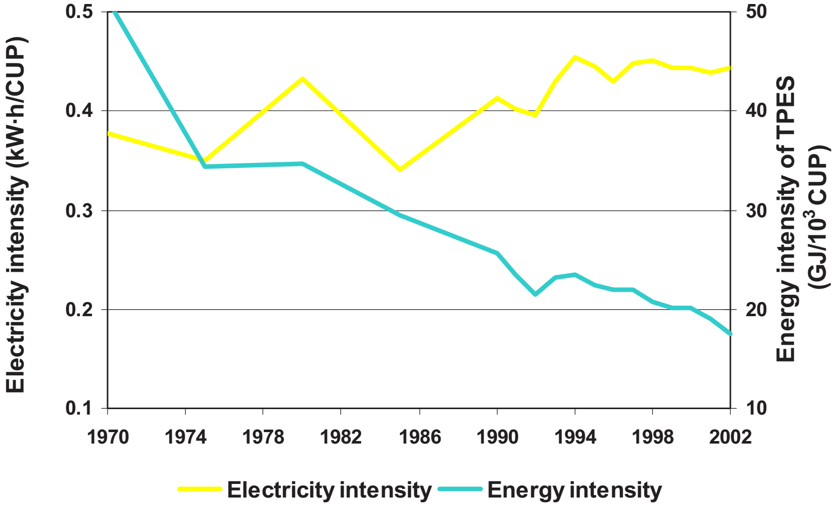

FIG. 2.9. TPES and electricity intensities. Source: Authors' elaboration from Refs [2.1–2.9].

energy production decreased by 27%. On the other hand, although some energy intensive industries were closed and others reduced their production, the tourism sector increased its activity, thus limiting the drop in total GDP to 31%. After the most critical year of the crisis (1993) and with the beginning of the economic recovery in 1994, there was a slight increase in the energy intensity of the TPES owing to the rise in domestic crude oil and associated gas production. However, this intensity later dropped as a result of structural changes in the overall economy and the implementation of energy conservation and efficiency programmes, reaching the value of 16.8 GJ/1000 pesos (0.4 toe/ 1000 pesos) in 2003.

Figure 2.9 shows that electricity intensity increased throughout the considered period, experiencing major fluctuations in the 1980s (from 0.38 in 1970 to 0.45 in 1994 kW·h/peso). Electricity conservation programmes, reductions in electricity losses and an increase in efficiency contributed to maintaining electricity intensity stable at around the same level between 1997 and 2003 (0.44–0.45 kW·h/peso).

The relation between the electricity intensity and the per capita GDP is presented in Fig. 2.10. From 1970 to 1985, although the per capita GDP followed an increasing trend, the electricity intensity fluctuated. During the crisis, the per capita GDP contracted while the electricity intensity increased. From 1995 to 2003, GDP started to grow again while electricity intensity remained fairly constant. The different energy programmes implemented

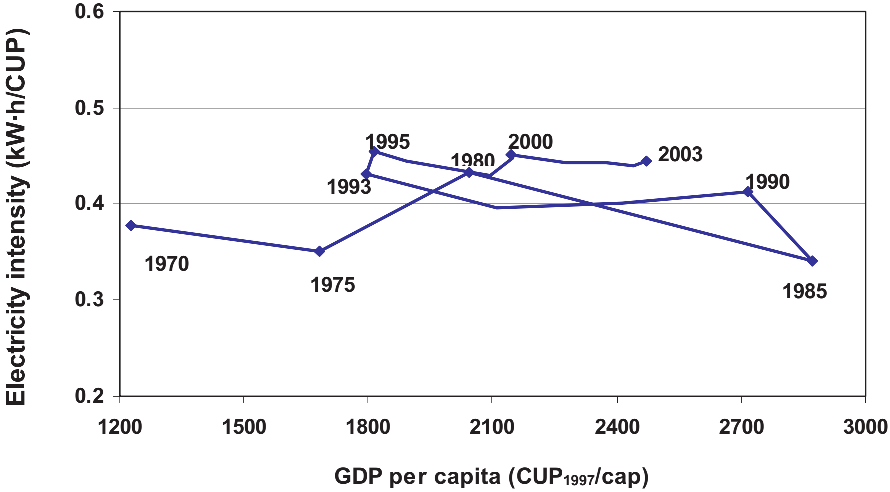

FIG. 2.10. Electricity intensity and GDP per capita. Source: Authors' elaboration from Refs [2.1–2.9].

during the economic recovery helped to keep electricity intensity at practically the same level as in the last several years.

2.2.8.2. Structural effects

The Cuban economy has experienced significant structural changes in the last several decades. Until the middle of the 20th century, the country's economy was based almost entirely on agricultural production, with only moderate industrial development limited to activities related to the sugar industry. Industrialization began in 1959, with the development of energy intensive industries such as nickel, steel, cement and engineering. The industrial sector represented 34% of the value added in 1990, while services represented 50%, agriculture 10% and transport 6%[10] (Fig. 2.11).

During the crisis of the 1990s, the industrial sector contracted for a number of reasons, including the partial closure of certain industries and the decline in production due to the lack of raw materials. During this time, the services sector played a more predominant role. The share of agriculture in GDP decreased, and that of transport increased. In 2003, industry represented only 21% of GDP, services increased to 65%, agriculture dropped to 6% and

[10] GDP data disaggregated by sector are not available for years prior to 1990.

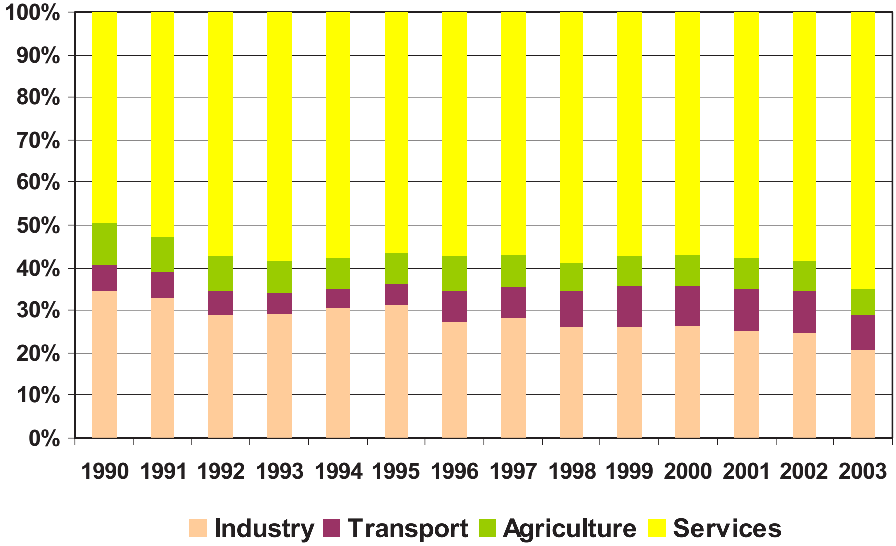

FIG. 2.11. Value added by sector. Source: Refs [2.1–2.9].

transport increased slightly to 8% (Fig. 2.11). Structural changes also took place within these sectors[11] and major changes occurred as a result of an increase in tourism activities and improvements in biotechnology, education and health.

Figure 2.12 shows the final energy intensity by sector. All of the sectoral intensities show declining trends during the considered period. The industrial sector with the highest intensity decreased by 19% between 1990 and 2003. Partial data for the transport sector show its intensity dropping by 74%.[12] The declining trends in sectoral energy intensities result from a more efficient use of limited fuels during the 1990s followed by effective programmes implemented in energy conservation and efficiency.

[11] Structural changes in economic sectors are described in Section 5.

[12] Available transport data do not represent the whole transport sector but only the transport activities of MITRANS.

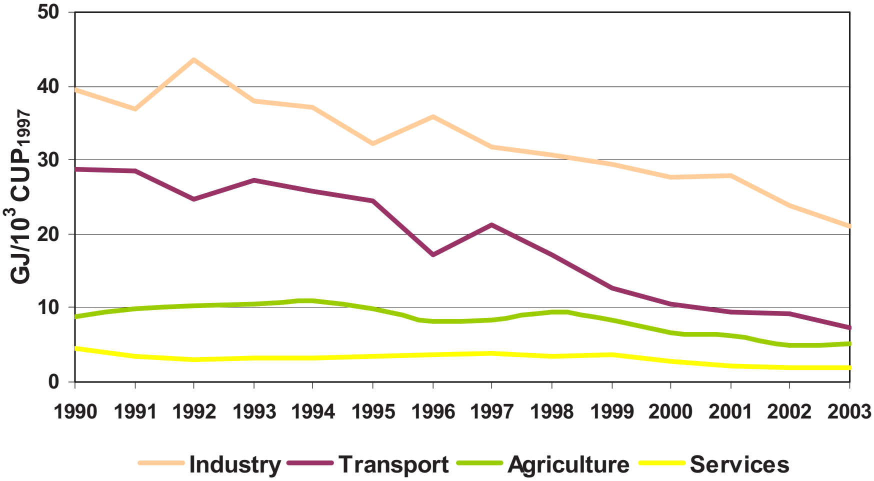

FIG. 2.12. Final energy intensity, by sector. Source: Authors' elaboration from Refs [2.1–2.9].

2.2.8.3. Technological effects

Supply side

The increase in the production and use of domestic crude oil for electricity generation and for cement and nickel production has been significant. In 2003, almost all electricity was generated using domestic fuels, which is an important achievement of the Government's policy to reduce the economy's dependence on imported fuel. In 1998, associated gas (which had previously been flared) began to be used for electricity generation and for city gas production. In addition, the modernization and modification of the thermal power plants have made it possible to reduce specific fuel consumption. Maintenance work, investments in electric transmission lines and measures adopted to reduce commercial losses have allowed the reduction of total electricity losses from 23.2% in 1997 to 17.5% in 2003. Refining capacity has also been rehabilitated and fuel transport has been significantly improved through the construction of oil and gas pipelines that connect the most important supply points and consumption centres.

Demand side

In 2002, a new electricity tariff system[13] came into force that encouraged a more rational use of electricity by consumers. However, in the public and household sectors, there is still room for improvement, as in these sectors the electricity is subsidized.

In the framework of the Cuban Electricity Rational Use Programme (PAEC), load supervisors assigned to the largest users contribute to achieving reductions in electricity demand. The benefits obtained from PAEC were used to subsidize the sale of more efficient equipment — such as compact lamps, and fluorescent and energy efficient light bulbs — to the public, with the aim of advancing rational energy use. The programme included the replacement of refrigerator gaskets and other parts, which also contributed to the reduction in electricity demand. In this way, PAEC has had a significant impact on reducing electricity demand and this has allowed the avoidance or rather postponement of the installation of more than 150 MW of electric generating capacity.

2.2.9. Social dimension

Before 1959, only 56% of the total population had access to electricity — not only because of the lack of physical access, but also due to the lack of sufficient income that would allow the population to pay for electricity. Since 1959, the Government has brought electricity to all places where it has been economically feasible. Between 1959 and 1975, electrification reached 70.5%. Another accelerated advance in electrification occurred between 1980 and 1990, when rates reached 94%. The crisis of the 1990s did not allow such accelerated electrification rates and between 1990 and 2003 it was only possible to achieve a 1.5% additional increase in electrification. In 2003, 95.5% of the total population had electricity [2.9] (Fig. 2.13).

It is expected that 100% of the population will have electricity in the coming years, provided there are financial resources available to implement relevant programmes. Currently, the feasibility of decentralized grid independent energy sources is being assessed, including photovoltaic panels, mini-hydropower plants, wind generators, hybrid systems, biomass and biogas, as alternatives to extension of, or integration into, the electricity grid.

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[13] The new electricity tariff system for the public sector was approved by Resolution 311-2001 of the Ministry of Finance and Prices on 29 August 2001 and went into effect on 1 January 2002.

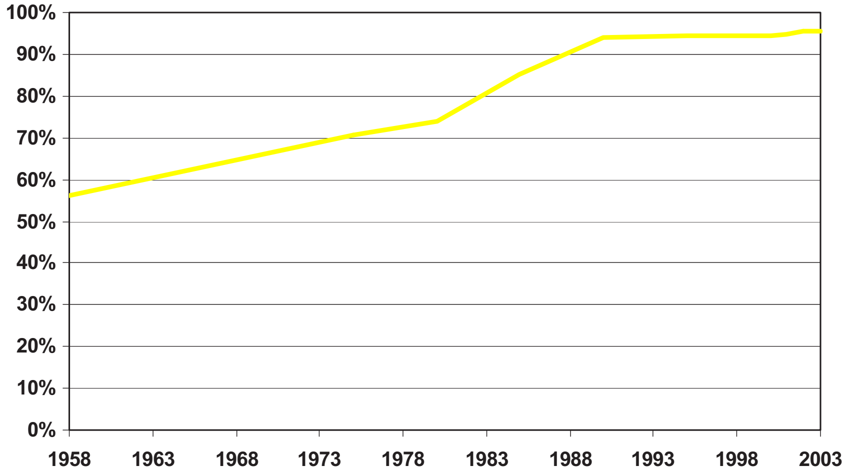

FIG. 2.13. Electricity access indicator. Source: Refs [2.3–2.9].

The 4.5% of the population that do not have access to electricity use non-commercial energy sources instead. These people live in isolated rural districts, mainly mountainous areas. The eastern region of Cuba is the most mountainous and it is estimated that only 87% of the population there has electricity (according to PAEC surveys).

Occasionally, after rural communities were connected to the electricity grid, problems arose concerning the installed generating capacity. The additional demand through these connections was calculated on the basis of meeting certain prime service needs such as providing lighting, television, radio, etc. The increase in the standard of living brought about by electrification, however, led to an immediate increase in demand for additional electricity services such as refrigeration, ironing and cooking which exceeded the existing installed generating capacity. Another consequence of the electrification of small communities was migration, as access to electricity attracted isolated residents, which further boosted electricity demand. These experiences should be kept in mind in the implementation of new electrification projects.

Average electricity use per household grew from 82 kW·h/household/month in 1970 to 140 kW·h/household/month in 2002. This growth occurred despite the fact that electricity demand in households has been controlled by restrictions imposed on the acquisition of some types of electric household appliance. Other factors have also had a considerable impact, such as the introduction of highly energy efficient appliances, subsidized programmes for replacing refrigerator gaskets, the shift to more energy efficient light bulbs, educational energy conservation campaigns and a new electricity tariff. These factors reduced the household electricity use in 2003 to 133 kW·h/household/month.

Until 1990, the dominant fuel in the household sector was kerosene. During the 1990s crisis, the fuel mix in the household sector changed. In 1995, electricity replaced kerosene as the main energy type used in the household sector. The shares of electricity, city gas and LPG have increased significantly in household energy use, reaching 47, 6 and 16% of the total energy use of the sector, respectively, in 2003. Kerosene accounts for 20%, alcohol 3%, charcoal 1% and fuelwood less than 1%.

The economic activity in Cuba between 1975 and 1985, the comprehensiveness and universality of the social programmes that were implemented during this period (which resulted in very high levels of electricity access) and the process of bringing the standards of living of all families closer together throughout the country supported the view that poverty as a social problem had been eradicated [2.15]. However, since the economic crisis of the 1990s, the issue of poverty has re-emerged.

The crisis and the reforms adopted to address the poverty issue have had different impacts on the population, mainly because of the use of two currencies (local and hard currencies). Economic activities on the black market have grown. With the possession of hard currencies legally permitted in the country, those families with access to that form of currency have a higher standard of living.

The few studies on poverty carried out in the country agree that current poverty in Cuba should be differentiated from that observed in other parts of Latin America and the Caribbean. Consequently, it has been suggested that, in the case of Cuba, the concept of 'population at risk' should refer to the population that has insufficient revenues to acquire basic foods and non-food goods, but which at the same time has a safety net qualitatively superior to that of the poor in the rest of Latin America.

Studies carried out in Cuba [2.16] show that the eastern region was the most affected by the crisis of the 1990s. About 30% of the urban population is settled in this region and about 22% of this population was considered to be at risk. A survey on the economic situation of households carried out in 1999 determined that 20% of Cuba's entire population was considered to be at risk. A major share of this population also had no access to electricity and used non-commercial energy to meet their minimum energy requirements.

Another aspect of energy use that has repercussions on the social and economic dimensions of sustainable development is the increasing use of hot water. Incentives and mechanisms are needed to reduce the cost of water heaters to make them affordable for the population. In addition, it is necessary to adopt stricter standards for the best use of solar radiation and natural ventilation in all types of building, to establish appropriate measures to control the implementation of the standards and to promote the sale of specific materials for such purposes.

2.2.10. Environmental dimension

The environmental dimension of sustainable energy development in Cuba is analysed with regard to the local and global influence of pollutant emissions. However, energy development also exerts an influence on land use patterns. Because of the structure of the energy system in Cuba, in which the use of fossil fuels prevails, GHG emissions from this sector comprise a significant proportion of the country's total GHG emissions. The local effects of sulphur dioxide (SO_2) emissions from the use of domestic crude oil are also considerable.

2.2.10.1. Local emissions of pollutants

The main local pollutant is SO_2 arising from the burning of domestic crude oil for electricity generation, which has increased substantially since the mid-1990s. By 2002, SO_2 emissions from electricity generation had increased 2.1 times compared with 1990 (Fig. 2.14).

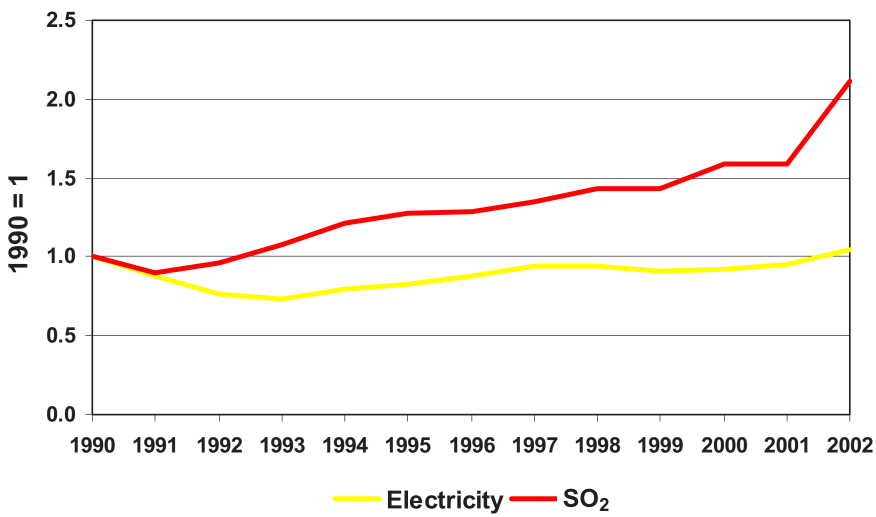

FIG. 2.14. Index of SO_2 emissions and electricity generation. Source: Ref. [2.17], authors' estimation.

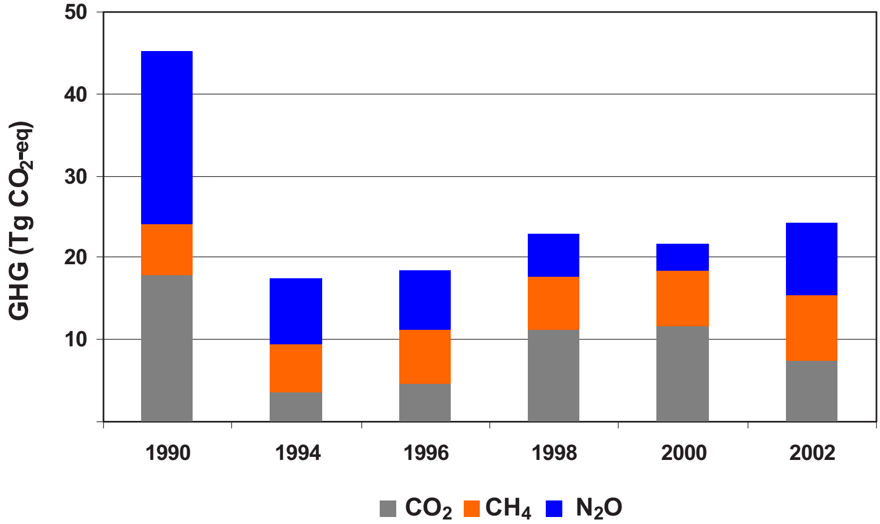

FIG. 2.15. Total net emissions of GHGs. Source: Ref. [2.18].

At the end of 1998, associated gas started to be used to generate electricity, which was reflected in a decrease in SO_2 emissions. However, in 2002, SO_2 emissions rose rapidly due to increased domestic crude oil consumption, which was up 82% compared with the previous year.

2.2.10.2. GHGs (global effect)

Total net emissions of GHGs in the country (Fig. 2.15) decreased dramatically by 1994 due to reduced energy use and to increased absorption levels resulting from changes in land use. After 1994, these emissions have shown a relatively gradual increasing trend. Details on GHG emissions, excluding absorptions, are presented in Section 6.

The energy sector accounted for 75% of total net GHG emissions in 1990 (Fig. 2.16). Later, with the increase in absorption from changes in land use (mainly the increase in forested area), the emissions from the energy sector were higher than the total net emissions.

Although most emissions from the energy sector have decreased in the last decade, methane (CH_4) emissions have increased considerably (13-fold compared with 1990) since 1994 due to drilling and the use of domestic crude oil and associated gas. Nitrous oxide (N_2O) emissions have remained nearly at 1990 levels (Fig. 2.17).

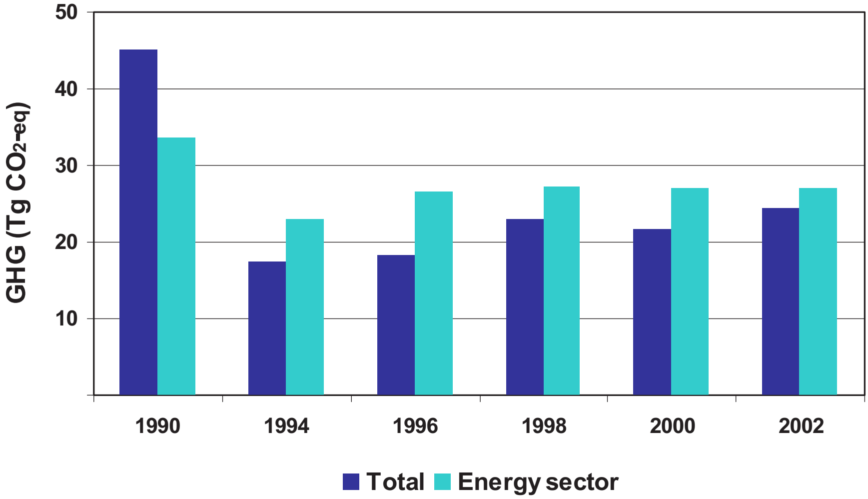

FIG. 2.16. Net GHG emissions total and from the energy sector. Source: Ref. [2.18].

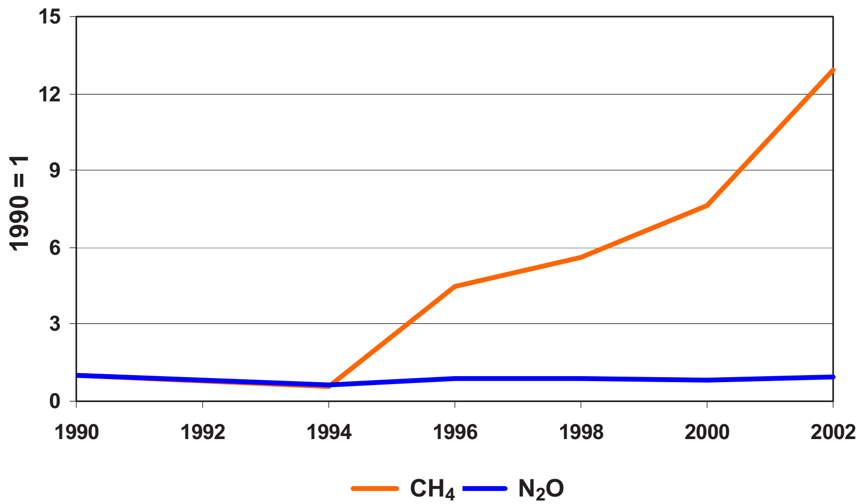

FIG. 2.17. Index of CH_4 and N_2O emissions. Source: Ref. [2.18].

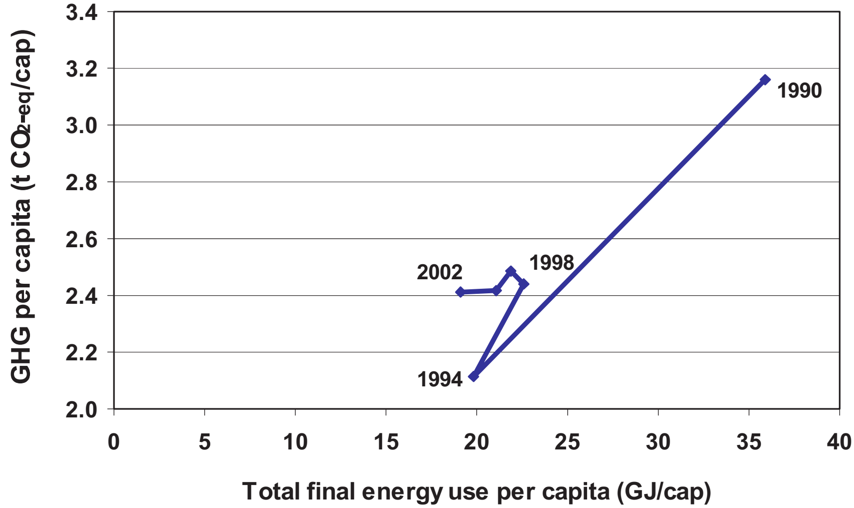

FIG. 2.18. Per capita GHG emissions from energy sector versus total final energy use per capita. Source: Authors' elaboration from Refs [2.3–2.9, 2.18].

The per capita GHG emissions of the energy sector decreased from 3.2 t of CO_2 equivalent per capita in 1990 to 2.1 t of CO_2 equivalent per capita in 1994 because of the abrupt reduction in the total energy use per capita, which was mainly due to the economic crisis. The economic changes introduced during the economic recovery have resulted in an increase in economic efficiency and thus per capita energy use and emissions decreased throughout 2002 (Fig. 2.18).

The intensity of the GHG emissions corresponding to the energy sector remained fairly constant through 1998 even though the final energy intensity was decreasing during this period. After 1998, the GHG intensity dropped sharply, following the same trend observed in final energy use intensity (Fig. 2.19).

2.2.11. Institutional dimension

Structural changes and reforms stated in the Law on Foreign Investments were carried out in the energy sector to allow the participation of private capital in energy industries. Foreign investment was implemented both in electricity generation and in the exploration and production of petroleum and associated gas.

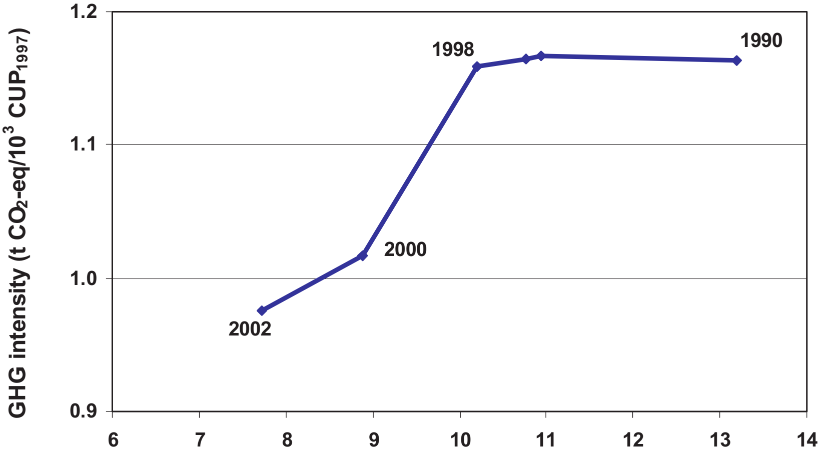

FIG. 2.19. The CO_2 equivalent energy sector emissions intensity versus energy intensity. Source: Authors' elaboration from Refs [2.3–2.9, 2.18].

By the end of the 1990s, oil production was shared equally between CUPET and the private sector. With respect to electricity generation, five gas turbine plants and a combined cycle plant currently operate as joint ventures among UNE, CUPET and Sherrit Utilities Inc. (a private organization), and a completely private thermal power plant operates on the Isla de la Juventud.

At present, a new law, which defines the regulatory framework of the electric industry, is under review by Government institutions. The law currently in force dates from 1975.

In addition, in 1998 a special tributary system was implemented to support the economic recovery of sugarcane agriculture. This new fiscal procedure provided for exemptions, deductions and allowances according to Law 73 of the tributary system allowing the price of sugarcane to double. As previously stated, in 2002 a restructuring process in the sugarcane industry was implemented.

2.2.11.1. Electricity sector

Since 1959, the electricity sector has experienced three clearly defined developmental stages:

First stage: Up to 1989, an expansion based on technology transfer took place (although using not very efficient technology) and a reliable supply of fuels at preferential prices was established. During this stage, the installed capacity increased from 476 MW in 1959 to 3999 MW in 1989. The major part (72%) was based on thermal power plants using fuel oil.

Second stage: From 1990 to 1995, fuel supplies were severely restricted and consequently the electricity supply and the entire national economy were seriously affected.

Third stage: Since 1996 up to the present, there has been an economic recovery and considerable changes in the energy sector have been implemented, including institutional reforms, the most important of which include:

- Creation of the National Energy Commission, which undertook, among other things, the following actions: substitution of fuel oil by bagasse in raw sugar production and reduction of fuel usage in the sugar refinement process, use of crude oil in thermal power plants in the production of cement, textiles, etc., and elaboration of the DPNES [2.10];
- Increases in the electricity tariff (stepped tariff) for the household sector;
- Introduction of the obligatory payment in hard currency for petroleum products and electricity in self-financed companies;
- Centralized control and distribution of fuels;
- Reorganization of electricity intensive industries (e.g. textile, construction materials and food industries), promotion of the general and intensive use of bicycles, trucks with trailers and railroad cars for the transport of passengers;
- Implementation of PAEC, distribution of compact lamps and subsidized energy efficient light bulbs, replacement of refrigerator gaskets and use of promotional videos and advertisements on rational energy use produced by the Ministry of Education;
- Decree Law No. 260 issued in December 1998 penalizing the illicit acquisition of electricity by altered power meters or illegal connections;
- New electric tariff for the non-household sector, differentiated by voltage levels, schedule of consumption and type of consumer (entered into force on 1 January 2001);
- Electrification of irrigation (mostly based on diesel motors) initiated in 2002.

2.2.11.2. Oil and gas sector

Activity in the oil sector in Cuba began in 1881, but only since 1960 has there been a systematic and detailed exploration programme. Since 1991, exploration programmes have been carried out with foreign companies from Brazil, Canada, France, Spain and Sweden, resulting in the discovery of new oil deposits. The extraction of crude oil and associated gas has grown significantly during the past 12 years, as discussed previously. The current refining capacity in Cuba is 2.9 million t of crude oil in three refineries; a fourth refinery under construction is in negotiation for its completion, which will increase the total refining capacity to 5.9 million t.

Cuba has two manufactured gas production plants, two bottling plants for LPG and two compressor plants for LPG use in transportation.

Institutional reforms

Among the institutional reforms in the oil sector is the programme for the substitution of domestic naphtha in city gas production with associated gas, mainly in Havana and Santiago de Cuba, with financing provided by foreign companies. This programme allows substitution of a large proportion of naphtha while at the same time raising the calorific value of the city gas. This programme also allows the expansion of services to a greater number of consumers and the substitution by LPG of kerosene and alcohol. LPG stoves and cylinders (10 kg gas capacity) are sold at subsidized prices.

Also, in 1998, automobile engines were changed and a shift from gasoline to diesel fuel was implemented to improve efficiency and thus reduce the environmental impact of the transport sector. Also, import standards were introduced to ensure that, in the future, means of transport will be more economic and less polluting. However, in 2002, taking into consideration the high price of diesel and the country's dependency on diesel imports, the Government decided to end the replacement of gasoline with diesel fuelled automobiles and the import of diesel automobiles was minimized.

Finally, national banks have started financing energy efficiency programmes in the hard currency necessary to buy equipment and materials, which otherwise would not be obtainable.

2.2.11.3. Renewable energy

With respect to renewable energy sources, Cuba has developed capacities and experience in the production of solar heaters and photovoltaics, turbines for mini-hydropower plants, windmills and different hydraulic applications such as rams, siphons, water pumps, solar dryers and distillers, and controlled climate chambers.

Different projects have been implemented to assess the economic and technical feasibility of using oleaginous plants for biodiesel production. The plantations that are not used to produce edible oils are used for this purpose as biodiesel is in high demand in the country and domestic production does not cover all the demand. Plantations of *J. curcas* are used to prevent desertification and to create new jobs in the semi-desert areas of Guantanamo province. Another difficult issue is the supply of fuel for diesel engines to provide electricity to rural communities in mountainous areas in the eastern part of the country. There, biodiesel production from the plant *R. communis* may become a local solution.

With the considerable solar energy capacities and the availability of highly qualified technical and scientific personnel and infrastructure, the country has been able to provide electricity for important community objectives. Its primary accomplishment has been the provision of electricity to more than 2400 schools, so that television and computers are accessible in remote areas (mountains and other places that are difficult to access), and to numerous community medical and social centres.

To reach 100% electrification rates in the coming years, it will be necessary to evaluate the technical and economic feasibility of the technologies available for use in each place. Possible solutions include expansion of the electricity grid, the use of photovoltaic systems, mini- or micro-hydropower plants, wind generators, biomass combustion systems, biogas, urban solid wastes and the use of residuals for energy purposes, as well as hybrid systems wherever it is considered necessary for reliability reasons.

Cuba's potential for achieving sustainable energy development is greatly aided by the availability of a well-educated and highly trained workforce capable of developing energy projects through every stage, from comprehensive energy planning and assessment of potential environmental impacts to project implementation.

Sugarcane biomass

In 1492, when the Spaniards arrived in Cuba, 95% of the territory was covered by forest. These forests were initially cut to provide wood and were later cleared for the cultivation of sugarcane and tobacco. This cutting reduced forest coverage to 16% of the territory by 1959 [2.19].

From 1959 to 1989, the administration and functioning of the State sugar sector was based on agro-industrial complexes, which also incorporated services and industrial transformation. There were also agricultural cooperatives with farmers integrating their lands and goods.

The preferential sugar prices paid by the former socialist countries of the CMEA helped maintain investment in the sugar sector and the diversification of sugar products during this period. They provided for spare parts for tractors, combines, trucks and specialized machinery for the harvest and fertilization of sugarcane.

With continued investment and the expansion of commercial facilities, the land devoted to sugarcane cultivation increased to 1.4 million hectares, equivalent to 38% of the cultivatable area in Cuba [2.7]. During the 1969–1970 agricultural cycle, the largest in the country's history, 156 sugar mills were in operation, and 81.8 million t of sugarcane and 8.1 million t of sugar were produced.

However, the preference given to the sugarcane sector did not allow other important crops to compete with sugar and consequently they were marginalized.

With the 1990s crisis, agricultural production collapsed. The Government implemented a number of fundamental reforms, such as the creation of basic units of agricultural production to facilitate the management of, and improvement in, the efficiency of large State enterprises and the liberalization of agricultural markets. A new system of payments and other incentives for the workers was established and the granting of small land parcels for the usufruct of producers was increased. However, these reforms were ultimately insufficient and the sugar sector has still not fully recovered.

Another important issue is that of alcohol, which is obtained from molasses using outdated technologies with low efficiencies. Alcohol production is also very limited given the other traditional uses of molasses. An alternative would be to introduce new distilleries to produce alcohol directly from the sugarcane juice, with high efficiencies and lower production costs.

Institutional reforms

Among the institutional reforms undertaken in the renewable energy sector are the following:

- Creation of the DPNES [2.10];
- Creation of the Renewable Energy Front (14 October 2002) as a specialized State organization to coordinate and finance the different State institutions involved in renewable energy issues;
- Restructuring of the sugar sector, which started in 2002.

2.3. MAIN ISSUES

The economic development of the country in the 1970s and 1980s led to a corresponding increase in the use of energy and electricity. Through the economic crisis of the 1990s, final energy use decreased and even after the recovery period and up to 2003 has continued to decrease. Electricity use dropped abruptly during the crisis but recovered after that and by 2003 was 4% higher than in 1990.

During the crisis of the 1990s, the lack of fuel availability affected all sectors of the economy. The shortage of fuels had a direct social impact that resulted in increases in electricity demand and in the non-sustainable use of fuelwood and charcoal. The sugar industry was particularly hard hit by the crisis and has not yet recovered.

However, a programme was implemented that allowed the economic recovery of the country based on incentives for production that (i) generated hard currency, especially through the expansion of tourism, (ii) increased domestic crude oil and gas production as well as electricity supply, and (iii) stimulated investments in general.

With the economic recovery, an average annual increase in GDP of 3.8% was obtained between 1995 and 2003. Nevertheless, in 2003, GDP was still 2% below the 1990 GDP. Service was the most dynamic sector in this growth, with tourism playing a very important role. Other significant factors that characterize the energy sector are the increase in the production of domestic crude oil and associated gas, the implementation of national energy and fuel conservation programmes, the modernization of thermoelectric power stations, reduction in total electricity losses, investments in infrastructure for fuel transport, programmes for the substitution of fuels and reduced dependency on energy imports.

The energy intensity of the economy has dropped, but the electricity intensity, with some fluctuations, has remained at around the same level from 1995 to 2003.

Access to electricity expanded to 95.5% of the population by 2003, but the supply of domestic fuels continues to be insufficient.

The main difficulties of the energy sector in the short and medium terms are related to the lack of financial resources for new investments and normal operation of the sector, the dependency on energy imports and insufficient institutional coordination in energy matters.

Therefore, the analysis of important issues is necessary to move towards sustainable energy development.

In the economic dimension there is great potential for efficiency improvements, mainly in the sugar industry (electricity cogeneration and alcohol production) and in electricity generation. The reduction of imports dependence can also be achieved by continuing to increase domestic fuels production.

Within the social dimension, achieving 100% electrification and improving the quality of energy services would raise living standards for the population.

In the environmental dimension, reduction of pollutants from energy activities should be achieved by efficiency improvements, technology innovation and updates, fuel changes, externalities, etc.

The major issue in the institutional dimension is the need to enhance the regulatory energy framework, including the need to develop new electricity laws, etc.

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3. ENERGY RESOURCES

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3.1. INTRODUCTION

Cuba, like most island nations, lacks a large energy resource base and satisfies most of its energy needs with imported fossil fuels. The evaluation of the availability of domestic energy reserves and resources, as well as their future extraction potential, is a necessary task in an assessment of sustainable energy development.

When estimates of potential availability of fossil fuels are carried out, a distinction is made between reserves and resources. In this study, reserves are known quantities that can be extracted with current technology at current prices. Resources are either less certain as to their existence or known to be technically or economically unfeasible or both.

In the case of renewables, the concept of resources needs to be modified. Renewable resources are part of a natural flow that can be regenerated in a time frame that is suitable for human activities. For this reason, it is necessary to refer to renewable energy potential rather than resources.

Both resources and reserves change as new technologies become available or due to changes in the market. This is another reason to distinguish between resources, reserves and energy potential.

3.2. ENERGY RESERVES AND RESOURCES

Comprehensive information about estimated reserves and the potential of energy resources in Cuba is not available. Nevertheless, based on available information, the authors have estimated the country's energy reserves and resources. These estimates are shown in Table 3.1. Figure 3.1 presents the general location of renewable resources in the country.

The reserves of crude oil and associated gas (4095 PJ or 97.8 million toe) are based on estimates made by CUPET in 2005 for onshore fields. The largest Cuban reserves of crude oil and natural gas are located in the EEZ. These offshore reserves are estimated to be almost eight times larger than the onshore reserves.

The sugarcane biomass potential is estimated from the volumes of bagasse and agricultural sugarcane residues that are produced annually based on an average harvest of 35 million t of sugarcane. The potential for electricity

TABLE 3.1. RESERVES AND POTENTIAL OF ENERGY RESOURCES AS OF 2003
([3.1–3.4], authors' estimates)

Resources	Units	Reserves or potential	Oil equivalent (million toe)
Crude oil and associated gas (onshore)	PJ	4 095	97.8
Crude oil and natural gas (EEZ) (offshore)	PJ	29 308	700
Bagasse and crop residues	Annual GW·h	17 500	1505
Peat	PJ	8 374	200
Hydropower	Annual GW·h	1 300	0.10
Biogas	Annual PJ	7.50	0.18
Wind energy	Annual GW·h	2 418	0.20
Firewood	Annual PJ	21	0.50

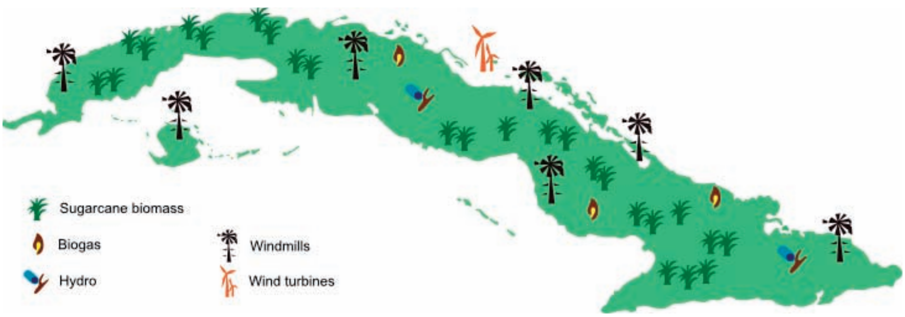

FIG. 3.1. General location of the main renewable energy resources in Cuba.

cogeneration using sugarcane biomass is determined on the basis of the optimal use of installed capacities, assuming an increase in the efficiency of the existing boilers and the introduction of high pressure boilers and biomass integrated gasification combined cycle schemes, so that 500 kW·h/t of crushed sugarcane can be obtained as the maximum potential. This is equivalent to 17 500 GW·h annually.

The wind energy potential to generate electricity is estimated at 2418 GW·h annually. This potential is based on an assessment of only part of the country. Assuming a utilization factor of 23%, this potential corresponds to 1200 MW. More optimistic studies show a potential of up to 2555 MW [3.3].

3.3. FOSSIL RESOURCES

3.3.1. Oil and gas

The oil industry in Cuba dates back to 1881, with the discovery of a naphtha field near Motembo, in the central region of the country. However, it was only after 1960 that a systematic and detailed prospecting programme began, comprising geological and geophysical studies and the drilling of deep wells for stratigraphic and prospecting purposes. Two large sedimentary basins have been defined: the North Basin and the South Basin.

Since 1991, exploration activities have been carried out with the participation of foreign companies; 12 000 km of seismic lines have been registered, 10 000 km have been reprocessed and 15 exploratory wells have been drilled. Altogether, 45 prospecting blocks have been delineated and agreements for 22 of these blocks have been negotiated with companies primarily from Brazil, Canada, France, Spain and Sweden.

As a result of this effort, new oilfields have been found in the North Basin, where heavy crude oil prevails. The Varadero and Puerto Escondido oilfields (both in production at the moment) are located in this northern region of heavy crude oils. The most recent oilfield discovery was in 1994; it is still in the exploration phase and its reservoir is being delineated.

In the South Basin, four oilfields have been identified, in which medium and light crude oils prevail; several wells have been drilled so far but without economic success.

Associated gas extraction began simultaneously with oil extraction, but it was not until 1992–1993 that part of the gas began to be utilized as an energy resource. In 1998, the use of associated gas became more extensive following the establishment of the joint venture company Energas.[14] This enterprise was created for the purpose of improving the environmental conditions of the tourist area bordering the oil and gas production fields in Varadero. From the

[14] Energas became the first independent power producer in Cuba, with a mixed investment from three partners: Sherrit Utilities Inc., which finances equipment; CUPET, which provides the associated gas; and UNE which supplies the electricity market. A 20-year contract was signed in February 1997 (see Section 4 for details).

FIG. 3.2. EEZ in the Gulf of Mexico where oil prospecting is being undertaken. Source: Ref. [3.6].

associated gas (containing up to 12% hydrogen sulphide (H_2S)), Energas produces electricity, LPG, naphtha and sulphur.

Currently, crude oil exploration and drilling activities are being intensified. New extraction techniques have been introduced to increase the productivity of wells. With these actions, oil and gas production has been increased substantially, with 188.4 TJ (4.5 million t) of crude oil produced in 2003 [3.5].

In 1999, the Government decided to open the EEZ, located in the deep waters of the Gulf of Mexico (Fig. 3.2), to foreign investment. It has been estimated through geological studies that resources in this zone exceed 29 308 PJ (700 million toe) [3.7]. The zone, covering 112 000 km^2, has been divided into 59 blocks of 2000 km^2 each, which are currently under tender.

Development of this extractive industry should continue to increase in the coming years. The study of other areas with oil extraction potential and the drilling of new wells continues, and more efficient and productive techniques are being introduced.

On the basis of 2003 extraction rates for crude oil and gas (about 4.5 million t) [3.5] and considering hypothetically that all the reserves can be extracted, estimated onshore reserves will last about 22 years and offshore reserves around 155 years.

3.3.2. Peat

Peat reserves are estimated at 8374 PJ (200 million toe) [3.2]. These reserves are localized in different areas of the country, with the Ciénaga de Zapata being the most important one. Since the beginning of the 1960s, studies on the feasibility of its use have been carried out. These studies have outlined the environmental impacts associated with exploitation of this resource (salinization of water reserves, elimination of endemic species, etc). The results of these studies led the Government to decide against exploiting the peat reserves (see Section 6 for details).

3.4. RENEWABLE RESOURCES

3.4.1. Biomass

Agriculture, besides representing the most important source of food and raw materials for Cuba, is a potential strategic source of renewable energy. Appropriate development of renewables in Cuba may provide technically and economically viable solutions for meeting increasing energy needs. Although the main source of biomass in Cuba is bagasse, there are also sugarcane crop residues and forest biomass, among other possibilities.

3.4.1.1. Sugarcane biomass

Sugarcane is a graminaceous plant whose components — fibre, water and sugar — are used extensively in industry. The forms of sugarcane biomass, such as bagasse and sugarcane crop residues (straw, tops and green leaves), are solid fuels obtained as by-products of the sugar industry.

Bagasse is the main solid fuel used in Cuba at the present time. Its combustion can be carried out directly in the production process without any type of conditioning. The sugarcane industry may use bagasse as its own fuel, which is produced in such quantities as to fully satisfy the thermal energy requirements of the sugar production process.

The calorific value of bagasse depends greatly on its moisture content. A decrease in the moisture value increases efficiency and reduces the amount of excess air needed for combustion, thus reducing the release of exhaust gases to the atmosphere.

The largest sugarcane harvests recorded were in 1970 and 1990. In 1990, sugarcane production was 81.8 million t with a productivity of 57.6 t/ha. From 1990 to 2002, sugarcane production — and therefore bagasse production — fell

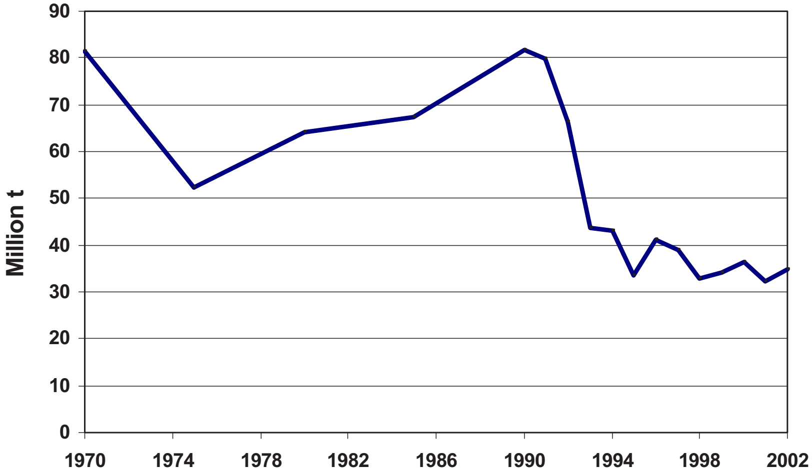

FIG. 3.3. Sugarcane production. Source: Refs [3.8–3.10].

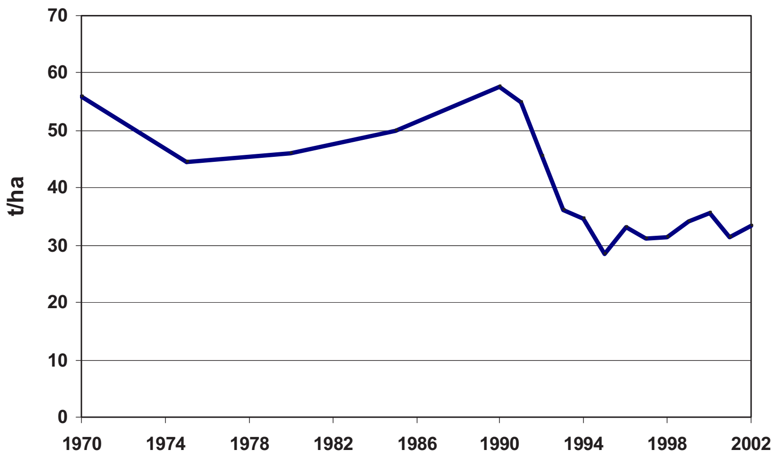

FIG. 3.4. Sugarcane yield. Source: Refs [3.8–3.10].

(see Fig. 3.3), reaching 34.7 million t with a productivity of 33.3 t/ha in 2002 (Fig. 3.4). The productivity decrease was caused by the limited use of fertilizers, the lack of fuels needed to support agricultural activities and a lack of financial resources. Consequently, in 2002, the sugar industry was restructured and this was accompanied by a further reduction in bagasse production.

With a sugarcane harvest of 35 million t, 7.8 million t of bagasse and a similar amount of sugarcane crop residues such as straw are produced. Since 2000, the use of sugarcane straw as a fuel has not been registered in the statistics because the straw that arrives at the plant is milled almost in its entirety with the sugarcane and is added to bagasse.

As an energy resource, the complete and efficient use of all parts of the harvested sugarcane would make available the equivalent of millions of tonnes of conventional fuel every year, in a renewable form, assuming sustainable agricultural practices regarding fertilizer and water usage.

3.4.1.2. Forest biomass

Existing fuelwood potential exploitable for energy purposes, without endangering the ecological balance, is estimated at 3.5 million m^3/a. The fuelwood is not evenly distributed, but is concentrated in mountainous areas, along coasts and on cays. At present, 73% of the national potential is located in seven provinces and on the special municipality of Isla de la Juventud [3.2].

The unsustainable use of fuelwood, mainly in the sugar industry, in local industries and in rural schools, has been decreasing as a result of measures adopted by the Government. Therefore, its share in energy use has fallen from its maximum value of 3.2 million m^3, reached during the economic crisis in 1993, to 1.9 million m^3 in 2002 [3.5].

3.4.1.3. Other biomass fuels

Other biomass fuels are available in Cuba with varied potential. The most significant is rice shells, with a potential of 35.9 TJ (857 toe) per year, followed by sawdust and woodchips (17.7 TJ, or 423 toe), coffee bran, coconut shells and others. In recent years, the production of sawdust and forest waste in the main producing provinces has decreased. The use of rice shells as an energy source has also dropped owing to its use as animal feed. The use of coffee residues for energy purposes has also decreased because of its use as an organic fertilizer.

Municipal solid wastes, which contain at least 50% organic matter, need to be considered as an energy resource for biogas production and electricity generation. There are a number of different projects related to the use of such wastes. These projects are currently in the assessment phase (see Section 6 for details).

3.4.2. Hydropower

Average annual precipitation in Cuba is 1400 mm. In the north of the eastern provinces, the precipitation levels reach 3000 mm. There are about 900 runoff water streams in Cuba, 60% of which flow directly into the sea. However, these waterways are not very extensive owing to the long and narrow shape of the country (with an average width of 97 km).

