CLIMATE CHANGE AND EXTREME EVENTS: VULNERABILITY OF ENERGY SYSTEMS IN CUBA

Elieza Meneses Ruiz[1],*, Leonor Turtós Carbonell[1], Ilse Berdellans Escobar[2], Ileana López[1], David Pérez Martin[1], Massimo Zucchetti[3] and Thomas Alfstad[2]

[1]Center for Information Management and Energy Development, CUBAENERGIA, Cuba
[2]Planning and Economic Studies Section, Department of Nuclear Energy, IAEA, Vienna, Austria
[3]Dipartimento di Energetica, Politecnico di Torino, Torino, Italy

ABSTRACT

Cuba is located in the Caribbean Sea to the south of Florida (United Stated of America). Its geographic characteristic, lengthened and narrow, makes it especially vulnerable to the effects of climate change, sea level rise and extreme weather.

Extreme events affect all economic sectors, including the energy sector. Depending on the nature of the event, some energy sources may be more adversely affected than others.

The projected energy supply scenarios for Cuba foresee development of renewable energy sources up to their maximum potential and also nuclear energy towards end of the study period. Despite this, the energy sector will remain dominated by fossil fuels. Two scenarios, a Business as usual (or reference) and a GHG mitigation were assessed. In the GHG mitigation scenario the expected installed electricity capacity mix in 2030 will be: 62% fossil fuels, 20% wind, 8% biomass, 6% hydro and 4% nuclear

The study carried out an analysis of the vulnerability of these energy sources to the climate change and extreme events, and how climate change and climatic predictions should be taken into account in the country energy planning. A model was developed, based on available data, to identify the most relevant parameters and determine their relevance for the different energy sources and types of climate risk.

Pollutant emissions were also assessed, pointing out the influence of the possible different alternatives.

KEYWORDS:
Climate Change, Extreme Events, Vulnerability, Energy

1 INTRODUCTION

Small islands, whether located in the tropics or higher latitudes, are particularly vulnerable to the impacts of climate change, sea-level rise, and extreme events [1]. Climate variation such as: increased frequency of extreme climatic events such as tropical hurricanes, increase in rainfall, longer duration of droughts, etc are expected in the Caribbean area. These climatic variations might affect the entire economy, including the energy sector. Depending on the nature of the event, some energy sources may be more adversely affected than others.

Policymakers require a coherent synthesis of all aspects regarding energy and climate change. Currently this cannot be obtained through energy supply models alone, since these do not include climatic variables. The objective of this study was to carry out an analysis of the vulnerability of the energy sources, considered in the country supply energy projections, to climate change and extreme climatic events. Assumptions for future change in climate were based on the Caribbean climatic predictions obtained from the IPCC Fourth Assessment Report. The study also explored how climate could be taken into account in the country energy planning through Integrated Assessment Models (IAMs), in order to minimized the negative effect of climate changes in the energy supply system.

The results from an energy scenarios study, carried out using the **M**odel for the **A**nalysis of **E**nergy **D**emand (MAED), and **M**odel for **E**nergy **S**upply **S**ystem **A**lternatives and their **G**eneral **E**nvironmental impacts (MESSAGE) were used as staring point [2]. The projected energy supply scenario, assessing the GHG mitigation, foresees the introduction of renewable sources up to their maximum potential and nuclear energy, even though fossil fuels will continue to have a dominant role.

2 METHODOLOGY FOR ENERGY SCENARIOS ANALISYS

In the framework of the International Atomic Energy Agency (IAEA) RESEARCH COORDINATION PROGRAM: “Greenhouse Gas Mitigation Strategies and Energy Options” [2], energy demand projections for a Business as usual (or reference) scenario and a mitigation scenario were developed using the MAED model [3]. The

* Corresponding author

corresponding supply scenarios were assessed using the MESSAGE [4].

2.1 Population & GDP projections

In both scenarios the same population and GDP growth were assumed (see Figure 1). The population in Cuba was assumed to decrease at an annual average rate of -0,036%, based on studies conducted by the Centre for Population Studies and Development [5]. The