The estimated hydropower potential is about 650 MW, with an annual generation of around 1300 GW·h. Of this potential, only 57.4 MW was used in 2004 in 157 facilities, with a generation of 128 GW·h [3.11]. Around 50% of this potential is located in the Toa-Duaba Basin. However, this potential cannot be exploited because the basin is an environmentally protected area with a large number of endemic species.

In 2000, a programme was initiated for the construction of 27 small hydropower plants in existing dams, as well as for siting small hydropower plants in the main mountainous massifs of the country. This programme will enable the installation of 46.1 MW capacity plant that could generate about 202 GW·h/a. Only one plant generating 3.2 GW·h/a has been completed. Currently, five new plants are under construction and the remainder should be completed by 2010. Their investment costs range from 1850 to 2380 pesos/kW of installed capacity.

Although turbines for these hydropower plants are produced in the country, the implementation of this programme has been postponed because of the lack of necessary financing. In order to extend the use of Cuba's hydropower potential, the economic and technical feasibility of new sites must be assessed, taking into consideration the benefits of this resource for electrification in isolated areas located far from the electricity grid. It should also be taken into consideration that, in the case of hurricanes and other natural disasters, hydropower can play an important role in the supply of electricity for different economic and social objectives in the event of disruption of the fuel supply to these locations.

3.4.3. Wind energy

In Cuba, windmills have been used as a basic solution to the problem of providing water to cattle; therefore, they are widespread throughout the country. In 2002, a total of 6767 devices contributed the equivalent of 75 TJ (1797 toe), while at the same time supplying water to cattle and for other agricultural activities [3.11].

Currently, the main obstacle to the efficient operation of this equipment is the lack of financial resources needed to conduct effective maintenance and repair activities. The development of windmills in the country has been limited by problems related to poor quality of equipment, lack of competitiveness of the windmills and lack of financing, in spite of the fact that there is significant demand for this equipment. The current cost of each mill in Cuba is 1200–1400 pesos. Between 300 and 600 units are produced annually, which cannot satisfy the annual demand of 4000 units. Each of these windmills can contribute about 1.4 toe/a.

The production of classic multivane mills has been restarted at the Bayamo factory in Granma province. The development of new models for pumping water is being studied and the possibility of using them to generate electricity is being assessed for specific applications such as electrification of fences, which can reduce the costs of pasturing.

Among the renewable energy sources available in the country, wind energy for electricity generation could provide a significant share of the country's energy balance. Its use in appropriate sectors and places will meet short term local demand and in the medium term could complement generation of electricity by the NES or by other isolated electric systems.

During the 1990s, studies were carried out to assess the potential of the wind resources in the country. The results were as follows:

— Cuba's first wind atlas, developed by the Institute of Meteorology, which was limited by the analytical tools used for taking measurements in meteorological stations;
— Measurements in 23 places carried out by the wind energy group Engineering Enterprise for Electricity with finance arranged by the non-governmental organization CUBASOLAR.

Between 2003 and 2005, a number of institutions, such as the Institute of Meteorology and ECOSOL [3.3], worked to generate a wind map of Cuba within the framework of the international project known as the Solar and Wind Energy Resource Assessment.[15]

The first results from this project identified 448 km^2 as having good wind potential (7–7.5 m/s wind speed at 50 m elevation) and 63 km^2 as having excellent wind potential (7.5–8 m/s wind speed at 50 m elevation). These results are shown in Table 3.2.

[15] This project was financed by the Global Environment Facility and carried out in 13 countries. Its main results are the generation of wind and solar maps of each participating country, a geographical information system that includes these and other maps with information that supports the investment process and feasibility analyses of the commercial use of these resources. The project concluded in 2005.

TABLE 3.2. PRELIMINARY RESULTS ON WIND RESOURCE AVAILABILITY [3.3]

Province	Good (km^2)	Excellent (km^2)	Total (km^2)	Total (MW)	Description
Cienfuegos	9	1	10	50	Zona del Escambray
Sancti Spíritus	38	0	38	190	Alturas de Meneses
Ciego de Ávila	11	0	11	55	Zona costera; cayos
Holguín	195	56	251	1255	Costa Nicaro; Moa
Santiago de Cuba	114	2	116	580	Mayarí Arriba; La Maya
Guantánamo	81	4	85	425	Maisí
Total	**448**	**63**	**511**	**2555**	

It should be noted that the areas of the north coast of the island, from Camaguey to Havana, recognized by the Cuban specialists as being areas with good wind potential (estimated to be of the order of 400 MW), are not included in Table 3.2. This is because the model used underestimated the wind values in the coastal areas. The potential of this region is being reviewed by the Institute of Meteorology.

The wind potential shown in Table 3.2 includes only those areas considered to have excellent potential.

In 1999, the wind park on Turiguanó Island was completed with two wind generators of 225 kW each and a 10 kW wind generator was installed at Cape Cruz, in Granma province. These facilities are connected to the national grid. In Romano cay, there is a hybrid wind–diesel system of 10 kW capacity that works autonomously. The signal transmission tower in La Cana has a hybrid system with a 6 kW wind generator [3.4].

3.4.4. Biogas

The exploitation of biogas is of great interest to Cuba, since it contributes to meeting energy demand primarily in the residential, agricultural and industrial sectors and in rural schools. It is not only the amount of gas obtained that is important, but also the places where it is produced. The biogas units are installed mainly in isolated rural areas, where the most common fuel used is fuelwood and where it is difficult to supply other fuels. The replacement of fuelwood by biogas contributes to environmental improvements.

Biogas potential is considered to be of the order of 176 000 toe annually. This potential is estimated from the available wastes from cattle and pigs, from residues of sugar production, as well as from alcohol and coffee production, in short, wastes which would otherwise constitute forms of environmental pollution.

Biogas potential exists for about 78 million m^3 of waste and biodegradable substances, mainly from sugar mills, alcohol distilleries and coffee processing plants. In addition to providing energy, the treatment of these wastes has an immediate effect on pollution control and means additional production of biofertilizers rich in potassium, which improves land quality.

Although the feasibility of using this source has been demonstrated, advances in its use have not been observed, although there have been positive experiences in the country. One of the reasons many facilities stopped working was the lack of appropriate business management mechanisms for assisting users in the maintenance and operation of the installed systems.

3.4.5. Solar energy

In Cuba, solar radiation has a significant energy value ($\sim$5 $kW{\cdot}h{\cdot}m^{-2}{\cdot}d^{-1}$). This value does not vary much from one place to another owing to the island's elongated shape and its east–west orientation. The variation is minimal from one month to another, which favours the use of this source of energy throughout the year. Solar radiation is used directly in thermal and photovoltaic transformations in the form of heat and electricity.

More than 8000 photovoltaic panels are installed in the country in rural schools, medical locations, social facilities, signal systems, etc., to provide an important supply of electricity during the day, during periods of high electricity demand for the mentioned activities, with minimal storage necessary for electricity use at night and for communication systems.

A programme evaluating the massive use of solar water heaters has been implemented.

3.5. MAIN ISSUES

The analysis of energy resources in Cuba shows that fossil fuels will maintain their dominant role in the national energy balance, mainly because of the current large share of domestic and imported oil and associated gas and the prospects for increases in domestic production. The Cuban oil and gas industry has been one of the most dynamic sectors in the Cuban economy in recent years, achieving significant progress in exploration and extraction and in the development of transport infrastructure for fuels.

However, the reserves being exploited in the north of the country are heavy crude oil with a high sulphur content. The use of this crude oil in the refining process is limited for this reason and the dependency on petroleum product imports is high. Preliminary studies carried out in the EEZ in the Gulf of Mexico have demonstrated the existence of light crude oil. The exploitation of this zone would enable the country to cover the demand for crude oil and petroleum products in the long term.

The decrease in sugar production, and therefore in sugarcane biomass, at the end of the 1990s has caused a reduction in the share of this renewable source in the country's energy mix. It is expected that restructuring of the sugar industry will enable the country to recover and return to previous levels of efficiency and productivity. To exploit this potential, it will be necessary to increase the sugarcane yield per hectare, to increase energy efficiency and to install boilers with more efficient parameters and new turbines in existing sugar mills in order to increase electricity cogeneration.

Wind energy is the form of renewable energy most likely to penetrate the market, since the preliminary potential can already cover up to 6–8% of current electricity generation. The wind atlas of the country was completed in 2007 and includes all the wind potentials identified in the country to date. The Government has decided to install 100 MW of wind energy plant in different parts of the country by 2008. It will be a challenge for the national industry to manufacture some of the parts of the wind generators, which would reduce their cost. The expected availability of electricity from wind converters is around 25%.

Exploitable hydropower potential is limited and whether or not it will be used will be determined mainly by technical, economic and environmental conditions.

The solar potential in Cuba is very high and its exploitation is currently very low. Social programmes dedicated to providing electricity to 100% of the population in the country have favoured the use of photovoltaics. Solar thermal energy could increase its share, at least in the public sector. Some subjective and objective problems need to be resolved, such as reassuring public opinion about the reliability of this kind of system and the enhancement of infrastructure for the maintenance of solar photovoltaic installations.

Although the country has large reserves of peat, these have not been exploited owing to the potentially negative environmental impacts. Nevertheless, studies are continuing to evaluate whether it is possible to exploit peat on a small scale in such a way that minimizes the environmental consequences.

In conclusion, the country has limited energy resources. If oil is discovered in the EEZ of the Gulf of Mexico and if it is possible to introduce biomass gasification integrated combined cycles, Cuba's dependency on energy imports would be reduced considerably. Furthermore, it is necessary to find alternative financing to increase the introduction of other forms of renewable energy that can meet the energy needs of isolated regions.

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4. TECHNOLOGIES, EFFICIENCY AND INFRASTRUCTURE

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4.1. INTRODUCTION

Starting in 1959, Cuba underwent a series of profound economic and social changes. Among these were the nationalization of industries, the implementation of agrarian reform which eliminated the division of the land into large estates, and the education and training of the population. Immediately after these actions were undertaken by the Government, the United States of America introduced an economic embargo of the country, resulting in supply shortages and the exodus of Cuban specialists, doctors and technicians. The lack of spare parts for equipment, mostly of North American origin, forced Cuban specialists and technicians to rely heavily on their ingenuity and to carry out all kinds of adaptations so that industries could continue working.

The technology in use at the time was eventually replaced with technology from the former Soviet Union, which, although not considered state of the art, enabled the country to develop and carry out an industrialization process. The Soviet technology was inefficient and wasted considerable energy. Cuba's industrial sector continued to grow, but not within a competitive framework. Special attention was devoted to creating the capacities necessary to construct sugar mills using domestic technologies and resources, and to developing different models of sugarcane harvesters and other agricultural equipment designed especially for the sugar agro-industry. In addition, the production of sugarcane by-products was emphasized.

The Cuban economy was opened up to foreign investment in the 1980s, but this investment became more significant after the economic crisis of the 1990s and the almost total elimination of supplies from the CMEA member countries. Many joint ventures were started in this period.

With the loss of inexpensive fuel imports from within the CMEA trade framework, Cuba focused on increasing its domestic production of oil and gas. It has had considerable success in its exploratory oil drilling with advanced technologies, 'at risk' explorations, etc., which have enabled the discovery of new oilfields and led to a considerable increase in domestic crude oil production. With the airtight sealing of oil wells, associated gas has begun to be used for electricity generation and the production of manufactured gas and LPG. In addition, infrastructure for fuel transport (gas and oil pipelines, supertanker bases, etc.) has been developed.

The electric power industry has also undergone significant development, ranging from the increase in capacities to the improvement of all voltage lines and substations throughout the system. The social impact of rural electrification, based mainly on renewable energy, has been significant. Electrification has also boosted development of Cuba's industrial sector, aimed at meeting energy needs through the production of small hydraulic turbines and the construction of windmills, solar photovoltaic systems, inverters and different applications related to solar energy (dryers, distillers, controlled climate chambers, etc.).

In stark contrast is the development of the sugar industry (with sugar being the country's most important export item), which was dramatic until the end of the 1980s, after which it was severely affected by the crisis of the 1990s and by the low price of sugar on the world market. Electricity cogeneration in the sugar industry accounted for 18% of all electricity generated in the country in 1970; by 2003 this figure had decreased to 5% [4.1–4.3].

4.2. DOMESTIC TECHNOLOGIES FOR SUSTAINABLE DEVELOPMENT

4.2.1. Sugarcane conversion

As the sugar industry grew in the 1970s and 1980s, the area devoted to sugarcane cultivation increased from 1.25 billion ha in 1970 to 1.42 billion ha in 1990, leading to an increase in sugarcane production from 52.2 million t up to 81.8 million t over the same period. The productivity increased from 41.7 t/ha in 1970 to 57.6 t/ha in 1990. The economic crisis of the 1990s significantly affected the sector and in 2003 the area devoted to sugarcane cultivation was down to 1.041 billion ha and sugarcane production had decreased to 34.7 million t and productivity to 33.3 t/ha [4.1–4.3].

The cultivation of sugarcane is carried out in seven-year cycles with an annual harvest season. After seven years, it is necessary to plough and sow the fields. As different insects and plant diseases have long affected sugarcane plantations, much research has been carried out in Cuba and other countries to develop improved varieties of sugarcane that are resistant to these pests and diseases.

Sugarcane biomass is in the green stem (75%) and in the sugarcane agricultural residues (SAR); the latter include shoots (the upper section of the plant, 30%), dry leaves (30%) and green leaves (40%) [4.4]. The profitable biomass, in terms of energy, is the bagasse and the SAR. Bagasse represents 30% of the crushed green stems and is the fibrous residue of this process. It is obtained with 50% moisture content, which means that for each harvested hectare it is possible to obtain 13.5 t (2.7 toe) of bagasse annually [4.5].

The use of SAR as a fuel depends mainly on whether these residues can be collected. In Cuba, 70% of the sugarcane harvest is automated by means of harvesters that reincorporate 50% of the SAR into the field. The 50% of the agricultural residues that are brought from the field are then separated from the harvested sugarcane in collecting and cleaning centres. On average, it is possible to gather 3.75 t (0.62 toe) of SAR per hectare of harvested sugarcane [4.5]. Cleaning centres were eliminated in 2002 and the sugarcane is now sent to the sugar mill with the agricultural residues.

The use of SAR in Cuba is limited to the production of briquettes for household and community cooking and for combustion in a locomotive adapted to burn this fuel. This practice, however, is not widespread throughout the country.

Bagasse is the main source of energy in sugar production. The mechanical energy requirements of the technological process of sugar production are low compared with the thermal energy requirements. The use of bagasse at low pressures allows for the possibility of using an electric power cogeneration system. Steam consumption for all these processes has shown values ranging between 370 and 550 kg of steam per tonne of sugarcane, depending on the thermal scheme used. Electricity input is about 21 kW·h/t of crushed sugarcane. A design that uses steam efficiently allows bagasse residues of the order of 20–25% to be obtained [4.6].

Although Cuban experts have tried to improve energy processes, most of the technologies for steam and/or electricity cogeneration in the sugar industry are obsolete (some are 50 years old). Their original design and thermal schemes were intended to burn all the bagasse, thus avoiding undesirable amounts of solid residues, which clearly indicates that efficiency was not important at the time they were built.

Practice has demonstrated that cogeneration can play an important role in the use of sugarcane residues as fuels and that there is enough renewable fuel for its expansion if the thermal scheme is optimized by selecting appropriate steam extractions and increasing energy efficiency. The introduction of new technologies such as biomass integrated gasification combined cycle can be an important step for future economic development and towards efficiency enhancement.

There are different types of furnace in the sugar mills — such as horseshoe, grill, cyclone and fluidized bed furnaces — with efficiencies ranging between 65% and 85%. The boiler efficiency depends on the efficiency of the combustion of the material to be burned and that of the transfer of heat to the water in the boiler.

During the combustion processes, efficiency losses take place through:

— Heat losses in the exhaust gases released to the atmosphere;
— Incomplete chemical combustion of bagasse;
— Mechanical drag of bagasse particles;
— Heat radiation to the environment;
— Ash content in the bagasse.

Recently, Cuban experts have participated in the design and building of boilers with improved efficiencies for use in the sugar industry.

Regarding the mechanization of the sugar agro-industry, in the 1970s Cuba became the world leader in the production and use of mechanical harvesters.[16] This resulted from a well-designed and well-implemented programme that started in 1964 with the introduction of mechanized lifting. In the 1970 harvest, 85% of the cut sugarcane was lifted mechanically. Currently, 77% of the sugarcane in Cuba is harvested using the KTP harvester. This harvester and all previous versions of this model have been manufactured using Cuban technology since 1977.

In 1981, Cuba's annual production capacity of KTP-1 harvesters was 600 units. Maximum output was reached in 1983 with the production of 650 units. In 1988, the first KTP-2 harvesters were manufactured, which provided substantial improvements over the previous model. Cuba has manufactured three main models: KTP-1, KTP-2 and, recently, KTP-2 M, which is at present the main model used, with more than 4000 units in operation. Two other models, the KTP-2000 and KTP-3000 harvesters, have also been manufactured in small series of 30–50 units, mainly for export, as have prototypes of models 3, 23, CCA-3 and 4000, among others [4.7].

The majority of the crop is harvested mechanically; the rest of the crop (23%) is harvested semi-mechanically, with manual cutting and mechanized lifting. GIMAC 983 lifters have been developed and several dozens have been manufactured for use in Cuba. Small series of 20–30 units have also been manufactured for export, designed in accordance with international technological standards.

In general, all agricultural processes used in the cultivation of sugarcane have been mechanized. Sowing has been the least developed of these processes. It was semi-mechanized by using automated transport of seeds and manual sowing. The remaining operations, including soil preparation, cultivation and

[16] The combine harvester performs the tasks of cutting and chopping and loads the sugarcane into trucks to be transported directly to the sugar mill.

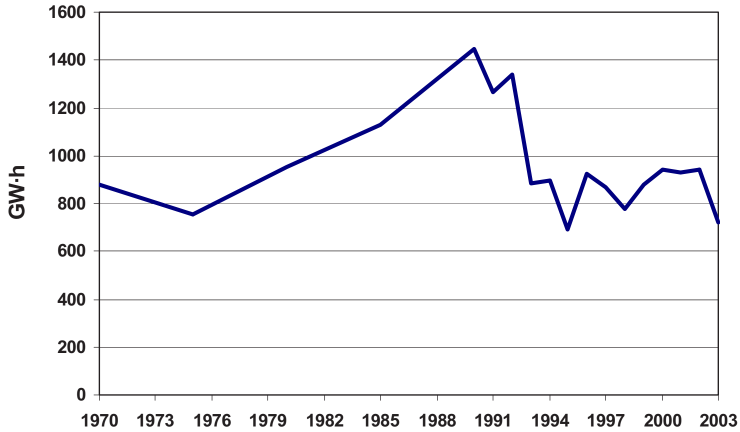

FIG. 4.1. Cogeneration in the sugar industry. Source: Refs [4.1–4.3].

fertilization, were, in general, mechanized using technologies developed domestically. Among the machinery and equipment that have been developed are floating smoothers, integral disk ploughs, drawn disk ploughs, mouldboard ploughs, subsoil ploughs, disk harrows, dyke harrows, fertilizers, sprayers and carts for sugarcane transport. There are a variety of models and versions of every one of these products, enabling mechanization of each task with levels ranging between 77 and 85% [4.7].

Important progress has been made in the production of the equipment and machinery used in sugar mill facilities. The Ministry of Steel and Mechanical Industry manufactures part of the equipment in its Santa Clara mechanical plant and MINAZ manufactures the rest of the equipment. In general, the domestic production of equipment and machinery in the past allowed the fulfilment of plans set by the Government regarding sugar industry growth, covering the workforce deficit and contributing to better working conditions and to the lowering of import dependency.

4.2.2. Electricity cogeneration

The sugar industry is the second largest electricity producer in Cuba. Its share in electricity generation decreased to 5% of the total electricity in 2003, although in 1970 it cogenerated 18% of the total electricity in the country (Fig. 4.1) [4.5].

In 1959, the installed capacity of cogeneration in the existing 159 sugar mills was 317 MW, which generated 369 GW·h. In 1990, the installed capacity increased to 726 MW and generation reached 1449 GW·h. In 2003, capacity decreased to 662.3 MW and 720 GW·h was generated [4.5]. Nevertheless, important changes have occurred in terms of efficiency. Electricity cogeneration per tonne of crushed sugarcane grew from approximately 17 kW·h/t in 1989 to 22.4 kW·h/t in 1997 and to 31 kW·h/t in 2003 [4.5].

This increase in efficiency has been achieved mainly as a result of the increase in the energy efficiency of the main equipment and facilities. This increase was realized by using solutions designed domestically, by installing 42 backpressure turbogenerators that were locally available and by keeping in operation only the most efficient sugar mills. As part of the restructuring of the sugar industry, 15 additional turbogenerators with a total capacity of 35 MW were relocated and brought into operation [4.8].

In spite of the lack of recovery in the sugar industry, in the past four years it has been possible to standardize[17] the electricity distribution systems in 62 small settlements situated near sugar mills comprising more than 50 000 families. This has had an important social impact by improving the quality of life of those families and represents a reduction in energy use estimated to range between 30 and 40% of the electricity supplied to these communities.

Although the sugar industry produces an amount of renewable biomass equal to 5.2 million toe annually, use of this biomass in electricity generation in the country's thermal power plants only amounts to 0.4 million toe. This fact is related, above all, to the suboptimal use of the installed capacity and the technological obsolescence of the industrial sector's energy base. Different variants for better use of this potential have been identified. These variants are classified or grouped according to the terms and financial resources required for their implementation [4.9]:

— *Optimal use of installed capacity.* The quantity of electricity cogenerated in a sugar mill can be maximized by operating the milling plant at its full capacity and ensuring the stable operation of the electric plant. These factors are determined by the regular supply of sugarcane to the sugar mill and the amount of time lost due to shutdowns.
— *Increase in the efficiency of electricity cogeneration using low pressure boilers.* The efficiency of the thermal cycle of electricity cogeneration is

[17] The standardization process transferred the ownership of distribution networks (which provide electricity to small settlements near sugar mills) to the Electric Union. It eliminates the illegal connections and electricity theft, and increases the quality of the service. Now, all the benefits and obligations of all electricity consumers are applied.

determined by the characteristics of the generator and steam turbine. The modernization or replacement of steam generators with the purpose of achieving a thermal efficiency of 80% and reaching steam pressures of 40 kg/cm^2 would make possible the generation of 27.5 kW·h/t of crushed sugarcane. If the backpressure turbines were also replaced with extraction condensation turbines, it would be possible to attain 33.5 kW·h/t of crushed sugarcane.

— *Use of thermoelectric plants in the sugar industry.* A significant increase in electricity cogeneration in the sugar industry has been achieved with the introduction of high pressure steam generators (80 kg/cm^2), which require the use of a generation scheme similar to those used in thermal power plants. In this case, because of the high total investment required, to be economically viable it is necessary to cogenerate electricity throughout the year. In Cuba, the most appropriate fuel is SAR, as these residues are gathered annually in quantities amounting to 1 million toe. The main technological problem to be solved is the compression and preservation of this material for long periods of time. Under current conditions, it is possible to produce 120 kW·h/t of milled sugarcane during the harvest and 300 kW·h/t of sugarcane residues outside the harvest season. Studies show the possibility of installing 1675 MW in Cuba's sugar mills and 41 units of 25 MW and 11 units of 50 MW in thermal power plants, with the possibility of generating up to 9648 GW·h/a.

— *Use of gas turbine cycles.* Thermal cycles for electricity generation with gas turbines have reached a commercial level with the use of natural gas or liquid fuels in thermal power plants. The high thermal efficiency of these technologies (over 40%) makes their investment costs per installed kW(e) the lowest of the technologies that are commercialized in the world at present. The use of sugarcane biomass as a fuel in these cycles has been delayed because the biomass gasifiers required for these applications are still in the research and development stage and work is being done to improve gas cleaning systems. In addition, aeroderivative turbines have not been evaluated under the working conditions of these thermodynamic cycles.

At present, financial support is being negotiated for the three plants Melanio Hernández, Héctor Molina and Jesús Rabí. These power plants are designed to operate throughout the year and to supply electricity to the sugar industry, to the sugarcane by-products plants and to the national grid. The first project, for the Melanio Hernández mill, will use regular bagasse during the sugarcane cutting time. Bagasse from a different variety of sugarcane (known as the 'energy sugarcane') and wood residues or forestry wastes will be used for the rest of the year, depending on their availability and price at each location. In the second project, for the Héctor Molina sugar mill, the use of bagasse during the harvest season and crude oil for the rest of the year is planned. Work is expected to be carried out until 2010 on these three biomass power plants, which will have a total installed capacity of 66 MW.

In addition, cogeneration projects using biomass integrated gasification combined cycle are being analysed. This technology uses an external gasifier for the production of combustible gases from bagasse, which are burned in a modified gas turbine. The combustion gases are circulated through a heat recovery boiler for steam generation; a portion of the gases is used for drying the bagasse. The efficiency in the conversion of biomass to electricity can reach 37%. This type of technology is considered to be at an initial commercial stage at the international level, as there are some facilities of this kind in Brazil.

4.2.3. Technology for the production and use of alcohol

The traditional technology for obtaining alcohol from molasses requires an input of 4.5 tonnes of molasses per tonne of alcohol produced. In the case of alcohol produced from sugarcane juice, 18 tonnes of sugarcane are required to produce one tonne of alcohol.

In Cuba, there are 17 alcohol distilleries with an installed capacity of over 1.5 million hL/a, with daily capacities ranging between 200 and 1200 hL. The maximum annual production (1.07 million hL) was achieved in 1990, for which about 480 000 t of final molasses was consumed (i.e. approximately 20% of the total molasses produced). In 2002, alcohol production was 590 000 hL [4.3]. This alcohol is used for medical purposes, for cooking and for the production of rum. The distilleries operate nearly 250 days a year.

Mixtures of fossil fuels and hydrated and absolute alcohol are being used in many countries. The advantages alcohol enjoys as a fuel are well known from the economic, strategic and environmental points of view. In some countries, the use of these mixtures is required by law. Also, this practice could be an important source of employment for Cuba in the agricultural sector, mainly in the sugar agro-industry, and alcohol could even become an export item.

In Cuba, the current demand for alcohol to be mixed with diesel fuel is approximately 80 000 t/a, equivalent to about 980 000 hL. The alcohol–diesel mixture has a concentration of alcohol of about 7.4% [4.10].

MINAZ and CETRA have carried out the following tests:

— Use of technical alcohol ‘A’ (hydrated) mixed with regular gasoline in a 25% blend in a joint MINAZ–CETRA project.

— A one-year road test of a fleet of 39 vehicles (light and heavy) belonging to the Camilo Cienfuegos, Héctor Molina and Antonio Guiteras sugar mills fuelled by an alcohol–gasoline mixture, which had positive results.
— Use of technical alcohol 'B', mixed by injecting it in a diesel motor in blends of up to 25%. Recently, the High Polytechnic Institute José Antonio Echeverría finished bench tests and reported positive results and will shortly install the engine in a vehicle belonging to the Camilo Cienfuegos sugar mill to begin road tests.
— Use of anhydrous alcohol mixed with diesel in blends of up to 8%. This project is the result of an agreement with the Central Commission for Foreign Currencies, to which MINAZ and MINBAS should soon present the results of this experiment.

Currently, the alcohol industry under MINAZ can produce about 1.83 million hL/a (assuming a 90% utilization rate and 330 days of operation). The production is carried out using the final molasses obtained in the sugar production process and the standard fermentation technology and atmospheric distillation. At present, absolute ('pure') alcohol is produced at only one distillery. Investment in a 1000 hL/d alcohol dehydrating plant that would use technical alcohol 'B' as a raw material has been proposed [4.6].

Sugar production is currently undergoing a restructuring process. A number of sugar mills with a potential production of about 3.5 million t of sugar are expected to remain in operation. That capacity guarantees an annual production of 1.4 million t of molasses (assuming an industrial yield of 12% and the production of 35 kg of molasses per tonne of sugarcane).

Of the 1.4 million t of molasses, some 600 000 t are allocated to meet the needs of animal husbandry and export markets, while another 226 000 t serves other, non-alcohol purposes. The 574 000 t remaining will be used to produce alcohol, which would be enough for about 1.42 million hL with an index of 405 kg/hL of alcohol at 100º Gay-Lussac. Current alcohol production is about 1.02 million hL.

The amount of alcohol produced for mixing with diesel (about 400 000 hL) would be enough — once it has been dehydrated — to satisfy 41% of the demand to mix with diesel in a static (current) scenario or 27% of the demand in a scenario with fairly high growth. Under these conditions, there is little possibility for alcohol exports. In order to increase alcohol production, ways must be found to reduce the amount of final molasses used in the process, to use other inputs for producing alcohol and/or to control the types of molasses that are given to cattle.

The use of alcohol as a fuel for cooking should decrease in the future, as there are plans to replace it with LPG and electricity. If mixed with oil products, this alcohol (500 700 hL) could be used for transport.

4.2.4. Fuelwood and charcoal production

Annual fuelwood production amounts to approximately 1.8 million m^3. Charcoal production, which was around 60 000 t in 2003 [4.3], is currently at a level that is sustainable in light of the forest reserves of the country and considering the replacement and reforestation rates. However, the sudden decrease in the availability of hydrocarbons during the crisis of the 1990s increased the use of fuelwood and charcoal, mainly for cooking, both in the public and household sectors. In turn, this pressure on fuelwood and charcoal supplies favoured the increased planting of tree species appropriate for use as fuel and in charcoal production; the spread of beehive type ovens for more efficient charcoal production (2.5 bags of charcoal per m^3 of fuelwood, instead of the 1.4 bags produced in traditional ovens); the general use of chicken incubators similar to those used in Brazil (such incubation traditionally has used 50% of the charcoal at the national level); and the development and increased use of efficient low density solid fuel cookers that are 5–10 times more efficient than traditional cookers.

During the past few years, the Ministry of Agriculture has been working on an energy forest programme and 27 000 ha have already been planted (which have been exploited since 1997) at a cost of 730 pesos/ha.

In view of its social benefits compared with fuelwood, priority has been given to charcoal production by the increasing use of the Brazilian beehive type ovens. In this introductory stage, a 30% efficiency increase has been reached in the conversion of fuelwood into charcoal compared with traditional ovens. According to international experience, a 70% increase in efficiency could be obtained and realize cost reductions of 60–70%.

Advanced procedures for the drying of fuelwood in Cuba resulted in a 20% increase in energy efficiency. Measures for the improved management and distribution of forests are being implemented, which include final cuts, harvesting, better use of forest residues and the immediate reforestation of the areas where trees have been felled.

4.2.5. Biogas production

Anaerobic treatment of organic wastes, aimed at neutralizing their harmful effects (domestic or industrial), not only helps protect the environment but also produces fuel – biogas – and organic fertilizers obtained from the wastes of the treatment plant.

In Cuba, research on anaerobic processing of cattle and pig wastes has been carried out since the 1970s. The use of these technologies has been encouraged. First, fixed dome biodigesters with and without drying beds were developed. Then, considering the need to find solutions for the treatment of waste from small scale, family run pig farms, a variant of the plug flow biodigester was developed. However, this activity experienced a decreasing trend until the 1990s, when it recovered to its initial levels as a result of the energy crisis. Nevertheless, the lack of maintenance and training of end users, and in particular the lack of companies in charge of commercializing these facilities, are responsible for the fact that the majority of these simple biodigesters and plants are no longer used.

At the beginning of the 1990s, a new model of treatment plant was introduced. The new design showed certain improvements, such as reduced wear, the ability to withstand higher pressures and higher fuel storage capacity. Although it was based on traditional designs, some design modifications were carried out, such as sludge extraction systems and the use of different domestic materials for construction. According to official data from the National Statistics Office, 85 biogas plants and 112 biodigesters are currently in operation [4.11] in the State sector (more than 1000 are estimated in the private sector). Among these plants is the Heriberto Duquesne mill/distillery, which produces biogas from alcohol wastes from other distilleries.

A preliminary study [4.10] found that the incorporation of 1600 digesters, with a capacity of 30–100 m^3, to be used in canteens, would provide about 10 000 toe/a. The study also pointed out that, to be economically feasible, they had to be constructed using local materials and had to be amortizable in two or three years, a task to be carried out by project companies. This meant that projects would be developed in which the cost of a digester ranged between 45 and 90 pesos/m^3, or about 2400–5600 pesos for a digester that can provide energy for cooking for about 100 people.

4.2.6. Technologies related to oil activity

The geological studies carried out in the past by US companies as well as more recent studies show the existence of geological structures in the EEZ that are favourable for oil prospecting. Crude oil extraction began to show signs of recovery in 1992, two years before the economic recovery that started in 1994. Although, initially, the extracted volume of crude oil was insignificant, a positive trend in the production was observed. The annual average was twice the volume registered in 1989 and approximately three times higher than that registered in 1991.

Oil exploration in Cuba is based on geological and geophysical methods including field surveys or field measurements, sampling, and seismic, electrical, gravimetric and magnetic surveys. Oil–gas and bacteriological analyses are also undertaken.

The increase in oil discoveries in deep waters and the fact that an increasing number of important companies are devoted to oil extraction aroused Cuba's interest in deepwater oil extraction technologies. Consequently, joint ventures have been established, especially with Brazil, Canada and Spain, for the exploration and exploitation of deposits in the EEZ. An important energy development programme was put into effect in February 2000, with the official opening of the EEZ in the Gulf of Mexico to foreign investment. This area is considered by experts to be the world's most potentially productive offshore oil zone and probably one of the last areas of the world not yet explored for oil.

By the end of 2000, important progress had been made in drilling the first exploratory oil well in the sea platform to the north of Ciego de Ávila province. The 75 km oil pipeline that stretches from the Varadero oil deposit to the supertanker base in the city of Matanzas was completed that same year. The pipeline transports crude oil, replacing the coastal traffic; this provides an economic benefit of more than US $10/t of oil transported.

Exploratory wells have already been drilled in the EEZ, as have assessment wells, used to establish the oil deposit limits. Some of these assessment wells have become production wells. Initially, when it was decided to put the wells into production, they were neither hermetically sealed nor interconnected. Under certain conditions, the oil naturally reached the surface, pushed by the pressure in the oil-bearing strata. However, in other instances it was necessary to install rocking beam pumps or to use other methods to retrieve the oil. When the number of production wells increased, it was decided to connect them wherever possible in order to raise the yield of the wells and to use the associated gas.

Most of the wells in the country are vertical but in some directional drilling technology has been used. Recent developments have made it possible to deviate up to 90^{o} from the vertical position using this kind of technology. Horizontal and multipipe drilling has allowed a four- to fivefold reduction in drilling terms and a five- to sixfold increase in production compared with conventional wells. Improvements in the Rotaflex pumping system have allowed well productivity to increase two- to threefold.

4.2.6.1. Oil refining

Most of the domestic crude oil is very heavy and has a high sulphur content; therefore, it is necessary to use additives (cutter stock, diesel, etc.) to make its extraction and transport easier. At the Matanzas supertanker base, it then undergoes a thermochemical process of dehydration and desalinization at atmospheric pressure. This process makes it feasible to obtain a better quality, higher value product that is easier to transport and which requires lower maintenance expenditures for the clients. This improved crude oil is used by thermal power plants and by the nickel and cement industries.

Before 1959, there were three oil refineries in the country, all of which belonged to North American companies. When these industries were nationalized, the supply of spare parts was immediately stopped. Through the years, the efforts and technical expertise of the Cuban staff has enabled damaged equipment to be repaired with spare parts designed domestically. These industries have been able to continue functioning as the result of the commitment and technical solutions provided by Cuban staff. Today, 86% of all the refinery equipment is produced in Cuba.

Currently, there are three refineries operating in the country, with a refining capacity of 2.9 million t of oil. The upgrading of a fourth refinery at Cienfuegos is being negotiated with foreign firms. When it is finished, the refining capacity of the country will increase to 5.9 million t. This refinery was built in the 1980s with technology from the former Soviet Union and was in operation until 1992 when it was shut down owing to the low efficiency of the plant and to the incomplete refinery process.

The increase in the domestic production of crude oil has enabled Cuba to increase refinery production and thus obtain finished products that are less expensive than imports, e.g. gasoline, diesel and LPG. Consequently, in the last several years, hydrocarbon import costs have been reduced and in 2000 savings of about 90 million pesos were realized.

Initially, there was limited production of these products in Cuban refineries, which processed 1 million t of crude oil in 1999. However, by 2000 that figure had increased to 2.1 million t. This increased production also allowed for an increase in the production of domestic fuels — LPG and kerosene — and thus improved supply to the population, with the support of the country's domestic fuel substitution programme [4.12].

The Ñico López refinery in Havana province, which is the only refinery capable of producing every product, imports a light crude oil with a low sulphur content that, when blended with the Cuban crude oil, enables the best yields to be obtained. In the case of the Hermanos Díaz refinery in Santiago de Cuba province, a more economic crude oil with a lower yield than the light crude oil

FIG. 4.2. Oil facilities in Cuba. Source: Ref. [4.13].

is processed. This refinery produces fuel oil which, in turn, is used by the Ñico López refinery.

These mixtures of selected imported and domestic crude oils have made possible a 20% increase in the proportion of national crude oil in the refining mixture without affecting the production of products or their quality.

The country's facilities for the extraction, storage and transport of oil and gas are shown in Fig. 4.2.

4.2.6.2. Use of associated gas

Up to 1998, associated gas from the main oil deposits (as in Varadero–Cárdenas) was flared without deriving any energy benefits, thus polluting the air and affecting the important tourist area of Varadero. To make use of associated gas and to counteract the environmental impact of flaring the gas, the Energas joint venture company was established with the Canadian company Sherritt International to produce electricity. Sherritt holds 33.3% of the shares, UNE holds another 33.3% and the remaining 33.3% of the shares are owned by CUPET. Sherritt contributes technology and financing, CUPET provides the raw material and UNE, the market. Energas, in addition to producing electricity in gas turbines and combined cycles (highly efficient technologies), also produces LPG, a condensate similar to naphtha (about 40–45 m^3/d) and high purity sulphur for industry (45–50 t/d).

The associated gas is now used in gas turbines for electricity generation in Jaruco. The processing plant used to clean this gas was modernized and enlarged so that the gas could be used as a raw material in the production of a higher quality manufactured gas at the Melones factory, in Luyanó. A new combined cycle plant is foreseen for these locations.

From Jaruco, the associated gas is supplied through a gas pipeline to the other distributor of city gas in the provincial capital, the Marianao factory. At present, most of the city gas in the capital is obtained from associated gas, which represents an annual saving of more than 8–9 million pesos, as it substitutes for naphtha. Now naphtha can be exported to finance other CUPET operations.

This situation has allowed greater availability and wider distribution of city gas, especially in Havana. The distribution system has been improved and enlarged, and gas meters are now widely used. The meters have led to a reduction in city gas use per household.

In addition, joint ventures have been established with a Dutch and a French company in order to build two new plants for LPG production, one of them in Havana and the other in Santiago de Cuba. The fuel substitution process has also begun in other provincial capitals.

4.2.6.3. Fuel transport

Existing oil and gas pipelines, as well as those in their final stage of construction, are shown in Fig. 4.3. These pipelines increase the safety of operation and reduce the losses and costs of transport activities. The transport system connects the oil deposits with the LPG and city gas producing plants,

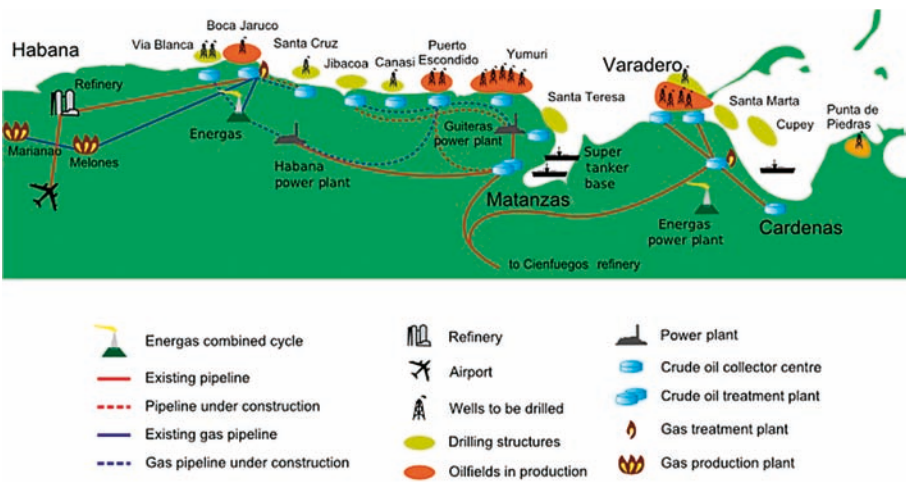

FIG. 4.3. Cuban energy network. Source: Ref. [4.14].

the supertanker base, the Ñico López refinery and the José Martí International Airport.

Before the construction of the oil pipeline, oil was transported from the port of Cárdenas to the supertanker base by ship, which resulted in an additional cost of 7–10 pesos/t, in addition to the high environmental risks due to fuel spillage in this important tourist area. Currently, the transport of crude oil through the pipeline costs slightly more than 1 peso/t. In addition, the oil pipeline has allowed a continuous supply of crude oil, whereas at times in the past high winds hindered shipping operations. Moreover, the oil pipeline enables the simultaneous loading and unloading of ships at the supertanker base.

To ease the flow of heavy crude oil through the oil pipeline and achieve quality in accordance with export requirements (1400 centistokes), a technique consisting of adding a solvent to the oil was introduced. Therefore, as the crude oil transported from Varadero to Matanzas is lighter, operations and mixtures become easier, the costs for the supertankers and the producing company are lower, and maintenance and electricity costs for pumping are reduced. The oil pipeline, with an original capacity of 1.5 million t, guarantees the transport of current oil production but could also transport up to 2.5 million t.

The pipeline from Puerto Escondido to the Matanzas supertanker base transports about 1000 t/d of fuel; in the past, this fuel was transported by truck using the Via Blanca road. The pipeline from Jaruco to the Ñico López refinery also obviates the need for road transport.

The turboduct enables aviation fuel to be transported directly from the Ñico López refinery to José Martí International Airport, thus avoiding its transport by train.

The gas pipeline from Puerto Escondido to Jaruco transports gas to the associated gas treatment plant. The oil wells in the area of Cárdenas–Varadero have also been hermetically sealed and the supply of gas is sent to the sulphur production plant, to gas turbines and to the Energas combined cycle plant for electricity generation.

Fuel for the thermal power plants of Nuevitas, Felton, Renté and Maximo Gómez is transported by ship.

The LPG is distributed to end users mainly in 19 kg cylinders; the distribution system, which relies on a fleet of trucks, has been enlarged. On average, between 20 000 and 27 000 gas cylinders are filled daily to maintain service.

4.3. OTHER IMPORTANT ENERGY TECHNOLOGIES

4.3.1. Hydropower

Cuba's hydropower industry has progressed through several developmental phases related to the use of different technologies, ranging from the simple waterwheel up to modern turbines [4.15]. The impetus for making use of Cuba's hydropower potential was the need to develop the country's industrial sector; therefore, the necessary equipment began to be imported years ago. The most significant development was the implementation of the programme for building micro- and mini-hydroelectric power plants that began in the 1980s. The majority of the turbines in use were produced in Cuba and comply with international standards (Table 4.1).

In Cuba, more than 400 possible locations for hydropower plants of different sizes have been assessed; 157 plants were in operation in 2004 [4.11]. The isolated hydropower plants, which constitute 82% of the total, render services to more than 30 000 inhabitants, 114 schools, 8 hospitals, 96 medical

TABLE 4.1. NATIONAL PRODUCTION OF TURBINES [4.16]

Pelton turbines				
No.	Model	Head (m)	Power (kW)	Regulation type
1	P18.30	15–50	0.8–5.0	Electro–manual
2	2P18.30	15–50	1.6–10	Electro–manual
3	P15.50	40–320	6.5–148	Electro–manual
4	2P15.50	40–320	13–296	Electro–manual
5	P24.65	30–150	19–216	Electro–manual
6	2P24.65	30–150	38–432	Manual
7	P15.110	300–450	650–1200	Manual
8	P30.15	15–50	0.6–3.5	Electro–manual
Michell-Banki turbines				
1	MB2	10–100	4.5–180	Manual
2	15ª2	5–16	6–53	Manual
3	B40.79	15–60	66–500	Manual–automatic
4	B40.60	10–40	21–330	Manual–automatic
5	Mb	4–20	5.8–8.8	Manual
6	MB60	15–50	130–1000	Manual–automatic

offices, 34 agricultural camps, 26 bakeries, 100 food stores and 165 other economic and social buildings.

The average cost of a 30 kW mini-hydroelectric power plant was approximately 60 000 pesos up to 1993, of which 35% corresponded to the equipment, 60% to construction, assembly and piping, and 5% to other costs (projects, studies, etc.). The distribution and total costs depend on the specific technology type, the country of origin of the imported parts and other factors related to the way the plant is used. The costs could be even less and compare favourably with costs elsewhere in the world for the following reasons:

— The enterprises have gained valuable experience since they have worked on the projects from the very beginning and have carried out simplifications and standardizations, have incorporated simple construction processes and have used local materials.
— The construction and assembly have been undertaken by small specialized teams with the support of the beneficiaries.
— The main equipment, such as turbines, has been mass produced. The domestic engineering industry has already developed eight Pelton type models and six crossflow or Michell-Banki type models that satisfy a great deal of the country's demand for turbines.

Compared with 1993, total mini-hydro plant costs have risen by 5–7%, with equipment costs now accounting for 40–42%, construction costs 50–55% (5–10% reduction) and other costs 10–3%.

4.3.2. Solar energy

Initially, the solar water heating systems installed in Cuba (known as traditional systems) were based on flat solar heaters coupled to thermal water tanks. Later, integrated (compact) solar heaters began to be used on account of their relatively low cost, simple construction and better functioning in tropical climates.

At present, solar heaters of all types are produced, assembled and sold in Cuba. There is enough productive capacity, especially in the Rensol enterprise (Ministry of Steel and Mechanical Industry), to meet the limited current demand for this kind of equipment. Lack of finance for its introduction has been one of the main obstacles to market penetration of this kind of technology.

According to the National Statistics Office, 1806 flat solar heaters with thermal tanks have been installed by Rensol. They are mainly to be found in the tourism sector, which has the foreign currency to finance their installation (as tourists pay for electricity in hard currency). In Cuba, the hotel industry and household sector are the greatest consumers of hot water at temperatures of between 40 and 50°C, heated mainly by electricity, gas, diesel and kerosene.

In 2001, 1.77 million tourists visited the country, each staying an average of 5.8 d (i.e. 10.3 million tourist-days). The average consumption of hot water at 50°C was over 3000 m^3/d or 1.2 million m^3/a. In terms of energy, this represents 43 112 MW·h/a, including energy losses in the distribution grid. Regarding sources of energy, the distribution was as follows: around 45% (19 400 MW·h) from electricity, 23.5% (10 131 MW·h) from heat recovery systems, 20% (8622 MW·h) from diesel boilers, 5% (2155 MW·h) from gas and 6.5% (2803 MW·h) from solar energy [4.17].

Before 1989, flat plate solar collectors with thermal tanks were manufactured in Cuba, but in the early 1990s, during the crisis, their production was stopped. In 1993, systems including imported, manufactured or domestically assembled flat plate collectors began to be marketed again within the country. Recently, the production of highly efficient compact collectors has been developed; these technologies use high quality materials and are appropriate for Cuba's climate.

There is a growing interest in the application of solar heaters in hotels, owing to the rapid recovery of investments and long term fuel cost savings. Nevertheless, the main problem with expanding the use of solar heating has been and continues to be the high initial investment. Although it can be recovered by fuel cost savings within one quarter to one third of the useful life of the equipment, the initial cost is greater than that of other conventional heating technologies. However, comparing the life cycle costs of both systems, solar is much more advantageous than conventional methods.

Solar drying of agricultural and industrial products is another use of thermal solar energy that is of great interest. To dry the medicinal plants demanded every year in Cuba (such as chamomile, calendula, herbs for kidney tea, peppermint, aloe vera, ginger, wild marjoram and plantain) using conventional drying techniques would require 1614 toe.

Research carried out on this topic has enabled the development of a domestic solar drying technology that can be used for a wide variety of products in high demand in Cuba. The production of pharmaceuticals from medicinal plants, wood for multiple uses and fodder, among others, necessarily rely on drying processes, which could account for up to 30% of the total cost of the product. There are about 15 solar dryers of different capacities currently installed in Cuba. Three dryers are located in Pinar del Río (two of 120 m^3 and one of 60 m^3 that contribute 300 000 m^3 of wood per year). In the near future, a facility with a capacity of 75 m^3 and two of 150 m^3 will begin operation in Matanzas province. Another one, also with a capacity of 75 m^3, will start up in

Camagüey. There are plans to increase drying capacities in different provinces for use in the wood industry to reach 1.6 million m^3 of wood production per year.

Electric distillers ranging between 1 and 4 kW are used in hospital laboratories, clinics, schools, universities and even industries, but for many reasons (higher cost, quality of distilled water, etc.) the application of solar distillers has not spread. A few solar distillers have been installed as experimental units in doctors' offices, in laboratories for the production of pharmaceuticals from medicinal plants, in some cays and in the production of small amounts of distilled water for automobile batteries. Their introduction and commercialization in the country will depend on the technical and economic feasibility of their use, on the quality parameters of the water obtained using these solar distillers and on the identification of potential clients for the product.

Rural electrification using photovoltaic panels has created an important demand for distilled water, which is needed to guarantee the normal operation of the electrolytic batteries of these systems. To operate correctly, these batteries require the periodic replacement of water lost mainly to evaporation and 'dragging' (approximately 1 L/month per system unit).

Solar distillation could also be introduced in gasoline stations, transport facilities for recharging automobile batteries and in plant biotechnology laboratories for breeding new species of plants.

In the biotechnology laboratories, a controlled climate chamber is used for plant breeding processes. This chamber includes a liquid optic filter on the cover in a pool shaped design which is aimed at allowing the passage of only the photosynthetic active radiation into the interior of the chamber and eliminating the non-useful radiation. The residual radiative heat inside this chamber is extracted by radiative absorption through cold surfaces and not through air conditioning, thus allowing control of humidity and the concentration of CO_2. The chamber was designed for the conditions prevailing in a tropical climate such as in Cuba, with the objective of making viable, with minimum energy use, the production of high quality in vitro hybrid seeds using biotechnological techniques, as well as for cultivating out-of-season vegetables or obtaining ornamental, exotic plants or plants from other climates.

Since 1987, the experimental polygon of Cuba's Institute for Solar Energy Research in Santiago de Cuba has housed a prototype 36 m^2 climate controlled chamber in which it has been possible to cultivate vegetables such as tomatoes, lettuce, beets, carrots and beans, demonstrating that the temperature and illumination have been satisfactorily controlled. At present, the chamber is being tested with other plant species.

The electrification of schools and other social entities using photovoltaic solar energy has been accelerated in recent years in order to fulfil Government programmes. At the end of 2002, the power installed in autonomous photovoltaic systems surpassed 1.5 MW(p).

In 2004, about 8600 autonomous photovoltaic systems for different applications were in operation in Cuba. Among the main community buildings that were electrified were 350 family doctors' offices, 5 hospitals, 2364 primary schools, 1864 community television rooms, 150 social clubs, dozens of houses, rural boarding schools, camping facilities, television relay stations, telephone systems, cooperatives and fish collection centres. An experimental photovoltaic demonstration system was connected to the grid in the Pinar del Río Museum of Natural History. A 'Radio Cuba' booster station was electrified in La Cana using a hybrid system (wind–solar) that includes 16 kW(p) of photovoltaic solar energy.

Panels and versatile photovoltaic solar systems for domestic use and export are produced in the Ernesto Che Guevara electronic component complex in Pinar del Río province. These systems use imported crystalline silicon photovoltaic cells. Although a technology has been developed locally for the production of these cells with 14% efficiency, it has not been possible to implement this new technology due to the lack of finance. Their production would be competitive for productive capacities larger than 5 MWp/a. At present, the productive capacity is 2 MWp/a in one work shift. Work is being undertaken to start manufacturing inverters and load regulators for these systems. An increase in the existing production capacities is also being assessed.

Preliminary estimates indicate that an investment to produce domestic photovoltaic cells would be very beneficial, both for substitution of imports and for export. The domestic production of cells would save 0.60–0.80 pesos/W(p), which represents 20–25% of the production costs of panels. With a production of 3 MW(p)/a, the investment would be recovered in about two years.

Other possibilities for higher integration of the domestic photovoltaic industry that have still not been put into practice are the production of batteries specifically for photovoltaic systems, as well as calibrated aluminium frames for the production of panels. Also, there has not been an evaluation of the feasibility of producing photovoltaic silicon from domestic sources.

4.3.3. Wind energy

The first Cuban demonstration wind farm began operation in April 1999, with a capacity of 0.45 MW. The wind farm is located on Turiguanó island and equipped with state of the art technology.

The installation of a 1.5 kW wind driven generator for a project on Isla de la Juventud is in an advanced phase; a feasibility study for a wind power project ranging between 20 and 30 MW is being prepared and the installation of a hybrid wind–diesel system (10 kW) is under way in Cayo Romano, as are two others in Maisí and La Gran Piedra.

In 2005, the Government announced the beginning of a wind energy programme aimed at installing 100 MW of capacity before 2008. The international bidding has started, as have measurements using 42 towers of 60–70 m in height at 10 places located across the country, mainly on the northern coast and on the Isla de la Juventud. The possibility of producing spare parts and components for the wind energy systems domestically, particularly the towers, is being assessed.

The use of wind energy for supplying water has made limited progress. Moreover, it has not been possible to take advantage of the existing productive capacities in the engineering industry to increase the use of wind technologies.

In 2004, the country had 6685 active windmills [4.11]. Currently, the main obstacles to exploiting this potential efficiently are maintenance and repairs, and ensuring that financial resources are available. The development of the productive capacity in the country has been limited by problems related to quality, lack of product competitiveness and lack of finance, despite the fact that there is a significant demand for this equipment. The current cost of each windmill in Cuba is 1200–1400 pesos; between 300 and 600 units are produced annually, although there is a demand for at least 4000 units per year [4.10].

At present there are two small manufacturing units within the Ministry of Agriculture devoted to the production of windmills. The first one, a joint venture with Argentina, produces between 200 and 500 units annually. The other, which is completely State owned, produces between 120 and 150 windmills per year.

4.3.4. Nuclear energy

Cuba has a long record of assimilating and using nuclear applications in different sectors. After 1959, activities such as training and technology assimilation were boosted, and infrastructures were created. Construction began on the first electric power reactor of the Juraguá nuclear power plant in 1983 and on the second in 1985. Both reactors are of the WWER 440 advanced antiseismic type, with a V-318 contention enclosure, a control system and a very stringent protection system with established efficiency and safety records.

The civil construction works of the first reactor reached 75%, the mechanical assembly 20% and the electric assembly 17%. Most of the auxiliary or secondary construction works were ready for use when, in 1992, the decision was made to stop construction due to the lack of a third partner to provide the remaining finance needed to finish the nuclear power plant [4.18].

Despite the halt in construction at the Juraguá nuclear power plant, Cuba has not given up its nuclear option for generating electricity and is keeping it as an option for the future.

4.4. ENERGY EFFICIENCY

Improving energy efficiency is an important means of reducing the use of energy and is one of the pillars of Cuba's Programme for the Development of Domestic Sources of Energy created in 1993. Table 4.2 shows the efficiency of the main energy technologies used. No information is available concerning the efficiency of fuelwood, charcoal and city gas stoves. The efficiency of these stoves was estimated by the authors.

4.4.1. Household appliances

Until the crisis of the 1990s, the most widely used household appliances (televisions, radios, washing machines, blenders, refrigerators, irons, etc.) came from the former Soviet Union and were high energy consumers compared with

TABLE 4.2. TECHNOLOGY EFFICIENCIES [4.19]

Technology	Efficiency (%)
Conventional thermoelectric power plants (CTE)	26–36[a]
Peak gas turbines	22
Gas turbines[b]	40
Hydroelectric power plants	
Combined cycles	45
Cogeneration	28
Diesel engines	43
Kerosene stoves	35
LPG stoves	54
Electric stoves	70
Refining[c]	64

[a] Lower efficiency refers to oldest CTE.
[b] Refers to gas turbines with associated gas operated as base load power plants.
[c] Calculated as production of light petroleum products divided by crude use.

the world average. During the crisis, the shortage of fuels resulted in the proliferation of very inefficient homemade electric stoves.

The Cuban Electricity Conservation Programme gave an important boost to energy efficiency and through it, defective refrigerator seals were replaced. Also important was the replacement of incandescent light bulbs with energy efficient ones and fluorescent lamps. A massive educational campaign was carried out and even included the distribution of books in elementary schools and the use of other teaching media.

In addition, a number of standards were approved, regulating the efficiency of imported as well as domestically produced appliances. Some examples are refrigerators and televisions. An example of the new standards is 'CN ISO 60969; 2002 auto-ballasted lamps for general lighting services'; an example of operation requirements is the Cuban standard 'CN ISO 117; 2001, domestic refrigerators'. Requirements for electric power use indices were also put in place.

An important step towards achieving higher energy efficiency has been the implementation of the programme for replacement of some fuels in the household sector, in particular kerosene and alcohol, by other domestic alternatives.

4.4.2. Environmentally friendly architecture

Energy efficiency in construction incorporates the best use of natural lighting, solar water heating, natural ventilation, protection from undesirable effects of the environment (sheltering from solar radiation, remodelling of building envelopes), the use of efficient and energy saving devices, the introduction of materials appropriate for individual construction requirements and the incorporation of energy diagnosis technologies and projects focused on environmentally friendly architecture and passive solar energy.

During the 1970s and 1980s, standards, regulations and calculation programmes for the development of projects appropriate to Cuba's climate were introduced. Translucent plates were also introduced and are now widely used in industries in compliance with international standards, as well as in construction systems known as Girón, in high school buildings in rural areas, in hotels and in industries. Solar protection elements, skylights for natural lighting and orientation with respect to the sun and wind were considered to advance efficient energy use and protection of the environment.

There are a number of laws, provisions and standards to ensure that investments are targeted at energy efficient projects, design, products and materials. Currently, the concept of comprehensive design is being promoted to encourage the building of structures that are appropriate for their specific contexts in order to create high performance buildings. To obtain such results, the energy efficiency and sustainability criteria are considered from the very beginning. Also, planners have begun to consider the influence of the urban environment on the microclimate of exterior spaces and, therefore, also on the interior atmosphere of non-air-conditioned buildings or on the use of energy in acclimatized buildings.

The Ministry of Construction, with the aim of applying the principles of environmentally friendly architecture and energy efficient solutions to projects and construction, considered the rational use of energy and thermal conditioning as an essential construction requirement stipulated by Ministerial Resolution 392/98. The Ministry of Construction also created Technical Standardization Committee (CTN) #40 on Environmentally Friendly and Sustainable Design in Construction[18], made up of specialists from design and engineering enterprises, the Faculty of Architecture from the High Polytechnic Institute José Antonio Echeverría, the CTN #88 Refrigeration and Air Conditioning and the Cuban Electrotechnical Committee. In addition, the Ministry began developing technical standards in support of environmentally friendly solutions, environmental quality and the rational use of energy in buildings.

Some recent building investments have been made in projects that used building technologies that are not suitable to the climate in Cuba and this has negatively affected the energy performance of these buildings. This situation is expected to change as new regulations are put into force and the process for granting licences is better controlled.

In Cuba, energy diagnosis programmes and methods have been developed that allow the evaluation of the energy situation in buildings and the proposal of solutions appropriate for the environmental conditions. To this end, the Ministry of Economy and Planning and other specialized institutions at the national and provincial level develop energy ‘diagnoses’ and audits.

4.5. CURRENT ENERGY INFRASTRUCTURE

4.5.1. Electricity generation and transmission

UNE is the group of State enterprises in charge of electricity generation, transmission and distribution. In 2003, 14 843 GW·h was generated across the

[18] Constituted in 1998 by Resolution 18/98 of the National Standardization Office, it is homologous to ISO/TC 205-Building Environment Design.

country. The total transmission and distribution losses in the same year were 17.5% of the gross generation.

The NES is a unique system that integrates the power generation points with the interconnected points, the Turiguanó wind park and independent electricity producers (see Table 4.3 and Fig. 4.4). NES consists of the power plants that belong to UNE, the sugar industry cogenerators, the interconnected hydroelectric power plants, the Turiguanó wind farm and Energas. The interconnection is carried out by means of double high voltage lines of 220 and 110 kV.

The electricity cogenerated by the sugar industry and produced in small, mini- and micro-hydropower plants is bought and distributed by NES. The Robustiano León hydropower plant (43 MW) belongs to UNE. Electricity produced by cogeneration in the nickel industry is used solely in that industry. Among the other independent electricity producers are the joint venture

TABLE 4.3. STRUCTURE OF NES IN 2003 [4.3]

Technology	Capacity (MW)	%
CTE	3161.4	71.6
Gas turbines	213.0	5.6
Hydroelectric power plants	57.4	1.3
Isolated diesel plants	74.7	1.7
Cogeneration (nickel + MINAZ)	904.4	19.8
Total	**4410.9**	**100**

FIG. 4.4. NES. Source: Authors' elaboration from Ref. [4.20].

company Energas and the Turiguanó wind farm. The Turiguanó wind farm (450 kW) is operated by ECOSOL Solar.

Isolated power plants based on diesel motors are located in different cays to guarantee electricity services in these areas. They are Cayo Coco, Cayo Guillermo, Cayo Santa María, Cayo Largo and the electric system of the Isla de la Juventud. The installed capacity in the cays is 63 MW.

Cuba is a narrow, elongated country requiring an extensive network of electric grids. On many occasions, damage has occurred as a result of hurricanes that have torn down high tension towers, as in the cases of hurricanes Michelle in 2001, Ivan in 2004 and Dennis in 2005, which affected much of the central part of the country and divided NES into two parts. The characteristics of Cuba's electric grids are given in Table 4.4.

Important power plants belonging to NES are located in the eastern part of the country because the development of industries using high levels of electricity was envisaged as occurring there. However, owing to the crisis of the 1990s, these industries were not built and at the moment it is necessary to transfer electricity from the eastern part of the country to the capital, which is the main electricity user. Such transfers result in significant transmission losses.

Evaluations have been made regarding a possible interconnection with Mexico through the Yucatan Peninsula. However, as Cuba is an archipelago, the interconnection with electric systems of other countries would be quite difficult and very expensive.

The crisis of the 1990s stimulated a rapid increase in crude oil extraction, and important adjustments were made so that thermoelectric power stations designed to burn fuel oil could use domestic crude oil instead. At the beginning of the crisis period, tests using the domestic crude were performed in one of the power units. On the basis of the positive results, the same adjustments were made to other power stations, thus allowing the recovery of the electric sector with respect to generation, even though efficiency was diminished.

TABLE 4.4. ELECTRIC GRIDS AS OF 2004 [4.20]

	Voltage			Distribution
	220 kV	110 kV	33 kV	
Extension (km)	2831.4	4084.2	9412.9	61 583
Transformers				114 039
Substations	17	99	← 2184 →	

4.5.2. Measurement and control

In Cuba, there is a meter controlled electricity distribution system that enables the amount of electricity used to be monitored and controlled. The efficiency campaigns and conservation measures carried out in the country are mainly supported by this system for measuring energy used. Tampering with electricity meters is a punishable offence, as is making illicit connections.

Electricity use is measured in accordance with a quality system regulated by the Metrology Law and General Provision 01-98, 'Instruments Subjected to Mandatory Verification'. Traceability is guaranteed, starting from the National Laboratory of Engineering Enterprise for Electricity Pattern. The laboratories involved are accredited by the National Accreditation Body of the Republic of Cuba, which belongs to MEP. Verification and repair of the electricity meters are the responsibility of the Ministry of Basic Industry and are implemented by the electric utility staff in each territory.

Metering the use of fuels is also of great importance. Therefore, factories producing gas and fuel meters have been established and new digital measurement technologies introduced. The gauging of tanks and liquid transport vehicles is obligatory, as is the measurement of flow in pipelines and in all fuel distribution devices according to the standards. Laboratories for the verification and calibration of instruments are duly accredited.

4.6. MAIN ISSUES

Most of Cuba's industrial sector is characterized by its inefficiencies and technological obsolescence as a result of two decades of economic crisis and the technology inherited from former socialist countries. The sugarcane agro-industry and the electric power industry are two of the sectors most affected. In the case of the electric power industry, it has been necessary to keep in operation facilities over 30 years old owing to the current electricity generation deficit. Regarding the sugar industry, the partial or complete closure of facilities could not be postponed owing to their low efficiencies, among other reasons.

Cuba has assimilated foreign energy technologies and in turn developed its own technologies to achieve development. This is especially true with respect to the sugarcane agro-industry, solar energy applications, hydropower and electric power generation.

The development of the oil and gas industry and transport and fuel distribution infrastructure has been very important. It has enabled an increase in electricity generation and a greater supply of domestic fuels, which has boosted the country's economic recovery. Particularly remarkable are the assimilation and adaptation of power stations to burn domestic crude oil and the increase in efficiency of electricity generation and the reduction in transmission losses.

In the sugarcane industry, a high level of mechanization in sowing and harvesting has been reached with tools and machinery produced domestically. This has allowed Cuba to increase production in some periods, to reduce the labour force needed in the fields and to raise income through the export of machinery and equipment. The restructuring process of the sugar industry has made it feasible to increase productivity and efficiency by replacing old equipment and machinery with new models. The results in the design and construction of boilers are remarkable, particularly in the sugar industry. The production of high parameter boilers is expected in the near future. This process of modernization and restructuring will continue in the coming years, provided that financial resources are available.

Significant developments have been made in the design and construction of turbines and other hydraulic devices. Important components, including two types of water turbine, have been developed domestically. The use of wind power has also increased and has been improved with the design and construction of small aerogenerators and water pumps. The production of the latter should increase in the coming years, given the existing domestic demand.

Technologies for the use of solar energy have been assimilated and developed. Examples of such solar technology applications include different models of heaters, dryers and climate controlled chambers. The last item is internationally patented and has many applications in agriculture and biotechnology. In spite of the strong domestic development in solar energy, there are many problems to be solved before its introduction on a larger scale.

The concept of environmentally friendly architecture is being considered in Cuba for the first time. In this respect, actions and measures have been carried out to promote its use in new construction projects.

Low efficiency prevails in electricity generation in Cuba's conventional thermal power plants, although this is not the case in gas turbines and combined cycles.

Although there have been important developments and growth in the transport and energy distribution infrastructure, they have not been enough to cope with the possible development of oil in the EEZ of the Gulf of Mexico.

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5. ENERGY AND ECONOMIC DEVELOPMENT

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5.1. INTRODUCTION

This section examines the role of energy in Cuba's economic development and builds on the overview of the national energy situation presented in Section 2, with an emphasis on its evolution in the 1990s, a period characterized by significant socioeconomic tensions resulting from the crisis brought on by the dissolution of the CMEA and the intensification of the economic blockade. Also, a detailed assessment of factors determining energy efficiency is carried out.

Section 5.2 presents a discussion of the country's socioeconomic evolution; Section 5.3 examines the relationship between economic growth and development in the energy sector; Section 5.4 evaluates energy and economic issues before the 1990s crisis; Section 5.5 reviews the energy and economic policies after the 1990s crisis; and Section 5.6 assesses energy intensities and identifies economic strategies to strengthen sustainable energy development.

5.2. SOCIOECONOMIC EVOLUTION

In the 20th century, Cuba experienced three large external shocks that affected its socioeconomic evolution: (i) the collapse of the sugar industry after World War I; (ii) the imposition of an economic blockade in the 1960s; and (iii) the disruption of trade arrangements with the dissolution of the CMEA in the early 1990s. The analysis of socioeconomic evolution focuses mainly on the most relevant macroeconomic, sectoral, social and economic developments of the 1990s, when the last of these three major crises affected the country.

The first major external shock for the Cuban economy took place soon after the end of World War I with the collapse of the country's sugar industry. Although with World War I sugar production experienced a rapid increase, in 1920 sugar prices on the world market dropped and sugar production in the country stagnated and was decapitalized [5.1–5.3].[19]

[19] This crisis had an important impact on the economic activity of the country, starting with the loss of 80% of exports, which, in an environment of high external dependency, resulted in high levels of unemployment (reaching 50%). The imports component of the GDP was approximately 40% [5.3].

Cuba's economy began to stagnate in the 1920s and it was only in the early 1950s that the real per capita GDP[20] returned to the 1919–1920 level. In 1934, with the signing of the Reciprocity Treaty with the USA, Cuba reopened its domestic market in exchange for a quota in the US domestic sugar market. This 'total opening' policy was implemented just when important steps were being taken to protect local markets in the international arena. Over time, the quota showed a progressive downward trend and in the long run it worked against Cuba's attempts to diversify its national industry [5.3].

In the 1930s and 1940s, some financial measures and Keynesian public expenditures were undertaken with the aim of overcoming the economic stagnation. While the economy revived temporarily as a result of the rise of sugar prices caused by World War II (1939–1945) and, later, the Korean War (1950–1953), the measures were not enough to overcome the crisis.

The second major external shock of importance for the Cuban economy occurred in the the early 1960s when, after growing tensions, the USA declared an economic blockade (also referred to as the embargo) against Cuba. Addressing the problems that arose from the economic blockade required extensive changes in both the structure and operation of the national economy. Significant transformations in the production and economic base began to take shape in Cuba, including the:

— Creation of infrastructure and provision of the equipment necessary to develop the agricultural and livestock sectors, with a special focus on social issues;
— Creation of the technical and material base to produce the capital goods needed to expand the agricultural and livestock sectors;
— Development of basic productive services and the skill level of the labour force to undertake the difficult process of industrialization;
— Raising of the standard of living of the great majority of the population and optimization of the use of human resources and materials [5.3].

After overcoming the disruptions caused by the dissociation from the North American economy in the early 1960s, Cuba began reorienting its trade towards the nations of the socialist block, which culminated in its formal incorporation into the CMEA in 1972. The CMEA's favourable trade terms, combined with Cuba's efforts to jumpstart its economy, led to a period of

[20] All data, growth rates, etc., in this section are in real terms.

historic economic growth and the creation of an egalitarian society in the Latin American region.[21]

However, Cuba's inclusion in the CMEA resulted in certain disadvantages that surfaced only once these trade arrangements ceased. These disadvantages arose from the incorporation of a technological mix that was far behind the international norm in technological terms, energy and electricity intensive technologies based on hydrocarbons, the disregard of fiscal balances, the country's isolation from foreign markets and the consequent lack of competitiveness in these markets [5.4].

The dissolution of the CMEA in the 1990s eliminated preferential trade arrangements for Cuba, creating a major crisis in the economy. The 1990s also saw a reinforcement by the USA of the economic blockade established in 1962 [5.5]. The estimated losses resulting from more than 40 years of embargo reached US $72 billion [5.6, 5.7], representing 2.5 times Cuban GDP_{1997} of 2003.

The basic problem faced by the Cuban economy was a shortage of hard currency and sources of finance, a problem characteristic of many developing countries. However, in this case it was more dramatic because of the economic blockade. This factor was very important in the reformulation of economic policies (industrial, commercial, etc.) and in the institutional transformations necessary for Cuba's competitive reintegration into the global economy.

The Cuban economy adopted a model of extensive development that put particular emphasis on import substitution of finished goods. However, Cuba was still heavily dependent on imports of basic raw materials, fuel and capital goods and remained a large exporter of natural resources and low value added products.

The precipitous drop in the share of raw sugar in total exports in the early 1990s has already been highlighted. There was a slight increase in exports of chemical products, almost all of which came from the pharmaceutical and biotechnology industry, and a notable increase in exports of non-edible raw products, where non-ferrous minerals, in particular nickel and cobalt, became increasingly important.

Drastic changes also occurred in the geographical distribution of exports, showing Cuba's tremendous efforts to reorient itself towards new markets. In line with these efforts, Canada and the regional market represented by the

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[21] According to estimates from the United Nations Economic Commission for Latin America and the Caribbean, between 1950 and 1971 the annual GDP growth rate was 3.4%, while between 1972 and 1985 it almost doubled, reaching an annual average of 6% [5.4].

countries of the Latin American Integration Association became significant export destinations.

An analysis of Cuba's competitive situation showed that slightly more than 90% of its traditional exports were in the group of products whose share was declining within the imports of the OECD countries.[22] However, during the early 1990s, products that have managed to accumulate considerable capacities, such as fish and fresh seafood, processed tobacco, canned fruits, medicinal and pharmaceutical products (especially biotechnology), and nickel and cement, were gaining share in OECD imports.

The first indications that the established economic pattern (which had shown average yearly growth of 7% in the period 1975–1985) was changing were observed in the 1980–1985 period. These included a drop in the yields of tangible fixed assets, increased external dependency, the low efficiency of investments reflected in oversized installed capacities, the use of inappropriate technologies and, in general, significant technological backwardness.

Consequently, in the 1990s, the country was forced to reorient its economy under extremely difficult conditions characterized by:

— Major shortage of foreign exchange;
— Tightening of the economic blockade, which made it more expensive to reorient trade and gain access to credits;
— Drop in the yields of tangible fixed assets;
— Growing current account deficit resulting from the increased dependency on imports;
— Low efficiency of investments reflected in oversized installed capacities, investment in inappropriate technologies and, in general, significant technological backwardness;
— Growing fiscal deficit;
— Significant increase in cumulative liquidity;
— High foreign debt;
— Extremely overvalued official exchange rate, while that of the black market was being quickly devalued, reflecting inflationary dynamics;
— Highly centralized and inflexible institutional organization based on soft budget allocations, taking the existing balance of materials as a reference;

[22] Generally, in evaluating national economic competitiveness, the share of exports to OECD countries is taken as indicative of most international trade, with this market being considered the most dynamic and demanding regarding quality requirements.

— Growing pressure on prices of goods and services controlled by the State caused by the growing excess liquidity, which is characteristic of repressed inflationary processes.

In view of the major depression that began in the early 1990s (the GDP in 1993 fell slightly more than 34% compared with 1989), the Government adopted an economic policy aimed at a gradual and controlled opening of the economy, starting with a significant export effort, accompanied by a major adjustment and resizing process in industry and in the State management apparatus (institutional reform), without abandoning the import substitution policy.

It is important to note that the first steps of the economic adjustment process were taken in 1986, when the 'process for correcting errors and negative trends' began. However, it was not until mid-1993 that the most important actions were taken, beginning with the legalization of the use of hard currency, the regulation of work for self-employed people, the opening of farmers markets in 1994 and, later, the cottage industry market, and the changes in the forms of land ownership with the creation of basic units of agricultural production.

Given the importance of economic opening in the process of economic revival (access to capital, markets and technologies), at the end of 1994 and in 1995, significant steps were taken with the enactment of the Law of Mines and the Law on Foreign Investments (which replaces Decree Law 50 of 1982 on Economic Association between Cuban and Foreign Entities).

At the same time, major organizational changes were undertaken in the institutional sphere, including the resizing of the State's central apparatus and the decentralization of foreign trade management (elimination of the State monopoly in foreign trade), as well as the creation of self-financing schemes in foreign exchange, of new economic institutions (business corporations with Cuban capital or privately owned Cuban companies) and of negotiating bodies within the main State organizations to foster relations with foreign capital. This process was accompanied by the introduction of new industrial management and business administration techniques, in which the tourism sector made important contributions, starting with the agreement on administration contracts.

Studies were carried out on the measures necessary to transform banking institutions to create a central bank and commercial banks with clearly established functions regarding the setting of monetary policy (determination of the type of interest and exchange rates), a national credit policy and a savings system. This stage has been crucial in determining the success of the country's economic policy.

The State's functions in the economy were also reorganized. The role of the State changed from manager to regulator, which was of great significance in the creation of a competitive environment favourable to economically efficient companies.

The adjustment measures applied by the Government managed to stop the downward economic trend. Since 1994, the economy has shown continuous revitalization, leading to the expansion of the industrial sector.

Despite poor sugar harvests between 1993 and 2000, the total value of exported goods grew at an average annual rate of 5.4%. This growth was due in large part to substantial increases in mineral exports, especially nickel and cobalt, exports from the tobacco and fishing industries and other exports, particularly scrap metal, steel bars, beverages and liquor, and coffee.

The export of services in 2000 showed remarkable growth of almost 220% compared with 1993. This translates into an average annual growth rate of 18.1% for that period, highlighting the importance of services in the country's export structure, particularly non-financial services (approximately 99% of the total services) and especially tourist services (hotels, shopping, transport, etc.).

The gross income from the tourism industry increased continually between 1989 and 2000 at an average annual rate of 23%, reaching 1.948 billion pesos. In addition, the number of tourists has also increased dramatically, reaching 1.7 million in 2000.

The trade deficit continued, although with a declining trend during the crisis period. This decline was a result, not of an increase in exports, but of the drastic contraction of imports caused by the crisis. In 2000, the trade deficit reached 674 million pesos (74% lower than the deficit for 1989), equivalent to 2.4% of the GDP at that year's current prices.

The impact that the substitution of domestic crude oil for imported fuel oil has had on the trade balance has been remarkable, because energy and food imports made up two thirds of the imports of goods in the early 1990s. Although in 1989, the fuel industry was responsible for almost 53% of the manufacturing industry trade deficit, by 2000 this had declined to only 36% [5.8].

The economic revival and growth are closely linked to the measures that began to be implemented in the country's fiscal policies and in the financial sector, especially after 1994. These measures have had an effect on reducing the liquidity accumulated by the population and companies, the issuing of currency, the fiscal deficit, the control and execution of the budget, the financial allotment mechanisms and the control of resources. In this sense, several items stand out, including the price increase measures for goods and services considered to be non-essential, the increase in electricity rates, the elimination of some free social services, the deregulation of the market for industrial and agricultural products, and the redefinition and reorganization of the tax system currently in force under the tributary system law.

As for the impact on the State budget, the combination of effects from the application of the tributary system law and the restructuring of the State apparatus — both its organizational and its productive structure (resizing) — and the implementation of financial allotment mechanisms and control of resources has led to a remarkable reduction in the fiscal deficit. This reduction highlights the drastic reduction in subsidies for losses and the increase of revenues from taxes and their contribution to profits. This is how more sustainable levels of public deficit were reached in combination with the restrictive monetary policy. With regard to GDP, the deficit reached its lowest value in 1997 at only 2% of GDP. At the end of 2000, it still was 2%.

Other factors that have also had an impact on these macroeconomic results are the consolidation of measures applied in the reorganization of the State apparatus and the banking system, and in the field of foreign trade and investments.

The conditions favouring foreign capital investments were also consolidated. In addition to the Law on Mines and the Law on Foreign Investments, a law on free trade zones and industrial parks was added, and complementary legislation was being prepared on the functioning of public corporations (to replace legislation established under the old commercial law) and the activity of real estate investments, which were used to expand the scope of possibilities for foreign capital participation.

Until now, foreign capital has been directed towards tourism and other activities where the country has quite clear comparative advantages stemming from its geographical location and endowment of natural resources. Thus, the promotion efforts in international trade are currently aimed at attracting investments in the manufacturing sector, particularly in the most dynamic branches of international trade.

However, important challenges for future economic development remain, among which are:

- The dual character of the economy, worsened by the legalization of the use of foreign exchange, which is having a negative impact, both economically (through distortions in the allocation of material and human resources) and socially by further deepening the income disparities in the population;
- The postponement of decisions regarding, in particular, the adjustment of the exchange rate and the interest rate, which jeopardizes the stability of relative prices (traded/not traded), distorting costs and, in general, exchange relations among entities and providing imprecise data to

investors and resource allocators by not reflecting relative prices, costs and economic benefits with the necessary reliability.[23]

An institutional, legal and regulatory framework must be established to provide the necessary comprehensiveness and coherence to the measures being implemented in the macroeconomic sphere (aimed at achieving stability) and in the microeconomic sphere (aimed at structural transformation of production and resizing of the State's central apparatus).

The reinforcement of the economic blockade exerts a negative impact on the expectations of foreign investors, makes transport (freight) costs and insurance more expensive, hinders access to credits from international financial institutions and makes the conditions for granting them increasingly onerous as the risk factor in the country increases.

Another important aspect is the prevailing market trade conditions. In this sense, the economy is highly vulnerable, given the high dependency on and concentration (low diversification) of exports, based mainly on natural resources and products derived from them, and the continued high dependency on imports, especially imports of energy, food, consumer goods in general and capital goods.

However, Cuba enjoys some significant comparative advantages that should enable it to continue the transformation process and the economic improvements that began in the early 1990s:

— The high levels of human capital based on continuous investment in general basic education, in secondary education and in technical and professional education (especially in the medical, biomedical, biotechnical and engineering sciences). As in the countries of east Asia, high level foreign specialists were hired to work in Cuba and a great number of Cuban students were sent abroad to receive scientific and technical educations, which was also a way of acquiring technology. Cuba also developed a strong capacity for innovation in some sectors of industry and services, in particular those related to health and biotechnology.

[23] It should be pointed out that, despite the recent measures taken with respect to the circulation of the US dollar as a unit of exchange in monetary/mercantile relationships in Cuba (i.e. the replacement of the US dollar by the Cuban convertible peso (CUC)), the promulgation of Resolution No. 92 (the creation of a unique currency account) does not change the situation regarding the challenges posed by the existence of both currencies and the need to adjust the exchange rate and all key prices.

— The existence of a political and economic power structure enabling the control and allotment of resources to support national priorities and develop an economic policy aimed at a controlled economic opening. The Government has the capability to achieve coordination among the different agents (companies, cooperatives, private sector and foreign investors).
— Good sociopolitical stability, despite the strong deterioration of the standard of living of the population during the period of economic crisis. There is a broad support for the Government from the population.
— A healthy population with extensive medical coverage, despite the considerable deterioration in the quality of health services as a result of the crisis.
— The accumulation of capacities and important production experience that constitute a basic starting point for economic recovery, despite the growing physical degree of fiscal decapitalization and technological backwardness.
— The existence of support infrastructure important for the economic transformation process (extensive network of roads, ports, airports, electric grids and lines of communication that cover practically the whole country), an element particularly highly regarded by foreign investors.

Economic and social development in 2004 was notable despite the fact that the country suffered particularly severe weather events (hurricanes and drought), experienced the failure of the main electricity generating unit of the NES and faced an intensification of the economic blockade.

The economy showed a 5% growth in GDP in 2004, with the significant contribution of the public services sector helping to improve the population's quality of life. Despite difficulties, 10 of the 22 branches of the industrial sector grew, particularly mining and non-ferrous metallurgy, with a 10.7% increase; the electronics industry, up 4.0%; and the sugarcane agro-industry, up 14.4%, with efficiency indicators above those of the previous harvest.

Although severe drought affected the country in 2005, the GDP growth rate was 11.8%. The main contributors to 2005 GDP were: investments (39%), tourism (26%) and international contracts for medical facilities and services in 60 countries [5.9]. Moreover, important prospects for investments exist with countries such as China (which offers very favourable financing options) in sectors such as mining, energy and infrastructure. In addition, economic and trade relations with Venezuela are being strengthened.

5.3. ECONOMIC GROWTH AND ENERGY DEVELOPMENT

The issue of economic growth and energy demand has been a subject of interest for many specialists, given the implications that such a relationship has for future energy demand, and consequently for the behaviour of prices on international markets.[24] Changes in the production structure of goods and services and in the consumption of goods and raw materials as a result of economic development are key factors in the determination of energy demand growth. The relationship between economic development and production structure is one of the factors that has been well documented [5.10, 5.11].

It is generally accepted that in the initial stages of economic growth, the share of the industrial sector in GDP increases, which implies that this sector's share of energy use relative to total energy use is quite large in the initial stages of development. In the most advanced stages of the development process, however, the share of services in the value of the GDP grows to such an extent that it becomes fundamental in the composition of the GDP and is accompanied by a 'lightening' of the energy density of the economy.[25] In Cuba, the services sector increased its share in GDP value added, reaching 59% in 2002.

Industrialization processes are characterized by large increases in energy use (resulting from an increase in the production of materials such as steel and cement, which are indispensable for infrastructure development and which present energy intensity values that are much higher than those that characterize the methods of 'traditional' agriculture, characteristic of economies in low stages of socioeconomic development). These increases cause the energy

[24] It is worthwhile to clarify that most analyses of energy demand only refer to the behaviour of commercial energy sources (oil and oil products, gas, coal and hydro), excluding traditional energy resources (fuelwood, charcoal and bagasse) whose 'transactions' in most of the cases, do not take place on the market and which are directly appropriated by the consumers, a distinction that is of unquestionable importance for developing countries. Medlock and Soligo draw attention to this limitation of energy demand analyses [5.12]. However, in favour of such analyses, they outline the remarkable reduction in the share of traditional sources (mainly biomass) in total energy use and point out that this use is concentrated in the residential and commercial sectors of these developing countries.

[25] Similar behaviour was observed by Malenbaum [5.15] in relation to the reduction of the material intensity with the growth of GDP, a phenomenon known since then as 'dematerialization'. Later studies have found similar behaviour for a wide spectrum of raw materials, energy resources and even for waste materials and polluting gases [5.16].

intensity of the economy to grow significantly at this stage (as observed in Cuba during the 1970s and 1980s).

Bernardini and Galli [5.13] identify three of the fundamental factors that guide the reduction of energy intensity and use of materials, namely:

(1) Changes in the structure of the final energy demand;
(2) An increase in efficiency in the use of the energy and the raw materials;
(3) The replacement of materials and forms of energy with more efficient ones.

It would be of interest, especially when analysing the relationship between energy and development, particularly in the economies of developing countries, to have clearly defined the conceptual differences among use, demand and requirements on the one hand, and supply and use on the other [5.14].

The concept of 'demand' is directly related to the existence of markets where prices and quantities give the signals for the execution of transactions. Thus, those amounts of energy, mainly from biomass, that are acquired by direct appropriation[26] would be outside this definition. The concept of requirement is directly related to the satisfaction of energy needs associated with a certain final 'service' (e.g. feeding, transport and comfort, in the case of homes) or related to the production of goods and services (driving force and heat, among others). Finally, the concept of use is linked to the quantities — of energy in this case — that really occur, in terms of both demand and requirements.

Just as in the case of demand, the term 'supply' refers to the energy that has gone through a formal market in which users willing to purchase a certain amount of it deal with producers willing to sell under certain conditions. The concept of supply (in the sense of provision), just like that of requirement, is wider and tries to cover all those energy flows that, whether going through the formal markets or not, contribute to meeting the energy requirements of the socioeconomic system in question.

It is evident that such distinctions are significant, from both the conceptual and the statistical points of view. These differences are considered

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[26] It is necessary to clarify that this group includes not only biomasses such as fuelwood and other wastes that are directly gathered or obtained as a result of a certain industrial process, but also those sources that are directly captured by the end users, as in the case of solar energy in its different variants.

in the energy demand and supply evaluations and scenarios developed and described in Section 10.

5.4. ENERGY AND ECONOMIC ISSUES BEFORE THE 1990s

From the point of view of energy sustainability, the energy situation prior to the economic crisis of the early 1990s can be characterized as one of high dependency on imported energy, high energy intensity, wide electricity coverage (almost 95% of the population served versus an average of 74% in Latin America) and quite modest use of renewable energy sources, especially biomass.

The evolution of energy activity in that period can be characterized according to five areas:

(1) *Production structure.* Exporter of natural resources and basic products derived from them, with low added value and high energy intensity; an industrial sector that produces energy intensive intermediary products; oversized installed capacities, with a low percentage of use and negative implications for energy efficiency; extensive agriculture, with a high level of mechanization and high energy demand, especially for diesel and gasoline.

(2) *Technological structure.* Equipment, technologies and engineering processes far behind the international frontier of technological possibilities; intensive energy technologies using mainly oil products and electricity.

(3) *Management.* Organizational, production and distribution patterns and resource assignment for the execution of goals or production plans detached from financial mechanisms of planning and control; substitution of minimizing cost objectives and, in general, of economic performance (more directly related to 'commercial' companies), for that of goal satisfaction and strongly committed to the objectives of distributive equity; high centralization of power, both in resource allocation and in decision making; 'chronic' shortage of financial resources and credits, which has determined, to a great extent, that activities directly generating foreign exchange be given priority while other important activities, such as those of rational energy use and energy efficiency, be relegated.

(4) *Foreign trade.* Favourable exchange relations, 'soft' credits, guarantees in energy (oil and petroleum products) and technological supply; the 'international division of labour' within the framework of the CMEA perpetuated the country's role as an exporter of raw materials and, as a result, the low diversification of national income sources; not very

demanding markets with regard to the quality of the exchanged goods and services, with strong competitive bias in relation to the rest of the international trade.

(5) *Energy policy.* Lack of an integrated and coherent policy on rational use of energy and lack of a strategy for sustainable energy development; fundamental emphasis on reducing the use of oil and oil products, not necessarily as a result of the application of any specific measures; insufficient energy regulatory framework regulation, supervision, and use of incentives and penalties in connection with the use of energy.

5.4.1. Energy and economic policies after the 1990s crisis

The economic crisis of the 1990s meant a dramatic reduction in energy imports, in particular of crude oil and petroleum products, most of which were sourced from the former Soviet Union, with which Cuba had mutually advantageous and privileged trade agreements regarding energy supply and related equipment. In 1993, the DPNES was elaborated and approved. This programme was an important step towards refocusing energy development in Cuba, showing, in particular, the strategic importance of the efficient use of energy and other national resources, both renewables and fossil fuels.

The efforts centred on issues related to the rational use of energy, efficiency improvements and searches for domestic resources, which would reduce the dependency on fuel imports, were significant in this period, both those included in the DPNES and others, such as the electricity rational use programme, which reached its goal. Particularly positive results were obtained in the oil and gas exploration and extraction activities, and in the recapitalization and partial modernization of the electricity generation system, where the opening of the sector to foreign investment played an important role.

Even under these conditions of extreme financial constraints and severe restrictions in the availability of foreign exchange, the resources directed to investments related to energy efficiency and the rational use of energy between 1993 and 2001 were more than four times the cumulative total investments made to those ends in the preceding three decades.[27] In the same way, there is a

[27] Not only is that which is invested in national and sectoral conservation programmes considered, but also the contribution of foreign investment, which, for example, includes: the emergence of independent electricity generators that make use of non-exploited natural gas resources and household gasification; the type of business for energy reconversions or BOOT (build, own, operate and transfer) projects, such as that of the Isla de la Juventud; and important modernizations in some high energy use industries.

marked contrast in the fact that in the 1995–1999 period, some 276 million CUC was invested in energy efficiency programmes and actions, whereas in the 1986–1990 period, when Cuba was in a far better economic and financial situation, resources were not dedicated to the programme on the rational use of energy. Under this programme, investments of around 129 million CUC led to savings of 1.9 million t of oil by 1999, equivalent to about 230–276 million CUC at 1990 oil prices [5.17].

The increase in oil and gas extraction in Cuba and the substitution of domestic crude oil and associated gas for imported fuel oil meant important savings of foreign exchange arising from the price differential between the two. In this sense, in 2000, the economic effect of the substitution of domestic crude and associated gas for fuel oil imports amounted to US $410 million. Regarding electricity generation in the thermal plants of the UNE alone, this effect meant savings of about US $250 million [5.17].

The conversion to burning domestic crude oil in the remaining thermal power plants was completed by 2003. Thus, in that year, almost all electricity in the country was generated from domestic crude oil, with a corresponding saving in foreign exchange.

As for oil imports, it should be noted that, in addition to the abrupt quantitative reduction, there was a significant change in the structure of these imports favourable to petroleum products. This change in the hydrocarbon import structure was basically due to the limitations arising from the manner in which the country approached the international markets for its oil purchases and the established conditions of convenience for those supplier–traders, which caused losses of hundreds of millions of dollars in the 1990s, starting from the refining margins that were lost at domestic refineries. Specialists in the field estimate the excess expenses incurred during the 1990s were about 1.38 billion CUC, arising from charter fees and interest surcharges from credits paid to traders, as a result of the US restrictions imposed on international trade with Cuba.

Nevertheless, this unfavourable situation has changed substantially since 2000, thanks to agreements regarding the supply of crude oil from Venezuela and to a new finance scheme in association with foreign companies, which are expected to increase refining activities. Indeed, in 2000, crude oil imports represented 13% of total energy supply, while petroleum products accounted for 35%. The agreement signed by the Venezuelan and Cuban Governments known as the ‘Caracas Convention’ stipulates the delivery by Petróleos de Venezuela of about 56 000 bbl of crude oil and petroleum products daily, under favourable terms of payment for Cuba (80% of the deliveries to be paid in 90 d and the rest paid in 10 years at an annual interest rate of 1%).

The share of energy imports in total imports and its proportion in relation to the total exports of goods and services in 2000 were at practically the same levels as in 1997, owing to the increase in prices and the unfavourable evolution of the exchange relations, but higher than in 1998 and 1999. However, compared with the 1989 figures, they have decreased greatly (see Table 5.1). The petroleum products imports had a determining role as can be seen from Table 5.1.

5.4.2. Energy intensity

Figure 5.1 shows the aggregated final energy intensity of the domestic economy. Between 1970 and 1985 the energy intensity decreased continuously from 41 GJ/1000 pesos (0.98 toe/1000 pesos) to 17 GJ/1000 pesos (0.40 toe/1000 pesos). This decline resulted from the combined effect of a period of strong economic expansion, in which the use of the productive capacities was close to a condition of 'full employment', and more effective use of imported fossil fuels, especially the strong incentives for institutions to reduce oil usage.[28]

Indeed, final energy use grew between 1970 and 1985, but while the energy use only grew by 14%, the GDP increased by 176%, which meant a reduction of the energy intensity by 67%. In contrast, the final energy use increase in the period 1985–1989 coincided with the virtual stagnation of the economy, causing energy intensity of the overall economy to increase by 15%.

In the 1990s, there was a strong contraction in final energy use as a result of the fall of most production levels. Particularly drastic was the contraction that took place in the first half of the decade, when final energy use decreased by 85%, while GDP fell by almost 41%. In this period, a reduction of the energy intensity took place as a consequence of the structural change induced by the crisis, which was favourable to those activities related to low energy intensity, such as services (Fig. 5.1), so that by 1995 energy intensity was 30% lower than in 1990.

Starting in 1994, several technical and organizational measures relating to energy use were implemented. These measures, put into practice in 1997, have

[28] Part of the foreign exchange resulting from savings obtained using domestic sources of oil was in the hands of the central organizations and companies, which were given a certain amount of independence regarding foreign exchange requirements, with a view to implementing new programmes supporting rational energy use. This regulation was modified as the lack of foreign currency became more evident. However, the foreign exchange from these activities was not exclusively dedicated to oil and electricity efficiency programmes.

TABLE 5.1. SHARE OF ENERGY IMPORTS (%) [5.18–5.20]

	Share of coal, coke, crude oil and petroleum products imports					
	1989	1995	1997	1998	1999	2000
Total imports of goods and services	29.9	23.2	22.2	15.9	15.3	23.1
Exports of goods and services	43.0	27.6	26.2	19.0	17.9	26.6
	Share of petroleum products					
	1989	1995	1997	1998	1999	2000
Imports of goods and services	29.6	22.9	21.8	15.4	15.0	22.6
Exports of goods and services	42.5	27.1	25.7	18.4	17.5	26.1

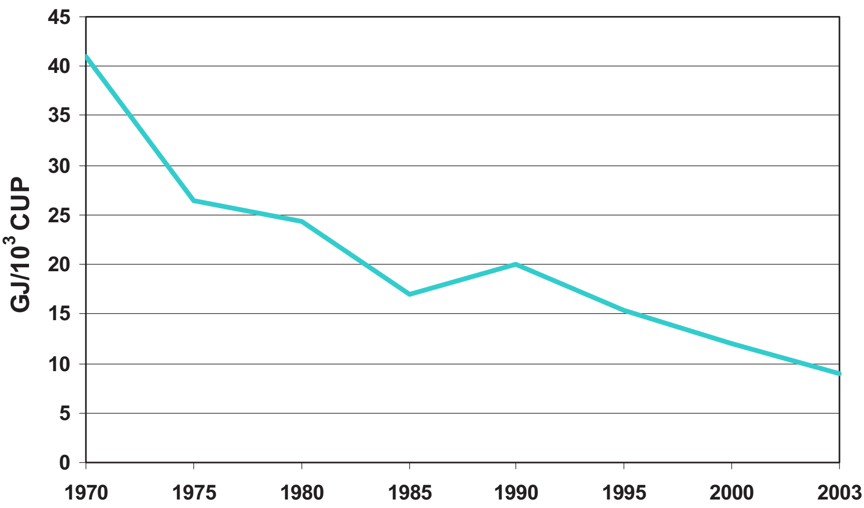

FIG. 5.1. Final energy intensity for the period 1970–2003. Source: Elaborated from Refs [5.18, 5.19, 5.21, 5.22].

had a positive impact on energy use efficiency. Between 1995 and 2003, the economy expanded at a 4.1% annual average, while energy use fell at an annual rate of 2.7% (Fig. 5.2).

In comparative terms, Cuban energy intensity of final energy use is high, 80% higher than the average for the Latin American and Caribbean region with regard to total intensity, and by 77% with respect to oil intensity

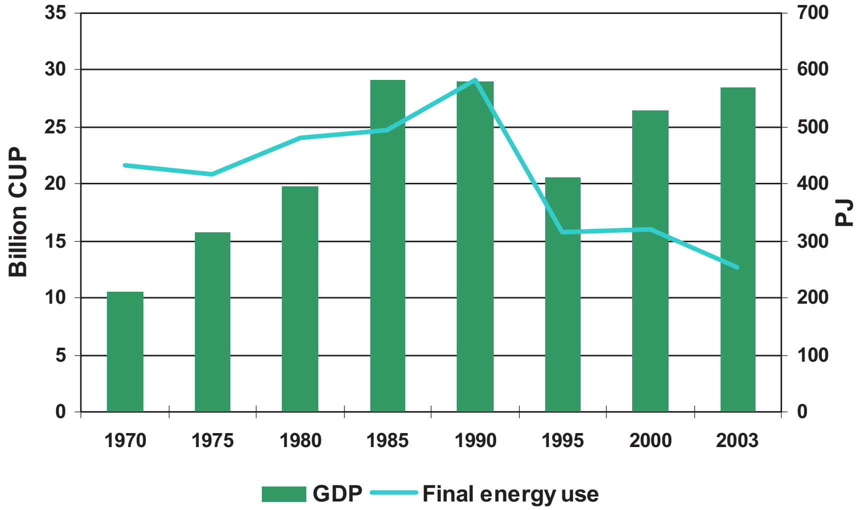

FIG. 5.2. GDP and final energy use. Source: Ref. [5.23].

(Table 5.2). However, this high energy intensity is not the result of a high endowment of energy, but rather, it is due in large part to factors related to the production structure of the Cuban economy that evolved during its membership of the CMEA, based on inefficient technologies and heavy dependence on petroleum products use.

It is important to assess the energy intensity in a more disaggregated manner to determine the contribution of the economic sectors to the overall final energy intensity and to the final energy use. Figure 5.3 shows a comparison of energy intensity trends in Cuba's main economic sectors for the period 1990–2002. The figure illustrates the general reduction trend in energy intensities experienced in all sectors. The manufacturing and transport sectors are the most energy intensive sectors of the Cuban economy but these sectors have experienced the most significant reductions in intensities over the time period considered.

A decomposition analysis of changes in the final energy use allows the determination of the effect different factors have on the energy intensity. The explanatory factors for the variation of energy use include activity level, efficiency factors and economic structure. Table 5.3 and Fig. 5.4 show these factors for total final energy use.

TABLE 5.2. COMPARISON OF ENERGY INTENSITIES OF DIFFERENT LATIN AMERICAN AND CARIBBEAN COUNTRIES AS OF 2001 *(Elaborated from Ref. [5.24])*

	Energy intensity (boe/million US $)		Energy use per capita (boe/cap)	
	Total	Oil products	Total	Oil products
Costa Rica	1.2	0.80	4.6	3.00
Jamaica	3.1	4.80	6.3	9.70
Dominican Republic	2.2	2.50	4.5	5.10
Chile	1.8	0.98	9.5	5.20
Brazil	1.5	0.82	6.4	3.60
Honduras	4.5	2.50	3.2	1.80
Guatemala	2.6	1.25	4.1	1.90
Uruguay	0.9	0.58	5.2	3.30
Latin America and the Caribbean	1.6	1.10	6.1	4.10
Cuba	**2.9**	**1.95**	**5.8**	**4.00**

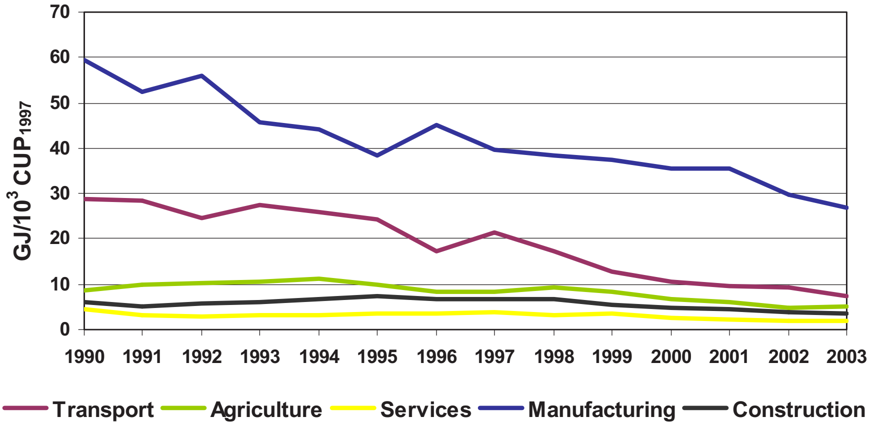

FIG. 5.3. Final energy intensity by sector. Source: Elaborated from Refs [5.20, 5.25, 5.26].

TABLE 5.3. EXPLANATORY FACTORS OF THE VARIATION OF FINAL ENERGY USE
(Authors' elaboration)

	Units	Efficiency	Structure	Activity	Total variation
			1975–1989		
Total final energy use	PJ	–145.8	9.1	236.0	99.4
Share	%	–146.8	9.2	237.0	100.0
			1990–1994		
Total final energy use	PJ	–80.5	16.9	–132.5	–196.2
Share	%	41.0	–8.6	67.6	100.0
			1994–2000		
Total final energy use	PJ	3.5	34.1	–30.6	7.0
Share	%	50.1	–438.1	438.1	100.0
			2000–2004		
Total final energy use	PJ	–74.7	–19.3	29.3	–64.7
Share	%	115.5	29.9	–45.4	100.0

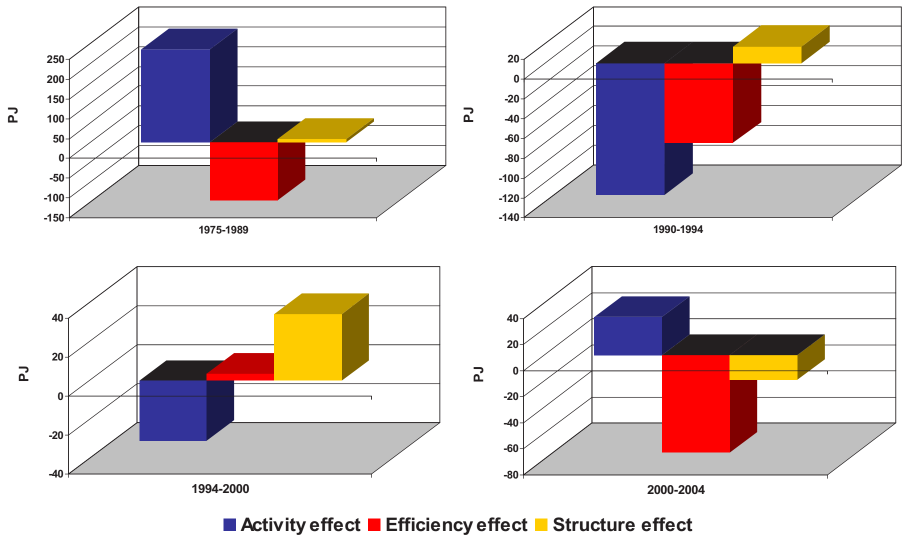

FIG. 5.4. Variation of final energy use. Source: Ref. [5.27].

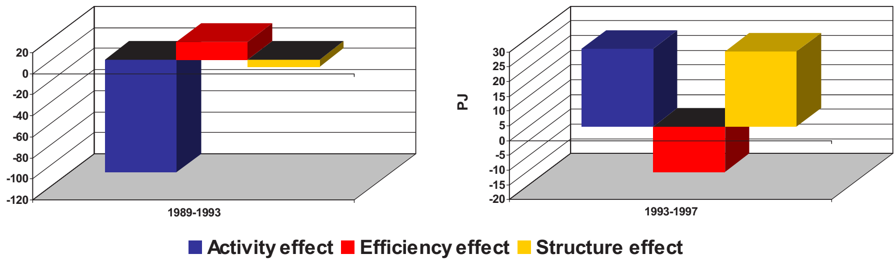

FIG. 5.5. Variation in energy use in the industrial sector. Source: Ref. [5.27].

During the period 1975–1989, activity level was the major factor affecting energy use. The positive changes in this factor and in the structure of the economy combined were larger than the changes or improvements in the efficiency factor. This situation determined that more energy was used during this period. In the period 1990–1994, the activity level decreased dramatically (crisis period), which, combined with the efficiency effect, determined an overall decrease in energy intensity. During the first years of the economic recovery (1994–2000), the activity level continued its decreasing trend while the effect of efficiency and structural changes was higher energy use. In 2000–2004, final energy use increased with the economic expansion but the net effect was a less energy intensive economy due to effective policies that affected efficiency and structure. One of the major factors affecting final energy use was the electricity conservation programme begun in 1997.

Certainly, the economic recovery that occurred as of 1994, and especially since 1997, has relied on the dynamics registered by traditional export activities (with the exception of sugar) and the incorporation of other activities such as steel and cement manufacture, which are high energy users.[29]

Figure 5.5 shows the changes in energy use in the industrial sector for the period 1989–1997 resulting from the activity, efficiency and structural factors. During the period 1989–1993, the activity level experienced a major decrease while the changes in efficiency and structure were minor. The net effect was a reduction in energy intensity. Over the four years 1993–1997, the industrial

[29] In the case of traditional export activities, reference is made in this case to the semi-manufactures of the mining and non-ferrous metallurgical industries, especially nickel and cobalt exports. As for the activities that are incorporated into such traditional exports, steel and cement are the most significant, both because of their 'weight' in the total of exported goods and from the point of view of their energy intensities.

sector recovered and the activity level increased, as well as the structural effect, implying a move towards the production of more energy intensive products. The net result during this period was an increase in energy use in the industrial sector.

The decreasing trend in the intensity of use of petroleum products in 2000 compared with 1997 in selected industries is shown in Table 5.4. The reduction in these intensities is a consequence of increased efficiencies in these industries observed during the period 1997–2000.

Energy efficiency in the main energy intensive industries has increased recently (see Table 5.5). Indeed, the six most energy intensive industries (steel, sugar, nickel, textiles, oil refining and cement), which represent almost 50% of the domestic final energy use, experienced net decreases in their specific

TABLE 5.4. REDUCTION IN INTENSITY OF USE OF PETROLEUM PRODUCTS IN 2000 COMPARED WITH 1997 FOR SELECTED ITEMS (%) [5.27]

Nickel + cobalt	7.1
Raw sugar	5.2
City gas production	44.0
City gas used by population	31.0
Steel	4.7
Cement	3.1
Textiles	21.0
Clothing	23.0
Bottles and flasks	42.0
Mechanical and electronics industry	27.0
Paper and cardboard	2.1
Gross fish catches	12.5
Milk products	7.0
Chemical industry	18.0
Construction	12.0
Trade	21.0
Tourist services	13.0
Remaining services	6.3
Agricultural	6.7

TABLE 5.5. SPECIFIC ENERGY USE IN ENERGY INTENSIVE INDUSTRIES
(Elaborated from Refs [5.20, 5.25, 5.26])

Indicator	1989	1997	1998	1999	2000	2001
Steel (toe/t)	0.5520	0.4880	0.5420	0.4870	0.4370	0.4520
Sugar (toe/t)	0.1930	0.2510	0.3310	0.2420	0.2340	0.2400
Nickel + cobalt (toe/t)	15.900	17.032	16.204	15.169	15.108	14.741
Textiles (toe/million m^2)	0.9400	1.0900	0.9750	0.8320	0.6980	0.6480
Petroleum products (toe/t)	0.0433	0.1050	0.1450	0.1060	0.0830	0.0660
Cement (toe/t)	0.1703	0.2020	0.1980	0.2040	0.2040	0.1920

energy use in the period 1997–2001, although in some cases partial setbacks took place in some years, such as sugar and steel production in 1998 and 2001 and cement in 1999 and 2000.

With the exception of values of specific energy use in sugar, oil refining and cement production, the rest of the energy intensities are lower than pre-crisis levels. The exceptions are primarily due to the existence of unused capacity, restrictions regarding demand (in the case of cement), or problems with the availability of basic inputs (as in the case of sugar, owing to the dramatic reduction in sugarcane availability). In the case of oil refining, the deterioration results from the change in the hydrocarbon import structure explained previously.

5.5. MAIN ISSUES

The highlights that emerge from the analysis of the relationship between Cuba's energy situation and its economic development are as follows:

— Cuba has shown an endogenous adaptive capacity in overcoming the dramatic socioeconomic situation caused by the crisis of the 1990s and returning to the path of economic recovery and development, without putting into practice the measures recommended by international financial institutions. Contrary to the economic reforms undertaken, to varying degrees, by the majority of countries in the region, those formulated by the Government were aimed at preserving the social progress made in the country prior to the crisis. In the economic field, the measures were aimed at avoiding, to the extent possible, the total dismantling of the country's production capacities and, especially, its trained human capital.

- The reduction of the country's energy vulnerability, largely through exploration and extraction of crude oil and associated gas, not only has strategic implications regarding national security, but also helps relieve problems caused by the trade balance.
- The shortage of finance and strong barriers barring access to credits have affected (and continue to affect) investments in the energy sector and have increased the expenditures on fuel imports, especially since the dismantling of trade relations with the former Soviet Union. However, under the current conditions of extreme financial limitations and severe restrictions on the availability of foreign exchange, in 1993–2001 the resources devoted to investments linked with energy efficiency and the rational use of energy were more than four times greater than the cumulative total investments in these areas in the preceding three decades.
- Despite reductions in the energy intensity of final energy use and improvements in efficiency in the electricity subsector, and despite the positive results of a set of national and branch programmes aimed at energy conservation and the rational use of energy, the prevailing economic structure favours energy use. Indeed, economic recovery has relied on highly energy intensive activities such as the production of nickel, steel and cement, among others.
- Among the energy policy issues in support of sustainable development to which top priority is to be given are: legal, standard, regulatory, planning and control, and institutional issues related to the energy system, in particular, reconsideration of the objectives and missions of the State Energy Inspection at different levels (from national to municipal); the role of energy service companies (ESCOs) and the creation of appropriate economic areas for their activities; and the role of the territories (or States) in the decentralized handling of local resources linked to sustainable energy.

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6. ENERGY, ENVIRONMENT AND HEALTH

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6.1. ENVIRONMENTAL OVERVIEW

During the colonial period and well into the 20th century, Cuba's economic development was based mainly on extensive agricultural production, with unsustainable use and exploitation of the land and severe deforestation [6.1]. Consequently, by the middle of the century Cuba had a problematic economic structure based largely on traditional agricultural production, with limited industrial development mainly concentrated in the sugarcane agro-industry, and an environment affected by deforestation. The social situation was critical, with high levels of poverty and low levels of health services.

The profound economic and social transformations achieved since 1959 have led to favourable changes in the living conditions of the population and to increased protection of the environment and conservation of natural resources. Among the concrete actions taken to protect the environment was the preparation and approval of the National Environmental Strategy, through which the country's main environmental problems and their significant negative effects on the health and living standards of the population were identified [6.2]. Today, Cuba's main environmental problems are soil degradation, deterioration of sanitation and environmental conditions in human settlements, contamination of inland and marine waters, deforestation and loss of biological diversity.

The environmental impact of the energy sector in Cuba is considerable. The widespread use of old technologies, the lack of waste treatment plants and the financial resources needed for the introduction of new technologies, technological malpractice and the lack of an environmental consciousness in the recent past are the main reasons for this negative impact. The following sections address the environmental legislation and policies currently in place and the environmental impacts of the different energy sources.

6.2. ENVIRONMENTAL LEGISLATION AND POLICIES

In 1994, the Council of State passed Decree Law 147 on the Reorganization of the Central State Government that, among other things, eliminated the National Commission for the Protection of the Environment and the Rational Use of Natural Resources. The functions and attributions of this commission were transferred to CITMA upon its creation. This solved a contradiction within the former managerial structure in the Cuban environmental area, in which governmental organizations were responsible for environmental issues that concerned the natural resources managed by the same organizations for productive purposes. Until then, the existing basic standard framework had been Law 33 of 1981 on the Protection of the Environment and Natural Resources. This law did not address the issue of sustainability and could not deal with changes that took place in the country's economy.

At the beginning of 1995, the basis for a hierarchical system of environmental regulations was established and several ministerial resolutions dealing with environmental impact assessments and inspections were issued. Since then, before any new investment in a project can be approved, a study on its environmental impact has to be implemented. These assessments have to include all necessary environmental considerations and the measures and strategies that need to be adopted to avoid or offset negative environmental impacts. For this reason, there are general environmental guidelines applicable to all sectors, as well as specific guides for industry, oil exploration and production, mining and hydrological projects.

The National Environmental Strategy, approved in 1997, constitutes the governing document of Cuba's environmental policy. Its objectives are to identify the most suitable ways to preserve and build on existing environmental achievements, to overcome past mistakes and inadequacies, and to identify the country's main environmental problems. It establishes the basis for reaching the goals of sustainable economic and social development more effectively.

Law 81 was also approved in 1997. Among other topics, this law deals with specific environmental policies and with the management, trade and use of energy resources. It considers the following issues: the responsibility of institutions and people in the prevention and solution of environmental problems originating from disasters; regulations concerning agriculture; regulations related to the sustainable development of tourism; the preservation of cultural patrimony and the protection of the environment in labour activities. Among the law's objectives is the creation of a juridical context that favours planning and development of socioeconomic activities so as to make them compatible with environmental protection and to promote civic action in support of these activities, starting with a greater awareness of environmental concerns and education.

In addition to the laws and decrees in place, and as part of the environmental policy followed in the country, sectoral environmental strategies have been proposed and are being developed to improve identification of the problems and to aid in the search for solutions. To evaluate the state of the environment and how it is being managed, ONE has developed an effective system of gathering and publishing environmental statistics. The use of economic instruments to stimulate positive actions or discourage negative activities that may have an impact on the environment and biological diversity is a new mechanism being used in Cuba. Besides the tributary system (referred to in Law 73, issued in 1994), the following instruments, among others, are used:

— A tax for the preservation of forest resources and fauna;
— Water and electricity tariffs to discourage the inefficient use of these resources;
— Taxes on the exploitation of mines and other payments to the Government as royalties for the mining and extraction of non-renewable resources.

In the field of energy and the environment, the information currently compiled and processed covers most of the activities in the country. According to Ref. [6.3], of the 325 environmental indicators studied, 221 are considered appropriate for describing the conditions of the country. Most of this information is supported by data management systems, which are being upgraded.

6.3. ENVIRONMENTAL IMPACTS OF ENERGY PRODUCTION

6.3.1. Sustainable use of biomass

Several types of biomass are used in a sustainable manner in Cuba. Most of the biomass used for obtaining energy is bagasse, a by-product generated by the sugar mills during the production of sugar. The sugar agro-industry also uses a major part of the total fuelwood consumed in the country.

In general, the burning of bagasse and fuelwood in sugar mills is carried out in boilers that are not equipped with emissions treatment systems. This is why many communities are affected by emissions of particles of very widely varying sizes. The situation is made worse by the fact that each sugar mill is located in the vicinity of a community of sugar mill workers and their families.

A significant part of Cuba's total CO_2 emissions is caused by biomass combustion. These emissions are not included in the national inventory of GHGs because they are reabsorbed during the growth of the sugar crops as a result of photosynthesis. The situation is different for other gases that result from biomass burning, which are not reabsorbed in the next harvesting cycle. These are unsustainable practices that need to be corrected in the future.

A by-product of sugar production obtained during the clarification and filtration of the sugarcane juice is one of the most common agro-industrial solid wastes in Cuba. In spite of its multiple uses, high amounts of this waste remain unused, resulting in serious problems of contamination in the disposal areas, with the consequent proliferation of insects and rodents, the contamination of surface waters and underground waters, and the emanation of objectionable odours [6.4]. Currently, there are several plants in operation in Cuba that produce biogas from the residuals of sugar production [6.5].

From 1998 to 2003, the reforested area in Cuba grew at annual rates ranging from 39 000 to 49 000 ha [6.6]. These high reforestation rates translate into a positive annual forest balance for the country, indicating that the deforestation process in Cuba has been stopped. The National Forest Strategy for the period 2004–2015 projects an increase in national forest area of 25% by the end of the period [6.7].

6.3.2. Non-sustainable use of biomass

The non-sustainable use of biomass in Cuba has been closely linked to the prevailing conditions in different time periods of the country's history. Prior to 1959, most of the rural population met their energy requirements with fuelwood and charcoal. Many families depended on charcoal, which was not produced in a manner sustainable over time. The charcoal was produced from forests and mangroves without consideration of the negative environmental impacts. The mangroves in the Ciénaga de Zapata area, which were a very important natural ecological barrier, were destroyed.

Mangroves extend all along Cuba's coastal areas, covering many cays of the archipelago. They are the first line of ecological defence and an essential part of the strategic ecosystem protection of coasts and cays. Moreover, mangroves provide important nutrients to the food chain and so are indispensable for the development of many marine species important to the economy.

As a result of the economic crisis of the 1990s, many institutions and families, especially in rural areas, met their energy requirements by using charcoal and/or fuelwood, which had a significant impact on the environment through the indiscriminate cutting of fuelwood. With the economic recovery, this situation has been changing. While a number of isolated rural communities continue to use fuelwood as a household fuel, a number of projects are being evaluated aimed at replacing these fuels with modern alternatives for cooking.

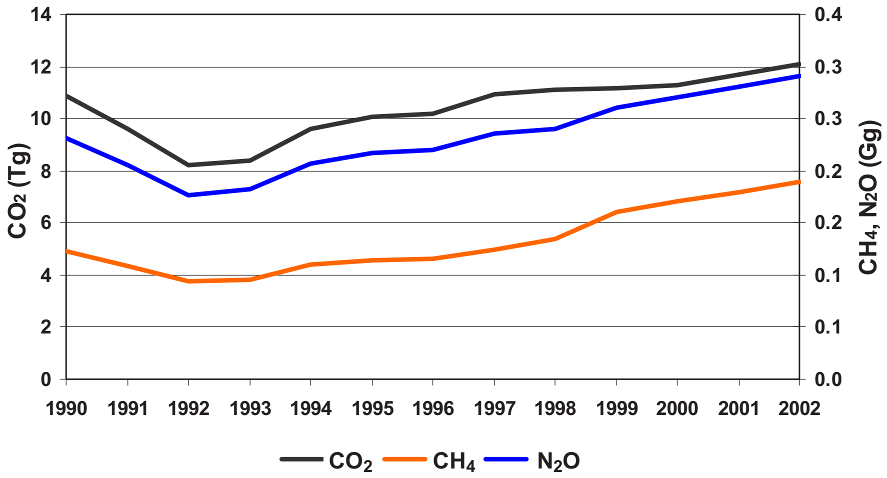

FIG. 6.1. GHG emissions from electricity generation. Source: Authors' estimation.

6.3.3. Electricity generation

In 2002, 93.3% of Cuba's electricity was generated from fossil fuels (see Section 4), which had a decisive effect on the emissions from this sector. The main pollutants from electricity generation are CO_2, SO_2, nitrogen oxides (NO_x) and particulates, of which CO_2 emissions represented 99.2% of the total GHG emissions resulting from electricity generation in 2002 (see Fig. 6.1).

In 1991 and 1992, the emissions of CO_2, CH_4 and NO_x from the electric power sector decreased with respect to 1990 as the country was forced to reduce electricity generation owing to a lack of the financial resources needed to buy fuels (Fig. 6.1). These emissions began to grow again in 1993 with the increased use of domestic crude oil. The rates of growth of CO_2, SO_2 and NO_x emissions and of electricity generation are shown in Fig. 6.2. The domestic crude oil has a high sulphur content (around 7%), which explains the faster rise in SO_2 emissions which began in 1992. From 1999, the CO_2 emissions growth rate fell owing to the use of the associated gas in more efficient gas turbines, in addition to the modernization of the 100 MW units of the national electric system and the incorporation of new 250 MW units. Electricity generation reached its 1990 level in 2000.

Electricity generation is the main source of SO_2 emissions in the energy sector (98.3%). Owing to the increased use of crude oil for electricity generation, SO_2 emissions have increased considerably since the early 1990s.

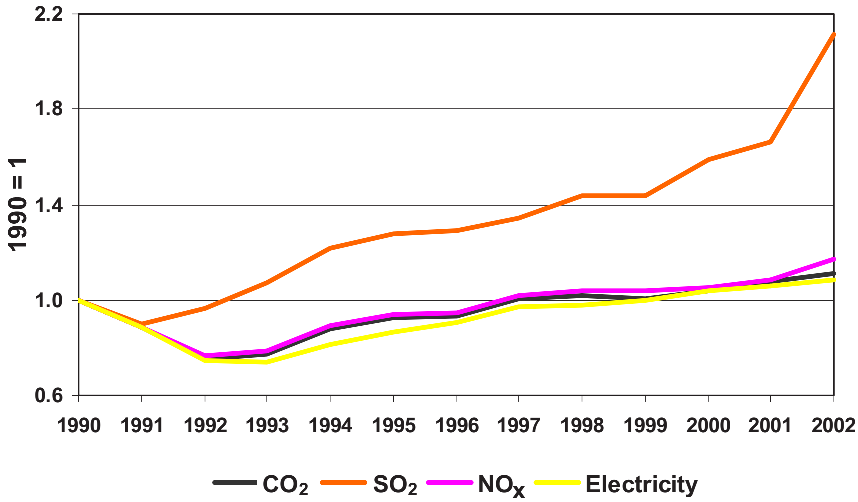

FIG. 6.2. Rates of growth of CO_2, SO_2, NO_x emissions and electricity generation. Source: Authors' estimation.

The 1990 levels of SO_2 emissions were exceeded by 7.3% in 1993 and by 111.4% in 2002.

The CO_2 and SO_2 emissions from electricity generation per gigawatt-hour between 1990 and 2002 are shown in Fig. 6.3. An increase of 14% in CO_2 emissions per gigawatt-hour is observed from 1992 to 1995. This increase is due to lower efficiency or higher fuel consumption in thermal power plants resulting from the direct burning of domestic crude oil without refining. Although a net decrease in CO_2 emissions per gigawatt-hour was observed after 1995, the values for 2002 are still higher than those for 1990. Sulphur dioxide emissions per gigawatt-hour from electricity generation increased during the overall time period due to the high content of sulphur in the domestic crude oil.

Among the Latin American countries, Cuba has one of the highest indices of CO_2 emissions per generated gigawatt-hour due to its high use of fossil fuels for electricity generation (Fig. 6.4).

6.3.4. Environmental externalities from electricity generation

Environmental externalities are the impacts that an activity has on the environment and on the welfare of the population that are not reflected in the market price. Externalities are usually associated with impacts on health, the

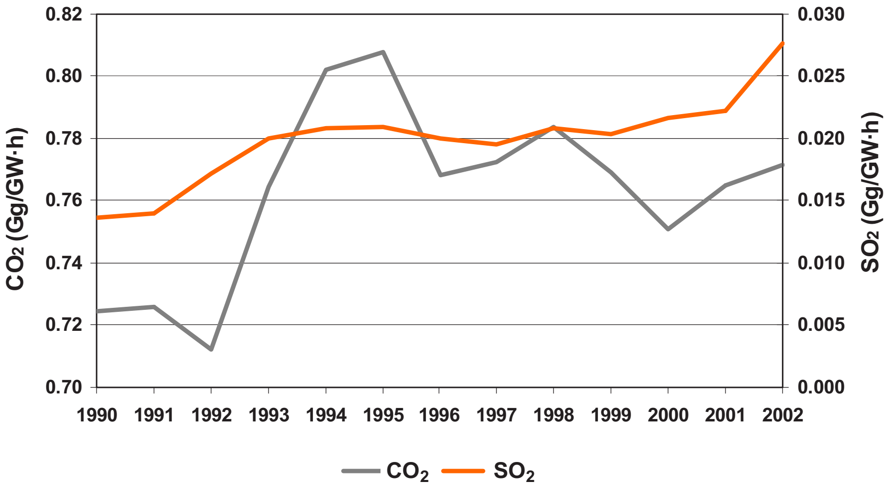

FIG. 6.3. CO_2 and SO_2 emissions from electricity generation per gigawatt-hour. Source: Authors' estimations.

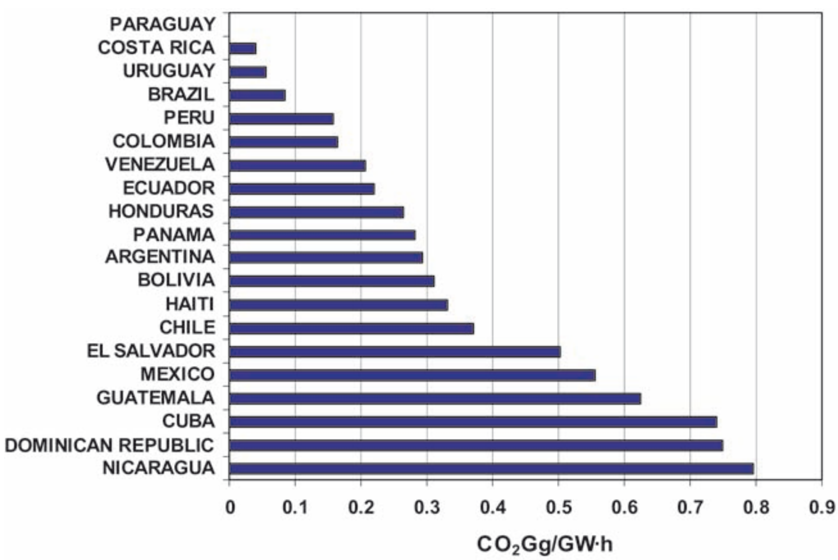

FIG. 6.4. CO_2 emissions per gigawatt-hour in Latin American countries in 2000. Source: Ref. [6.8].

environment and aesthetics due to atmospheric emissions, water pollution, waste disposal and changes in land use [6.9].

Atmospheric pollutants cause a wide range of adverse effects on human health. Among the most common are decreased air flow in the respiratory tract, deterioration in physical fitness, irritation of the ocular mucosa, lowered resistance to respiratory infections, increased frequency and duration of asthma attacks and even a higher incidence of lung cancer [6.9].

Since 1998, work has been carried out to estimate the costs associated with the environmental and human health impacts of electricity generation. Although only impacts on human health have been evaluated so far, other areas can be affected as well, such as building materials, ecosystems, forests, agricultural harvests and global warming, only to mention the most relevant that have not yet been assessed.

According to estimates carried out by Turtós et al. [6.9], for units in the NES with installed capacities greater than 50 MW, the total emissions of SO_2, NO_x and PM10 (particulate matter with a diameter of less than 10 μm) reached 504 015 t, 21 172 t and 20 996 t, respectively, during 2003.

With regard to the PM10 and NO_x concentrations, the estimated hourly, daily and annual average values were lower than the limits defined. The results are based on calculations of instantaneous emissions and assuming a uniform distribution of the annual emissions. If a non-uniform distribution of annual emissions over short periods of time is considered, when the power plants are working at full load, the limits can be exceeded.

Concerning SO_x, given the high concentration of sulphur in the domestic crude oil used in most of the power plants, the hourly and daily estimated concentrations in several places have exceeded the limits. The 24 h limits used are in accordance with the stipulations of Cuban air quality standards (50 and 40 μg/m^3 for SO_2 and NO_2, respectively, and 50 μg/m^3 for PM10 using the soot standard); for 1 h, the standardized 20 min limits were used (500 and 85 μg/m^3 for SO_2 and NO_2, respectively, and 150 μg/m^3 for PM10, likewise using the soot standard). The annual values used were those recommended by the US Environmental Protection Agency and the World Health Organization (50 and 40 μg/m^3 for SO_2 and NO_2, respectively, and 50 μg/m^3 for PM10), which correspond to the maximum values for 24 h set for Cuba.

Regarding deposition, the critical load values for the conditions in Cuba are not available. The maximum values obtained are likely to be of the order of or exceed the values established for diverse ecosystems in Europe (250–1500 eq·ha/a (equivalent hectares per year)). The average values obtained vary between 4.6 and 44 eq·ha/a, while the maximum values range between 187 and 1836 eq·ha/a.

The emissions of pollutants from the power plants evaluated resulted in total external annual expenditure on human health of 111 million pesos. The specific costs of the emitted pollutants were in the range of 187–278 pesos/t for SO_x, 250 pesos/t for NO_x and 284–5685 pesos/t for PM10. This increases the costs by between 0.56 and 1.15 c/kW·h, with the lower cost corresponding to the most efficient power plants located in rural areas with low local demographic density and the higher costs corresponding to power plants located close to or in large urban areas. Another important conclusion was that the impact of mortality (expressed as a reduction in life expectancy or years of life lost) on total costs is much higher (more than 80% of the total impact) than that of morbidity.

Total external costs to human health caused by power plants using desulphurized associated gas turbines were estimated at 0.4 and 1.2 million pesos for simple and combined cycles, respectively, resulting in increases in the costs of 0.17 and 0.13 c/kW·h for gas turbines and combined cycles, respectively. These are the lowest cost values obtained for the power plants assessed [6.10].

The research carried out in this field has led to improvements in the methodologies and calculation tools used in some of the main steps of externality estimates. These improvements will allow an enhancement of the current environmental legislation.

6.3.5. Fuel spillage

Cuba's coastal areas are constantly subject to petroleum contamination. It is well known that a considerable percentage of the transported petroleum is decanted in the Caribbean area and in the Gulf of Mexico by tankers or supertankers. Different studies have proved that the main sources of hydrocarbon contamination in this region are the illegal dumping of ballast water and discharges from tankers [6.11].

Over the years, the coast has been polluted by leaks from ships resulting from accidents on the southern coast of the Guanacabibes peninsula; in Cienfuegos Bay; in Varadero, damaging its beaches; in Holguín and Santiago de Cuba; and in the vicinity of the eastern beaches (Jibacoa) [6.1]. Marine and port activities also contribute to the deterioration of coastal waters due to the illegal dumping of oleaginous bilge water from the ships anchored in port, the dumping of oil used in shipyard areas, the handling of fuels and petroleum spillages during transport [6.12].

It is not only the maritime transport of fuels that has had negative environmental impacts, but also the inappropriate management of solid and liquid wastes during oil exploration and production, the direct deposition of industrial wastes on land and failures in waste treatment systems.

Concerning oil pollution in Havana Bay, it has been reported that the mean recorded for 2001 (0.40 mg/L) confirms that oil contamination of the bay water has been curbed. Pollution occurs at a level that can be dispersed naturally [6.7].

6.3.6. Hydropower

The environmental impacts of hydropower facilities that do not use dams (called ‘runoff river’ plants) are considerably smaller than those of plants that use the dam system. The probable negative environmental effects of dams are:

— Modification of ecosystems;
— Loss of fertile soils;
— Increase in water related illnesses such as schistosomiasis and malaria;
— Modification of deposits and water quality;
— Danger of flooding due to the breaching of water containments;
— Modification of the fishing and agricultural regimes;
— Displacement of human settlements;
— Possible effects on seismic characteristics or climate and, consequently, damage to biodiversity.

The Robustiano León hydroelectric power plant is the country’s most important hydro plant, both for its installed generating capacity (43 MW) and for its impact on the environment. This hydropower plant, located on the Hanabanilla River, uses a tunnel and a dam system.

The Government has long been concerned about the impact of this type of technology on the environment, as was evident in its decision to halt completely construction of the country’s most ambitious hydropower project, which was planned for the Toa River basin (360 MW). Unfortunately, the construction and operation of the Toa River plant and the beginning of construction on the tunnel resulted in the devastation of the left riverbank [6.1].

This basin, declared a biosphere reservoir by the United Nations Educational, Scientific and Cultural Organization, has a precipitation regime of up to 3500 mm annually. The basin is one of the most outstanding geographical features of the Sagua–Baracoa mountain chain, where the best preserved Amazon type forests in the greater North American region are found. The basin is home to over 1700 species, of which about 54% are endemic and about 100 are considered endangered species.

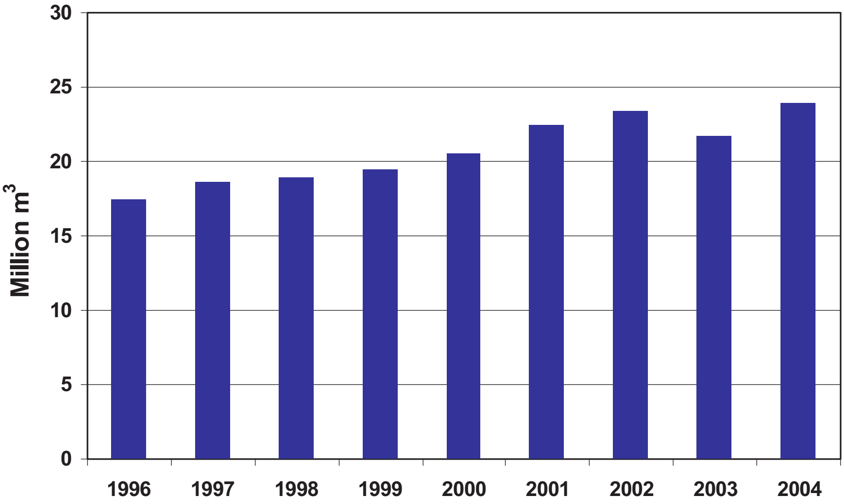

FIG. 6.5. Volumes of urban solid wastes collected. Source: Refs [6.13, 6.14].

6.3.7. Urban solid wastes

Studies carried out in 2000 by the Division of Community Services have shown a return to the trend of increasing urban solid waste generation that existed in 1989, before the economic crisis of the 1990s. This increasing trend is causing grave concern and shows the need to address this situation with new alternatives. The estimated generation for 2002 was 0.72 kg/inhabitant/d (see Fig. 6.5).

With the rise in urban solid waste generation recorded in the second half of the 1990s, Cuba's levels of urban solid wastes are comparable to those in developed countries such as Austria, Denmark, France, Germany, Spain and the USA, which in turn is taken as an index of the standard of living of a country. In this analysis, the high percentage of organic matter in Cuba's urban solid waste (over 50%) stands out and should be examined [6.15].

Cuba lacks the facilities to obtain energy from urban solid wastes. Owing to poor practices in the treatment and disposal of such wastes, in addition to CH_4 emissions, local fires frequently occur, with the consequent atmospheric emission of other contaminants. The volume of CH_4 generated from urban solid wastes in 2002 was estimated at 105.21 Gg [6.16]. Projects for obtaining energy or for energy recovery from these wastes have been seriously evaluated for some time in Cuba. Among the projects in the evaluation stage are some that deal with obtaining fuel oil from catalytic depolymerization.

6.3.8. Other energy sources

Alcohol is another energy source used in Cuba that has a negative impact on the environment. Alcohol is used in households to preheat kerosene stoves for cooking. In Cuba, alcohol is produced using the final molasses from sugar production; this production is carried out in distilleries that at present generate large amounts of wastes that are detrimental to the environment and that are discharged into aquatic bodies without adequate treatment.

Solar energy is another energy source used in Cuba, mainly for electrification in isolated, mountainous areas. The systems installed are isolated and the environmental impact caused by the maintenance and final deposition of batteries is quite small. Cuba has a plant for solar panel assembly, which generates small quantities of wastes (mainly cell fragments). These wastes are disposed of in appropriate sites. Currently, the possibility of reusing these wastes in the production of other goods is being analysed. The same is true of the production of solar heaters; most of the wastes are recyclable material and the production volumes are very small.

Although the country has important peat reserves, the environmental implications have limited its use. The evaluation of the environmental impact of exploiting peat in the Ciénaga de Zapata demonstrated that, where the extraction can be carried out on a large scale, the peat layer would be eliminated. This in turn would affect the containment of saline water, with a consequent change of the ecosystem, salinization of the soil, transformation of the vegetation and migration of the fauna. It would also affect the wells supplying potable water to the local population and to tourists and water for irrigation. Taking these issues into account, peat exploitation was not recommended [6.17].

6.4. IMPACT OF ENERGY USE

6.4.1. GHG emissions

The CO_2 emissions from the energy sector constitute around 95% of Cuba's total CO_2 emissions (Fig. 6.6). The main sources of these emissions are electricity generation, combustion processes in the manufacturing and construction sectors and the transport sector.

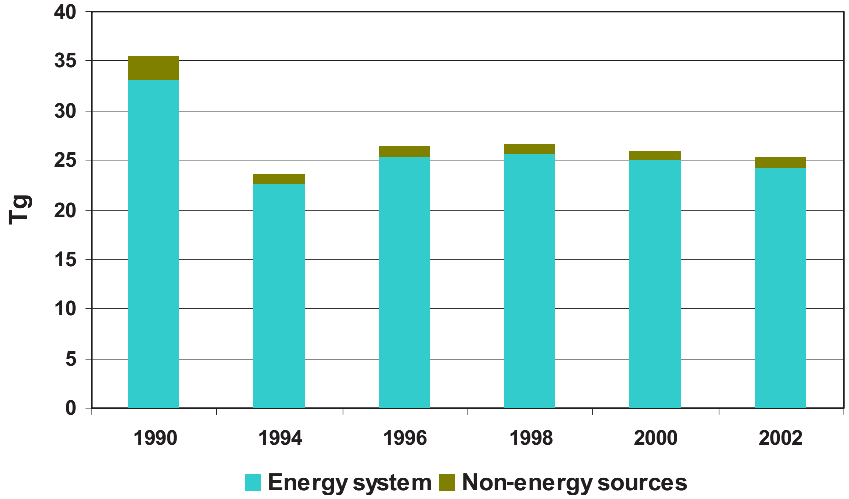

FIG. 6.6. Contribution of the energy sector to total CO_2 emissions. Source: Ref. [6.16].

In 1990, the total CO_2 emissions from the energy sector were 33.2 Tg. In 1994, owing to the economic crisis (see Section 5), fuel use in the country diminished by 43.8% compared with 1990 and CO_2 emissions from the energy sector decreased by 31.8%.

With the economic recovery that began in 1994, GHG emissions from the energy sector began to increase and by 1998 they had reached 76.4% of the CO_2 emissions reported for 1990. Since 2000, CO_2 emissions have decreased slightly because of structural changes in the economy and the corresponding reduction in energy use.

The contribution of the energy sector to CH_4 emissions is lower than that for CO_2. For the years 1990 and 1994, this contribution was only 0.6%. However, in 1996 an increase took place as a result of the increased use of domestic crude oil and associated gas and by 2002 the energy sector accounted for 30.5% of total CH_4 emissions (Fig. 6.7).

Emissions of N_2O from the energy sector correspond to only a very small fraction of total N_2O emissions (Fig. 6.8). The overall N_2O emissions continued to decrease through 2000 but have followed an increasing trend in the last few years.

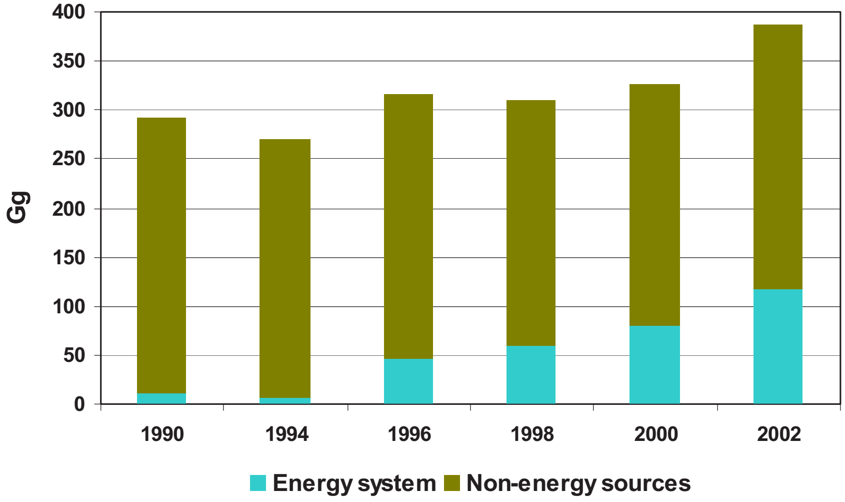

FIG. 6.7. Contribution of the energy sector to total CH_4 emissions. Source: Ref. [6.16].

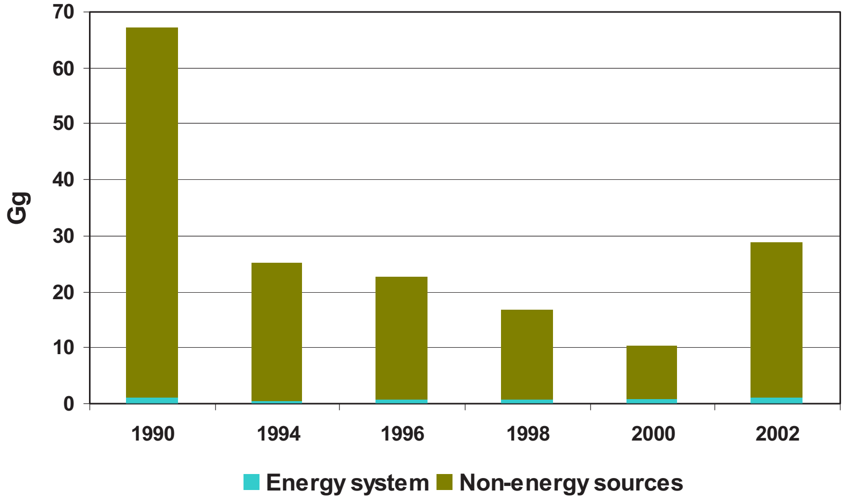

FIG. 6.8. Contribution of the energy sector to total N_2O emissions. Source: Ref. [6.16].

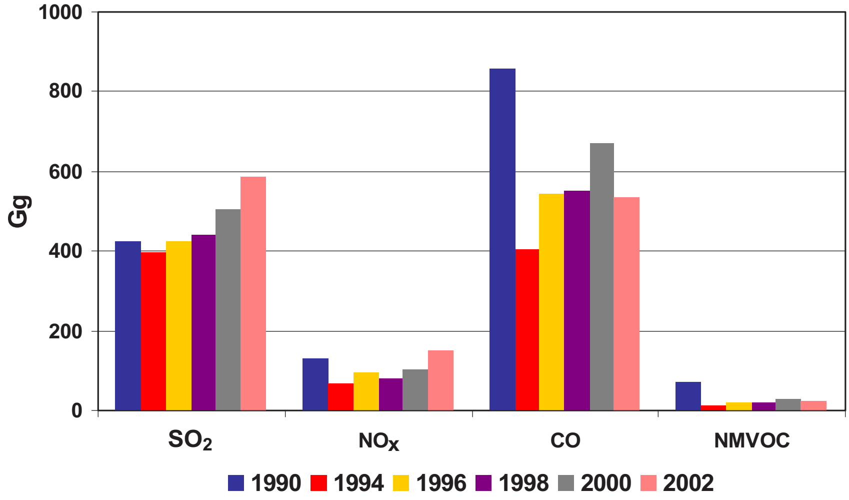

FIG. 6.9. SO_2, NO_x and CO emissions from the energy sector. Source: Ref. [6.16].

6.4.2. Other pollutants

After 1990, emissions of SO_2, NO_x, carbon monoxide (CO) and other non-methane volatile organic compounds (NMVOCs) from the energy sector declined owing to the decrease in fuel use (Fig. 6.9). In 1996, these emissions began to grow, but only those of SO_2 reached the 1990 levels owing to domestic crude oil use. Emissions of SO_2 from the energy sector accounted for 98% of the total SO_2 emissions in the country in 2002.

More than 90% of the total NO_x emissions in the country are produced by the energy sector. The main sources in this sector are the energy, transport and manufacturing industries. The CO emissions in the energy system are mainly associated with transport and the burning of bagasse in the manufacturing sector. In 2002, CO emissions reached 58.7% of their 1990 levels.

The main sources of NMVOC emissions in the energy sector are transport and manufacturing. In 2002, NMVOC emissions from the energy sector constituted 9.6% of the country's total NMVOC emissions.

6.4.3. Transport emissions

All the fuel used in the transport sector is fossil fuel. The mobile sources contribute to the emissions of pollutants, mainly CO_2, CO, NO_x and NMVOCs. Figures 6.10 and 6.11 show the development of the emissions from the

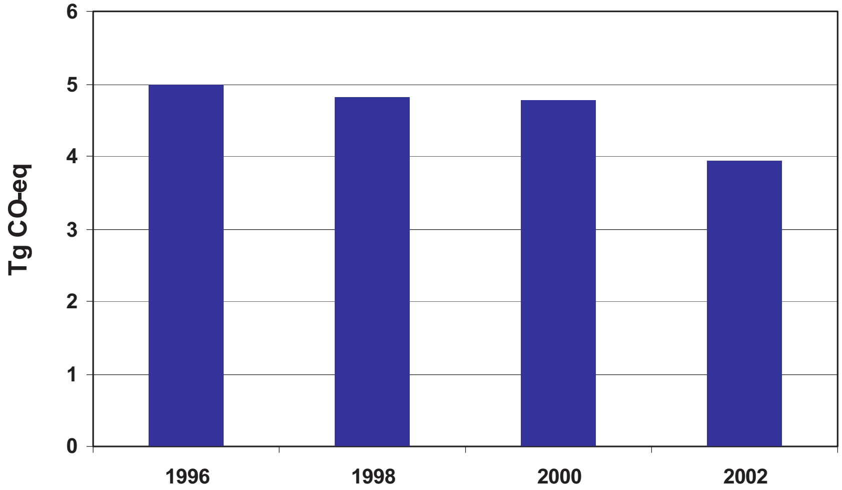

FIG. 6.10. GHG emissions from mobile sources. Source: Refs [6.18–6.21].

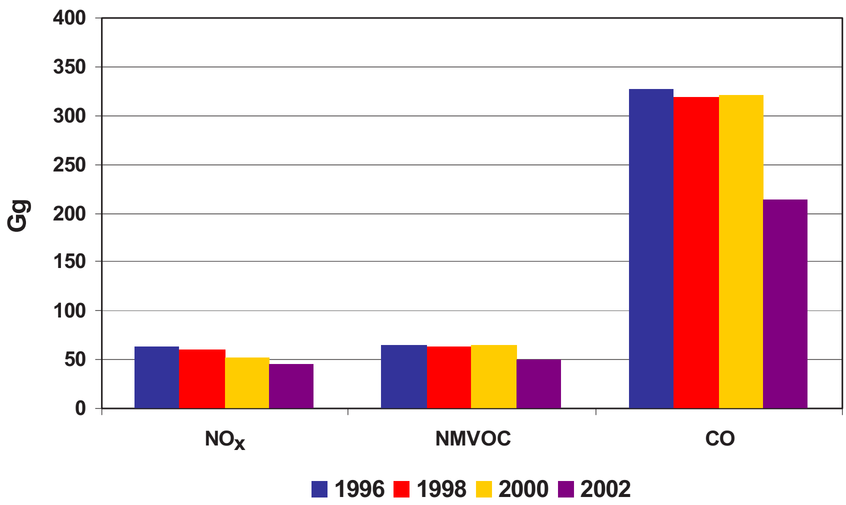

FIG. 6.11. CO, NO_x and NMVOC emissions from mobile sources. Source: Refs [6.18–6.21].

transport sector since the late 1990s. Emissions of CO_2 and CO constitute 91 and 6%, respectively, of the total emissions of the sector. Other pollutants represent 3%.

The emissions from mobile sources have diminished in recent years due to restrictions on the use of fuel, particularly diesel fuel. Road transport has the highest incidence of emissions in this sector, accounting for more than 65% of the total pollutant emissions of the transport sector.

6.4.4. Negative effects on air quality

Since 1986, the mean concentrations of gaseous oxidized compounds have increased [6.7, 6.22, 6.23]. These compounds are the main precursors of acid rain and they can have different harmful effects on terrestrial and aquatic ecosystems, as well as on biodiversity. Emissions from agricultural and industrial sources are primarily responsible for this increase.

There are locations in Cuba where the air quality is seriously affected. In the eastern area of Havana Bay, important urban areas converge with a great concentration of industry (including a thermal power plant, a refinery, food industries, port facilities, construction works and a shipyard). A study carried out in that area in 1999 by Cuesta et al. [6.24], from the Atmospheric Chemistry and Pollution Centre, which is part of the Meteorological Institute, concluded that emissions associated with the refinery process and the rest of the polluting sources are affecting the air quality in the area. The main pollutant is H_2S, reaching concentrations ranging between 3 and 27 times the acceptable maximum concentration established by the Cuban Air Quality Standard.

Measurements made in the Mariel area show that concentrations, both instantaneous and over 24 h, surpass the acceptable concentrations in a radius of approximately 25 km, thereby affecting nearby populations. The polluting sources in that area are a thermoelectric power plant and a cement plant [6.7].

6.5. MAIN ISSUES

The large share of fossil fuels in Cuba's energy mix results in high emissions of pollutants. There are areas with high concentrations of pollutants and worsening air quality and health and environmental conditions in general. Sulphur dioxide emissions have increased significantly in the past decade owing to the increase in the use of domestic crude oil to generate electricity. Since 1998, the use of associated gas in electricity generation has enabled a reduction in the growth rate of SO_2 emissions. The lack of financial resources has not allowed the installation of emission reduction systems and monitoring systems have suffered a gradual deterioration. This situation makes it difficult to enforce the environmental standards in place.

With the economic crisis of the early 1990s, the unsustainable use of fuelwood and charcoal increased. The use of these fuels has since decreased as the result of the increase in the use of other fuels for cooking.

An increase in the shares of renewable energy and associated gas in electricity generation would allow a reduction in the emissions from this energy activity in the future. An improvement in the existing air quality standards and their effective application, as well as the introduction of other mechanisms such as an emissions tax, would favour the introduction of renewable energy.

In addition, the introduction of emission reduction technologies for those plants that use domestic crude oil, or replacement of this fuel with one having a lower sulphur content, is also a pressing need.

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7. ENERGY AND SOCIAL ASPECTS

D. PÉREZ, Y. GÓMEZ

7.1. SOCIAL FEATURES OF ENERGY PRODUCTION AND USE

In this section, the social aspects of Cuba's energy system are described, based on the accessibility and availability of energy services and the affordability and acceptance of these energy services by the population. Accessibility refers to the existence of modern energy services and supporting infrastructures that allow the population, regardless of income level, place of residence, race, religion, etc., the use of modern fuels. Logistics and the economy determine the amount and kinds of energy and energy services available in each place. Even if energy services are accessible to the population, problems with their availability during particular time periods may exist; thus, this section discusses the problems of availability of modern fuels in Cuba. Affordability relates to the ability of the population to pay for the energy services that are accessible and available. Energy prices should be low enough (without affecting the profitability of the producing companies) to enable everyone's minimum requirements for modern energy services to be satisfied. Acceptability concerns the social and/or environmental problems related to energy chains, ranging from production and use to the disposal of waste generated by energy production. Making an assessment of the acceptability of an energy option is often difficult and sometimes involves many issues, including social, environmental, cultural, economic and religious aspects at local and regional levels.

7.1.1. Accessibility

Energy access in Cuba is a public service for all citizens, which should be ensured at a minimum level of quality and safety. The accessibility of energy services varies depending on the population's rural or urban location. Modern energy services include commercial forms of energy such as electricity, city gas, LPG, gasoline, diesel and kerosene and exclude traditional energy fuels such as fuelwood and charcoal which were used in the past in an unsustainable manner.

The evolution of energy use in the household sector from 1970 to 2002 is presented in Fig. 7.1. Increasing trends in the use of gas, electricity, kerosene and alcohol (to preheat stoves) were observed up to around 1990. During the years of the crisis a dramatic reduction in the use of kerosene and alcohol was

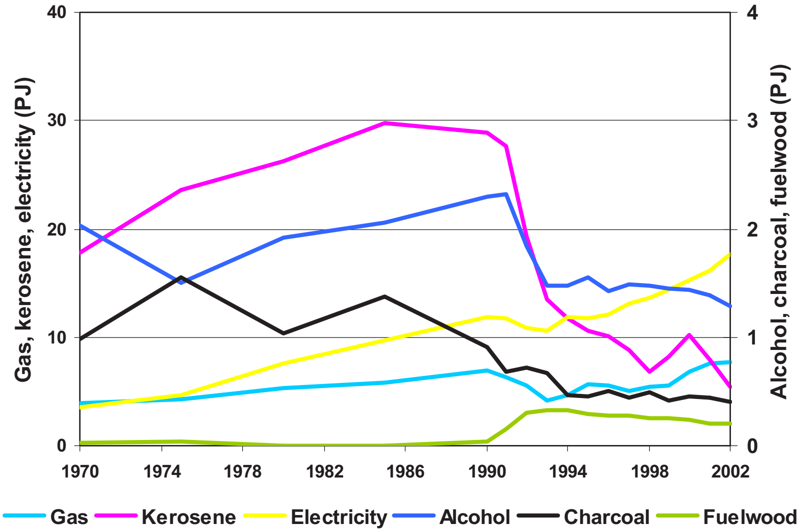

FIG. 7.1. Household energy use. Source: Refs [7.1–7.10].

observed, while electricity and gas use experienced a period of stabilization followed by a resumption of increasing use, particularly after 1995. The decreasing trends in the use of fuelwood observed before the crisis reversed as the population was forced to use this fuel to offset the shortages of kerosene resulting from the drastic reduction in imports of fuel from the former Soviet Union. Fuelwood use grew abruptly, reaching its maximum level in 1993. At that point, a sustained decrease began, mainly in the industrial sector, although to a lesser extent the greater supply of other fuels for households contributed as well.

Kerosene and alcohol for preheating cooking stoves were the main fuels used in the residential sector between 1970 and 1994, although by 1985 their shares had begun to decline [7.1–7.3]. These fuels have always been rationed in Cuba and the crisis forced the Government to reduce even further the quantities distributed. Even at these reduced levels, in many areas, mainly in rural parts of the country, not even 50% of the established rationed amount could be distributed because of a lack of affordability and difficulties in supplying these fuels to rural areas and especially to remote mountainous areas.

In 2002, residential energy use represented 12% of Cuba's total energy consumption. The main form of energy used was electricity (52%), primarily for lighting, air conditioning and household appliances, although a small amount was also used for cooking (for which there are no reliable data).[30] Other important forms of energy were kerosene (15.9% of the total residential energy use), LPG and gas (22.8%). Alcohol accounted for another 3.8%, charcoal for 1.2% and fuelwood for 0.6% in 2002 [7.8].

The share of kerosene has continued to decline (except for a slight increase in 2000[31]) as a result of the city gas fuel substitution process initiated in Havana and Santiago de Cuba. This process will benefit three million inhabitants in its first stage and, in later stages, will be extended to other provinces.

Cuba has created a modern infrastructure for LPG production and distribution. The LPG is bottled in 19 kg gas cylinders (each containing 9 kg of gas) and is distributed by truck to the population. The fuel is rationed according to the number of persons inhabiting a dwelling. Each cylinder costs 7 pesos; for a family of four, the acquisition cycle is one cylinder every 19 days. LPG use could be increased with increased availability and the elimination of rationed distribution. As part of a Government programme to increase access to LPG by the population, gas cookers and LPG cylinders subsidized by the Government were delivered to the population, especially those in the country's capital. The low income segment of the population has access to this service.

In 2005, the production and distribution of city gas was increased and modernized. Currently, the associated gas is used to produce a mix of methane–air with higher calorific content at lower cost.

Currently, a system of rationed and subsidized distribution exists which is aimed at guaranteeing the accessibility of modern fuels to the whole population throughout the country. Nevertheless, it is estimated that only about 50% of the perceived needs of the overall rural population for fuels is currently satisfied.

As the supply of modern fuels has not met Cuba's growing energy demand due to the growth of population and higher standards of living, electricity use in households has risen owing to its convenience and cleanliness. However, this increase has been restricted due to limitations imposed on the acquisition of household appliances that are not considered essential goods.

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[30] Estimates by PAEC regarding the energy use patterns of the 5.4 million inhabitants of Cuba's main cities show that around 20% of all energy is used for cooking and water heating.

[31] The increase in kerosene in 2000 resulted from increased supply after a period of restrictions and from delays in the fuel substitution programme.

7.1.1.1. *Access to electricity*

Until the mid-20th century, Cuba's main economic activities were agriculture and livestock production, for which large areas of forest were cut down, resulting in widespread deforestation.

Agricultural production has historically been centred on sugarcane, and by the 19th century Cuba was one of the most important producers of sugar in the world. The sugar industry was vigorously developed, using the most modern technologies available at that time. Improvements in the island's sugar technology led to increases in production. This in turn prompted improvements in the island's transport infrastructure and, with the opening of the Bejucal–Havana line in 1837, Cuba became one of the first countries in the world to transport its sugarcane by rail. Investment in rail transport continued and in 1900–1902 the first two electric tramways were introduced; the first connected the towns of Regla and Guanabacoa and the second was in Havana [7.11].

In the past, the main resources used to satisfy primary energy needs (cooking and lighting) were fuelwood and natural gas. In the cities, lighting by means of natural gas or carbide lamps was introduced around 1820, followed later by the use of arc lamps and electric bulbs. In 1889, public lighting was introduced in Cárdenas, followed, one year later, by public lighting in three cities — Havana, Matanzas and Camagüey — as well as at ten sugar mills [7.12].

In 1902, the Cuban Electric Company (a North American company) began installing a system to provide lighting to a sector of Havana. That power plant, which generated alternating current, began operation in 1905. In 1906, an electric railroad was installed, the first of its type in Latin America, connecting the neighbouring villages of Güines and Guanajay with their generating plant, located in Rincón de Melones, by Havana Bay. This installation also provided service to the settlements near the transmission lines, located 40–45 km from Havana [7.13].

It was not until well into the 20th century that electric power was used for other purposes. In 1911, an electric power plant was installed in a sugar mill with enough capacity to provide lighting, to power the mill's electric motors and to meet the electricity needs of the surrounding community, as well as those of neighbouring towns. Between 1917 and 1920, three small and mini-hydropower plants were installed (Guaso, 1.7 MW; San Blas, 1 MW; and Piloto, 0.295 MW) to provide electricity to those settlements [7.13].

In 1958, electric services were provided by more than 60 isolated systems. The western system (from San Cristóbal, Pinar del Río province, up to Nuevitas, in Camagüey) and the eastern system (south of the former Oriente province, from Guantánamo up to Manzanillo) were the most important. They were operated by the Cuban Electric Company (with private capital). This company had an installed capacity in thermal plants of 397.1 MW (almost 84% of Cuba's total installed capacity, including 5 MW from independent power producers) and 13 098 km of electric lines of all voltages. Only 56% of the country's population had access to electricity at that time [7.14].

Low access to electricity in 1959 was due to physical constraints as well as a lack of financial resources by a large part of the population in places where the electricity was available. In 1960, the electric utilities were nationalized. Since then, the electrification process has been aimed at supporting social and economic objectives.

In 1973, the country's two isolated electric systems (the western and the eastern) were interconnected and the NES was created. By 1985, 71.6% of the total population was living in urban areas.[32] This figure increased only slowly thereafter, reaching 75.8% by 2003.

By 2004, almost 95.5% of the population had access to electricity, although this figure was 87% in the Sierra Maestra mountainous areas. The extreme difficulty of bringing electricity to mountainous areas is one of the current challenges to the Government's bid to provide electricity to 100% of the population. The high costs of expanding the national grid to those places has led to the application of new technologies — such as photovoltaic panels; micro-, mini- and small hydropower plants; and wind and hybrid systems — to supply electricity to schools and other social and community centres.

Concerning that part of the rural population scattered in isolated areas, the task of electrification has been very complicated from both the technical and economic points of view. Thus, since the 1980s the focus has generally been on providing electricity to settlements, not only for strictly economic reasons, but also to promote a community network that facilitates access to the social benefits that the rest of the population enjoys, in particular free education and medical services.

In recent years, the solution for over 220 small communities, largely located in areas of limited access, has been the installation of solar panels. Such photovoltaic systems have enough capacity to light the community doctor's office and residence and to provide electricity for a refrigerator to keep drugs

[32] According to the definition used in the population and housing censuses in Cuba, an area is considered to be urban if it has the following characteristics: (a) a resident population of 2000 inhabitants or more; (b) a resident population of between 500 and 2000 inhabitants, street lighting and three or more of the following: an aqueduct, paved streets, a sewer system or septic tanks, medical services, and/or an educational centre (schools); or (c) a resident population ranging between 200 and 500 inhabitants and all six of the following characteristics: street lighting, an aqueduct, paved streets, a sewer system or septic tanks, medical services and an educational centre.

and medical equipment cool, as well as to power a radiocommunication device and a television [7.15].

Electrification in support of social goals has been a priority, with electricity being provided in 2001–2002 for a number of important end uses, for example: 350 family doctor's offices, 5 hospitals, 2364 primary schools, 1864 television rooms, 150 social clubs, dozens of houses, rural boarding schools, camping facilities, television relay stations, telephone exchanges, fishing collection centres and cooperatives [7.16]. Special attention was given to electrification within the programmes aimed at disseminating cultural and other information to the population in rural areas.

These actions have contributed considerably to improving the quality of life of a great number of people. They have also contributed to the economic development of the region, as well as to stemming the flow of migrants to urban areas from the mountainous and rural areas in general.

With increased access to the national electricity grid in rural areas, electrification of the rural population grew from 56% in 1958 to 79.4% in 1992 [7.3]. Efforts continue to be aimed at bringing electricity to the rest of the rural population by means of micro- and mini-hydropower plants, photovoltaic panels (many contributed by individuals and non-governmental organizations from Germany, Italy, Norway and Spain, among others) and, more recently, wind and hybrid systems.

The overall social impact of the Government's programmes to electrify rural areas has not been fully quantified. However, opinion surveys show high support for the programmes in those communities that have cooperated significantly in the implementation and care and maintenance of these programmes.

In terms of per capita use, electricity increased rapidly, reaching 1120.8 kW·h per capita in 1990, which was 2.4 times higher than in 1970. Between 1990 and 1995, primary energy and electricity use per capita fell dramatically as a result of the crisis (Fig. 7.2). After 1994, electricity use per capita increased and was slightly higher in 2002 than in 1990, but primary energy use per capita decreased in later years. This is due to the fact that decreases in biomass use per capita are larger than increases in crude oil and gas use per capita.

It is important to note that the share of population with access to electricity in Cuba is about 20% higher than the average share for the countries of Latin America and the Caribbean[33] [7.8, 7.17]. However, even with the social developments of the second half of the 20th century, some 174 105 dwellings in

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[33] The average electrification rate for the Latin American and Caribbean region was estimated to be around 74% in 2002 [7.17].

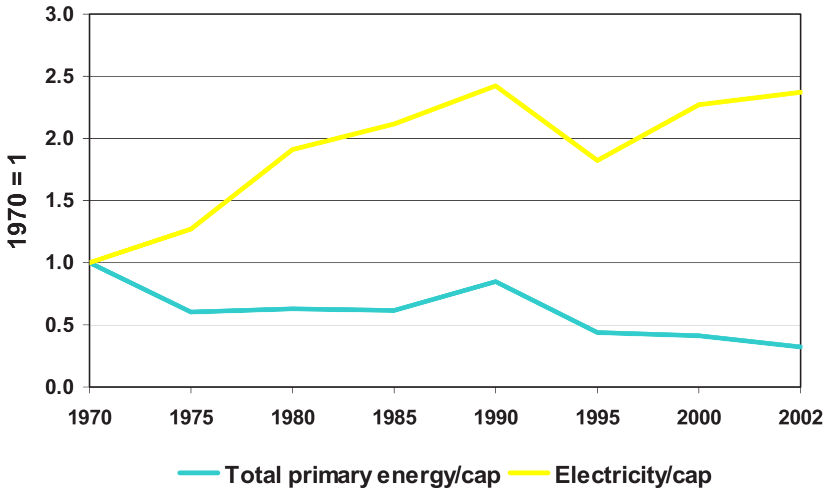

FIG. 7.2. Index of TPE and electricity use per capita. In 1970, the TPE/cap was 24.5 GJ/cap and the electricity/cap was 0.463 kW·h/cap. Source: Refs [7.1–7.10].

Cuba are still considered to be without electricity. This constitutes a social problem for the country, which aims at eliminating all barriers hindering the social welfare of its inhabitants, regardless of class, race or geographical location[34] [7.8].

7.1.2. Availability

Cuba's energy system is characterized by (i) a limited domestic supply of energy resources and consequently high imports of essential fuels; (ii) an ageing infrastructure for the generation, transport and distribution of forms of energy including electricity and petroleum products; and (iii) vulnerability with respect to natural phenomena such as hurricanes and tropical storms (see Section 8). These factors have dramatically affected the availability of energy

[34] According to the data published by the National Office of Statistics, in 2002 there were 174 105 dwellings without access to electricity (by any available means), of which some 58 602 can be provided with electricity. Electrification efforts are the most difficult in the five eastern provinces, where 77% (83 848) of the dwellings considered to be unsuitable for electrification by currently available means are located.

services to the Cuban population during specific time periods. The temporary unavailability of energy services, otherwise accessible to the population, has created major inconveniences and has disrupted progress on major economic and social development programmes.

The economic crisis of the 1990s is a clear example of this situation. During this crisis, important fuels were not available due to the lack of resources for their import. Consequently, different sectors of the economy, including the industrial and household sectors, had to satisfy their energy needs by means of traditional fuels such as fuelwood, which in turn meant deforestation. Alternatively, some industries and households increased their use of electricity. For example, the proliferation of electric cookers with very low efficiencies represented an alternative to satisfy household energy requirements. This situation had severe negative effects on electricity services, including blackouts ranging from 8 to 10 hours a day in Havana. The amount of electricity not served during the 1992–1995 period jumped to very high levels (see Fig. 8.1). The household sector saw much less dramatic declines in electricity use, as compared to other sectors, at the height of the crisis and experienced a much more dynamic recovery process than the rest of the economy. Already by 1996, electricity use in this sector had almost returned to pre-crisis levels. Nevertheless, the temporary unavailability of energy services to satisfy basic energy demands represents an important aspect of the Cuban energy system that adversely affects social development.

7.1.3. Affordability

Theories about how energy prices (tariffs) should be set differ, ranging from incorporating marginal costs to subsidizing energy use for the poorest segments of society. In Cuba, electricity tariffs are different for the various sectors. The main aims in setting the tariffs are to:

- Guarantee the efficient use/operation and development of the electricity system to ensure high quality;
- Provide services to the domestic economy at the lowest prices in order to increase its competitiveness;
- Charge clients according to the costs they impose on the electricity system;
- Send a signal through pricing that encourages energy efficiency.

The State regulates electricity tariffs, which disaggregate costs according to the levels of voltage to which clients are connected; this is the reason why there are fixed and variable factors such as fuel price, etc. The current electricity tariff eliminates subsidies and indicates the real cost of electricity.[35]

In the residential sector, the tariff is 9 c/kW·h for the first 100 kW·h used, 20 c/kW·h for use between 100 and 300 kW·h and 30 c/kW·h for use above 300 kW·h [7.18]. Thus, the segment of the population with the lowest income, which usually uses less electricity than those segments of the population with higher standards of living, pays less for the electricity it uses, since it does not surpass 100 kW·h/month. This level of usage is so low because people in this segment of society have few electrical household appliances and use the electricity basically for lighting. However, many families exceed 300 kW·h/month. On average, Cuba's electricity use per household was 140.1 kW·h/month in 2002 [7.3], which is equal to an average price of 17.02 pesos per month per client or dwelling (with an average of 3.16 inhabitants per dwelling). This value represented 4.8% of the average wage of a worker in 2004.

However, it should be pointed out that electricity generation has a high cost component in foreign exchange, equivalent to 72%, which far exceeds the prices the population pays for this service. Table 7.1 shows the annual average prices of fuels for the household sector. Only the prices of electricity and manufactured gas increased between 1995 and 2002. However, in 2004, the prices of diesel and automotive gasoline increased by 15% and 10% over the prices in 2002, respectively.

In Cuba, energy inequalities concern not only access and prices, but also the quality, cleanliness and efficiency of the energy services provided. In the

TABLE 7.1. AVERAGE ANNUAL PRICES OF FUELS IN THE HOUSEHOLD SECTOR [7.9]

Product	Unit	1995	2002	Increment (%)
City gas	pesos/10^3 m^3	155.80	180.00	15.5
Electricity	c/kW·h	12.45	13.33	7.1
LPG	pesos/bbl	20.98	20.98	0.0
Gasoline/alcohol	pesos/bbl	19.08	19.08	0.0
Kerosene	pesos/bbl	13.43	13.43	0.0

[35] In effect, the variable component of the electricity tariff is based on a fuel price that is established yearly, which is why any variation from the foreseen fuel prices is transferred to the tariff using an adjustment coefficient that is the ratio of the real fuel price to the base price.

specific case of electricity, the residential and public sectors are subsidized in that in these sectors electricity is paid for in pesos, whereas in all other sectors electricity costs are largely paid in hard currency.[36]

In addition, fuel prices and electricity tariffs are structured so as to guarantee that the entire population has access to energy services. Electricity use has also been kept in check as a result of the Government's electricity and fuel conservation programmes and the new multitiered schedule of tariffs for electricity charges.

7.1.4. Acceptability

In Cuba, energy acceptability is related to whether the population is willing to use a particular type of fuel regardless of its negative impacts both on health and the environment. All energy services have an impact on the environment and on human health, although each energy chain has its own level of impact. In Cuba, 93.3% of the electricity is generated using fossil fuels, predominantly domestic crude, with its high sulphur content. Thus, the main local impact is the emission of SO_2, with its corresponding effects on human health.[37]

Another energy chain that impacts human health and the environment in Cuba is charcoal production, which often includes the cutting of the mangrove swamps that serve as an ecological defensive barrier for the island. The petroleum and gas industry and the supply of other fuels also have environmental impacts (see Section 6).

Awareness of these impacts is reflected in public opinion at the local level. However, public opinion also suggests that these negative effects are preferable to not having the energy services that cause them. Therefore, with respect to acceptability there are no specific forms of energy that the Cuban population considers unacceptable to satisfy their corresponding energy needs,

[36] At present, there is a tariff, to be paid in hard currency, in the electricity subsector that covers end users from all sectors except households and the public sector, based on an agreed power level and the energy used. This tariff takes into account the different blocks within the energy use schedule (i.e. morning, evening, nights and peak hours). As for the residential electricity tariff, the most significant change in the past 35 years was the price reform undertaken as part of the general policy of price increases for public services and consumer goods considered to be 'sumptuary', and the elimination of certain services formerly provided free of charge that was aimed at reducing fiscal deficits and excess money in circulation (see Ref. [7.19]).

[37] Section 6 details these effects and provides estimates of the damage caused to health from the emissions of atmospheric pollutants resulting from electricity generation.

but there is awareness of the health and environmental consequences resulting from the further development of some types of energy system. Some examples include the development of hydropower in some environmentally protected areas and the exploitation of the country's peat resources.

7.2. SOCIAL PROFILE OF CUBAN ENERGY DEVELOPMENT

Although Cuba is a developing country, through its social system it has managed to eliminate many social differences, thus achieving a certain level of equity. Moreover, it has provided access to social services (health, education, sports, social security, etc.) for the entire population, which has minimized poverty in the country. However, with the crisis of the 1990s, energy services were affected, income disparities increased and poverty again became an important social issue.

Cuba is currently intensifying the programmes that favour the economic and social well-being of its population, taking into consideration improvements in its energy system. In doing so, the country is trying to fulfil the targets and commitments set out in the Millennium Declaration and the Millennium Development Goals.

The main Millennium Development Goals are to:

— Eradicate extreme poverty and hunger;
— Achieve universal primary education;
— Promote gender equality and empower women;
— Reduce child mortality;
— Improve maternal health and reduce maternal mortality;
— Fight against HIV/AIDS, malaria and other diseases;
— Ensure environmental sustainability;
— Develop a global partnership for development.

In this section, only those aspects related to energy and social issues are discussed, such as poverty, employment, education and gender equality. Other basic services affected by energy include water and sanitation services.

7.2.1. Poverty

Cuba ranks among the top five Latin American countries with respect to the United Nations Human Development Index [7.20], which is established in part on life expectancy at birth. Another element is literacy, that is, the percentage of people 15 years old and older who can read, write and understand simple sentences related to daily existence. In 2003, Cuba's index was 0.681 [7.20], ranking it 21st among the developing countries.

Life expectancy in Cuba is 76.7 years, the country's literacy rate is 96.9% and the education index is 0.91, all of which are among the highest levels in the world. Statistics show that the country has 596 doctors for every 100 000 inhabitants, and that 95–100% of the population has access to affordable essential pharmaceutical products.

The crisis of the 1990s and the reforms adopted in its wake had different impacts on different segments of the population. These differences arose mainly to the existence of two currencies, after the legalization of the use of foreign currency in 1993. This led to the segmentation of markets for goods and services and of the economy in general. As a direct consequence of the crisis, the activities related to the black market economy grew. In mid-1993, when the population was legally allowed to own hard currency, economic recovery was very different for those families with access to hard currency[38] than for those without it.

The few studies on poverty carried out in the country differentiate between the poverty in Cuba and that observed in other countries in Latin America and the Caribbean. The term 'population at risk' has been suggested to denote the population with insufficient income to acquire a basket of basic food products and other goods, but having at the same time qualitatively higher protection than that received by the poor in other countries in Latin America and the Caribbean.

Studies show that the effect of the crisis of the 1990s was greatest in the eastern region of Cuba, where 30% of the urban population lived and where 22% of the population was considered to be at risk. Studies carried out in 1999 based on a survey of the economic situation of households showed that the population at risk reached 20% of the total population.

There is an implicit level of energy development at each level of human development. To evaluate the index of energy development, three energy components are considered: (i) commercial energy use per capita, (ii) the portion of commercial energy in the total final energy used and (iii) the percentage of the population with access to electricity. Of the three components, commercial energy use per capita represents the issue of most concern for Cuba. As explained in Section 2, per capita energy use is still below the level observed in 1970. This is in part related to a decrease in the use of traditional or unsustainable fuelwood, but this decrease has not been fully

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[38] For example, those families that receive remittances (frequent delivery of hard currency) from relatives living abroad.

compensated for by an increase in the use of commercial fuels. Therefore, poverty or the human level of development is still affected by the fact that only about 50% of the rural population's perceived demand for fuels is currently satisfied. The situation is different in relation to the per capita electricity use. The trend from recent years indicates a continuation in the increase of per capita electricity use that reflects greater satisfaction of the corresponding demand. The second component, the portion of commercial energy in total final energy, is following a very positive trend with the rapid reduction of fuelwood observed in the last several years. Finally, the third component, the share of population with access to electricity, is also following a very positive trend, having reached a value of more than 95% by 2004.

7.2.2. Employment in energy production

Before 1959, the sugar industry created seasonal employment during the harvest period (approximately 120–150 days per year). Sugar workers had no opportunities for employment during the rest of the year, leading to what was known as 'dead time', with all its attendant difficulties for seasonal workers and their families. Development of the sugar agro-industry in subsequent years eliminated these effects and workers in this sector remained employed throughout the year, some of them maintaining and developing plantations and others fitting out, maintaining and preparing the industrial complexes for the next harvest.[39]

With the recent restructuring of the sector, almost 50% of the sugar mills and the same proportion of plantations have been closed. This restructuring was needed due to the changes that have taken place in the international sugar market, the drop in sugar prices, subsidized sugar beet production in developed countries and the obvious inefficiency of Cuba's agro-industrial chain, in particular, the drastic drop in agricultural yields as a result of the economic crisis of the 1990s.

To offset the negative social impacts of the contraction of the sugar agro-industry, the Government ensured that unemployed sugar sector workers were trained to assume new tasks in forestry development, cattle production and cultivation of replacement crops grown on the former sugarcane plantations. Twenty-five per cent of the workers in the sugarcane sector moved to other sectors.

[39] The harvest period is when the sugarcane is cut, transported to the sugar mill and processed to obtain raw sugar, refined sugar or its derivatives, or subproducts such as alcohol, sugarcane syrups, boards, pulp for manufacturing paper and furfural.

The development of oil exploration and extraction activities, the programmes for the substitution of domestic fuels for imports and the construction of fuel transport infrastructure (oil pipelines, gas pipelines and a supertanker base) have been a vast source of employment, although mostly of highly skilled personnel. Therefore, it has been necessary to increase personnel training. New programmes in higher education and many post-graduate courses have been created, including a master's degree programme and PhD studies in these fields.

New jobs are also being created with the opening of new areas in the EEZ of the Gulf of Mexico for oil exploration, where discovery of new oil deposits in the deep waters is considered very likely. The jobs created here mainly concern the assimilation and transfer of state of the art technologies to enable development of infrastructure for transport, refining and use of hydrocarbons in the country.

Other important sources for the creation of new jobs in the energy field include: hydropower, mainly the assessment of its possible use to address local demand; the work of specialists in each territory who organize and guide companies on energy efficiency issues; programmes for the rational use of electricity, fuels and lubricants and social programmes aimed at broadening the scope of energy service industries and training assembly technicians and especially users of photovoltaic panels. In addition, the development of energy equipment manufacturing industries could contribute new jobs in the near future as a result of the new projects in the Energy Revolution in Cuba programme. The development and introduction of new technologies for the production of biodiesel and ethanol could also help to create new jobs.

Another source of employment and improvement in the standards of living of rural residents has been the forestry development programme, with the introduction of wardens, personnel training and the sustainable management of forests.

7.2.2.1. Unemployment

The recent restructuring of the sugar industry (with the consequent reduction in plantations and sugar mills) has resulted in a labour surplus. The Government has reallocated and retrained the workforce, keeping the unemployment rate down. According to the 2002 census, unemployment decreased from a high of 7.6% in 1996 to 1.9% in 2004 [7.10].

During the most critical years of the economic crisis of the 1990s, particularly 1992–1994, more than 155 000 workers were laid off, mainly due to the closure of industries and to the decrease of services rendered. This situation resulted, in part, from a lack of fuel and electricity. However, the employment

TABLE 7.2. UNEMPLOYMENT RATE [7.8, 7.21]

Years	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Unemployment rate (%)	6.1	6.2	6.7	7.9	7.6	7.0	6.6	6.0	5.5	4.1	3.3	2.3	1.9

situation has improved, returning to pre-crisis levels. Even during the crisis, those workers who were sent home were still paid 60% of their wages, and as the economy recovered, they returned to work.

Table 7.2 shows the gradual increase in the unemployment rate during the 1990s and its subsequent reduction up to 2004. Although economic recovery began in 1994, it was not until 1997 that the unemployment rate started to decrease. This reduction became particularly significant after the implementation of the Government's recent social programmes.

7.2.3. Education and gender equality

Significant changes have been carried out to improve education, such as using photovoltaic panels to provide electricity to all schools without access to the national electricity grid, providing personal computers to all the schools in the country, creating a new television learning channel with university level programmes and carrying out comprehensive training programmes targeting disadvantaged youths who are not studying or working. This improvement of the educational system helps provide new generations with the knowledge that contributes to energy conservation and to preservation of the environment, important pillars for sustainable energy development. In addition, all municipalities in the country have access to universities.

In addition, gender equality continues to be promoted, with women being empowered to participate in the economic, political and social life of the country. Among the main achievements in this area are the following: life expectancy at birth is 78.23 years for women; the literacy rate is similar for women and men; women represent 44.9% of the graduates from technical and professional schools and 64.7% of the graduates from higher education; 66.4% of the country's professionals and technicians are women; 47.7% of the workers in the scientific and technical sector and 67.3% of the workers in education are women [7.10]. Many women are currently working in energy related organizations in both technical and managerial positions.

Furthermore, urbanization programmes, rural electrification, the substitution of modern for traditional fuels for cooking, the extension of drinking water and sanitation services, etc., have alleviated women of many of the burdensome household chores that have traditionally fallen to them, reducing their negative impact — for example, the impact fuelwood use for cooking has on health — and allowing them to devote more time to alternative activities, such as their education and that of their children. However, disparities between rural and urban areas still remain.

7.2.4. Access to water and sanitation services

Since 1959, among the many social programmes that have been implemented are those aimed at improving access to drinking water and sanitation services. The water supply and sanitation system currently covers 8.5 million inhabitants living in 2729 urban and rural settlements [7.22]. However, marked differences in the levels of coverage persist between rural and urban areas. In 2002, 95.2% of the population had access to drinking water: 98.4% in urban areas and 85.4% in rural ones [7.8]. Considerable energy is necessary to provide these services, mainly for pumping water to the most populated cities in the country. The company Aguas de La Habana, which provides water to the capital, is among the ten largest consumers of electricity in the country. Therefore, the availability of electricity is crucial in providing these basic services to the population.

With the economic crisis of the 1990s and the lack of basic inputs, improvements in drinking water and sanitation services were postponed. The primary objective at the end of the crisis was to return water quality levels to those of the 1960s. The quality levels have been improved, but they continue to be a high priority task. At the beginning of the 1990s, Cuba had virtually no suppliers of equipment and other inputs for the construction and rehabilitation of water supply and sanitation systems. In addition, limitations in the availability of electricity for pumping purposes represented a problem. This lack of supplies (including electricity) was reflected in the low availability of water and sanitation services. The most critical period — between 1990 and 1995 —was characterized by the limited operation of pumping stations due to the lack of spare parts, irregular and reduced hours of service and limited water treatment owing to chemical shortages.

7.3. MAIN ISSUES

Cuba has high levels of electrification, access to water supply and sanitation services, industrialization, urbanization and reforestation. Government programmes supporting these have contributed to the country's economic and social development.

All Cuban citizens have the right to receive energy services at a minimum level of quality and security. Also, fuel prices and electricity tariffs are structured so that the services are affordable for the whole population, while at the same time energy conservation is promoted.

In the case of household fuel usage, there is a system of rationed distribution, guaranteeing access to fuels for the whole population throughout the country. Currently, only 50% of the perceived need for fuel in rural households is being satisfied. Improvement in this situation is important for sustainable energy development.

With the crisis in the 1990s, poverty and fuel shortages re-emerged as national problems. However, the programmes for electricity and fuel conservation, for the substitution of domestic fuels for imports and for rural electrification, particularly in support of social objectives, have had encouraging results.

Among Cuba's main energy related social goals are the provision of electricity to 100% of the population in the near future; the continuing education of the population with regard to energy issues, with particular emphasis on energy conservation and protection of the environment and human health; the promotion of sustainable development in the country and the generation of enough electricity to completely eliminate the electricity not served. In this respect, the issue of availability of energy services at the specific time they are demanded is a major concern in pursuit of social goals and sustainable development.

Although the number of sugarcane plantations and industrial facilities has been reduced, the restructuring of the sugar agro-industry should increase productivity (yield of sugarcane per hectare) and electricity generation efficiency (kW·h/t of crushed sugarcane).

Cuba's hydropower and wind potentials should be evaluated, along with the development of 'energy forests' and the best use of forest biomass, animal wastes, oxidation ponds, sugarcane alcohol, wastes from refineries and citrus production, and solid urban waste, for their energy use and to create new jobs.

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8. ENERGY SECURITY

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8.1. INTRODUCTION

'Energy security' is the capability of a nation to muster the energy resources it needs to ensure its welfare [8.1] and implies the fulfilment of relevant technical and economic requirements, among which is the stable availability of energy from diverse sources in sufficient quantities, at reasonable prices and appropriate levels of quality. Other attributes closely related to energy supply security are competitiveness and environmental protection.

The energy policies of most countries have focused mainly on guaranteeing a secure and sufficient energy supply, and many countries consider the production and use of energy to be a central policy challenge. Efforts to exert influence on, or control over, oil and gas fields, or the marine and terrestrial routes used to transport these resources, can generate considerable tensions and political problems that can influence international relations, the economy, and scientific and technological developments.

Currently, it is extremely difficult to analyse energy security problems without considering the growing influence of globalization and the increasing importance of international competition [8.2]. With the increased interdependence of the world economy, economic growth is often based on an increased share of the international flow of manufactured goods and services. A country's international competitiveness plays an ever increasing role in its economic development.

Technology has become crucial to increases in productivity and is considered to be one of the most important factors for international competitiveness and, consequently, economic growth. The technological change that has taken place in developed countries during the past 20 years has redefined comparative advantages and thus altered the levels of competitiveness of different countries and the international division of labour. These changes have hindered developing countries from entering into the more dynamic flows of production and international trade, further widening the technological gap between developing and developed countries and reinforcing the former's role as consumers, rather than developers, of new technological knowledge, to the detriment of their productive capacities.

The oil crises of the 1970s highlighted the issue of energy supply security [8.2] and were particularly significant factors in promoting technological changes regarding energy use. These changes supplemented and reinforced the development not only of incipient technologies, as in the case of new materials, genetic engineering and biotechnology, and electronics (the development of which has had a positive impact on the further diffusion of advanced technologies and on changes in production patterns, trade and the mobility of capital), but also of established technologies and processes.

The oil price increases of 1973 and 1979 had a strong impact on both developed and developing countries, especially energy importers, inducing the emergence and consolidation of new producers and the adoption of important programmes for the conservation, substitution and rational use of energy, mainly in the OECD member countries.

Among the risks to energy supply security are those arising from geopolitical tensions in the main producing areas as well as those relating to the finite nature of hydrocarbon reserves (oil in particular). Moreover, since the end of the 1960s, concerns have arisen regarding the impact on the environment of existing patterns of energy use.

Three decades after the global oil crisis, energy supply security problems and the possible depletion of reserves remain matters of concern. Moreover, the focus of energy policies on securing energy supply has broadened to address problems related to its efficient use by end users, as well as to concerns about the environmental impacts resulting from the use of different energy forms, including fossil fuels and nuclear energy. This, in turn, has led to the current efforts aimed at diversification, rational use, substitution and conservation of energy, as well as to changes in energy use patterns and behaviour.

The world crude oil import dependence presented in Table 8.1, reported by the Organization of the Petroleum Exporting Countries (OPEC), shows the large increase of this dependence in some regions of the world, including Asia and the Pacific, followed by North America and Western Europe in the last five years. For the Middle East, Latin America and Africa there have been smaller increases.

The effects on the environment of the use of natural resources are central to the concept of sustainable development. Energy security in the context of sustainable development must take into account the impacts from the current production and energy use patterns, especially those stemming from increased GHG emissions resulting from fossil fuel combustion and the corresponding implications concerning climate change and environmental deterioration.

Finally, energy security issues have been seriously affected by the reforms carried out at the macroeconomic level at the beginning of the 1980s. These reforms had dramatic consequences for many developing countries, especially for the majority of the Latin American countries burdened by massive foreign debt incurred during the 1970s.

TABLE 8.1. WORLD CRUDE OIL IMPORT DEPENDENCE (10^3 bbl/d) [8.3]

Region	Year					% change	
	2001	2002	2003	2004	2005	05/04	05/01
North America	10 842.6	10 590.0	11 237.7	11 685.9	12 152.0	4.0	12.1
Latin America	1 831.1	1 848.0	1 881.5	1 877.7	1 902.3	1.3	3.9
Eastern Europe	972.1	954.7	992.0	1 007.4	1 023.6	1.6	5.3
Western Europe	11 514.2	11 298.5	11 639.6	12 040.5	12 579.1	4.5	9.2
Middle East	487.3	491.5	501.2	504.6	507.0	0.5	4.0
Africa	777.0	778.0	731.5	761.1	792.1	4.1	1.9
Asia and Pacific	12 424.6	12 145.1	13 510.9	14 912.9	16 653.2	11.7	34.0
Total world	**38 848.9**	**38 105.9**	**40 494.4**	**42 790.0**	**45 609.3**	**6.6**	**17.4**

In the energy sector, the transition to an open market through the privatization of certain stages of the energy chain, especially the electricity subsector, has affected the option of implementing specific programmes in a coordinated manner. For this reason, the expansion of supply to rural areas in some countries has proved extremely difficult [8.4].

In the open market models established in most of Latin America and the Caribbean, the tools used to develop programmes for the rational use of energy and, in general, for the management of renewable resources are tied to the laws operating in the market and therefore are subject to their limitations. In this respect, one of the most concerning issues of the new regulatory frameworks is the lack of planning and expansion of electricity systems in some countries.

8.2. RECENT ENERGY SUPPLY SECURITY PROBLEMS

Energy security, broadly defined, has been a primary concern of the Government for the past five decades. Cuba's most important energy supply security problems result from the economic blockade in place since the 1960s and the economic crisis brought on by the collapse of the socialist system in the 1990s.

As described in previous sections, Cuba's economy was severely affected by the economic blockade against Cuba which started in 1962. During the early 1960s, the country's energy supply was particularly affected. After 1962, the country was supplied with oil by the former Soviet Union as part of a series of trade agreements that were mutually advantageous concerning prices and finance. These trade relations gave Cuba the fuel supply security necessary to undertake ambitious economic and social development programmes in the 1970s and 1980s, and helped the country to avoid the disastrous impacts of the oil crises of the 1970s that occurred in other energy importing economies, particularly developing countries.

Despite national energy conservation efforts in this period, especially concerning crude oil and petroleum products, the dependence on imports did not decrease. In 1989, imports of crude oil and petroleum products represented almost 30% of the total imports of goods and services, an equivalent in value to about 42% of the country's exports of goods and services. That same year, imports of crude oil and petroleum products reached 72% of the country's energy supply, equivalent to about 623 PJ (14.9 million toe) [8.5].

The collapse of the socialist system in Eastern Europe, and in particular the dissolution of the former Soviet Union, was an enormous blow to the Cuban economy. The consequences of these events were particularly dramatic in the energy sector. The Cuban economy was highly dependent on imported fuel and it relied heavily on the CMEA countries for new technologies and spare parts for the energy sector. Moreover, within the framework of the CMEA and with the former Soviet Union directly, it enjoyed favourable trade relations and access to finance and credit, all of which abruptly disappeared with the disintegration of this economic bloc.

In light of this economic shock, imports of crude oil and petroleum products decreased sharply. The supply of parts and equipment needed to maintain or expand the national electricity system fell to a minimum. This, in turn, led to an electricity shortage across the country that became critical in 1993–1994. The fuel supply to the residential sector was also greatly affected.

It was necessary to halt important energy projects owing to a lack of finance, which led to the delay and even the cancellation of important investments, for example, those in the thermal power plants in Havana and Holguín, and the Juraguá nuclear power plant.

In 1993, the DPNES was developed and approved to counteract the growing shortage of financial resources for purchasing energy under the new global market conditions. This programme was the most important step towards a new approach to energy development in Cuba. The results obtained in crude oil and gas exploration and extraction activities were particularly positive, as were those concerning partial recapitalization and modernization of the country's electricity generation plants, the opening of the energy sector to foreign investment, and changes in the structure of energy imports (see Sections 2, 5 and 9).

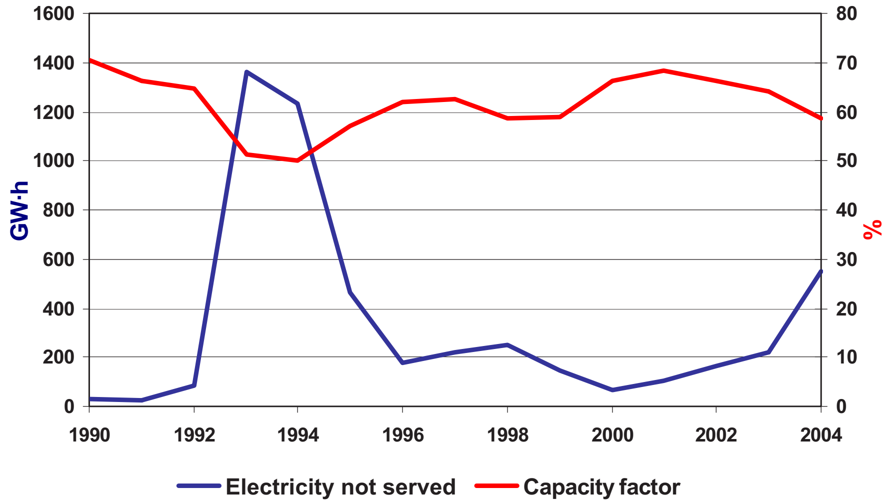

FIG. 8.1. Power plant capacity factor and electricity not served. Source: Ref. [8.6].

8.3. ADDITIONAL ASPECTS OF ENERGY SUPPLY SECURITY

The quality and the continuous availability of electrical services are additional aspects of energy supply security. The capacity factors of the electric power plants of the national electric company, Electric Union, were 12.8% lower in 2004 than in 1970, mainly owing to the ageing of the power plants. In the case of electricity not served, current values are below the peak values observed between 1992 and 1995. However, the increase in this indicator during 2003 and 2004 is a cause for concern. Service interruptions caused by hurricanes during the 2003–2004 hurricane season contributed to that increase (Fig. 8.1).

Of the external factors affecting Cuba's energy supply security, the most compromising remains the country's exclusion from almost all international financial/credit institutions, partly a result of the economic blockade, which limits Cuba's trade with the rest of the world, particularly energy trade and technology transfer.

Of the internal factors, the main limitations to energy security arise from the replacement of imported fuels, especially fuel oil, with domestic crude oil, which has a slightly lower energy performance. The main negative effect of the use of this fuel results from its high sulphur content, which, in addition to its detrimental environmental impact, has a negative impact on the operation of power plants. The use of crude oil in electric generating plants reduces the capacity by almost 10%, largely by increasing the frequency and level of maintenance required, as well as the number of emergency shutdowns and capacity limitations, which in turn affects the availability of electricity for final use (Fig. 8.1).

Another major problem concerning energy supply security in Cuba relates to limitations of the electricity distribution and transmission networks. The present transmission system faces serious problems arising from its technological obsolescence, chiefly concerning substation automation, the lack of a safe communication network and maintenance deficits, all of which make its operation unreliable. Moreover, the system lacks the reserves needed to handle any emergency and it remains extremely vulnerable to severe meteorological events. Interruptions in the energy system have serious implications for the stability and security of service, since they can cause variations of voltage and frequency, with negative impacts for clients, particularly in the industrial sector. Among the more serious negative impacts are disconnections from and sometimes failures in the generating units and total or partial losses of electricity service in different areas of the country.

The distribution system also has technical features that affect the quality and reliability of the electricity service. As with the transmission system, the distribution system is highly vulnerable to different climatic phenomena and to other destructive events. Moreover, the equipment and lines are old and technologically outdated, which causes networks to work outside of their normal voltage parameters. As with the transmission system, the distribution system lacks the necessary reserves necessary to maintain service in the face of an emergency.

Another factor limiting energy supply security is the need to guarantee a reliable and high quality energy supply, in particular to Havana. In recent years, service to the capital has been affected by several factors, including the obsolescence of most of the generating units located in the capital and the 50 MW units of the M. Gómez thermal power plant to the west of the capital. To meet the increased energy demand from consumers in the western part of the country, particularly in the city of Havana, electricity was transmitted from one end of the country to the other, leading to considerable losses and compromising service. The importance of ensuring a reliable supply to the capital is obvious. In addition to strategic considerations, one fifth of the country's population is concentrated in the capital, as well as more than half of its economic activity.

This situation prompted the authorities to connect the capital at the Matanzas substation to the A. Guiteras thermal power plant to the east of the city by means of a 220 kV double circuit. This has led to a lack of stability in energy supply and voltage regulation, in addition to transmission losses. For this reason, reinforcing the so-called ‘Havana loop’ by reinforcing the 110 kV network and incorporating new generation capacities into this loop is a high priority.

Energy supply is also affected by problems with fuel transport, particularly coastal transport, which have sometimes caused temporary shortages in territories and even interruptions in electricity service, as well as contamination problems resulting from the spillage of hydrocarbons, either resulting from accidents or during handling.

Other factors that have a negative impact on the security of energy supply include accidents in electricity generation and refining facilities, problems at storage stations and with the transport of fuel, and the interruptions in energy services resulting from the frequent tropical storms and hurricanes.

Damage to the national power grid from Hurricane Kate in 1985 caused serious interruptions in electricity service to households and industry. The experience gained by the NES made it possible to design, together with input from the civil defence, effective contingency plans that have significantly reduced the impacts of these meteorological phenomena on the electrical system. During the 2001–2002 hurricane season, the country was battered by three tropical hurricanes of great intensity (Michelle, Lily and Isidore), which affected approximately 50% of the national territory and caused serious interruptions in the electric power supply. However, such interruptions were less severe than those registered in 1985. This also occurred in the 2004 and 2005 hurricane seasons with hurricanes Ivan and Dennis, respectively.

8.4. POTENTIAL IMPACTS FROM REGIONAL ENERGY IMPORTS

The recent trade agreements with Venezuela provide for the sale of crude oil and petroleum products to Cuba under favourable conditions. This has relieved much of the financial pressure that the country has faced since the suspension of the trade agreements with the former Soviet Union. The agreement with Venezuela should provide Cuba with 2–3 million t/a of oil and petroleum products, equivalent to almost half the country’s fuel imports in 2002.

Efforts aimed at regional integration are important, and the energy sector is certain to play a leading role in this respect. At present, there are many projects aimed at integrating regional energy markets, especially those relating to natural gas and those for the interconnection of electricity systems. Cuba could benefit from such integration, particularly if investment in oil and gas exploration off its shores is undertaken by Latin American oil companies, some of them world leaders in oil and gas exploration and extraction activities.

8.5. STRATEGIES TO IMPROVE ENERGY SUPPLY SECURITY

Cuba's national strategy to improve energy security has six fundamental pillars:

(1) *Increased economic competitiveness.* This is necessary not only for improving energy security, but also for increasing the sustainability of national socioeconomic development. Cuba's main obstacle in this respect is the shortage of foreign exchange needed to undertake the technological modernization necessary to increase efficiency and productivity and, therefore, reduce energy demand.

(2) *Fuel conservation and rational use of energy.* A fundamental limiting factor in the development of programmes aimed at fuel conservation and the rational use of energy is related to the shortage of financial resources. Much remains to be done to increase the effectiveness of economic–financial instruments and incentives to enlarge the scope of the rational energy use policy, including unexploited or insufficiently used areas, mainly in the electricity sector, the sugar agro-industry, the residential sector, the production of basic materials and the transport sector, where approximately 80% of the national potential of assessed energy savings is concentrated.

In addition, the capacities necessary to raise international funds for projects supporting the rational use of energy should be developed. This could begin with the creation of a multi-organizational negotiation team to monitor project proposals systematically and submit them as a strategically integrated package in agreement with the demands of the financial entities.

(3) *Efficient exploration and use of crude oil and gas.* Important steps are being taken with the commencement of drilling in two of the offshore blocks of Cuba's EEZ in the Gulf of Mexico, with the participation of international oil companies specializing in exploration and extraction of oil and gas. Finding oil deposits of better quality than those obtained in the so-called heavy crude oil strip north of the Havana and Matanzas provinces would increase Cuba's energy self-sufficiency, since this would increase the possibility of obtaining refined products from the increased share of domestic crude oil in the refining process.

Another important aspect that involves both financial aspects and technological and R&D efforts is the use of domestic heavy crude oil in electricity generation and in the refining process, and the mitigation of the adverse environmental effects (e.g. acid rain) of the technologies that consume or process it.

(4) *Development of renewable energy sources.* Important efforts are being carried out to assess Cuba's technically and economically accessible renewable resource potential, including the recent creation of the Renewable Energy Front, with the participation of top level specialists and decision makers from the institutions dealing with this issue. The Renewable Energy Front operates under the supervision of the Ministry of Science, Technology and Environment. As with energy conservation and the exploration and extraction of hydrocarbons, Cuba must strengthen its capacity for obtaining sources of external cooperation and for raising international finance for this field.

(5) *Legal and institutional support of the energy sector.* High priority must be given to the normative, legal and regulatory aspects of energy activities and to the improvement of State control mechanisms, particularly the strengthening of the State energy inspection. This includes, first, the introduction of standards for buildings and for equipment production and imports, and the improvement of existing standards, as well as the reinforcement of practices related to energy efficiency and the use of renewable sources.

The adoption of a new electricity law currently under review would provide significant support for institutionalizing the rational use of energy. Another useful step would be the creation of a regulatory agency having the greatest autonomy possible and its own legal status.

Among the actions likely to have the greatest positive impact on improving energy security are the following:

— Improvement of tariff and pricing policies;
— Diversification of financing mechanisms and forms;
— Measures to increase the role of the territories or provinces in energy management and in the use of locally available renewable sources;
— Strengthening of the institutions that promote the rational use of energy, particularly ESCOs;
— Promoting the production of energy saving equipment and the use of renewable sources (mainly relying on foreign investment and without excluding the possibility of exports to third countries);
— Progressive improvement in energy planning, reinforcing a strategic approach.

(6) *International involvement.* Cuba would benefit from active involvement in the efforts of regional integration and in international forums related to technological, energy and environmental issues, and in strengthening bilateral alliances aimed at creating the necessary environment for trade, technology transfer, R&D and foreign investment for guaranteeing national energy supply.

8.6. MAIN ISSUES

In the case of Cuba, energy security goes beyond the typical security framework of energy supply to encompass the economic blockade which affects Cuba's access to some markets for its traditional products and obstructs international credit options.

Recent problems concerning security of national energy supply include:

- Shortages of foreign exchange necessary for the purchase of fuel and spare parts, for new investments and for the implementation of programmes supporting the rational use of energy.
- High dependence on imported energy, including oil and petroleum products.
- Use of domestic crude oil, with energy performance slightly below that of the imported fuels it replaces, especially fuel oil. The main negative aspect is the high sulphur content, which has adverse operational and environmental effects.
- Interruptions in energy services resulting from hurricanes and tropical storms, and from breakdowns and accidents related to the transport of fuels, especially coastal transport.

The strategies employed to improve Cuba's energy security situation are based on:

- Increased economic competitiveness;
- Fuel conservation and rational use of energy;
- Efficient exploration and use of oil and natural gas;
- Development of renewable energy sources;
- Legal and institutional support of activities in the energy sector;
- Active involvement in the international arena focused on regional integration efforts and international forums related to technological, energy and environmental issues, and on strengthening bilateral alliances aimed at creating the necessary environment for trade, technological transfer and foreign investment for guaranteeing national energy supply.

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9. POLICY OPTIONS FOR ENERGY DEVELOPMENT

D. PÉREZ

9.1. INTRODUCTION

During the oil crisis of 1973, developed countries adopted policies to promote alternative energy sources to reduce dependence on oil and to maximize efficiency for all forms of energy, especially through the development of efficient end use technologies and equipment. Growing concerns regarding the environmental impacts of energy systems added weight to the search for alternatives to oil. However, as Cuba was not greatly affected by the global oil crisis, its economic and social development continued to be based on inefficient and high energy consuming technologies.

Nevertheless, in the early 1980s, the Government recognized the need to establish an energy policy aimed at achieving energy efficiency and rational energy use. The first major steps taken in this direction were the creation of the National Energy Commission in 1983 and the holding of the First National Energy Forum in 1984. During the 1980s, measures reinforcing energy activities were adopted and many research institutions began to consider energy as a priority activity.

The crisis of the 1990s led to an abrupt reduction in energy imports that affected the whole society. The struggle for energy solutions became the key activity for institutions and provinces, and the primary focus for many specialists, technicians and workers. This crisis prompted the Government to establish the DPNES in 1993 [9.1]. This programme has been an important driving force behind the changes observed in the Cuban energy system since that time.

The decentralization and economic reform process implemented by the Government in response to the crisis created a framework that supported policies on the rational use of energy. The first step taken was to fix domestic energy prices in foreign exchange currency for the growing number of entities that deal in such currency. These prices accurately reflect the real energy supply costs. Additional policies included regulation and energy planning. These changes, together with the reform of the financial and banking system, made it possible to begin incorporating mechanisms that, in practice, make efficiency improvements and rational energy use viable forms of financing energy projects.

In response to the crisis of the 1990s, a new approach to development strategies in the Cuban energy sector was adopted. The new strategies were aimed at offsetting the devastating impact that Cuba's unfavourable indicators of energy efficiency, availability and dependence had under the new international conditions. Under these new circumstances, the strategic importance of efficient energy use and the development of renewable energy sources became even more relevant.

This section reviews the energy policies implemented by Cuba regarding the expanded use of domestic crude oil and associated gas, increases in renewable energy sources, improvements in energy efficiency, and the introduction of electricity and fuel conservation programmes. Although these policies were not motivated by the search for sustainability in energy development, they make an intrinsic contribution to sustainable energy development through the positive results obtained from them, which demonstrate their value and the need to strengthen and to modify them. This section also discusses the basis for new energy policies whose application would contribute to Cuba's sustainable energy development. Finally, it briefly addresses the wide range of economic, environmental, industrial, social, institutional and transport policies that influence domestic energy demand, although a detailed examination of these policies is beyond the scope of this report.

9.2. NATIONAL POLICY ORGANS

9.2.1. Gas

Different policies have been implemented to increase the use of associated gas, LPG and city gas in Cuba. These policies have resulted in:

- The use of 15 billion m^3 of associated gas per year that was previously flared;
- Mitigation of the environmental impacts from the flaring of gas on the important tourist areas of Varadero and Boca de Jaruco, where 60 t/a of sulphur was released to the atmosphere daily before 1998;
- Diversification of the energy matrix and a reduction in dependence on external sources;
- Production of low cost electricity and increased efficiency in electric power generation, in addition to the production of LPG, naphtha and sulphur.

In 1998, electricity generation using associated gas started with a 35 MW gas turbine; by 2004, five gas turbines and a combined cycle plant reached a total of 240 MW. At the same time, efforts were made to create the necessary infrastructure to support such tasks, for example, oil wells and gas pipelines were sealed. All associated gas, previously flared before 1998, in the Varadero zone is now used for electricity generation.

Combined crude oil and associated gas reserve estimates in the EEZ of the Gulf of Mexico are more than 29 000 PJ (700 million toe) (see Section 3).

Option: Increase the use of associated gas for electricity generation

With the increase in oil extraction at Boca de Jaruco, the amount of associated gas has also increased. Currently, approximately 1 billion m^3 of gas is flared daily in the area. Extension of electricity generation in the area by the construction of a 180 MW combined cycle plant by 2008 is being implemented. Making use of the associated gas will increase the efficiency of electricity generation and reduce generation costs, which will have important positive economic and environmental effects.

With the increased use of associated gas from current oil production and from any new discoveries in the EEZ, it will be possible to expand the national electricity system with gas combined cycle plants instead of thermal power plants.

Option: Use associated gas in transport

Since 1998, a number of vehicles have been converted to run on compressed natural gas (CNG). At present, there are two CNG service stations, where a portion of the installed CNG capacity is used to supply the converted vehicles. Eventually, all the installed CNG capacity is expected to be used to supply converted vehicles and the use of CNG is expected to expand to include taxis and buses in Havana and other cities around the country.

Replacing fuel imports, particularly diesel, with CNG will decrease Cuba's import dependence and could have environmental benefits (particularly for the city of Havana), as diesel combustion leads to emission of particulate matter, which is damaging to human health.

Option: Change in the use of LPG and city gas

In 2000, a programme was created aimed at substituting LPG and city gas for kerosene and alcohol in households. This programme, which began in Havana and Santiago de Cuba, includes the expansion of the city gas service in Havana. It has contributed greatly to reducing environmental impacts and increasing the population's quality of life. Currently, 518 000 customers benefit from these services, with an additional 35 000 new customers in Havana and Santiago de Cuba added in 2005–2006.

The modernization of the production and distribution of city gas in Havana led to the replacement of expensive and polluting carriers (naphtha and coke) with associated natural gas, as well as the recapitalization of the distribution network and the introduction of meters for households.

In 2006, the Government launched the programme aimed at substituting electricity for the kerosene, alcohol, charcoal and fuelwood still used for cooking. LPG use will be reduced in the household sector because it has higher costs than electricity. The supply of city gas to clients will be maintained at current levels, but small increases in its use will occur due to expected higher demand from these clients.

9.2.2. Crude oil and petroleum products

The production of domestic crude oil has increased at an annual average rate of 17% since 1997, reaching 3.7 million t in 2003 [9.2]. In the past, the production of petroleum products has largely depended on the international political situation, which has generally favoured imports over domestic refining. This situation has changed in favour of domestic refining, especially in the light of the oil supply agreement with Venezuela, which resulted in a 40% increase in refining in 2003 over the previous year [9.2].

One measure that has played a significant role in achieving energy efficiency is the requirement for self-financed companies to pay for petroleum products and electricity in foreign exchange. Self-financed companies are those that export and/or sell in foreign exchange in the domestic market. Industries providing goods or services to companies that, in turn, sell in foreign exchange are also included. Requiring payment in foreign exchange for energy in the productive sector, which presupposes the establishment of real prices for fuels and their alignment with opportunity costs, has produced a significant change in the behaviour of consumers concerning conservation and the efficient use of energy.

Regarding taxes on fuels, only sales of gasoline and diesel in gasoline stations operating with foreign exchange are taxed. All other supplies are tax free.

Important investments in electricity generation have allowed not only the modernization of the main thermal electric power plants, but also their adaptation for use of domestic crude oil, leading to important savings in the import of fuels for electricity generation. In addition, modernization has also reduced the financial pressures on the national balance of payments and guaranteed that, at present, almost 100% of the electricity in the country is generated using domestic fuels.

The use of domestic crude oil has also been extended to cement production, where 100% of the sector's fuel needs are met using domestic fuels. More recently, domestic crude oil has also begun to be used in nickel production.

Fuels are allocated and rationed by the Government. However, instead of using physical quotas, finance is allocated to the consumers. The only fuels that can be freely obtained on the market, with prices in foreign exchange, are the different types of gasoline and diesel for privately owned vehicles.

Option: Increase the production of petroleum products from domestic crude oil and increase refining capacity

With the demand for crude oil in electricity generation, cement production and, increasingly, nickel production currently being met using domestic sources, and with the expected increase in the extraction of crude oil, mainly in the EEZ of the Gulf of Mexico, Cuba is likely to have surpluses of better quality crude oil in the future. Such surpluses would enable an increase in the domestic production of petroleum products, thus increasing self-sufficiency with regard to fuels and possibly leading to the export of petroleum products at a subsequent stage. Reaching this level would require an increase in the nation's refining capacity. An overall refining capacity of 5.9 million t/a is expected to be reached in 2008–2009, up from 2.9 million t/a in 2005. To satisfy nearly 90% of petroleum products demand by 2025, it will be necessary to increase the refinery capacity to 9.4 million t/a.

9.2.3. Renewable sources

Cuba's renewable energy options include solar applications such as photovoltaic systems, heaters, dryers and solar distillers; hydropower (small, mini-, micro-hydropower plants, pumping storage, pumping systems such as motor winches, hydraulic rams, etc.); and wind generators and windmills for electricity and water supply, respectively, which have already been introduced in the country to a limited extent.

Option: Increase the use of non-combustible renewable sources

Photovoltaic systems, mini- and micro-hydropower plants, wind driven generators and hybrid systems combining photovoltaic and wind driven generators are currently considered the best alternative means of providing electricity to the roughly half a million people (4.5% of the population, according to Ref. [9.2]) living in mountainous or other isolated areas far from the grid.

Solar heaters, dryers and distillers are widely used in the tourism, agriculture and services sectors, and in public service facilities such as hospitals, day care centres, primary and secondary boarding schools, residential homes for the elderly and medical care centres for pregnant women. Their widespread use should reduce the unit cost of this equipment.

Likewise, water pumping devices are in great demand for water supply in rural areas, especially in areas used for cattle production, particularly in the eastern provinces during periods of drought.

Appropriate technical and economic feasibility studies should be undertaken to examine the possibility of expanding the use of photovoltaic–wind power hybrid systems. Similar studies should also be undertaken for wind power systems in the cays, as well as for 30 MW wind farms. By 2008, 100 MW of wind energy could be installed, reaching 700–1200 MW or, in the most optimistic scenario, around 2555 MW by 2020 or 2025.

9.2.3.1. Biomass

Sugarcane biomass

The main biomass used in Cuba is sugarcane biomass or bagasse. Forest and other biomass have a very small share of domestic energy use. Fuelwood use has been reduced in recent years and this trend is expected to continue until the use of charcoal and fuelwood is phased out by 2015.

The sugar industry's energy programme consists of projects aimed at generating electricity both to satisfy the demand from sugarcane production itself and to supply NES. The projects can be divided into three types:

(1) Measures aimed at resource and fuel conservation and maximum exploitation of existing installed capacities by using the equipment in inactive sugar mills, which could reach 616 MW.
(2) Measures aimed at increasing installed capacity in sugar mills by adding facilities, including condensing turbogenerators or extraction–condensation turbogenerators, to mills where few investments are required and to those mills with distilleries. These sugar mills should operate about 7000 h annually in the future, installing an additional 120 MW.
(3) Measures aimed at constructing sugarcane biomass power plants next to sugar mills that operate throughout the year (55 MW).

Option: Increase the efficient self-generation of electricity in the sugarcane sector

Measures are being considered to reduce the use of steam and electricity and to increase efficiency in the use of sugarcane biomass. The generation indices are expected to reach values above 60 kW·h/t of crushed sugarcane by 2010. By this time, the Ministry of Sugar Industry is expected to cogenerate 2000 GW·h while consuming 1544 GW·h, representing a net delivery to NES of 454 GW·h each year. Starting in 2010, this contribution to NES is expected to be gradually increased, mainly by increasing technical parameters and efficiency up to levels of 130 kW·h/t of crushed sugarcane. Approximately 500 kW·h/t of crushed sugarcane could subsequently be obtained in integrated bagasse gasification combined cycle plants. This technology is not currently commercially available but it can be considered after 2015. All of these measures should be fully implemented to achieve all the expected benefits.

Forest biomass

Forest biomass has limited potential in Cuba. At present, the use of sawdust for energy use is very limited, and the economic and technical feasibility of increasing its use needs to be assessed. With reforestation of areas formerly used for sugar plantations, however, planted forests could potentially be used for energy. The implementation of the Isla de la Juventud project, which includes the gasification of forest biomass for electricity generation, should contribute to the development and better use of this resource in the country.

9.2.3.2. Biofuels

Sugarcane is used to produce alcohol in Cuba's 17 distilleries. This production peaked at 1.07 million hL in 1990. Later, with the reduced sugar harvests during the 1990s, alcohol production decreased; it has stabilized in recent years at about 600 000 hL annually. This production is used mainly domestically for cooking purposes and in the production of alcoholic beverages [9.3].

The Ministry of Sugar Industry has carried out tests in truck fleets using mixtures of 8% alcohol in diesel and 25% alcohol in gasoline with satisfactory results. There are a number of ongoing technological development and research projects using hydrous alcohol, which lowers alcohol production costs.

Preliminary studies of biodiesel production from *J. curcas* (a small tree or shrub) and *Higuereta* (the source of castor oil) have also been carried out. A pilot plant to produce 450 t/a of biodiesel from *J. curcas,* including investigating the potential increases in harvesting areas, has been under implementation since 2006. It is necessary to assess the feasibility of increasing the cultivation of *J. curcas* using unused land.

Option: Increase alcohol production for use as a transport fuel

Alcohol production is to be increased to 4 million hL per year by 2010. Thus, mixtures of 8% alcohol in diesel and 25% alcohol in gasoline could be introduced in automotive transport, with a consequent decrease in pollutant emissions and costs. In addition, new jobs could be created and a comprehensive diversification programme could be developed, with the sugar industry becoming more flexible to produce either sugar or alcohol. Once national self-sufficiency for the alcohol mixtures has been achieved, fuel could be exported where demand for such fuels already exists.

In addition, an assessment is being conducted on the production of biodiesel from *J. curcas* and *Higuereta* for use as a motor fuel, in mixtures with diesel and for replacing diesel additives. Technologies to eliminate the toxic residues of biodiesel production need to be developed.

9.2.4. Solid waste

Solid wastes increased from 1997 to 2003, reaching 22.1 million m^3 [9.2], which caused disposal problems. Moreover, the decomposition of organic matter, which made up more than 50% of the waste in 2002 [9.4], constitutes a source of fires.

The anaerobic decomposition of the organic matter also produces CH_4 and CO_2. According to the estimates of the National Inventory of Emission and Absorption of Greenhouse Gases, urban solid wastes deposited in almost 800 sites around Cuba generated more than 105.2 Gg of CH_4 in 2002 [9.5]. This potential could be used for electricity generation. Several evaluations have been carried out in this respect, but no projects have been implemented.

Wastes from sugar production, which are used in isolated places, are another major source of pollution. Biogas from these wastes could be used for cooking, metal cutting work and gas lighting, as fuel for transport and also for generating electricity. It is also possible to obtain biogas from distillery waste, and from bovine and sheep wastes.

Option: Use of methane from different sources for electricity generation and other uses

The technology to generate electricity using methane is commercially available. Assessment of the potential use of methane for electricity generation and other uses in Cuba needs to be carried out.

9.2.5. Electricity

In the light of the crisis of the 1990s, the Electric Union adopted a two pronged strategy. On the supply side, it aimed at modernizing the main thermal power units and putting into service new generating capacities, and on the demand side, it aimed at implementing PAEC in Cuba. PAEC, which was based on the DPNES, was implemented in 1997. It drew on international experience, particularly that of Peru and Mexico, and considered fuel conservation and the rational use of energy to be one of the most important national options in reducing electricity demand.

PAEC's objectives[40] were the following:

— To reduce maximum demand by at least 150 MW and the annual consumption growth rate by 2% over the 1998–2000 period;
— To encourage the rational use of energy and environmental protection in new generations by promoting better energy use habits;
— To develop standards and a pricing policy that would guarantee the energy efficiency of all new electrical appliances used in the country.

The following measures were included in PAEC, listed in order of electricity demand reduction potential according to estimates [9.6]:

— Implementation of an emergency programme to decrease losses from NES transmission lines;

[40] In order to achieve these objectives, the following projects were developed: (a) an educational project, with the goal of presenting this material to children at all school levels; (b) a standards and pricing project to regulate efficiency and encourage the use of lower energy consuming electrical appliances; (c) a project to motivate energy savings by informing the public about the savings measures applicable to the different electricity consuming sectors; and (d) an assurance programme to guarantee the technical, financial and material resources required for the projects.

— Expansion of the requirement to pay for electricity usage in foreign exchange to more than 60% of non-residential sales and intensification of electricity audits;
— Installation of four million energy efficient light bulbs;
— Replacement of faulty seals in approximately one million domestic refrigerators;
— Replacement of incandescent and mercury street lights with highly efficient sodium lamps;
— Implementation of broadcast campaigns and educational programmes;
— Imposition of a ban on the use of air-conditioning at State run workplaces during peak hours (from 18:00 to 22:00);
— Establishment of standards and technical requirements for residential electrical appliances, both imports and those manufactured domestically.

The actual maximum electricity demand reached by NES was 2138 MW in 2000, 162 MW lower than the projected figure; thus PAEC achieved its objective. Nevertheless, work continues in all project areas to reduce the effects of the increased number of electrical appliances owned by the population and the continued recovery in the industrial and services sectors, which have increased overall electricity use. For these reasons, in 2001 a technical team was created to carry out studies and prepare energy demand reduction projects for those sectors.

Important advances have been made through the rational energy use campaigns broadcast on television, the educational work using textbooks in primary and secondary schools, the contests held in schools up to provincial level and the efficiency standards put in place for electrical appliances and new buildings.

PAEC has had its greatest impact in increasing the energy efficiency of the economy. The emphasis was initially on the household sector, particularly lighting and refrigeration, but it has been expanded to include the business sector and other energy applications. PAEC is an example of coordinated work among different national institutions, provincial governments, citizens, social organizations and the mass media.

A successful programme has also been undertaken to upgrade the electric power transmission and distribution system to reduce losses from the electric grid. Measures have been adopted to reduce non-metered services and an anti-fraud programme has been instituted, with corresponding legal support.

It has also been possible to advance electrification of the rural and mountainous areas using renewable energy sources such as mini-, micro- and small hydropower plants, photovoltaic panels, wind generators and hybrid systems, where the non-governmental organization CUBASOLAR has had a decisive role.

There have been improvements in technological information services, in the management of R&D and in the elevation of the role of international cooperation. Cuba is working with international companies and organizations to implement a number of projects of considerable energy and environmental significance. In particular, with assistance from the UNDP, the Global Environment Facility, the United Nations Industrial Development Organization, the Food and Agriculture Organization of the United Nations and others, Cuba is carrying out demonstration projects on electricity generation from bagasse and sugarcane residues, from other biomass and from different types of solar energy application.

The use of electricity has also grown in the household sector owing to a number of factors, including the growth in population and in the ownership of electrical appliances, although growth in the latter category has been limited by restrictions on appliance sales. It is necessary to keep in mind that current models are much more efficient than older models and that energy efficiency standards now apply to both domestically manufactured and imported appliances. However, programmes that subsidize appliances such as rice cookers, electric cookers and electric stoves will extend the use of electricity in the household sector.

The use of electricity has also grown in the agricultural sector, owing to the shift from diesel to electricity for power irrigation systems.

Option: Increase actions supporting fuel conservation and the rational use of energy

The work of load supervisors will continue with respect to more than 350 major industrial consumers of electricity in order to encourage rational energy use and to shift electric loads from peak hours. In addition, cogeneration in sugar mills should be increased during peak hours. The increase in efficiency would allow bagasse surpluses to continue cogenerating electricity at least one month beyond the end of the sugar harvest.

Considerable inefficiencies result from large idle capacities in transformers and engines and from the use of productive facilities far below their capacities.

Textbooks on rational energy use are being used in different education centres, and work continues on educational programmes and advertisements for television. Educational efforts have been increased at all levels and throughout the community to address the important energy saving potential in the household and public sectors, which have less incentive to save because they receive subsidized electricity.

Furthermore, work should continue on the sale of more efficient equipment, with stickers indicating their energy use, and on the widespread application of new efficiency standards for appliances and buildings.

9.2.6. Fuels and lubricants

High fuel prices and the need to conserve and use fuels efficiently motivated CUPET to develop a fuel and lubricant conservation programme. For this reason, in 2001, the Attention to the Client System programme was created to provide personalized attention to centres with high use of fuels and lubricants. This system is led at the national level, with provincial groups created to carry out diagnoses and to develop conservation plans.

The aims of this programme are to direct the efficient and rational use of fuels and lubricants, increasing the levels of fuel conservation in the country, and to measure the level of satisfaction of all CUPET clients and energy consumers. The programme provides a technical service concerning the handling, storage and efficient use of fuels and lubricants, deals with necessary quality improvements of the products, and provides training to clients, consumers and the population in general. It also evaluates the structure of the fuel market and identifies future prospects, and takes care of claims, suggestions and complaints about CUPET products or services.

Option: Actively support the fuel and lubricants conservation programme

The supply of domestic crude oil will continue to be guaranteed for the operation of all thermal power plants, cement factories and nickel cogeneration facilities and refineries. The replacement of diesel with fuel–diesel mixtures in combustion facilities and the replacement of naphtha with diesel in the processing of domestic crude oil were completed in 2006. The use of associated gas in electricity generation will increase with the completion of a new combined cycle plant in 2008. The use of gas for LPG production and city gas will increase as the demand for these fuels increases during the study time period.

Also, it is necessary to assess the effect of changes in energy use patterns according to the massive distribution of domestic equipment implemented as part of the Cuban Energy Revolution project. The effect of other actions in the transport, industrial and services sectors also needs to be assessed.

9.2.7. Energy efficiency and sources of finance

Recently, a number of programmes and actions have been implemented in the different sectors to increase energy efficiency, especially in the nickel industry, tourism, the sugar industry, transport, steel and cement production, agriculture, the machinery industry and, more recently, the non-durable industry (e.g. clothing, pharmaceuticals). In some of these sectors, foreign investment has played an important role.

In the energy efficiency market, operating basically within the sector financed with foreign currency, particularly in tourism, a group of ESCOs has recently emerged. This development has allowed the national bank to participate in the financing of investments for energy efficiency and modernization, although such investments are still in the early stages.

The Financial Fund for Energy Efficiency was created to make feasible investments in the energy efficiency field. The fund is operated by an interministerial commission headed by the president of the Central Bank. The commission has supported the actions of ESCOs, taking advantage of the possibilities offered by the growing efficiency market.

To promote efficiency in the use of renewable sources such as bagasse and sugarcane residues for electricity generation, a special tariff was adopted, to be paid in foreign currency to MINAZ for the electricity contribution to the system. This measure is smaller than but similar to the measure adopted by the National Institute of Hydraulic Resources regarding the electricity produced.

Among the decisions adopted by the Government concerning energy, the creation of the Renewable Energy Front in 2002 stands out. Its objectives are the following:

— To provide the country with a specialized State instrument that favours and promotes the use of renewable energy sources and submits proposals to the Government regarding policies in support of renewables that eliminate current limitations hindering development in this field;
— To give priority to and increase the sustainable, rational and beneficial use of renewable energy sources in the country;
— To favour and encourage cohesion and integration among the different institutions and ministries, promoting closer links and greater incidence in this strategic activity.

Other factors of great relevance in energy activities are improvements in energy planning (increasingly based more on availability of finance and the integration of income and expenditure budgets in foreign exchange for more than 400 activities); improvements in control systems in the use of fuels, both in MINAZ and in the Ministry of Agriculture; and measures to avoid corruption and the diversion of fuels for non-planned objectives or for illicit purposes.

In addition, the tax system accords preferential treatment to the acquisition of highly energy efficient appliances by reducing the import taxes on this equipment.

Option: Promote energy efficiency

The greatest potential for energy efficiency improvements are in the sugar industry (26.6%), the household sector (18.7%) and the electricity subsector (15.5%), followed by transport (7%), nickel production (6.8%), production of petroleum products (4.9%), cement (3.4%) and the agricultural sector (2.9%) [9.7].

The sugar industry could achieve significant increases in energy efficiency through increased agricultural yields and industrial efficiency. For its part, the electricity subsector's main efficiency potential is in power generation and energy distribution activities, where modernization and maintenance play key roles.

The effects of electricity saving measures as well as those of the fuel substitution programme are included in the household sector.

The estimated medium term saving capacity represented 25% of the domestic final energy use in 1998. About 40% of this saving capacity can be ascribed to the recovery effect directly associated with the increased use of productive capacities and the improvement in economic efficiency in general.

The analysis of the energy efficiency capacity over the long term reflects important structural changes compared with that over the medium term. The first four sectors listed above account for more than 80% of the reduction in the energy intensity of the economy over the medium term and about 65% over the long term. Thus, the electricity, household and basic materials sectors, which account for over 50% of the energy saving potential over the medium term, contribute only approximately a third of this potential over the long term [9.7].

One sector that is likely to reduce further its energy intensity is the services sector (including tourism). The dynamism of this sector with regard to energy use is notable throughout the economic recovery stage that began in 1994. According to these estimates, the relative importance of the 'market' in which the existing ESCOs currently operate in the country will at least double over the next 20 years.

Other sectors likely to increase their contribution to lower energy demand are the metal production industries and construction sectors. They have shown the most dynamic economic recovery, a trend that should continue in the future, as the sectors include high technology industrial production. In the case of construction, the trend should continue because of the need to build infrastructure to achieve dynamic growth and meet the large needs of recapitalization, both in the productive sector and in housing.

The transport sector should also significantly increase its share in fuel conservation, keeping in mind that only in the long term will it be possible to implement investment for technological renovation, which is greatly needed, and which has a relatively extensive recovery period. The contribution of this sector to fuel conservation is also influenced by the fact that, from both the technical and the economic viewpoints, it is one of the more depressed at present, which is why any gradual increase in efficiency should have notable impact on the magnitude of future transportation fuel demand.

The household sector is likely to maintain an important, although smaller share, considering that efficiency measures are relatively easily implemented in the medium term, since the recovery period for the necessary investments is relatively short.

The share of basic materials, in general, will decrease owing to the fact that over the medium term the most important activity with regard to energy use, the nickel industry, will show greater advances in the efficient use of its reserves than the rest of the industries, in part because of the effects of foreign investment. In addition, this sector is not considered to have the potential for additional long term expansion (which is not the case over the medium term), not only because it is based on limited natural resources, but also because many energy intensive industries are included in this sector.

In conclusion, the efficiency improvement in different sectors needs to be assessed as an important means of accomplishing long term sustainable energy development.

9.2.8. Nuclear energy

In the mid-1970s, Cuba began a broad capacity building programme aimed at training professionals and technicians in the field of nuclear energy. Construction of Cuba's first nuclear power plant (four reactors of 417 MW WWER model 318) began in the 1980s [9.8]. The reactor model was the most advanced developed by the former Soviet Union, with automated control systems by Siemens. The reactors also had a containment dome.

Construction of the first unit of these reactors is 70% complete. However, for economic reasons, and because of the end of the advantageous commercial relationships with the former Soviet Union, construction of the Juraguá nuclear power plant was halted in 1992. Subsequent attempts to continue with the participation of a third party have been unsuccessful.

Qualified personnel from the Cuban nuclear energy programme were gradually redeployed, mainly to the electricity sector, and part of the equipment is currently being used in thermal power plants.

The Cuban nuclear programme is currently directed towards nuclear applications in the health, industry and agriculture sectors and to environmental preservation. However, the introduction of nuclear energy could play an important role in diversifying Cuba's energy mix, increasing its energy sustainability and reducing the environmental impacts, and should be assessed as an option in the country's long term energy development plans.

9.3. INTERNATIONAL COOPERATION

9.3.1. Technology transfer

Cuba has a network of institutions that initiates, modifies, imports and disseminates new technologies. This network includes financial, legal, scientific, technological and educational institutions, among others, dealing with public policies concerning taxation, export promotion, science, technology and technological innovations, etc.

Until the crisis of the 1990s, technology transfer was an accelerated process carried out within the framework of the CMEA. After this crisis, Cuba developed a broad training and education programme for human resources that currently constitutes the primary basis of technological assimilation and adaptation. However, under current international trade conditions, the transfer of technologies has been much more difficult, especially the transfer of technology originating in the USA.

9.3.2. Clean development mechanism (CDM)

Cuba signed the United Nations Framework Convention on Climate Change (UNFCCC) on 5 January 1994 and ratified the Kyoto Protocol on 30 April 2002. Its participation in the UNFCCC regime allows, as a developing country, the implementation of CDMs.

In accordance with Agreement No. 4604, adopted on 20 November 2002, the Executive Committee of the Council of Ministers stipulates that the Ministry of Science, Technology and Environment is responsible for the national management and implementation of the CDM programme. On 19 May 2003 CITMA approved the Rules for the Attention and Implementation of

CDM Projects [9.9] and created the National Group for the Implementation of the CDM programme. The National Group is presided over by CITMA and is made up of representatives from the Ministry of Foreign Investment and Economic Cooperation, the Ministry of Foreign Affairs, MEP and the Ministry of Finance and Prices.

National priorities related to CDM are concerned mainly with the development and application of renewable energy sources, energy efficiency, the absorptive capacity of forests and the management of solid wastes.

9.4. MAIN ISSUES

It was not until the end of the 1980s that concrete steps were taken regarding the formulation of energy policies aimed at energy efficiency improvements and rational energy use. Among the steps taken was the formulation and implementation of the DPNES, approved in 1993.

The DPNES implemented by Cuba to expand its use of renewable energy and domestic crude oil and associated natural gas and to increase energy efficiency, as well as the electricity and fuels conservation programmes, have been generally successful. The programme related to sugarcane biomass has been less successful.

The application of policies supporting these objectives was motivated, not by concerns regarding sustainable energy development, but by factors related to the satisfaction of the minimum energy demand of the country. However, the positive results of those policies argue for their continuation, intensification or modification because of their intrinsic contribution to sustainable energy development.

New options that would contribute to sustainable energy development in Cuba include: an increase in the production of alcohol as fuel and petroleum products; greater use of non-combustible renewable sources such as wind generation, photovoltaic systems, mini-, micro- and small hydropower plants; increases in the efficiency of cogeneration in the sugar industry and in the use of methane in electricity generation; and, over the long term, the introduction of nuclear energy.

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10. SCENARIOS

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Scenarios provide a framework for exploring future energy perspectives, including a continuation of current dynamics and alternative paths developed on the basis of different assumptions relevant to sustainable energy development. It is important to note that scenarios are neither forecasts nor predictions, but are images of alternative futures based on internally consistent and reproducible sets of assumptions [10.1]. Thus, scenario outputs and assumptions are inseparable parts of the overall integrated modelling process.

This section presents alternative scenarios developed for Cuba for the period 2002–2025. One basic reference (REF) scenario is developed to explore future paths for both energy demand and supply. The optimization of the supply system is further analysed by the development of three alternative scenarios in addition to the REF scenario: a fossil fuels (FOS) scenario that emphasizes the use of fossil fuels; a renewables (REN) scenario that emphasizes intense use of renewables; and a mixed fuels (MIX) scenario that combines assumptions about the use of fossil fuels and renewables. Finally, a sensitivity analysis is performed in which alternative assumptions related to imported crude oil and petroleum products prices are taken into consideration. This section summarizes the methodology, assumptions and resulting characterizations of these alternative scenarios.

10.1. METHODOLOGY

10.1.1. Overall methodology

The comprenhensive assessment of the development of Cuba's energy system follows an integrated approach based on assumptions derived from analysis and evaluation of different criteria for sustainable energy development. In this integrated approach, top–down assumptions about the country's economy, population and lifestyles are combined with bottom–up disaggregated specifications and constraints concerning the resources, fuels and technologies needed to develop the energy demand scenario and the alternative scenarios for the optimization of energy supply. This integrated approach is illustrated in Fig. 10.1. The assessment includes three major modelling and analysis components:

(1) *Energy demand*. This component provides detailed sectoral energy demand projections by applying the MAED [10.2] based on numerous scenario assumptions concerning demographic developments, technological progress, behavioural changes, economic structural change and economic growth.
(2) *Energy supply optimization*. This component allows the formulation of optimal scenarios of energy and electricity supply mixes using MESSAGE [10.3], taking into consideration available resources, present energy infrastructures, current and future conversion technologies, and socioeconomic, technical and environmental (policy) constraints.
(3) *EISD*. The EISD system of indicators [10.4] allows the evaluation of past and future energy trends in the social, economic and environmental dimensions of the major issues selected by Cuban experts in their sustainable energy development criteria (see Section 1).

Projected economic and demographic growth, structural economic change and the dynamics of sectoral energy intensities, as taken from previous sections, are the key drivers of future energy demand. The energy demand projected by MAED serves as input to the energy supply system optimization based on MESSAGE. The integrated modelling system includes a feedback component that allows plausibility checks, a final demand and supply balance, and convergence of energy demand and supply with previously quantified sustainable development targets. Through this iterative process, assumptions become integral parts of the scenario results.

The resulting trends developed from each scenario, coupled with past trends, are analysed using the EISD to evaluate the possible evolution of important energy issues concerning the criteria for sustainable energy development.

10.1.2. Methodology of MAED

MAED was used to project energy demand for the basic REF scenario. MAED evaluates future energy demand scenarios on the basis of medium to long term socioeconomic, technological and demographic development assumptions.

The model systematically relates the specific energy demand for producing various goods and services to the corresponding social, economic and technological factors that affect this demand. Energy demand is disaggregated into a number of end use categories, each corresponding to a given service or to the production of a certain item.

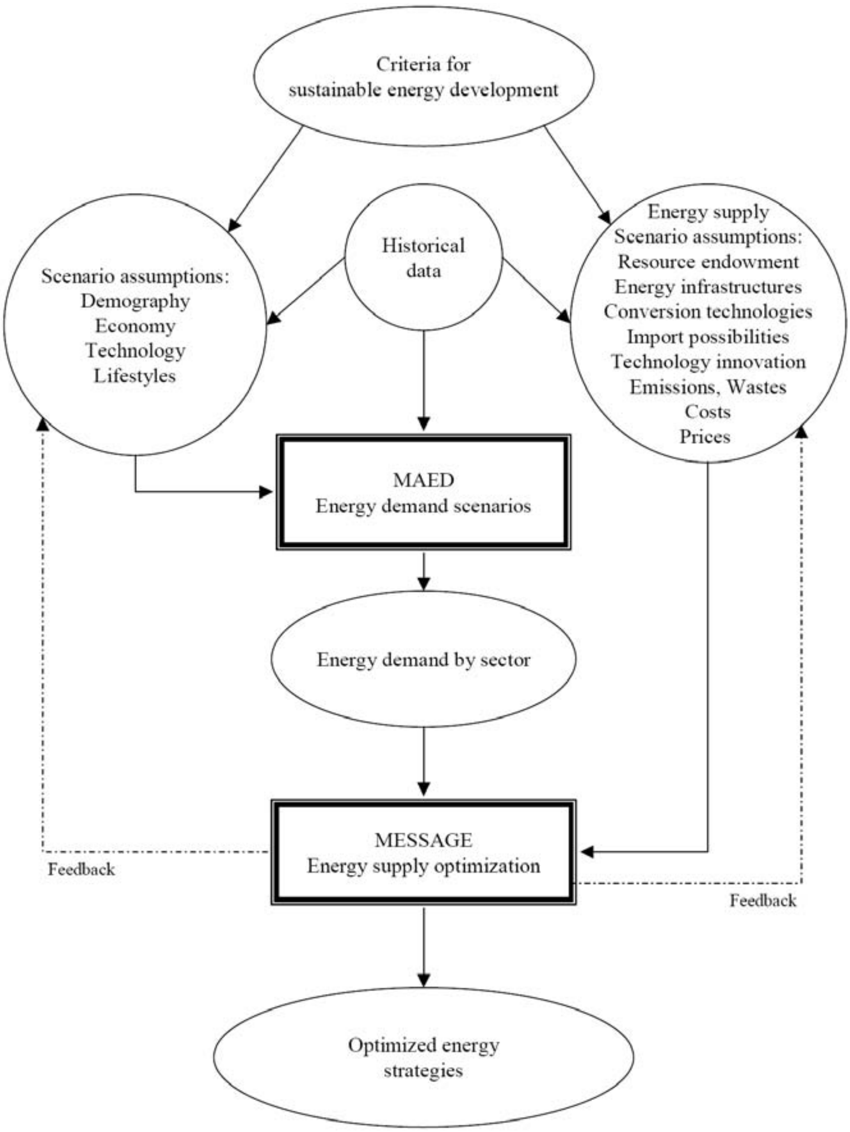

FIG. 10.1. Conceptual modelling framework.

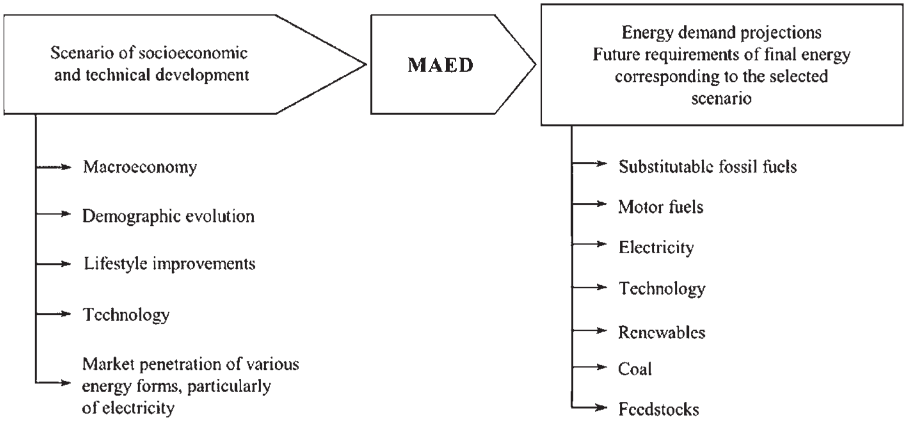

FIG. 10.2. Major inputs and outputs of MAED.

The nature and level of the demand for goods and services are functions of several determining factors, including population growth, number of inhabitants per dwelling, number of electrical appliances used in households, personal mobility and preferences for transport modes, national priorities for the development of certain industries or economic sectors, improvement in efficiency of certain types of equipment and market penetration of new technologies or energy forms. The expected future dynamics of these determining factors, which constitute 'scenarios', are exogenously introduced. The main inputs and outputs of MAED are depicted in Fig. 10.2.

10.1.3. Methodology of MESSAGE

MESSAGE is designed to formulate and evaluate alternative energy supply strategies consonant with user defined constraints on new investment, market penetration rates for new technologies, fuel availability and trade, environmental emissions, etc. The underlying principle of the model is the optimization of an objective function (e.g. least cost, lowest environmental impact, maximum self-sufficiency) under a set of constraints. The backbone of MESSAGE is the techno-economic description of the modelled energy system. This includes definition of the categories of energy forms considered (e.g. primary energy, final energy, useful energy), the fuels (commodities) and associated technologies actually used (e.g. electricity, gasoline, ethanol, coal or district heat), as well as energy services (e.g. useful space heat provided by type of energy/technology). Technologies are defined by their inputs and outputs (main and by-products), 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). Economic characteristics include investment costs, fixed and variable O&M costs, imported and domestic fuel costs and estimates of levelized costs and shadow prices.

Fuels and technologies are combined to construct so-called energy chains, where the energy flows from supply to demand. The defined limitations on supplying fuels are that they can belong to any category except useful energy, that they must be chosen in the light of the actual problem and that limits on availability inside the region/area and import possibilities must be specified. The technical system provides the basic set of constraints to the model, together with demand, which 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 lives. During the optimization process, this determines the need to construct new capacity employing 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 a 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 fuels, ensuring timely availability entails considerable cost and management effort. Electricity has to be provided by the utility at exactly the same time as it is demanded. 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).

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 chain. This helps to evaluate the impact of environmental regulations on energy system development. The major inputs and outputs of MESSAGE are depicted in Fig. 10.3.

MESSAGE uses the projections of useful or final energy demand from MAED to generate the energy supply system. MESSAGE formulates and

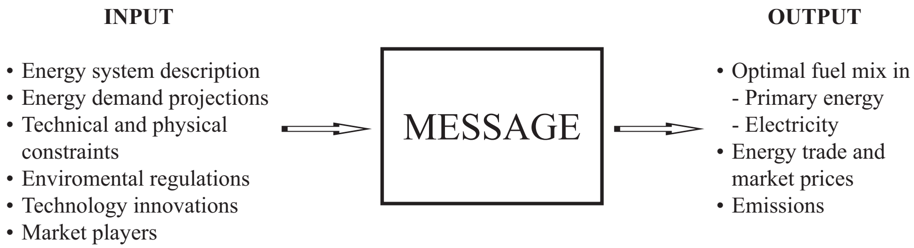

FIG. 10.3. Major inputs and outputs of MESSAGE.

evaluates alternative energy supply strategies consonant with the criteria and constraints specified. The underlying principle of the model is the optimization of an objective function under a specified set of constraints.

The most powerful feature of MESSAGE is that it provides the opportunity to define constraints for all types of technology related variables. The user can, among other options, limit one technology in relation to 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 for SO_2 emissions), 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 the summer months). The model is extremely flexible and can also be used to analyse energy and electricity markets and climate change issues.

10.2. STUDY APPROACH

For the analysis of energy demand, the economy is disaggregated into agriculture, construction, mining, manufacturing, transport, household and services. The manufacturing sector is further disaggregated into four subsectors: (i) basic materials, (ii) machinery and equipment, (iii) non-durable goods and (iv) miscellaneous. Transport activities include freight and passenger transport.

The energy demand and supply analyses were performed at the national level. However, for electricity, MESSAGE considers the interconnected electricity system, isolated power plants, including micro- and mini-hydropower plants, and cogeneration by the industrial and sugarcane sectors.

The base year for the study was taken to be 2002 because of the comprehensive quality of the data set for that particular year (some data for more recent years are still under review). However, the data available for more recent years were used to guide projections for those years, making the projections more realistic. A study horizon of 23 years, from 2002 to 2025 subdivided into five-year intervals, was chosen. The final energy demand estimated with MAED was used as the starting point for the optimization of the national supply system.

10.3. GENERAL ASSUMPTIONS AND CRITERIA

10.3.1. General assumptions

Both the quantitative description and the qualitative definition of the scenarios are based on numerous assumptions and criteria concerning sustainable energy development in Cuba. These were discussed extensively by experts from Cuba and from international organizations. The Cuban teams of experts then selected the following policy objectives:

Demography

- The population will continue growing at a declining rate until 2015, after which it will start to decrease.
- The level of urbanization will continue to increase.

Economic situation and development

- Economic recovery will continue with annual GDP growth rates of about 3.85% over the long term.
- The economic blockade of Cuba will continue.
- By 2025, the GDP per capita will be 2.4 times that for 2002.
- Technology modernization will continue.
- No major structural changes in the economy are expected, only changes within some sectors.

International environment

- Cooperation with other countries inside and outside the region will increase.
- A favourable atmosphere for foreign investment is assumed in some sectors.
- Investment by foreign countries in the Cuban energy sector will increase.

Lifestyle

- The number of households will continue to increase, with fewer occupants per household.
- The number and efficiency of electrical appliances will increase.
- The number of cars per thousand inhabitants will increase.
- Mobility will increase within the country.

Transport

- The structure of freight transport will change, with an increase in the use of rail transport and a decrease in the use of trucks between cities.
- Passenger and freight transportation will increase.

Technological improvements

- Energy intensities in the industrial sector will decrease owing to technological improvements.
- New technologies and related policies will allow an increase in the share of renewable energy.
- The extraction and use of indigenous crude oil and gas will increase.
- The participation of indigenous technology in energy development will increase.

10.3.2. Criteria for sustainable energy development

The sustainable energy criteria defined by the Cuban experts as being major priorities include the following generic characteristics:

- Energy options allow the progressive reduction of energy imports.
- Domestic energy resources are increasingly used.
- Energy resources are used more efficiently.
- Energy options and technologies are progressively less damaging to the environment.
- Energy options permit universal availability and optimal quality of energy services (optimal national availability of energy services).
- Energy policies support the increase in research and development and the participation of domestic industry in energy development.

10.4. ENERGY DEMAND ANALYSIS

To ensure the credibility of the modelling exercise, it was verified that MAED could replicate past and present trends. After calibrating and reproducing the values of energy demand for the base year (2002), the REF scenario was developed. The scenario was developed representing consistent sets of four groups of scenario parameters: (i) demographic evolution, (ii) economic development, (iii) lifestyle change and (iv) technology change.

10.4.1. General data for base year

The total population of Cuba by December 2002 was 11.25 million [10.5]. The urban population represented 75.3% of the total. The working age population was 6.6 million and the economically active population was 47%.

The GDP for 2002 was 27.69 billion pesos. Table 10.1 shows the GDP distribution per sector according to the MAED structure and as reported in the Statistical Yearbook of Cuba.

TABLE 10.1. GDP STRUCTURE AND VALUES IN 2002
(million 1997 pesos)
(Authors' elaboration from Ref. [10.5])

Sector in the MAED	Sector in Statistical Yearbook of Cuba	Million pesos
Agriculture	Crops, livestock, forestry and fishing	1 875.7
Construction	Construction	1 618.7
Mining	Mining (mineral) and quarrying	324.5
Manufacturing:	Manufacturing industries	
Basic materials		857.2
Machinery and equipment		502.8
Non-durable goods		3 091.4
Miscellaneous		336.4
Total manufacturing		4 787.8
Services	Commerce, restaurants and hotels Financial establishments, goods, properties and services to companies Communal, social and personal services Import rights Transport, storage and communications	18 348.5
Energy	Electricity, gas and water Extractive (oil and gas)	731
Total		**27 686.2**

The 2002 final energy use by sector is shown in Table 10.2. Bagasse, wood and charcoal are considered to be of non-commercial energy use.

10.4.2. Quantitative description of energy demand scenarios

10.4.2.1. Demography and economy

In the REF scenario, moderate economic and social development is considered in which the population projections elaborated by the Centre for Demographic Studies [10.6] and the economic growth projections calculated by the National Institute for Economic Research [10.7] are taken into consideration.

The population increase is estimated on the basis of the fertility rate, life expectancy and rate of migration. The projection of the Cuban population [10.6] shows slow growth up to 2015 and then a decreasing trend. This behaviour takes into consideration that:

- The fertility rate (children per woman) will change from 1.5 in 2000 to 1.55 in 2025.
- Life expectancy will increase from 72.94 to 74.24 years for men and from 76.9 to 79 years for women from 2002 to 2025.
- The migration rate will be constant during the study period, with a net emigration of 23 000 persons.

The fertility rate and life expectancy in Cuba are comparable with those of developed countries. This situation is expected to continue because of future emphasis on family planning, sex education and widespread access to contraceptives. Other factors contributing to that reality include gender equality in access to education, job opportunities and social programmes.

The average annual GDP growth rate during the study period is assumed to be 3.85%. This level of economic growth is based mainly on the assumption that the economic blockade of Cuba will continue during this period. The GDP growth rate is assumed to be lower than in previous years because the re-establishment of productivity capacities in the wake of the 1990s crisis has already occurred. After 2015, the GDP growth rate is projected to decrease because exports of traditional products (beverages, tobacco, sugar, etc.) are limited for reasons associated with physical production and the market.

The historical and projected values of GDP and population and their annual growth rates are shown in Fig. 10.4 and in Table 10.3.

TABLE 10.2. FINAL ENERGY USE PER SECTOR IN 2002 (TJ)
(Authors' elaboration from Ref. [10.5])

Sector	Fuel				Electricity	Total commercial	Non-commercial	Total
	Fossil	Motor fuels	Coke	Total fossil				
Manufacturing	66 579.9		515.0	67 094.9	13 774.6	80 869.4	59 406.5	140 275.9
Agriculture	3 979.0			3 979.0	707.6	4 686.6	1 653.8	6 340.4
Construction	1 998.5			1 998.5	230.3	2 228.8	28.3	2 257.1
Mining		9 234.0		9 234.0		9 234.0		9 234.0
Transport		55 076.3		55 076.3	7.0	55 083.3		55 083.3
Household	13 159.1			13 159.1	17 710.2	30 869.3	1 886.2	32 755.4
Services	12 083.7			12 083.7	9 388.1	21 471.8	4 962.7	26 434.5
Total	**97 800.2**	**64 310.3**	**515.0**	**162 625.5**	**41 817.8**	**204 443.3**	**67 937.4**	**272 380.7**

TABLE 10.3. POPULATION AND GDP GROWTH

	2002	2005	2010	2015	2020	2025
Population (10^6)	11.25	11.39	11.49	11.53	11.50	11.38
Annual growth rate* (%)		0.42	0.18	0.07	0.06	0.22
GDP (10^9 $pesos_{1997}$)	27.69	29.40	34.95	43.56	54.28	66.04
Annual growth rate* (%)		2.02	3.52	4.50	4.50	4.00
GDP/cap ($pesos_{1997}$/cap)	2460.78	2580.71	3041.10	3776.52	4720.26	5805.36

* Annual growth rates are for the intervals between years shown (2002–2005, 2005–2010, etc.).

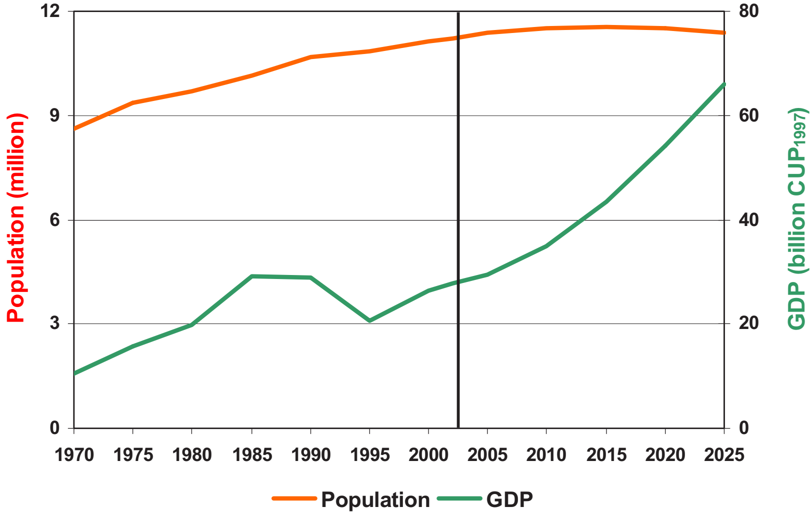

FIG. 10.4. Population and GDP growth. Historical data from Refs [10.5, 10.8–10.15].

10.4.2.2. Economic structure

The structure of the economy is assumed to remain fairly constant throughout the whole time period considered in this study because the major structural changes have already occurred and the current economic structure is expected to remain relatively stable in the next decades. However, changes in several subsectors of the industrial and service sectors are expected. The REF scenario assumes that technological and organizational measures adopted after the crisis of the 1990s will continue to define the overall structure of the economy and that of the manufacturing sector (Tables 10.4 and 10.5).

Investments are mainly planned in the mining and tourism subsectors. Exports will continue to be primarily of traditional products. Exports of non-traditional products (biotechnology, pharmaceuticals, genetic engineering technology, medicine, etc.) will increase after 2015. In addition, the current programme of fuel conservation and rational use of electricity will continue.

In the energy sector, an increase in the extraction of crude oil and associated gas, as well as an increase in the refining of domestic crude oil, are assumed. In the agriculture sector after 2015, the substitution of imports by domestic production is expected. In the sugarcane subsector, production will be concentrated and productivity will increase. In the manufacturing sector, the most important change will be the increased participation of the machinery and

TABLE 10.4. SHARE OF GDP BY SECTOR (%)

Sector	2002	2005	2010	2015	2020	2025
Agriculture	6.8	6.8	6.4	6.3	6.3	6.3
Construction	5.8	5.8	6.4	6.5	6.5	6.5
Mining	1.0	1.0	1.0	1.1	1.1	1.1
Manufacturing	17.3	17.3	17.3	17.3	17.3	17.3
Energy	2.8	2.8	3.2	3.2	3.1	3.1
Services	66.3	66.3	65.7	65.6	65.7	65.7

TABLE 10.5. SHARE OF GDP BY MANUFACTURING SUBSECTOR (%)

Subsector	2002	2005	2010	2015	2020	2025
Basic materials	17.9	18.0	18.2	18.2	18.2	18.2
Machinery and equipment	10.5	10.8	11.0	11.0	11.5	11.5
Non-durable goods	64.6	64.5	64.5	64.5	64.5	64.5
Miscellaneous	7.0	6.7	6.3	6.3	5.8	5.8

TABLE 10.6. ANNUAL GDP GROWTH RATE BY SECTOR (%)

Sector	2005	2010	2015	2020	2025
Agriculture	2.02	2.35	4.17	4.50	4.00
Construction	2.02	5.41	4.83	4.50	4.00
Mining	2.02	2.97	6.51	4.50	4.00
Manufacturing	2.04	3.52	4.50	4.50	4.00
Energy	2.02	6.44	4.50	3.90	4.00
Services	2.02	3.34	4.47	4.53	4.00
All sectors	2.02	3.52	4.50	4.50	4.00

equipment subsector. The average annual GDP growth rates by sector and by subsector of the manufacturing sector are shown in Tables 10.6 and 10.7, respectively.

The historical evolution and the projections of GDP for two major economic sectors (services and manufacturing) are presented in Fig. 10.5.

TABLE 10.7. ANNUAL GDP GROWTH RATE IN MANUFACTURING SECTOR BY SUBSECTOR (%)

Subsector	2005	2010	2015	2020	2025
Basic materials	2.22	3.75	4.50	4.50	4.00
Machinery and equipment	2.99	3.90	4.50	5.40	4.00
Non-durable goods	2.00	3.52	4.50	4.50	4.00
Miscellaneous	0.43	2.25	4.50	2.84	4.00
Total manufacturing sector	2.04	3.52	4.50	4.50	4.00

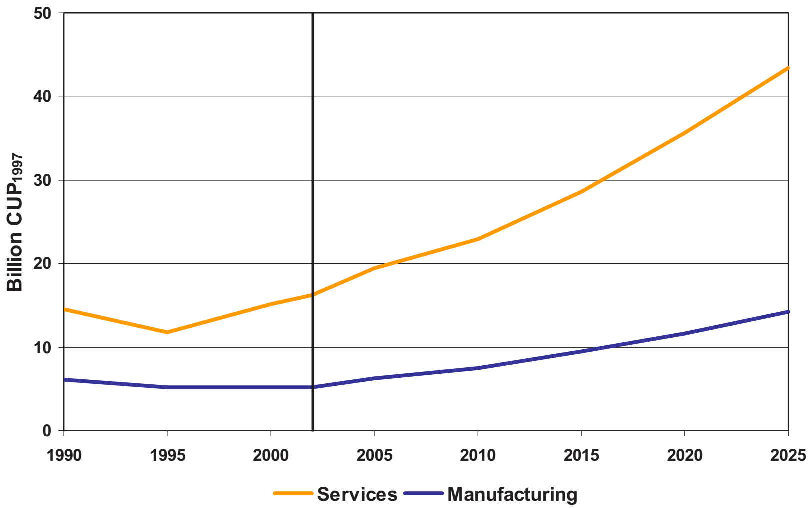

FIG. 10.5. Historical evolution and projections of GDP for the manufacturing and services sectors. Historical data from Refs [10.5, 10.10–10.15].

10.4.2.3. Lifestyle parameters

Scenario data for selected lifestyle parameters are presented in Table 10.8. The selected parameters are for the household, transport and services sectors. The number of persons per dwelling is assumed to decrease as the number of households increases faster than the population grows. The share of electrified dwellings is assumed to increase to 100% by 2010, implying full access to electricity. Specific electricity use per dwelling increases over the entire period, reflecting greater electricity use and higher levels of ownership of electrical appliances. In addition, a moderate rise in the percentage of houses with air-conditioners (2% in 2002, up to 15% by 2025) and water heaters (3% in 2002, up to 20% by the end of the period) is assumed.

In the transport sector, growth in freight and passenger transport services is expected throughout the study period. The use of cars for urban passenger transport and trains for intercity transport will increase. In freight transport, trucks within cities and trains between cities will be greatly used. Car ownership is assumed to increase.

The total service floor area is assumed to increase to satisfy growing demand for services.

It is assumed that the use of fuelwood and charcoal in the country will be phased out by 2015. These fuels will be replaced by LPG, city gas and electricity, according to policies that are being implemented to improve the standard of living of the population.

10.4.2.4. Technology

For this study, it is assumed that the economic blockade will continue throughout the study period; therefore, the atmosphere for investment in energy technologies will be favourable only in the mining and services sectors. Investment is also expected in the services sector to accommodate the expected increase in tourism in particular.

In the oil subsector, investments in technologies and further implementation of the exploration programme are assumed, so that an annual increase of 5% in the production of crude oil and gas is achieved during the study period. Refinery capacity is also assumed to increase by 3 million t. In the electricity subsector, technological changes are assumed to continue, from the adaptation of power plants to the use of domestic crude oil instead of fuel oil. In the manufacturing and construction sectors, only minor technological changes are assumed. In the agriculture sector, diesel for irrigation will be replaced by electricity.

Technology is a major factor that determines energy intensities (the energy required per unit of value added of GDP). While energy intensities in Cuba have decreased rapidly since the mid-1990s (about 4% annually), owing to the utilization of excess capacity resulting from the economic crisis at that time, an overall annual reduction of about 1.1% is assumed for the combined manufacturing, agriculture and construction sectors. This assumption is based on improvements in the performance of technologies in line with the changes expected in the major energy areas specified above.

The specific reductions in energy intensities assumed for the manufacturing, agriculture and services sectors are 1.5, 2.1 and 0.8%, respectively.

TABLE 10.8. SELECTED LIFESTYLE PARAMETERS

Parameter	Unit	2002	2005	2010	2015	2020	2025
Number of households	10^6	3.54	3.58	3.65	3.72	3.77	3.79
Inhabitants per household		3.18	3.18	3.15	3.10	3.05	3.00
Electrified dwellings	%	95.50	96.00	100.00	100.00	100.00	100.00
Electricity use per dwelling	kW·h	1395.92	1665.54	2763.56	3190.20	3839.74	4927.35
Population living in cities with public transportation	10^6	5.40	5.64	5.86	6.11	6.32	6.26
	%	48.00	49.50	51.00	53.00	55.00	55.00
Urban transport activities	10^9 passenger·km	31.15	33.34	35.94	38.38	41.55	45.67
Car ownership	cars/10^3 inhabitants	13.99	14.29	15.22	15.91	16.67	18.18
Intercity transport activities	10^9 passenger·km	16.06	16.46	17.24	17.88	18.40	25.03
Freight transport activities	10^9 t·km	77.72	79.92	87.02	98.01	111.47	126.44
Service floor area	10^6 m^2	25.67	27.08	32.85	38.04	43.35	48.60

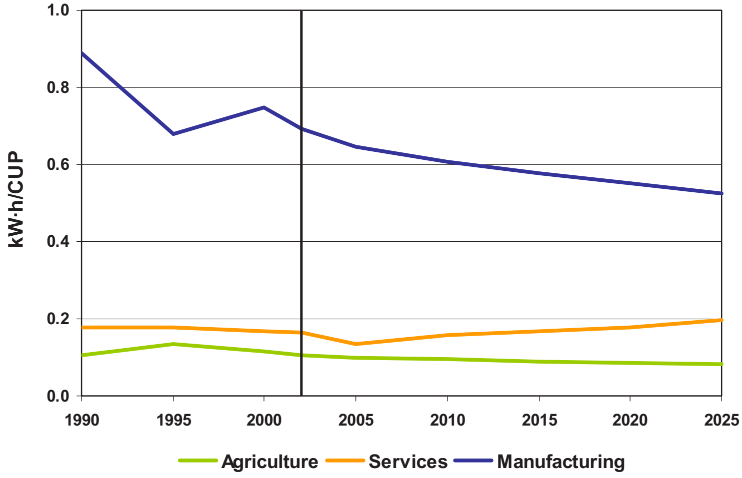

FIG. 10.6. Electricity intensities. Historical data from Refs [10.5, 10.10–10.15].

Figure 10.6 shows the electricity intensity (final electricity use per unit of value added) in the manufacturing, agriculture and services sectors. The electricity intensity in the services sector grows by 2.3% annually owing to the increased use of electrical equipment (e.g. lighting, air-conditioning, computers) in this sector. In the manufacturing and agriculture sectors, electricity intensity drops at an annual rate of 0.9% due to improvements in efficiency anticipated in both sectors.

The energy intensities in the transport sector (fuel use by passengers or freight transported) are assumed to grow during the study period (Fig. 10.7). No considerable changes in the efficiency of transport technologies are considered, although transport activities are expected to grow. An annual increase of 1.8% in the passenger transportation activity is foreseen, from 47.2 billion passenger·km in 2002 to 70.7 billion passenger·km by 2025. Freight transportation during the study period also grows by 2.1%, from 77.7 billion t·km in 2002 to 126.4 billion t·km by 2025.

The energy and electricity intensities in the household sector (total final energy or electricity use per inhabitant) are assumed to grow during the study period (Fig. 10.8). Energy intensity grows by 5.1% (from 2.9 TJ/cap (782 ktoe/cap) to 9.1 TJ/cap (2481 ktoe)) while the electricity intensity grows by an average annual rate of 5.9% (from 437 kW·h/cap to 1642 kW·h/cap). The increase in intensities is due mainly to an increase in the use of electrical appliances.

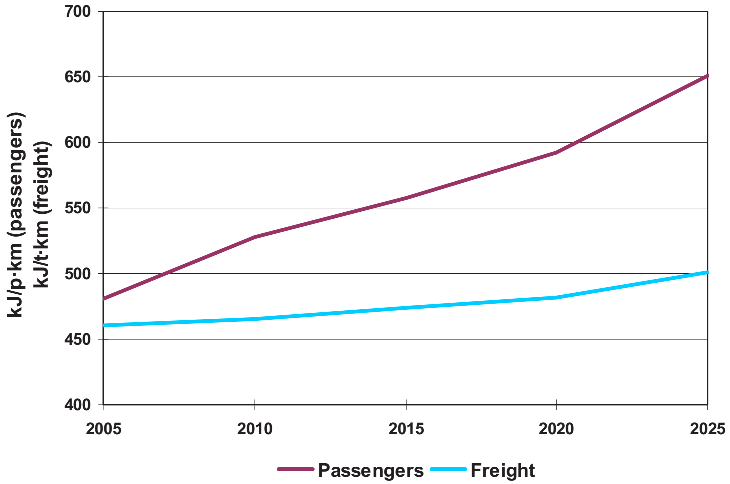

FIG. 10.7. Energy intensities in the transport sector.

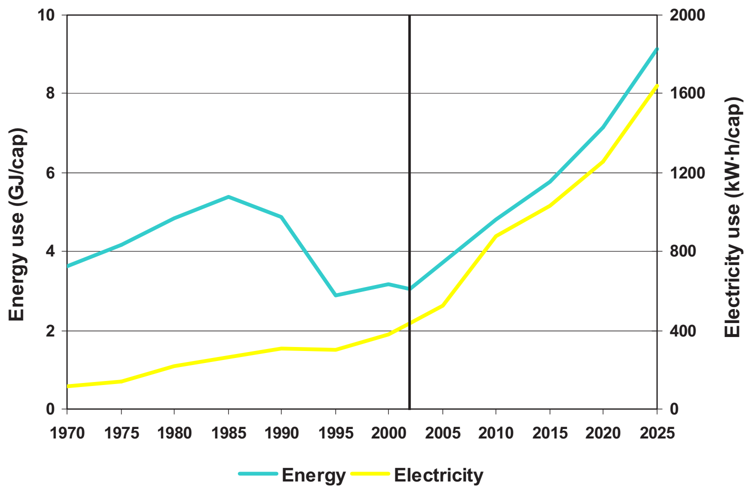

FIG. 10.8. Energy intensities in the household sector. Historical data from Refs [10.5, 10.8–10.15].

10.4.3. Results: Final energy demand

The projections of final energy demand by sector are presented in Table 10.9 and Fig. 10.9. The total final energy demand grows at an annual rate of 3.3%, reaching 463 PJ (11 024 ktoe) by 2025, more than doubling over the 23-year period. The household sector experiences the largest increase in total energy demand, with its share increasing 7.3% to 22.4% by 2025. Conversely, the shares of the manufacturing, transport and agriculture sectors decrease during the same period. The shares of the services, construction and mining sectors remain fairly stable throughout the period (see Fig. 10.10).

TABLE 10.9. TOTAL FINAL ENERGY DEMAND BY SECTOR (PJ)

Sector	2002	2005	2010	2015	2020	2025
Agriculture	6.5	6.6	6.8	7.8	9.2	10.6
Manufacturing	82.1	86.0	97.7	115.8	137.4	159.1
Construction	2.2	2.3	2.9	3.5	4.1	4.7
Mining	9.2	9.7	10.6	13.9	16.4	19.0
Transport	58.2	60.7	68.6	77.8	89.2	109.3
Household	32.8	42.2	55.4	66.5	82.2	103.9
Services	26.4	28.4	33.1	39.4	47.0	56.5
Total	**217.4**	**236.0**	**275.1**	**324.8**	**385.5**	**463.1**
			Share (%)			
Agriculture	3.0	2.8	2.5	2.4	2.4	2.3
Manufacturing	37.8	36.5	35.5	35.7	35.6	34.3
Construction	1.0	1.0	1.0	1.1	1.1	1.0
Mining	4.2	4.1	3.9	4.3	4.3	4.1
Transport	26.8	25.7	24.9	24.0	23.1	23.6
Household	15.1	17.9	20.1	20.5	21.3	22.4
Services	12.2	12.1	12.0	12.1	12.2	12.2

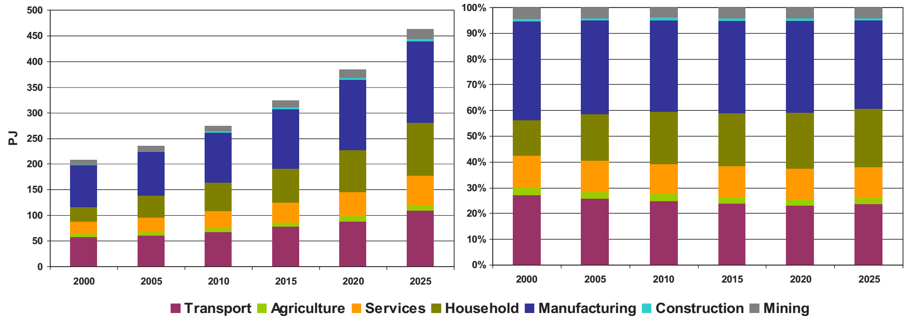

FIG. 10.9. Final energy demand by sector.

FIG. 10.10. Sectoral shares in final energy demand.

10.5. ENERGY SUPPLY ANALYSIS

MESSAGE defines optimal energy supply systems for the alternative scenarios based on a set of inputs, including:

— A description of the existing energy supply system and associated infrastructure, from domestic resource extraction of all primary sources available (oil, gas, biomass, nuclear, hydro, wind, solar, etc.) to refineries, power plants, other conversion plants, and transmission and distribution systems for all fuels, including petroleum products, other liquids, natural gas, solids, electricity and heat;
— Technical, economic and environmental characteristics of all energy conversion technologies and processes of the national energy supply system, as well as the technology candidates potentially available in the future;
— Energy trade e.g. oil and petroleum products, gas, ethanol, coal and electricity;
— Environmental protection requirements.

Four alternative energy supply scenarios were developed to evaluate the Cuban energy supply system based on the one demand scenario:

REF: Assumes continuation of the current situation (business as usual).

FOS: Assumes the intensive use of fossil fuels based on the exploitation of a considerable number of new fields in the EEZ of the Gulf of Mexico.

REN: Assumes the intensive use of renewables based on policies for the exploitation of the estimated renewable potential.

MIX: Considers a mix of assumptions from both the FOS and REN scenarios and additional changes in the energy matrix.

10.5.1. Energy supply scenario assumptions

The specific assumptions, constraints and other conditions stipulated by the Cuban experts for the definition of the four alternative supply scenarios are listed in Table 10.10.

TABLE 10.10. SCENARIO ASSUMPTIONS, CONSTRAINTS AND OTHER CONDITIONS

Options	Scenario	Assumptions, constraints and other conditions
Crude oil and gas	REF	Production increases by an average annual rate of 5% Production is restricted to onshore Crude oil and gas may be used in electricity generation
	FOS	Onshore production increases by an average annual rate of 5% 641 million t of crude oil and 16 billion m^3 of gas are available from the EEZ Crude oil and gas may be used in electricity generation Offshore crude oil may replace imported crude oil in refineries
	REN	Production increases by an average annual rate of 5% Limited crude oil use in electricity generation (only at existing capacities) Gas may be used in electricity generation
	MIX	Onshore crude oil and associated gas reserves are exhausted by 2015 Half of the estimated reserves of crude oil (321 million t) and gas (8 billion m^3) are available from the EEZ Crude oil and gas may be used in electricity generation
Petroleum products	REF	Refinery capacity can be doubled after 2010 Diesel and fuel oil increase their shares in electricity generation
	FOS, MIX	After 2010 no limitations on refinery capacity are imposed Diesel and fuel oil increase their shares in electricity generation
	REN	The use of oil products in electricity generation is limited to the same level of use as in base year capacities

TABLE 10.10. SCENARIO ASSUMPTIONS, CONSTRAINTS AND OTHER CONDITIONS (cont.)

Options	Scenario	Assumptions, constraints and other conditions
Hydropower	REF, FOS	The potential is not fully exploited (only up to 100 MW)
	REN	The potential can be fully exploited (up to 400 MW)
	MIX	The potential is not fully exploited (only up to 250 MW)
Bagasse and alcohol	REF, FOS	Electricity cogeneration capacity increases Cogeneration efficiency increases Alcohol production increases in a limited way No new use of alcohol is considered
	REN	Existing cogeneration capacities are retired in 2015 High efficiency cogeneration technologies are introduced The potential of all renewables can be fully exploited New technologies to produce alcohol from sugarcane are introduced Alcohol mixed with gasoline and diesel is used in the transport sector
	MIX	The increase in cogeneration capacities is limited Cogeneration efficiency increases Alcohol production increases in a limited way No new use of alcohol
Solar	REF, FOS, REN, MIX	Limited use in rural electrification
Wind	REF, FOS, REN	Estimated potential up to 1200 MW
	MIX	Limited exploitation of defined potential up to 500 MW
Nuclear	REF, FOS, REN	Not considered
	MIX	Can be introduced

10.5.1.1. Crude oil, petroleum products and gas

Oil and gas activities increased substantially between 1992 and 2002, reaching an average annual production growth rate of 15%. In 1998, the associated gas started to be used in electricity generation and in city gas production. From 1998 to 2002, the average annual rate of use of associated gas was 47%. Before 1998, only a minor part of associated gas was used in power plants, as the major part of the gas was flared.

Prospective studies carried out by CUPET during the period 2004–2006 [10.16] show that the average annual increase in crude oil and associated gas production will be 5%, the level assumed in the REF and FOS scenarios. Some of this domestic crude oil is to be used in existing power plants and the rest is to be mixed with imported light crude oil in the refinery process. In the MIX scenario, onshore production will be exhausted by 2015. Crude oil will continue to be used in electricity generation and refining.

The possibility of exploiting the offshore oil fields in the deep waters of the EEZ is considered in this study. The FOS scenario considers that the full amount of the estimated reserves will be available, while the MIX scenario assumes that only half these reserves will be available.

Refinery capacity in the base year was 2.9 million t of crude oil for the existing three refineries. These refineries process a mix of 83% imported light crude oil and 17% domestic heavy crude oil. All scenarios consider the expansion of this capacity by 3 million t after 2010 with the completion of the fourth refinery, currently under construction. In the REF and REN scenarios, this capacity is limited to 5.9 million t.

In the FOS and MIX scenarios, no limitations are imposed on total refinery capacity using crude oil from the EEZ after 2015. On the basis of this assumption, the construction of a refinery with an annual capacity of 6.5 million t of crude oil is considered, representing an investment of 1.3 billion pesos. This new refinery will produce LPG, gasoline, jet fuel, diesel and fuel oil.

10.5.1.2. Biomass and alcohol

Bagasse and alcohol from sugarcane are assumed to be produced in the four scenarios. The bagasse is used to generate electricity and steam for the sugar industry. The alcohol is produced for non-energy uses (beverages, pharmaceuticals, perfumes, etc.) and for energy use, especially for preheating kerosene stoves.

An average annual production of sugarcane of 35 million t is assumed in this study. Considering that 1 t of sugarcane produces 280 kg of bagasse, the quantity of bagasse expected to be available is 9.8 million t.

The technology for alcohol production in Cuba is very old and based on an average yield of 38 kg of molasses per tonne of sugarcane. On the basis of this technology, 405 kg of molasses is necessary to produce one hectolitre of alcohol. In the REF and FOS scenarios, no technological changes in alcohol production are considered.

Nevertheless, Brazil has developed the technology to produce alcohol directly from sugarcane juice at a yield of 85 L/t of crushed sugarcane [10.17]. The possibility of introducing this technology is considered in the REN and MIX scenarios.

The other biomasses taken into account in the study are fuelwood and charcoal; however, their use is assumed to have been phased out by 2015.

10.5.1.3. Import–export

The import of crude oil and petroleum products is considered. Imported crude oil is mixed with domestic crude oil for processing in refineries. Petroleum product imports cover the demand for petroleum products in the absence of sufficient domestic production. The main petroleum product imports include diesel, fuel oil, jet fuel, LPG, gasoline and coke.

The prices of imported fuels assumed in this study are as follows:

— Crude oil: 27 pesos/bbl;
— Gasoline: 71.54 pesos/bbl;
— LPG: 20.98 pesos/bbl;
— Diesel: 42.48 pesos/bbl;
— Fuel oil: 29.67 pesos/bbl;
— Jet fuel: 43.99 pesos/bbl;
— Coke: 80.45 pesos/t.

These prices are based on the 2005 exchange rate of one peso equating to US $0.92. The fuel prices are assumed to remain constant during the overall study period for all scenarios. A sensitivity analysis of fuel price escalation is explained later in the section.

10.5.1.4. Electricity

The installed electric generating capacity in Cuba in 2002 was 3959 MW, of which 76.6% was in thermal power plants using crude oil, 14.4% in sugarcane cogeneration, 1.4% in hydropower plants, 5.4% in gas turbines and combined cycles using associated gas, and 1.9% in gas turbines using diesel (see Section 2).

For all scenarios the following assumptions are made:

— All existing power plant units with capacities of less than 100 MW will be retired before 2010;
— A 180 MW combined cycle power plant using associated gas is expected to become operational by 2008;
— An increase of 89 MW of installed capacity for cogeneration with bagasse is assumed before 2010;

— Two phases of hydropower of the National Institute of Hydraulic Resources programme (first phase 28.3 MW, second phase 8.3 MW) will be implemented between 2005 and 2015 [10.18];
— An additional 100 MW of wind capacity will be available by 2008;
— An additional 713 MW from diesel engines will become available between 2005 and 2008.

The new technologies considered for electricity generation and their characteristics are listed in Table 10.11. The options considered in each scenario are shown in Table 10.12.

The following candidates were included: 150 MW and 250 MW thermal power plants, 38 MW diesel engines using crude oil, 24 MW and 32 MW bagasse cogeneration plants, 35 MW gas turbines using diesel, 110 MW modular new design nuclear power plants based on the Pebble Bed Modular Reactor [10.19] and 200 MW pumped storage plants. Other technologies

TABLE 10.11. COSTS AND MAIN CHARACTERISTICS OF ELECTRICITY GENERATION TECHNOLOGIES

Technology	Efficiency (%)	Capacity factor (%)	Investment costs (pesos/kW(e))[a]	Fixed O&M costs (pesos/kW)	Construction period (years)
Thermal power plant	37	85	900	50	4
CCGT	43	85	700	20	2
Gas turbines using diesel[b]	35	95	400	60	<1
Diesel engine with fuel oil	45	90	900	30	<1
Pumped storage	n.a.[c]	n.a.[c]	700		3
Bagasse power plant	25	70	880	45	3
BIGCC	50	85	1490	30	4
Wind generators	n.a.[c]	25	1200	13–20	2
Nuclear power plant	33	80	1500	40	5

[a] kW(e) installed electricity kilowatt.
[b] Peak plant.
[c] Not applicable.

TABLE 10.12. ELECTRIC TECHNOLOGY CANDIDATES BY SCENARIO

Candidate	REF	FOS	REN	MIX
Thermal power plant (150 MW)	x	x		x
Thermal power plant (250 MW)	x	x		x
Bagasse power plant (24 MW)	x	x	x	x
Bagasse power plant (32 MW)	x	x	x	x
Gas turbine with diesel (35 MW)	x	x		x
Diesel engine with crude oil (38 MW)	x	x		x
Wind generator			x	x
CCGT		x	x	x
Hydropower plant			x	x
Pumped storage (200 MW)			x	x
BIGCC			x	x
Nuclear power plant (110 MW)				x

considered in this study but without limitation in units or capacities are wind generators, biomass integrated gasification combined cycle (BIGCC) plants and combined cycle gas turbine (CCGT) plants.

The maximum use of defined renewable potentials (see Section 3) is considered in the REN scenario. In the MIX scenario these potentials are limited; the BIGCC is limited to 200 MW, hydropower to 250 MW and wind potential to 500 MW. In addition, in the REN scenario, existing bagasse cogeneration capacities will be retired by 2015 to make possible the introduction of new BIGCC plants.

10.5.2. Results of energy development scenarios

10.5.2.1. TPES

On the basis of the assumptions discussed in previous sections, the energy supply system is optimized for the four alternative scenarios to satisfy the total final energy demand. The resulting projections of TPES are presented in Tables 10.13–10.16 for the REF, FOS, REN and MIX scenarios, respectively (see also Fig. 10.11).

TABLE 10.13. TPES: REF SCENARIO (PJ)

Energy source	2002	2005	2010	2015	2020	2025
	Domestic					
Gas	21.4	23.9	28.8	31.6	33.1	34.6
Oil	142.1	171.5	192.6	264.9	311.8	394.5
Hydropower	0.4	0.4	0.5	0.9	1.0	1.0
Sugarcane biomass	93.8	105.5	105.5	105.5	105.5	105.5
Fuelwood	11.7	10.1	2.8	1.6	0.0	0.0
Wind + solar	0.0	0.1	1.0	1.1	1.4	1.9
Total	**269.4**	**311.5**	**331.2**	**405.6**	**452.8**	**537.6**
	Imports					
Oil	165.8	155.1	229.7	214.0	246.5	286.8
Coal	0.5	0.5	0.7	0.8	1.0	1.3
Total	**166.3**	**155.6**	**230.4**	**214.8**	**247.5**	**288.1**
	Domestic + imports					
Gas	21.4	23.9	28.8	31.6	33.1	34.6
Oil	307.9	326.6	422.3	478.9	558.3	681.4
Coal	0.5	0.5	0.7	0.8	1.0	1.3
Hydropower	0.4	0.4	0.5	0.9	1.0	1.0
Sugarcane biomass	93.8	105.5	105.5	105.5	105.5	105.5
Fuelwood	11.7	10.1	2.8	1.6	0.0	0.0
Wind + solar	0.0	0.1	1.0	1.1	1.4	1.9
Total	**435.7**	**467.2**	**561.6**	**620.4**	**700.3**	**825.7**
	Fuel share (%)					
Gas	4.9	5.1	5.1	5.1	4.7	4.2
Oil	70.7	69.9	75.2	77.2	79.7	82.5
Coal	0.1	0.1	0.1	0.1	0.1	0.2
Hydropower	0.1	0.1	0.1	0.1	0.1	0.1
Sugarcane biomass	21.5	22.6	18.8	17.0	15.1	12.8
Fuelwood	2.7	2.2	0.5	0.3	0.0	0.0
Wind + solar	0.0	0.0	0.2	0.2	0.2	0.2

TABLE 10.14. TPES: FOS SCENARIO (PJ)

Energy source	2002	2005	2010	2015	2020	2025
	Domestic					
Gas	21.4	24.0	28.8	111.6	122.0	136.6
Oil	142.1	171.5	192.6	448.5	506.2	599.4
Hydropower	0.4	0.4	0.5	0.9	1.0	1.0
Sugarcane biomass	93.8	105.5	105.5	105.5	105.5	105.5
Fuelwood	11.7	10.1	2.8	1.6	0.0	0.0
Wind + solar	0.0	0.1	1.0	1.1	1.4	1.9
Total	**269.4**	**311.6**	**331.2**	**669.2**	**736.1**	**844.5**
	Imports					
Oil	165.8	155.1	229.7	20.0	33.6	47.3
Coal	0.5	0.5	0.7	0.8	1.0	1.3
Total	**166.3**	**155.6**	**230.4**	**20.8**	**34.6**	**48.5**
	Domestic + imports					
Gas	21.4	24.0	28.8	111.6	122.0	136.6
Oil	307.9	326.6	422.3	468.4	539.8	646.7
Coal	0.5	0.5	0.7	0.8	1.0	1.3
Hydropower	0.4	0.4	0.5	0.9	1.0	1.0
Sugarcane biomass	93.8	105.5	105.5	105.5	105.5	105.5
Fuelwood	11.7	10.1	2.8	1.6	0.0	0.0
Wind + solar	0.0	0.1	1.0	1.1	1.4	1.9
Total	**435.7**	**467.3**	**561.6**	**690.0**	**770.7**	**893.0**
	Fuel share (%)					
Gas	4.9	5.1	5.1	16.2	15.8	15.3
Oil	70.7	69.9	75.2	67.9	70.0	72.4
Coal	0.1	0.1	0.1	0.1	0.1	0.1
Hydropower	0.1	0.1	0.1	0.1	0.1	0.1
Sugarcane biomass	21.5	22.6	18.8	15.3	13.7	11.8
Fuelwood	2.7	2.2	0.5	0.2	0.0	0.0
Wind + solar	0.0	0.0	0.2	0.2	0.2	0.2

TABLE 10.15. TPES: REN SCENARIO (PJ)

Energy source	2002	2005	2010	2015	2020	2025
	Domestic					
Gas	21.4	24.0	28.8	62.1	63.9	106.8
Oil	142.1	171.5	192.6	196.6	202.3	338.2
Hydropower	0.4	0.4	0.5	7.7	7.8	7.9
Sugarcane biomass	93.8	105.5	105.5	105.5	105.5	105.5
Fuelwood	11.7	10.1	2.8	1.6	0.0	0.0
Wind + solar	0.0	0.1	1.7	4.0	7.1	9.7
Total	**269.4**	**311.6**	**331.9**	**377.4**	**386.5**	**568.0**
	Imports					
Oil	165.8	155.1	226.8	212.4	241.7	278.9
Coal	0.5	0.5	0.7	0.8	1.0	1.3
Total	**166.3**	**155.6**	**227.4**	**213.3**	**242.7**	**280.2**
	Domestic + imports					
Gas	21.4	24.0	28.8	62.1	63.9	106.8
Oil	307.9	326.6	419.4	409.1	444.0	617.1
Coal	0.5	0.5	0.7	0.8	1.0	1.3
Hydropower	0.4	0.4	0.5	7.7	7.8	7.9
Sugarcane biomass	93.8	105.5	105.5	105.5	105.5	105.5
Fuelwood	11.7	10.1	2.8	1.6	0.0	0.0
Wind + solar	0.0	0.1	1.7	4.0	7.1	9.7
Total	**435.7**	**467.3**	**559.4**	**590.7**	**629.3**	**848.2**
	Fuel share (%)					
Gas	4.9	5.1	5.2	10.5	10.1	12.6
Oil	70.7	69.9	75.0	69.2	70.6	72.8
Coal	0.1	0.1	0.1	0.1	0.2	0.1
Hydropower	0.1	0.1	0.1	1.3	1.2	0.9
Sugarcane biomass	21.5	22.6	18.9	17.9	16.8	12.4
Fuelwood	2.7	2.2	0.5	0.3	0.0	0.0
Wind + solar	0.0	0.0	0.3	0.7	1.1	1.1

TABLE 10.16. TPES: MIX SCENARIO (PJ)

Energy source	2002	2005	2010	2015	2020	2025
	Domestic					
Gas	21.4	24.0	28.8	28.7	28.7	24.6
Oil	142.1	170.7	179.2	492.9	554.5	659.0
Hydropower	0.4	0.4	0.5	4.4	4.5	4.6
Sugarcane biomass	93.8	105.5	105.5	105.5	105.5	105.5
Fuelwood	11.7	10.1	2.8	1.6	0.0	0.0
Wind + solar	0.0	0.0	0.7	0.7	0.7	0.7
Nuclear	0.0	0.0	0.0	9.8	19.6	29.4
Total	**269.4**	**310.7**	**317.6**	**643.6**	**713.6**	**823.8**
	Imports					
Oil	165.8	155.9	243.1	20.4	34.1	47.9
Coal	0.5	0.5	0.7	0.8	1.0	1.3
Total	**166.3**	**156.5**	**243.8**	**21.2**	**35.1**	**49.2**
	Domestic + imports					
Gas	21.4	24.0	28.8	28.7	28.7	24.6
Oil	307.9	326.6	422.3	513.3	588.6	706.9
Coal	0.5	0.5	0.7	0.8	1.0	1.3
Hydropower	0.4	0.4	0.5	4.4	4.5	4.6
Sugarcane biomass	93.8	105.5	105.5	105.5	105.5	105.5
Fuelwood	11.7	10.1	2.8	1.6	0.0	0.0
Wind + solar	0.0	0.0	0.7	0.7	0.7	0.7
Nuclear	0.0	0.0	0.0	9.8	19.6	29.4
Total	**435.7**	**467.2**	**561.4**	**664.9**	**748.7**	**873.0**
	Fuel share (%)					
Gas	4.9	5.1	5.1	4.3	3.8	2.8
Oil	70.7	69.9	75.2	77.2	78.6	81.0
Coal	0.1	0.1	0.1	0.1	0.1	0.1
Hydropower	0.1	0.1	0.1	0.7	0.6	0.5
Sugarcane biomass	21.5	22.6	18.8	15.9	14.1	12.1
Fuelwood	2.7	2.2	0.5	0.2	0.0	0.0
Wind + solar	0.0	0.0	0.1	0.1	0.1	0.1
Nuclear	0.0	0.0	0.0	1.5	2.6	3.4

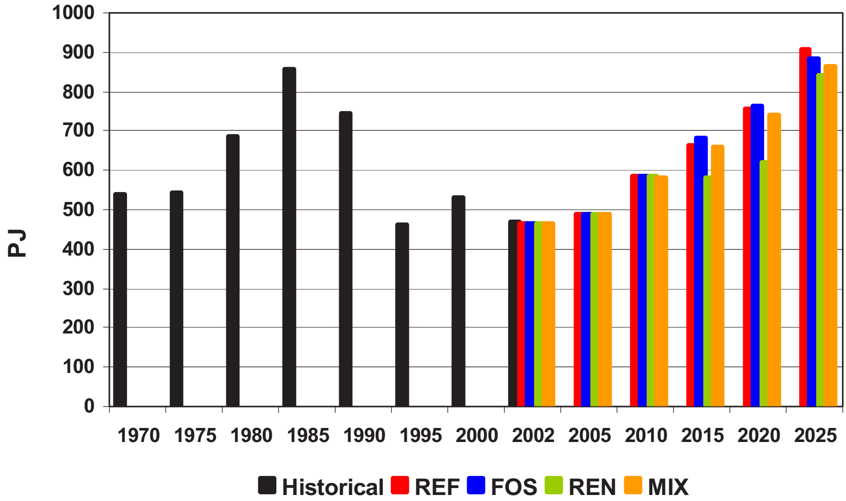

FIG. 10.11. TPES. Historical data from Refs [10.5, 10.8–10.15].

After 2005, TPES increases in all scenarios but does not reach values higher than the peaked TPES values observed in 1985 (before the crisis) until after 2020. For the REN and REF scenarios, the TPES values in 2025 are still lower than those for 1985. The TPES annual growth rates for the study period vary between 2.8 and 3.2%, with FOS having the highest and REF the lowest rate.

Domestic primary energy supply is highest in the FOS and MIX scenarios owing to the assumed higher availability of domestic crude oil and gas, especially from the EEZ. Imports of crude oil end by 2015 in both the FOS and MIX scenarios, although imports of petroleum products are necessary throughout 2025. Conversely, in the REF and REN scenarios, imports of both crude oil and petroleum products are necessary and by 2025 they still remain a large part of TPES (around 34%).

A fuel switch is observed in all scenarios. In the REF and MIX scenarios, a decrease in the sugarcane biomass share is compensated for by an increase in the oil share. The sugarcane biomass share decreases even though its contribution in real terms to TPES is assumed to remain constant in all scenarios for the entire time period. This assumption is based on the expectation that the number of sugarcane plantations in Cuba will not increase. In the FOS and REN scenarios, the gas share also increases considerably, compensating for the drop in sugarcane biomass. Among the four supply scenarios, the MIX scenario has the most diverse mix of shares by 2025. In this scenario, the gas share drops

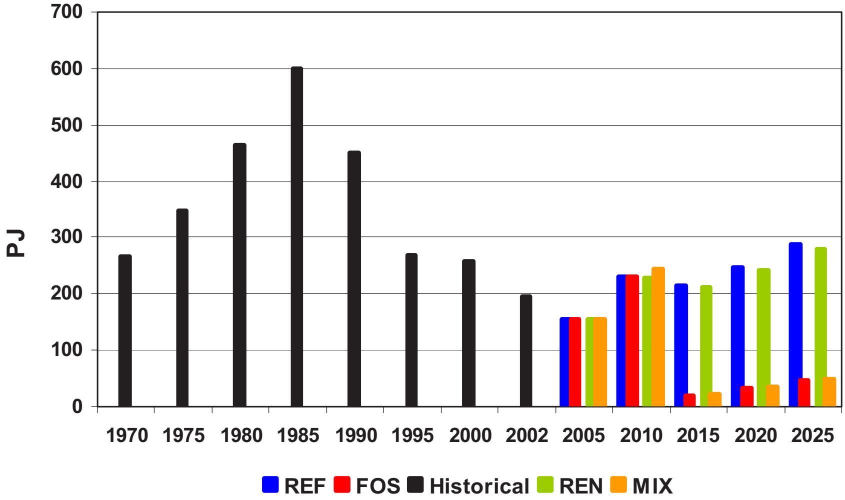

FIG. 10.12. Total imports in TPES. Historical data from Refs [10.5, 10.8–10.15].

considerably by 2025 and the nuclear energy share grows to 3.4%. In this scenario, the onshore oil and gas reserves are assumed to be exhausted by 2015. The use of fuelwood is assumed to decrease at the same rate in all scenarios and to be phased out by 2015. This assumption is based on Cuba's current programme to eliminate the unsustainable use of fuelwood and increase the population's standard of living by replacing fuelwood used in households with electricity and gas.

Figure 10.12 shows total TPES imports. In the FOS and MIX scenarios, crude oil imports stop by 2015 due to the exploitation of offshore crude oil from the EEZ.

Crude oil imports during the study period are higher in the REF and REN scenarios than in the FOS and MIX scenarios. This is due to the assumptions in the REF and REN scenarios of a low growth rate of onshore crude oil and associated gas production and the lack of crude oil from the EEZ.

10.5.2.2. Electricity generation

Electricity generation in the four supply scenarios is presented in Tables 10.17–10.20. Electricity generation is assumed to grow at the same annual growth rate of 4.6% for all scenarios. The use of fossil fuels in electricity generation is about the same in the REF and FOS scenarios and is lower in the

TABLE 10.17. ELECTRICITY GENERATION: REF SCENARIO (GW·h)

Energy source	2002	2005	2010	2015	2020	2025
Oil	12 565.3	12 484.6	18 261.6	22 579.2	27 259.4	36 099.9
Bagasse	938.2	988.2	1 427.8	1 844.7	1 844.7	1 844.7
Hydro	105.6	102.5	142.8	241.0	266.0	291.6
Solar	5.6	5.9	5.9	5.9	5.9	5.9
Gas	1 097.5	2 225.9	2 767.3	2 767.3	2 767.3	2 767.3
Wind	0.4	0.4	198.4	198.4	198.4	198.4
Total	**14 712.6**	**15 807.6**	**22 803.8**	**27 636.6**	**32 341.8**	**41 207.8**
	Share (%)					
Oil	85.4	79.0	80.1	81.7	84.3	87.6
Bagasse	6.4	6.3	6.3	6.7	5.7	4.5
Hydro	0.7	0.6	0.6	0.9	0.8	0.7
Solar	0.0	0.0	0.0	0.0	0.0	0.0
Gas	7.5	14.1	12.1	10.0	8.6	6.7
Wind	0.0	0.0	0.9	0.7	0.6	0.5

TABLE 10.18. ELECTRICITY GENERATION: FOS SCENARIO (GW·h)

Energy source	2002	2005	2010	2015	2020	2025
Oil	12 565.3	12 484.6	18 261.6	14 759.5	18 035.1	24 586.2
Bagasse	938.2	988.2	1 427.8	2 380.8	2 797.8	3 512.6
Hydro	105.6	102.5	142.8	241.0	266.0	291.6
Solar	5.6	5.9	5.9	5.9	5.9	5.9
Gas	1 097.5	2 225.9	2 767.3	10 050.9	11 038.6	12 613.1
Wind	0.4	0.4	198.4	198.4	198.4	198.4
Total	**14 712.6**	**15 807.6**	**22 803.8**	**27 636.6**	**32 341.8**	**41 207.8**
	Share (%)					
Oil	85.4	79.0	80.1	53.4	55.8	59.7
Bagasse	6.4	6.3	6.3	8.6	8.7	8.5
Hydro	0.7	0.6	0.6	0.9	0.8	0.7
Solar	0.0	0.0	0.0	0.0	0.0	0.0
Gas	7.5	14.1	12.1	36.4	34.1	30.6
Wind	0.0	0.0	0.9	0.7	0.6	0.5

TABLE 10.19. ELECTRICITY GENERATION: REN SCENARIO (GW·h)

Energy source	2002	2005	2010	2015	2020	2025
Oil	12 565.3	12 484.6	18 065.1	14 758.9	14 753.7	14 759.5
Bagasse	938.2	988.2	1 427.8	3 666.9	7 538.9	9 496.2
Hydro	105.6	102.5	142.8	2 133.2	2 158.2	2 183.7
Solar	5.6	5.9	5.9	5.9	5.9	5.9
Gas	1 097.5	2 225.9	2767.3	6 084.4	6 108.2	12 393.0
Wind	0.4	0.4	394.9	987.3	1 777.1	2 369.4
Total	**14 712.6**	**15 807.6**	**22 803.8**	**27 636.6**	**32 341.8**	**41 207.8**
	Share (%)					
Oil	85.4	79.0	79.2	53.4	45.6	35.8
Bagasse	6.4	6.3	6.3	13.3	23.3	23.0
Hydro	0.7	0.6	0.6	7.7	6.7	5.3
Solar	0.0	0.0	0.0	0.0	0.0	0.0
Gas	7.5	14.1	12.1	22.0	18.9	30.1
Wind	0.0	0.0	1.7	3.6	5.5	5.7

TABLE 10.20. ELECTRICITY GENERATION: MIX SCENARIO (GW·h)

Energy source	2002	2005	2010	2015	2020	2025
Oil	12 565.3	12 484.6	18 261.6	19 911.8	23 677.5	31 410.2
Bagasse	938.2	988.2	1 427.8	3 759.9	4 013.7	4 609.4
Hydro	105.6	102.5	142.8	1 222.1	1 247.1	1 272.7
Solar	5.6	5.9	5.9	5.9	5.9	5.9
Gas	1 097.5	2 225.9	2 767.3	1 642.3	1 406.8	1 022.7
Wind	0.4	0.4	198.4	198.4	198.4	198.4
Nuclear	0.0	0.0	0.0	896.2	1 792.3	2 688.4
Total	**14 712.6**	**15 807.6**	**22 803.8**	**27 636.6**	**32 341.8**	**41 207.8**
	Share (%)					
Oil	85.4	79.0	80.1	72.0	73.2	76.2
Bagasse	6.4	6.3	6.3	13.6	12.4	11.2
Hydro	0.7	0.6	0.6	4.4	3.9	3.1
Solar	0.0	0.0	0.0	0.0	0.0	0.0
Gas	7.5	14.1	12.1	5.9	4.3	2.5
Wind	0.0	0.0	0.9	0.7	0.6	0.5
Nuclear	0.0	0.0	0.0	3.2	5.5	6.5

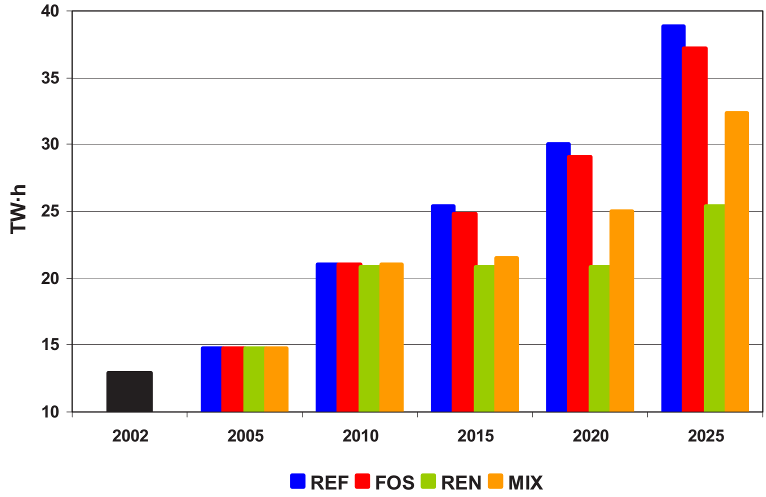

FIG. 10.13. Electricity generation from fossil fuels.

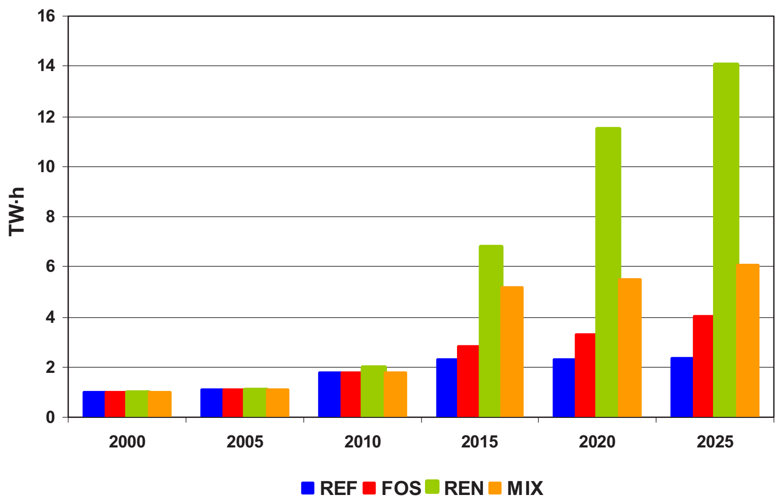

FIG. 10.14. Electricity generation from renewable fuels.

MIX and REN scenarios (Fig. 10.13). In the MIX and REN scenarios, the additional generation is achieved by using a higher level of renewable fuels, as shown in Fig. 10.14. Considerable increases of hydropower and wind are observed in the REN scenario. For the MIX scenario, the additional generation is basically achieved using more fossil fuels and nuclear.

Fossil fuels (oil and gas) represent the largest share of total electricity generation in all cases. By 2025, the fossil fuel share will be 94% in the REF scenario, 90% in FOS, 79% in MIX and only 66% in REN. The renewables share is highest in the REN scenario (at 34%). In the MIX scenario, electricity generation using renewables represents 15% and nuclear represents 6.5% of the total.

10.5.2.3. Electric generating capacity

The evolution of the electric generating capacity in the four supply scenarios is shown in Tables 10.21–10.24. By 2025, the electric generating capacities will vary from 7604 MW in the FOS scenario to 8462 MW in the REN scenario. The total capacity is greater for the REN and MIX scenarios, where renewables have higher shares. The lower capacity factors in renewables explain the need for more generating capacity in these scenarios.

TABLE 10.21. ELECTRIC GENERATING CAPACITY: REF SCENARIO (MW)

Energy source	2002	2005	2010	2015	2020	2025
Oil	3169.8	3046.8	3470.8	4572.8	5218.8	6472.8
Bagasse	571.9	571.9	661.0	717.0	717.0	717.0
Hydro	57.4	58.5	65.2	68.8	86.8	95.1
Solar	1.5	1.6	1.6	1.6	1.6	1.6
Gas	160.0	330.0	405.0	405.0	405.0	405.0
Wind	0.5	0.5	100.5	100.5	100.5	100.5
Total	**3961.1**	**4009.3**	**4704.1**	**5865.7**	**6529.7**	**7792.0**
			Share (%)			
Oil	80.0	76.0	73.8	78.0	79.9	83.1
Bagasse	14.4	14.3	14.1	12.2	11.0	9.2
Hydro	1.4	1.5	1.4	1.2	1.3	1.2
Solar	0.0	0.0	0.0	0.0	0.0	0.0
Gas	4.0	8.2	8.6	6.9	6.2	5.2
Wind	0.0	0.0	2.1	1.7	1.5	1.3

TABLE 10.22. ELECTRIC GENERATING CAPACITY: FOS SCENARIO (MW)

Energy source	2002	2005	2010	2015	2020	2025
Oil	3169.8	3046.8	3470.8	3470.8	3926.8	4838.8
Bagasse	571.9	571.9	661.0	789.0	821.0	917.0
Hydro	57.4	58.5	65.2	68.8	86.8	95.1
Solar	1.5	1.6	1.6	1.6	1.6	1.6
Gas	160.0	330.0	405.0	1327.2	1452.3	1651.6
Wind	0.5	0.5	100.5	100.5	100.5	100.5
Total	**3961.1**	**4009.3**	**4704.1**	**5757.9**	**6388.9**	**7604.6**
	Share (%)					
Oil	80.0	76.0	73.8	60.3	61.5	63.6
Bagasse	14.4	14.3	14.1	13.7	12.9	12.1
Hydro	1.4	1.5	1.4	1.2	1.4	1.3
Solar	0.0	0.0	0.0	0.0	0.0	0.0
Gas	4.0	8.2	8.6	23.1	22.7	21.7
Wind	0.0	0.0	2.1	1.7	1.6	1.3

TABLE 10.23. ELECTRIC GENERATING CAPACITY: REN SCENARIO (MW)

Energy source	2002	2005	2010	2015	2020	2025
Oil	3169.8	3046.8	3470.8	3470.8	3470.8	3470.8
Bagasse	571.9	571.9	661.0	1088.0	1530.0	1801.0
Hydro	57.4	58.5	65.2	338.8	356.8	365.1
Solar	1.5	1.6	1.6	1.6	1.6	1.6
Gas	160.0	330.0	405.0	825.0	828.0	1624.0
Wind	0.5	0.5	200.0	500.0	900.0	1200.0
Total	**3961.1**	**4009.3**	**4803.6**	**6224.2**	**7087.2**	**8462.5**
	Share (%)					
Oil	80.0	76.0	72.3	55.8	49.0	41.0
Bagasse	14.4	14.3	13.8	17.5	21.6	21.3
Hydro	1.4	1.5	1.4	5.4	5.0	4.3
Solar	0.0	0.0	0.0	0.0	0.0	0.0
Gas	4.0	8.2	8.4	13.3	11.7	19.2
Wind	0.0	0.0	4.2	8.0	12.7	14.2

TABLE 10.24. ELECTRIC GENERATING CAPACITY: MIX SCENARIO (MW)

Energy source	2002	2005	2010	2015	2020	2025
Oil	3169.8	3046.8	3470.8	4192.8	4724.8	5788.8
Bagasse	571.9	571.9	661.0	941.0	973.0	1053.0
Hydro	57.4	58.5	65.2	208.8	226.8	235.1
Solar	1.5	1.6	1.6	1.6	1.6	1.6
Gas	160.0	330.0	405.0	405.0	405.0	405.0
Wind	0.5	0.5	100.5	100.5	100.5	100.5
Nuclear	0.0	0.0	0.0	110.0	220.0	330.0
Total	**3961.1**	**4009.3**	**4704.1**	**5959.7**	**6651.7**	**7914.0**
	Share (%)					
Oil	80.0	76.0	73.8	70.4	71.0	73.1
Bagasse	14.4	14.3	14.1	15.8	14.6	13.3
Hydro	1.4	1.5	1.4	3.5	3.4	3.0
Solar	0.0	0.0	0.0	0.0	0.0	0.0
Gas	4.0	8.2	8.6	6.8	6.1	5.1
Wind	0.0	0.0	2.1	1.7	1.5	1.3
Nuclear	0.0	0.0	0.0	1.8	3.3	4.2

Figure 10.15 shows the fuel shares in electric generating capacity for 2002 (base year) and for the four scenarios in 2025. In all scenarios, fossil fuels (oil and gas) continue to be the dominant fuels. The REN scenario has the lowest fossil fuel shares at around 60% and the highest renewable share in terms of solar, wind, hydropower and bagasse. MIX is the only scenario in which nuclear power plays a role. In this scenario, the nuclear capacity starts in 2015.

10.5.2.4. Economic aspects

The investment analysis in this section only considers the costs of newly installed capacity. These costs change depending on the technologies in the four scenarios (Fig. 10.16). The addition of technologies with low investment costs, such as the gas combined cycles in the FOS scenario and thermal power plants in the REF scenario, leads to the lowest cumulative investment costs observed for both scenarios by 2025. The highest cumulative investment at the end of the

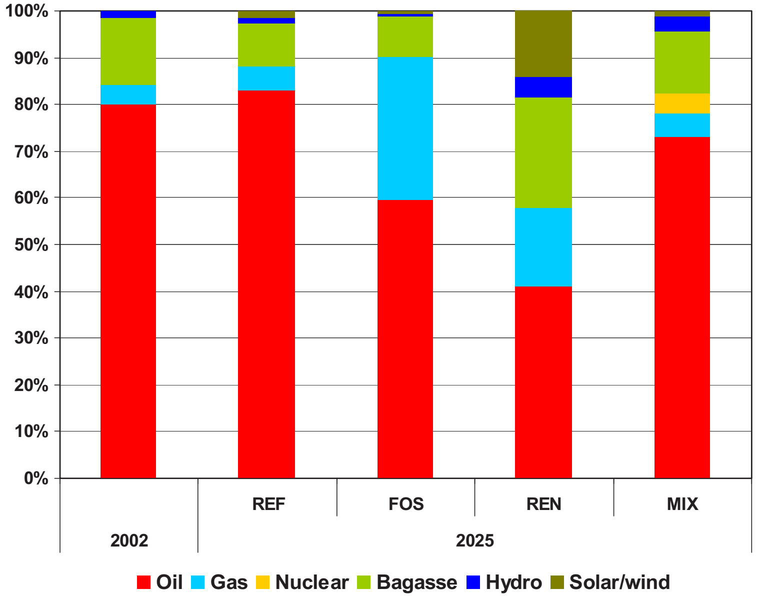

FIG. 10.15. Fuel shares in electric generating capacity.

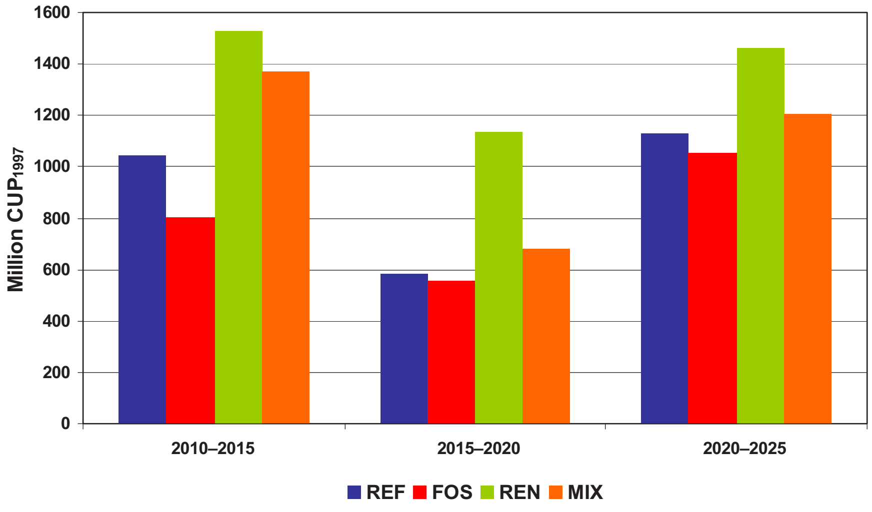

FIG. 10.16. Investments in electricity generation.

study period corresponds to the REN scenario and is related to the installation of 1200 MW in wind turbines and new BIGCC plants using bagasse totalling around 2000 MW by 2025.

10.5.2.5. Environmental impacts

Table 10.25 shows the CO_2 emissions for the entire energy sector and those due to electric generation for all scenarios. The REN scenario has the lowest annual growth rate of CO_2 emissions (2.4%) while the REF scenario has the highest (3.8%). The CO_2 emissions in the FOS scenario are lower than in the REF scenario because the FOS scenario uses much more gas for electric generation, replacing large amounts of crude oil used for this purpose in the REF scenario. The electric generation contribution to CO_2 emissions from the energy sector by 2025 ranges from 41% in the REN scenario to 50% in the FOS scenario.

The emissions from the energy sector grow in all scenarios throughout the study period (Figs 10.17–10.19). The increasing trend in emissions is due to the role of fossil fuels in both energy and electricity supply. The REN scenario has the largest share of renewable resources and the lowest CO_2 emissions.

The SO_2 emissions increase in all scenarios (Fig. 10.19) as a result of the predominant use of oil in all scenarios. In 2015, the emissions in the MIX scenario drop considerably owing to the addition of a nuclear power plant, combined with the use of crude oil with low sulphur content (only 3%) from the EEZ.

TABLE 10.25. ESTIMATED CO_2 EMISSIONS (Gg)

Scenario	2002	2005	2010	2015	2020	2025
			Energy			
REF	24 209.9	26 241.9	33 474.9	39 258.9	46 033.5	56 711.2
FOS	24 209.9	26 241.9	33 474.9	35 026.5	40 604.0	49 186.9
REN	24 209.9	26 241.9	33 258.9	32 761.4	35 350.3	42 067.5
MIX	24 209.9	26 224.9	33 200.9	37 210.6	42 738.3	51 346.2
			Electricity			
REF	10 407.5	11 162.1	16 583.2	18 424.0	21 415.7	27 005.5
FOS	10 407.5	11 162.1	16 583.2	17 101.7	19 681.9	24 649.7
REN	10 407.5	11 162.1	16 367.2	15 123.3	15 136.4	17 414.6
MIX	10 407.5	11 162.1	16 583.2	16 178.4	18 445.9	23 202.8

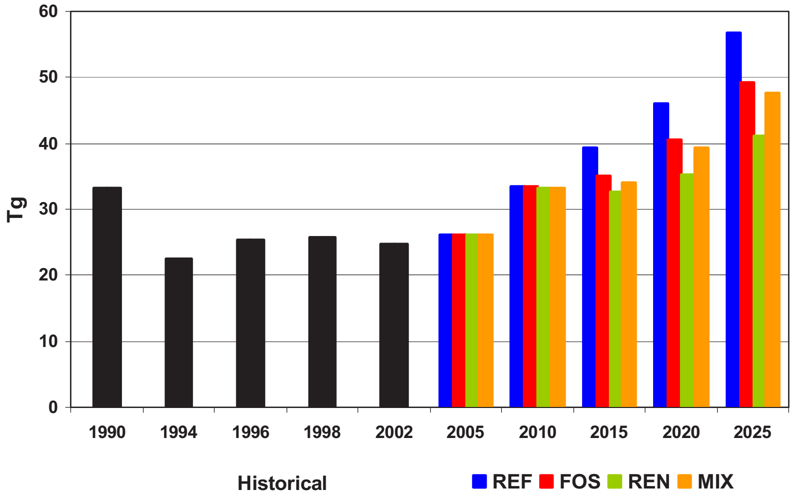

FIG. 10.17. CO_2 emissions from the energy sector. Historical data from Ref. [10.20].

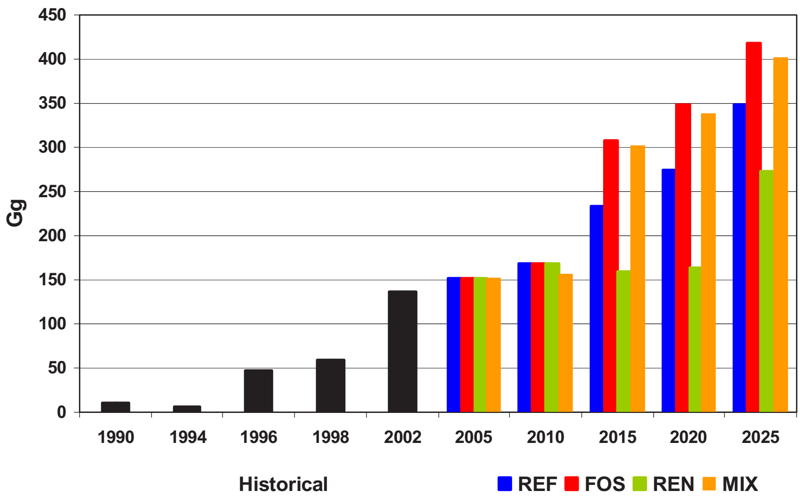

FIG. 10.18. CH_4 emissions from the energy sector. Historical data from Ref. [10.18].

Although in the FOS scenario the crude oil and natural gas from the EEZ are available, only the onshore crude oil, with 7% sulphur content, is used for electricity generation. Thus, the SO_2 emissions increase, even when the share of desulphurized associated gas grows. In the REF scenario, the emissions grow at an annual rate of 3.9%.

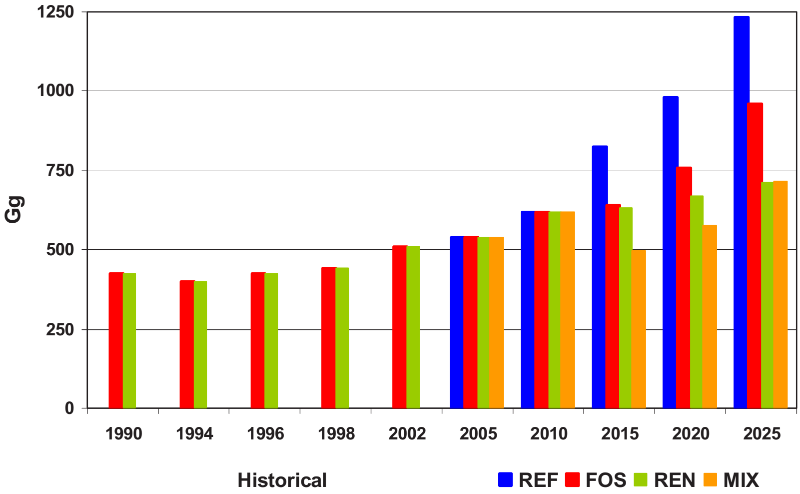

FIG. 10.19. SO_2 emissions from the energy sector. Historical data from Ref. [10.20].

In the REN scenario, the use of onshore crude oil determines the emissions trend. However, the annual growth rate of emissions is the lowest in this scenario (1.4%) owing to the use of renewable resources and desulphurized associated gas.

10.5.3. Sensitivity analysis

In view of the large uncertainties related to international crude oil prices and the extensive use of fossil fuels in the Cuban energy mix, a number of variants were analysed based on two alternative assumptions concerning imported oil prices.

The analysis is based on two oil price scenarios (base and high variants) of the Energy Information Administration study [10.21]. This study starts in 2004, considering for that year a crude oil price of US $40.5/bbl. Its base variant considers that the high oil prices observed in 2005 and 2006 are not sustainable and will decrease, but will not return to the lower levels of previous years. The high variant assumes that high oil prices will continue, but in view of the oil market prices observed recently, the assumptions underlying this study were optimistic.

Taking into account the assumptions of the two EIA oil price scenarios, two different variants for the four scenarios were developed. The price variations are introduced after 2010. Before this year, fuel prices are assumed to remain constant based on the agreement with Venezuela to supply crude oil and petroleum products at current prices (27 pesos/bbl) up to 2010.

The variants are defined as follows:

- Base variant: A crude oil price in 2010 of 43.8 pesos/bbl that increases to 50.1 pesos/bbl by 2025.
- High variant: A crude oil price in 2010 of 58 pesos/bbl that increases to 83.6 pesos/bbl by 2025.

Table 10.26 shows the assumed imported crude oil prices for each variant for the 2005–2025 period.

Prices for imported petroleum products are assumed to increase in the same proportion as crude oil prices.

Only the variants of the REF and REN scenarios are analysed in this section since the ones for the FOS and MIX scenarios resulted in only minor changes that do not provide interesting cases.

Variants of the REF scenario

In the REF scenario, only the high variant of oil prices implies significant changes in the results. In this scenario, fossil fuels play a major role; thus, to diminish the effects of price increments, new and more efficient capacity (but still based on fossil fuels) replaces old capacity. This new capacity has higher efficiency than the electricity capacity in use since the base year. The result is a reduction in overall fuel use for electricity generation in the high variant in comparison with the REF scenario. Figure 10.20 shows fossil fuel electricity generation using current generating capacities and new capacities, and the comparison of the total fuel use for electricity generation for both cases.

Variants of the REN scenario

In the REN scenario, both the base and high variants produce about the same changes in results. The increment in oil prices induces an increase in the

TABLE 10.26. IMPORTED CRUDE OIL PRICES (pesos/bbl)

Variant	2005	2010	2015	2020	2025
Base	27	43.8	44.3	46.9	50.1
High	27	58.0	70.6	78.8	83.6

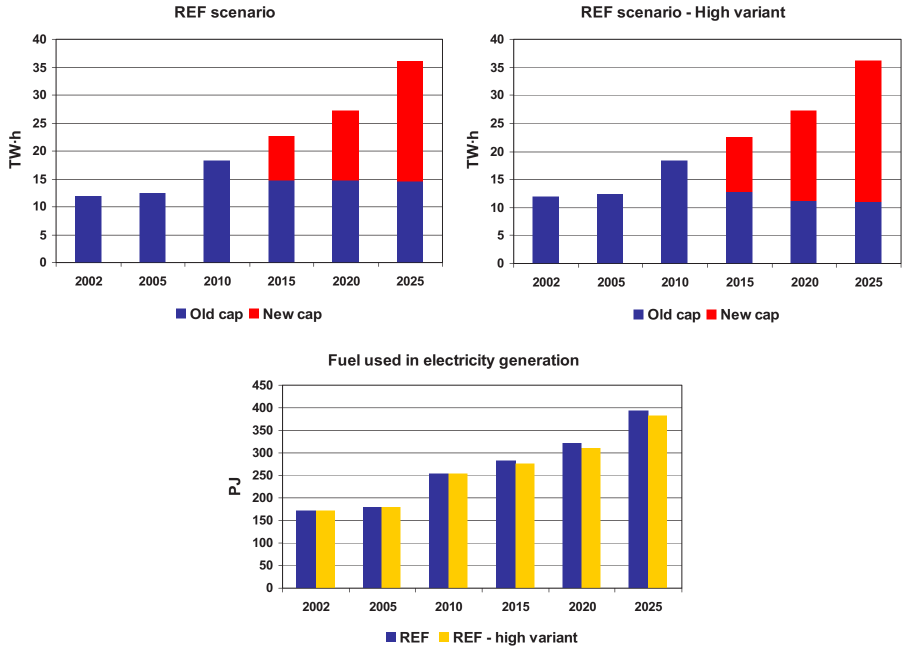

FIG. 10.20. Fossil fuel electricity generation with old and new capacities, and total fuel used in electricity generation for REF and REF–high variant scenarios.

use of bagasse technologies, reaching all the available potential by 2015. Therefore, electricity generation using bagasse increases while electricity generation using fossil fuels decreases. These changes result in an overall reduction of fuel use for electricity generation in the variants with respect to the original REN scenario by 2015. After 2015, since the total renewables potential is used, fossil fuel use starts to grow again to meet the electricity demand for the later periods. By 2025, the base and high variants as well as the original REN scenario have about the same levels of electricity generation as fossil fuels. Figure 10.21 shows the electricity generation mix and the overall fuel use in electricity generation for the REN scenario and the two variants.

10.6. SUSTAINABLE CRITERIA ANALYSIS

The scenarios developed in this study can be evaluated with respect to the sustainable energy development criteria specified by Cuba (see Section 10.3.2.) using some of the corresponding EISD (see Table 1.1, Section 1). Table 10.27 lists the criteria and corresponding EISD.

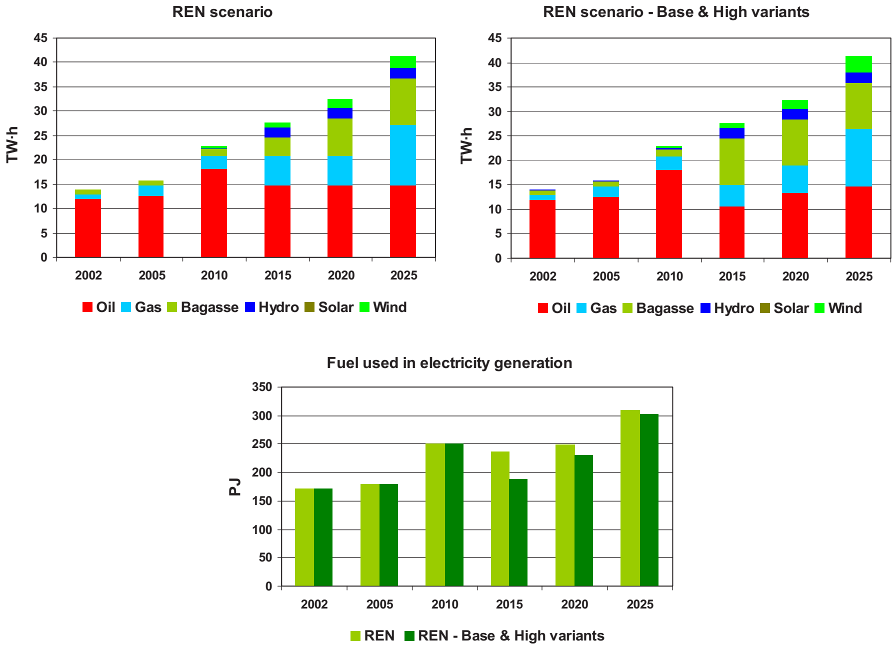

FIG. 10.21. Electricity generation mix and total fuel used in electricity generation for the REN scenario and the REN–base and high variants.

10.6.1. Social dimension

One of the main social and sustainable development criteria for Cuba is to extend energy services to the whole Cuban population and to improve the quality of these services. In order to reach this objective, the following assumptions were taken into account in this study:

— 100% of the population will have electricity after 2010;
— Kerosene will be replaced by electricity and gas in cooking;
— The use of fuelwood and charcoal will be eliminated;
— The number of cars per capita will increase;
— Passenger and freight transportation will increase.

These assumptions are taken into account in the development of the corresponding demand scenarios.

Other important aspects related to the social dimension are affordability and disparity. To assess the progress concerning these social criteria, the per

TABLE 10.27. SUSTAINABLE ENERGY CRITERIA AND CORRESPONDING EISD

Sustainable energy criteria	Corresponding EISD
Social	
1. Optimal national availability of energy services	SOC1: Household share without electricity or commercial energy ECO1: Per capita energy use
Economic	
2. To reduce energy import dependency	ECO11: Fuel shares
3. To increase use of the domestic energy resources	ECO13: Renewables share ECO15: Net import dependency
4. To boost energy conservation	ECO2: Energy use per unit of GDP
5. To increase R&D and boost participation of the domestic industry in energy development	ECO3: Efficiency of energy conversion ECO6–10: Energy intensities
Environmental	
6. To reduce the environmental impact of energy use	ENV1: GHGs ENV3: Air emissions

capita final energy and electricity use (ECO1) can be used. These indicators are shown in Fig. 10.22. Both indicators increase, showing progressive satisfaction of the increasing energy needs of the Cuban population. By 2025, the final energy use per capita increases 1.7 times and electricity use per capita 2.8 times with respect to 2002 levels. The growth rates are modest and correspond to a population increase of only 1.1% during the same period (see Fig. 10.4). Nevertheless, the levels of per capita energy use do not exceed those observed immediately prior to 1990.

10.6.2. Economic dimension

The indicator ‘net energy import dependency’ is introduced to measure the level of dependency on foreign sources. It is defined as the ratio of total net imports (primary plus secondary energy imports minus exports) to TPES.

Net energy import dependency in 2002 was 45% (Fig. 10.23). In the REF scenario, this value decreases to 33% by the end of the study period. The

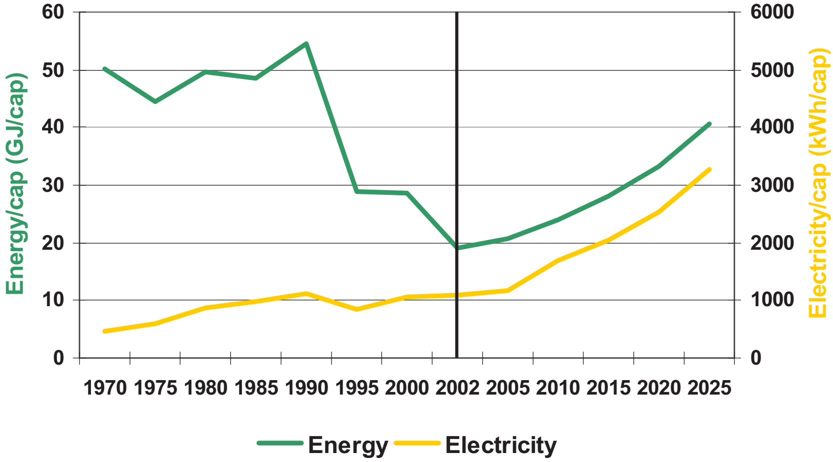

FIG. 10.22. Electricity and final energy use per capita. Historical data from authors' elaboration.

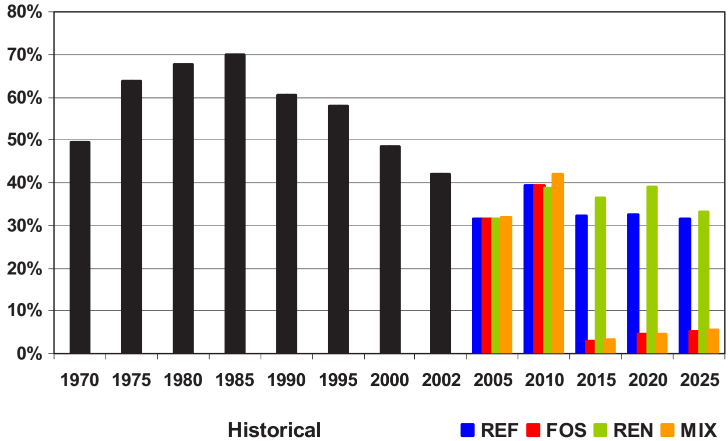

FIG. 10.23. Net energy import dependency. Historical data from authors' elaboration.

highest energy import dependency is in the REN scenario, 35% in 2025, but this is still lower than in the base year.

For both the REN and the MIX scenarios, crude oil production is restricted to onshore resources. Because of its poor quality, this crude oil has limited use in refineries and thus the increase in refinery capacity is limited. Therefore, it is necessary to increase the imports of petroleum products.

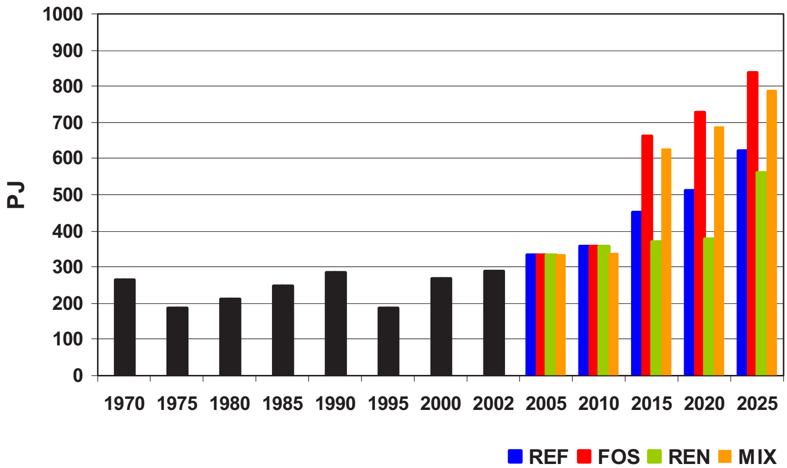

FIG. 10.24. Total domestic primary energy use. Historical data from Refs [10.5, 10.8–10.15].

In the FOS and MIX scenarios, the net energy import dependency is reduced to 5% at the end of the study period. In these scenarios, there are no imports of crude oil after 2015 and the petroleum products imports are reduced considerably. This is possible owing to the opportunity to extract crude oil from the EEZ; this oil would be used mainly in refinery production.

It can be concluded that in the FOS and MIX scenarios, a major reduction in net energy import dependency is achieved. In the REF and REN scenarios, the reduction in energy imports is only marginal.

The increase in the use of domestic energy resources (Fig. 10.24) is directly linked to the reduction in energy imports; therefore, the FOS and MIX scenarios have the highest use of domestic resources (2.9 and 2.8 times the value of the base year, respectively). In these scenarios, the use of crude oil and gas grows according to the assumed exploitation of the EEZ energy resources after 2015.

The REF and REN scenarios show lower use of domestic energy resources owing to the assumptions of a limited growth rate of onshore crude oil and associated gas production and a lack of exploitable resources from the EEZ. In the REN scenario, the renewable resources are used more efficiently up to 2020. By 2025, when these resources are not enough to meet the demand, the use of associated gas in electricity generation increases.

Efficiency in overall energy use can be assessed by the relationship between TPES and final energy use. In this study the efficiency in primary energy use (Fig. 10.25) increases in the REN scenario, from 63% in the base

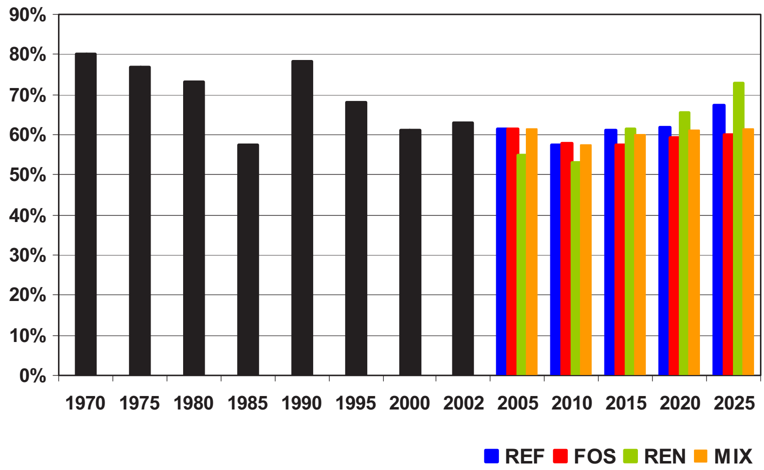

FIG. 10.25. Efficiency in primary energy use. Historical data from authors' elaboration.

year up to 73% by 2025. This increase is the result of the introduction of highly efficient technologies in electricity generation, such as CCGT and BIGCC plants. The use of other renewable sources such as hydro and wind also influences energy efficiency in a positive way.

The efficiency is defined in the other scenarios by the weight of the fossil technologies used for electricity generation in each scenario. The efficiency in these scenarios remains fairly constant at about 60–61% after 2015.

The fossil fuel efficiency for electricity generation is shown in Fig. 10.26. The efficiency is similar in the REF, FOS and MIX scenarios, given the prominent share of fossil fuels in electricity generation in these scenarios. The assumption of limited exploitation of renewable resources in these scenarios implies the introduction of more efficient fossil fuel technologies. In the REN scenario, around 35% of the generation is carried out using renewable energy; therefore, the generation with fossil fuels takes place using the less efficient currently installed capacities. In this scenario, the efficiency increases after 2020 owing to the use of CCGT.

The oil refining efficiency is defined as the average amount of finished light product output (gasoline, diesel, kerosene, aviation fuel, jet fuel, naphtha and LPG) per unit of crude oil fed into the refineries. This efficiency increases (Fig. 10.27) in the FOS and MIX scenarios, owing to the installation of a new, more efficient refinery for the production of light products. In the REF and REN scenarios, the total installed refinery capacity has lower growth during

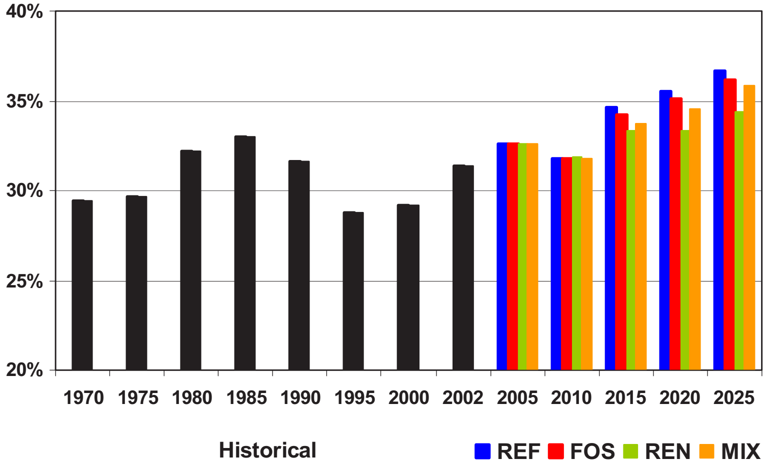

FIG. 10.26. Fossil fuel efficiency in electricity generation. Historical data from authors' elaboration.

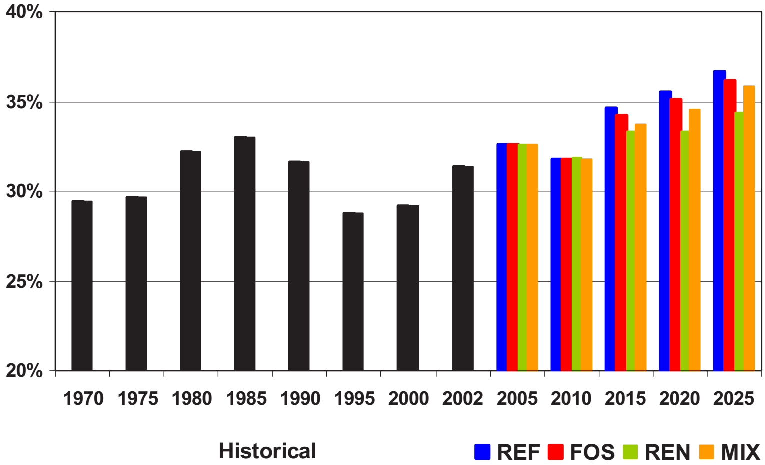

FIG. 10.27. Oil refining efficiency. Historical data from authors' elaboration.

the study period and therefore the old capacity determines the overall lower efficiency.

The introduction of new technologies such as BIGCC, nuclear power plants, wind turbines and alcohol production from sugarcane juice allows increased research activities and the partial or total development of these domestic industries. It is estimated that the domestic production of wind

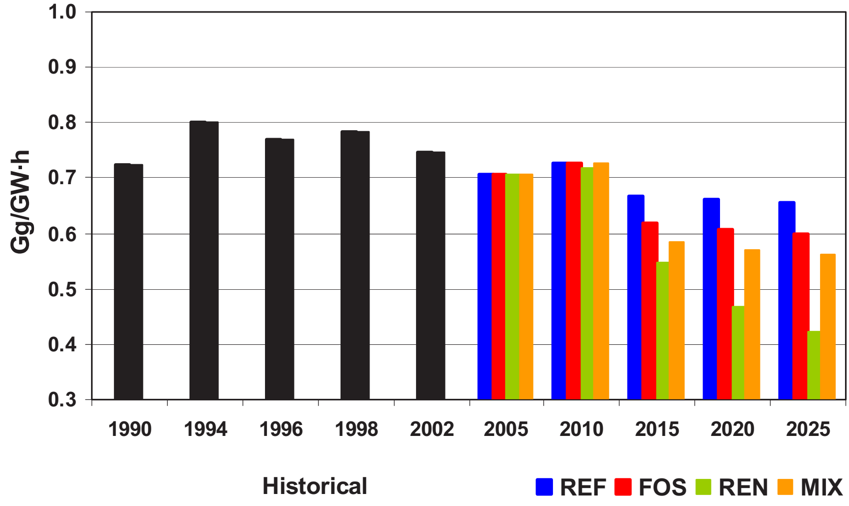

FIG. 10.28. CO_2 emissions per gigawatt-hour generated. Historical data from authors' elaboration.

turbine towers can reduce the investment cost of wind turbines by 30%. The construction of high parameter boilers for the sugar industry, solar panels, hydro devices and hydro turbines, windmills for pumping water for livestock and other uses, biogas digesters, solar heaters, climate control chambers, and solar dryers and distillers, and the introduction of technologies to produce ethanol, biodiesel, etc., also contribute to increased participation of domestic industries in the country's energy development.

10.6.3. Environmental dimension

Although the total pollutant emissions are not reduced in any scenario, as previously explained, the increase in efficiency in all scenarios, mainly in electricity generation, allows a decrease in the pollutant emission per unit of electricity generated.

The CO_2 emissions per generated gigawatt-hour (Fig. 10.28) decrease throughout the study period, between 12% in the REF scenario and 43% in the REN scenario. The high reduction in the REN scenario is due to the increase in the use of renewable sources for electricity generation. In the other scenarios, although the technology is efficient, the fossil fuel share determines higher CO_2 emissions.

The SO_2 emissions per generated gigawatt-hour decrease in all scenarios with respect to the base year (Fig. 10.29). The MIX and REN scenarios present

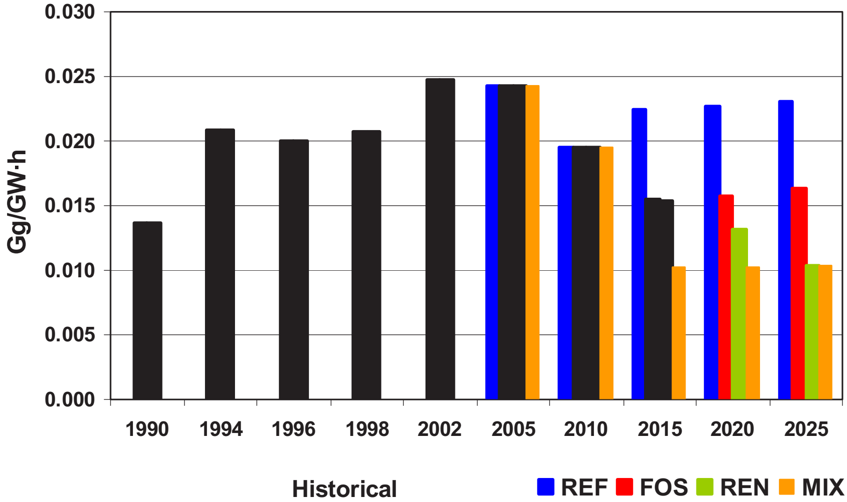

FIG. 10.29. SO_2 emissions per gigawatt-hour generated. Historical data from authors' elaboration.

the lowest values due to the shares of renewables and desulphurized gas in these scenarios and nuclear in the MIX scenario. In the FOS scenario, generation using gas and renewables represents 40% of total generation, stabilizing emissions per gigawatt-hour. From 2010 in the REF scenario, even though the generation using crude oil increases, the use of renewables, and of gas from 2015 onwards, reduces the growth rate of this indicator.

GHG emissions from the energy sector per capita increase in all scenarios (Fig. 10.30). The lowest annual growth rate corresponds to the REN scenario (2.4%) as a consequence of the sizeable use of renewable resources. The REF scenario has the highest annual growth rate (3.8%).

In summary, the sustainability analysis indicates that the MIX and FOS scenarios better reflect the country's goal of reducing imports, and by consequence the dependency on foreign energy resources, than do the REF and REN scenarios. The REN scenario is more consonant with the goals of reducing negative environmental impact and increasing the use of renewables.

10.7. MAIN ISSUES

The expected economic and social development in Cuba implies unavoidable growth in energy use. A major part of the future energy demand will be satisfied by fossil fuels, as reflected by the scenarios developed in this

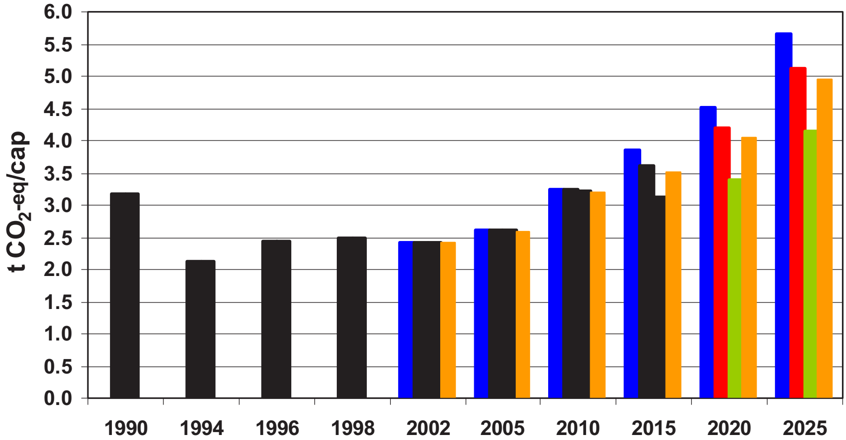

FIG. 10.30. GHG emissions from the energy sector per capita. Historical data from authors' elaboration.

section. The reliance on fossil fuels is due mainly to the limited availability of renewable sources and the implementation of programmes aimed at improving standards of living, such as the substitution of fuelwood and charcoal with gas and electricity for cooking.

The scenario analysis shows that the dependency on fossil fuels is projected to continue into the future, even when renewable sources are used. Nevertheless, if the crude oil and natural gas potential of the EEZ of the Gulf of Mexico materializes, the net energy import dependency could be substantially reduced, including imports of petroleum products if new refinery capacity is built.

Electricity generation grows at an annual growth rate of 4.8% with fossil fuels having the largest share, varying from 90% in the REF scenario by 2025 to 66% in the REN scenario. The electric generating capacity needed by 2025 varies from 7605 MW in the FOS scenario to 8463 MW in the REN scenario.

Since electricity is generated mainly using fossil fuels, emissions grow considerably in all scenarios. The lowest annual growth rate in CO_2 emissions corresponds to the REN scenario (2.4%) and the largest to the REF scenario (3.8%). Nevertheless, the introduction of more efficient technologies and renewable technologies allows emissions per generated gigawatt-hour to decrease in all scenarios.

The sensitivity analysis performed using two alternative assumptions concerning imported fossil fuel prices demonstrates that in the REF scenario, where the use of fossil fuels prevails, the electricity generation from the capacities in use since the base year is replaced by new, more efficient technologies. In the REN scenario, renewable technologies are introduced earlier; by 2020 the whole renewable potential considered in the study is used.

Sustainable criteria analysis shows that the FOS and MIX scenarios are better than the REF and REN scenarios from the point of view of the reduction of net energy import dependency and utilization of domestic energy resources. Regarding efficiency in TPES and in electricity generation, and lower emissions, the REN scenario prevails.

Although pollutant emissions grow in all scenarios, the values per unit of generated energy decrease, with the REN scenario showing the greatest reduction. The greatest possibilities for increasing R&D and boosting domestic industries are observed in this scenario.

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11. CONCLUSIONS AND LESSONS LEARNED

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This study is the third in a series of national studies conducted under a unique partnership initiative officially registered with the United Nations Commission on Sustainable Development by the IAEA, in cooperation with participating Cuban organizations and the United Nations Department of Economic and Social Affairs. Similar studies for Brazil and South Africa were completed in 2006.

This section presents the main conclusions derived from this comprehensive assessment of the Cuban energy system performed within a sustainable development framework. It also outlines 'other accomplishments' of, and 'lessons learned' from, the cooperative effort conducted jointly by Cuban and international experts. It concludes with some reflections about 'next steps' that may be followed to continue advancing the concepts and ideas supporting sustainable development at the national and international levels.

11.1. CONCLUSIONS

The major conclusions described in this section result from the analysis of the Cuban energy system within the primary dimensions of sustainable development — social, economic and environmental — consistent with the major themes used by the United Nations. Other conclusions relate to important issues of the Cuban energy system, including technology development, security and planning.

Cuba has high levels of electrification (95.5%), access to water supply and sanitation services, industrialization, urbanization and reforestation. Government programmes supporting these goals have contributed to the country's economic and social development. With the crisis in the 1990s, poverty and fuel shortages re-emerged as national problems. However, the programmes implemented for rational electricity use and fuel conservation, for the substitution of domestic fuels for imports, and for rural electrification, particularly in support of social objectives, have had encouraging results.

In the case of fuel use in households, there is a system of rationed distribution, guaranteeing access to fuels for the whole population throughout the country. Currently, only about 50% of the perceived fuel needs in households is being satisfied in rural areas. To a lesser extent, urban areas also have unsatisfied fuel needs. Improvement in this situation is necessary to ensure full satisfaction of energy needs and to raise the standard of living.

Cuba's main energy related social goals are to provide electricity to 100% of the population; to continue educating the population about energy issues, with particular emphasis on rational energy use and protecting the environment and human health; to promote sustainable development in the country; and to generate, reliably, enough electricity to completely eliminate the reccurrence of non-served electricity time periods. In this respect, the issue of availability of energy services at the specific time they are demanded is a major concern for Cuba in support of its social and economic goals and sustainable development.

With respect to energy and economic development, Cuba has shown a highly adaptive capability to overcome the dramatic socioeconomic situation caused by the crisis of the 1990s. The reduction of the country's energy vulnerability, largely through exploration for, and extraction of, crude oil and associated gas, not only has strategic implications regarding national security, but also helps relieve problems caused by the trade balance. The shortage of finance and the strong barriers to gaining access to credits have affected (and continue to affect) investments in the energy sector and have increased the expenditures on fuel imports. However, despite lack of access to finance and severe restrictions on foreign exchange, in the period 1993–2001, the resources devoted to investments linked to energy efficiency and the rational use of energy were more than four times greater than the cumulative total investments in these areas in the preceding three decades.

Despite reductions in the energy intensity of final energy use and efficiency improvements in the electricity subsector, and despite the positive results of a set of national and local programmes aimed at energy conservation and the rational use of energy, the prevailing economic structure favours energy use. Indeed, economic recovery has relied on highly energy intensive activities such as the production of nickel, steel and cement.

Among the highest priority energy policy issues in support of sustainable development are legal, standard, regulatory, planning and control, and institutional issues related to the energy system, in particular: the reconsideration of the objectives and missions of the State Energy Inspection at different levels (from national to municipal); the role of ESCOs and the creation of appropriate economic areas for their activities; and the role of the territories (or States) in the decentralized handling of local resources linked to sustainable energy.

The negative environmental impacts resulting from energy systems represent a major concern for the Cuban authorities. The large share of fossil fuels in Cuba's energy matrix results in high emissions of pollutants. There are areas with high concentrations of pollutants and worsening air quality, and health and environmental conditions in general. Emissions of SO_2 have increased significantly in the past decade owing to the increased use of domestic crude oil to generate electricity. Since 1998, the use of associated gas in electricity generation has enabled a reduction in the growth rate of SO_2 emissions. The lack of financial resources has not allowed the installation of emission reduction systems, and monitoring systems have suffered a gradual deterioration. This situation makes it difficult to enforce the environmental standards already in place.

With the economic crisis of the early 1990s, the unsustainable use of fuelwood and charcoal increased. The use of these fuels has since decreased owing to the increased use of other fuels for cooking.

An increase in the share of renewable energy and of associated gas in electricity generation would allow a reduction in emissions in the future. An improvement in the existing air quality standards and their effective application, as well as the introduction of other mechanisms such as an emissions tax, would favour the introduction of renewable energy. The introduction of emission reduction technologies for those plants that use domestic crude oil, or replacement of this fuel with one having a lower sulphur content, is also a pressing need.

Cuba has assimilated foreign energy technologies and in turn developed its own appropriate technologies to achieve development. This is especially true with respect to the sugarcane agro-industry, solar energy applications, hydropower and electric power generation. Nevertheless, most of Cuba's industrial sector is characterized by its inefficiencies and technological obsolescence as a result of the economic crisis and the technology inherited from the former socialist countries. The sugarcane agro-industry and the electric power industry are two of the sectors most affected. In the case of the electric power industry, it has been necessary to keep in operation facilities over 30 years old because of the current electricity generation deficit. Regarding the sugar industry, the partial or complete closure of facilities could not be postponed because of their low efficiencies, among other reasons.

On the other hand, the recent developments in electricity generation, in the oil and gas industry, and in the transport and fuel distribution infrastructure, have been very effective. They have enabled an increase in electricity generation and a greater supply of domestic fuels, which has boosted the country's economic recovery. Particularly remarkable are the assimilation and adaptation of power stations to burn domestic crude oil, the increase in efficiency in electricity generation and the reduction in transmission losses.

In the sugarcane industry, a high level of mechanization in sowing and harvesting has been reached with tools and machinery produced domestically.

This has allowed Cuba to increase production yields, to reduce the labour force needed in the fields and to raise income through the export of machinery and equipment. The restructuring of the sugar industry and the replacement of old plant and equipment with new models increased the industry's productivity and efficiency. New boiler designs and construction were instrumental in shaping up the industry. The domestic production of high performing boilers is expected shortly. This process of modernization and restructuring will continue in the coming years, provided that financial resources are available.

Technologies for the use of solar energy have been assimilated and developed. Examples of such solar technology applications include different models of heaters, dryers and climate controlled chambers. In spite of the strong domestic development in solar energy, there are many problems to be solved before its introduction on a larger scale.

Although there have been important developments and enlargements in the transport and energy distribution infrastructure, they have not been enough to cope with the possible development of oil activities in the EEZ of the Gulf of Mexico.

For Cuba, energy security goes beyond the typical security framework of energy supply to encompass the economic blockade, which affects Cuba's access to some markets for its traditional products and limits international credit options.

Recent problems concerning security of national energy supply include: (i) shortages of foreign exchange necessary to finance purchases of fuel and spare parts for new investments and for the implementation of programmes supporting the rational use of energy; (ii) high dependence on imported oil and petroleum products; (iii) use of domestic crude oil, with high sulphur content and energy performance slightly below that of the imported fuels; and (iv) interruptions in energy services resulting from hurricanes and tropical storms, and from breakdowns and accidents related to the transport of fuels, especially coastal transport.

Strategies to improve Cuba's energy security are based on: (i) increased economic competitiveness; (ii) fuel conservation and rational use of energy; (iii) efficient exploration, exploitation and use of oil and natural gas; (iv) development of renewable energy sources; (v) legal and institutional support of activities in the energy sector; and (vi) active involvement in the international arena focused on regional integration efforts and international forums related to technological, energy and environmental issues, and on strengthening bilateral alliances aimed at creating the necessary environment for trade, technology transfer and foreign investment needed to guarantee national energy supply.

Although Cuba has a very limited energy resource base, the success in implementing some of the policies currently in place and its leadership in the development of qualified human resources and appropriate technologies provide an excellent opportunity for the country to achieve a higher level of sustainable energy development. Policies proposed in this study (e.g. increased production of alcohol and petroleum products; greater use of non-combustible renewable sources such as wind generation, photovoltaic systems, and mini-, micro- and small hydropower plants; and increases in efficiency and implementation of energy conservation programmes) may represent effective mechanisms by which to achieve this goal.

The integrated picture resulting from the scenario and energy indicator analyses shows that Cuba is generally heading in the right direction for realizing many of its sustainable development goals. However, there is room for improvement. The regular application of indicator analysis combined with scenario development can be a powerful tool for monitoring the continuing appropriateness of energy policies in the context of sustainable development over time. Such continuous monitoring is invaluable as a means of identifying, at an early stage, policy areas that need correction or adjustment.

11.2. OTHER ACCOMPLISHMENTS

The present study comprises the interlinking of energy system modelling and the use of indicators for sustainable energy development to assess the consonance between energy policies and energy development strategies, on the one hand, and the social, environmental and economic development goals of the country on the other. This 'marriage' of scenario and indicator analysis is a unique feature of the project that has already captured international attention.

Capacity building in the areas of energy and environmental planning within a sustainable development context was one of the main goals of this project. This was planned and accomplished on a number of different levels, primarily through a process of: (i) defining sustainable development criteria in the context of the energy sector and reconciling the different objectives and elements thereof, (ii) developing expertise in modelling a number of different possible futures for the national energy system under a variety of policy assumptions and (iii) using indicators to measure progress in achieving selected sustainable development goals.

Defining sustainable development and its various components, and selecting appropriate policies to achieve sustainable development goals, is a continuous process. The same is true for delineating the relationship between energy use, sustainable economic development and environmental protection.

Reaching a consensus for the purposes of this study was an essential and iterative process, with no single correct outcome. In this regard, the project could be described as developing a rigorous discipline of introspection with regard to energy policy and sustainable development choices in Cuba. Scenario modelling has great advantages in such cases for exploring and comparing a range of possible outcomes for further consideration.

Development of scenarios permits analysts to probe the possible future outcomes of present and past policy choices. The national teams in Cuba developed expertise in the use of energy system assessment models, to be used for devising scenarios of possible future energy system development paths and for mapping their consequences. IAEA and Cuban experts worked together to make credible quantitative assessments of energy system developments. The main scenarios and a number of related variants chosen for the present study show different outcomes but by no means cover all possible futures. More complete analysis would require additional scenarios, but the limited scenario assessment of this study serves to illustrate the importance of current policy choices for future progress towards sustainable development.

The national teams developed expertise in the construction and application of indicators as a measure of progress towards achieving sustainable development goals and the contribution of the energy sector thereto. The indicators were used to review past and current trends in the social, economic and environmental dimensions of sustainable development, and permitted the teams to link these trends to future scenarios developed with the integrated modelling tools.

11.3. LESSONS LEARNED

This study has proved to be a challenging but very valuable exercise. Extensive discussions were necessary among major stakeholders to accomplish very important tasks within a holistic framework. One of these tasks was the definition of the Cuban criteria for sustainable energy development. This task required stakeholders to reflect on the most desirable path to follow to reach energy sustainability. When final consensus was reached, it was recognized that defining sustainable development criteria is like trying to hit a moving target, that is, it is a continuous and ever changing process. Nevertheless, having experts from different organizations working together and ‘brainstorming’ about this subject proved to be a valuable activity.

Another challenging task was the formulation of future scenarios based on consistent sets of assumptions using integrated modelling tools. The modelling exercise proved to be a dynamic process in which assumptions and parameters needed to be considered in a flexible and transparent manner, allowing the necessary sensitivity analysis to be conducted.

The overall analysis with EISD allowed experts to link past and current trends with possible future consequences developed with the integrated modelling tools. The task proved to be enlightening, especially when assessing the scenarios with respect to the sustainable development criteria and goals specified by Cuba.

Finally, quantitative and qualitative analyses were 'interwoven' within each other and among all the sustainable development dimensions. This was necessary to be able to incorporate in the analysis a number of important issues difficult to quantify or simulate but necessary for the formulation of effective policies.

11.4. NEXT STEPS

The benefits of capacity building tend to be lost over time unless the skills and expertise acquired are continually used and enhanced. The national teams in this respect have already started to build upon the modelling and analytical skills developed during the course of this project, providing further scenario analysis for developing national energy plans and associated policy strategies. In this respect, the capacity building part of this project has been highly successful.

With the habit of introspection and self-criticism ingrained, further use of these tools for policy analysis can provide continued insight. The present study should therefore be viewed not as the end of a process but rather as the beginning. Developing viable policies for sustainable energy development requires balancing a number of sometimes conflicting variables and interests. Further analysis of this balancing act is always worthwhile. More detailed strategies for further development and refinements to the domestic oil industry and related sectors could be one fruitful avenue for discussion. Exploring the conditions that have fostered development of human resources and appropriate domestic energy technologies could be another profitable study. Looking more deeply at the development impact of different levels of quality in delivered energy services in the context of affordability and availability could be a most useful approach for clarifying future strategies. Enhancing energy efficiency in energy intensive industries and shifting towards a less energy intensive industrial profile are interesting propositions for sustained energy development. Studies that map the consequences of optimizing different energy mixes could prove instructive as to the costs and consequences of different development paths.

At the international level, the approach, modelling framework and guidelines developed in this study might be useful to other countries attempting the systematic construction of their own national profiles on sustainable energy development. Information exchange among countries on experiences and lessons learned will allow improvements and refinements in the approach and methods proposed in this study.

Countries will find this study of Cuba useful as an example to review before embarking on the overall assessment of their own energy systems, in the formulation of potential future energy demand and supply scenarios, and in the definition of sustainable energy strategies designed to help policy makers pursue their sustainable energy development objectives.

ACRONYMS AND ABBREVIATIONS

BIGCC	biomass integrated gasification combined cycle
CCGT	combined cycle gas turbine
CDM	clean development mechanism
CETRA	Transport Research Institute
CITMA	Ministry of Science, Technology and Environment
CMEA	Council for Mutual Economic Assistance
CNG	compressed natural gas
CSD	Commission on Sustainable Development
CUBAENERGÍA	Centre for Information Management and Energy Development
CUC	Cuban convertible peso
CUPET	CUBAPETROLEO S.A.
DPNES	Development Programme for National Energy Sources
EEZ	economic exclusion zone
EISD	energy indicator for sustainable development
ESCO	energy service company
Eurostat	Statistical Office of the European Communities
GDP	gross domestic product
GHG	greenhouse gas
IEA	International Energy Agency
LPG	liquefied petroleum gas

MAED	Model for Analysis of Energy Demand
MEP	Ministry of Economy and Planning
MESSAGE	Model for Energy Supply Strategy Alternatives and their General Environmental impacts
MINAZ	Ministry of Sugar Industry
MINBAS	Ministry of Basic Industry
MITRANS	Ministry of Transportation
NES	National Electric System
NMVOC	non-methane volatile organic compounds
PAEC	Cuban Electricity Rational Use Programme
PM10	particulate matter with a diameter of less than 10 micrometres
SAR	sugarcane agricultural residues
SIDS	small island developing State
TPES	total primary energy supply
UNCHE	United Nations Conference on the Human Environment
UNDESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNE	National Electric Union
WEA	World Energy Assessment
WSSD	World Summit on Sustainable Development

UNITS

bbl	barrel of oil
boe	barrel of oil equivalent
eq·ha/a	equivalent hectares per year
Gg	gigagram
Gg/GW·h	gigagram per gigawatt-hour
GJ	gigajoule
GJ/cap	gigajoule per capita
GJ/peso	gigajoule per peso
GW·h	gigawatt-hour
ha	hectare
hL	hectolitre
TJ	terajoule
kJ/p·km	kilojoule per passenger-kilometre
kJ/t·km	kilojoule per tonne-kilometre
ktoe/cap	thousand tonnes of oil equivalent per capita
kW(e)	kilowatt (electrical)
kW(p)	kilowatt (photovoltaic)
kW·h/cap	kilowatt-hour per capita
PJ	petajoule
p·km	passenger-kilometre
Tg	teragram

t·km	tonne-kilometre
toe	tonne of oil equivalent
TW·h	terawatt-hour

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This country profile is the product of an international effort to apply a novel approach to the comprehensive assessment of national energy systems within a sustainable development context. It comprises a qualitative and quantitative analysis of Cuba's energy needs, supply options and security objectives; domestic resources; technology development and innovation; and alternative future scenarios that consider sustainable development criteria and goals. Social, economic and environmental issues and trends are examined in detail using statistical analysis of historical data, integrated demand and supply modelling systems, and energy indicators for sustainable development. The quantitative assessment is complemented by discussion of major institutional and infrastructural factors. The report summarizes the analyses, identifies priority energy areas for Cuba and explores policy options useful to decision makers and specialists in energy and the environment.

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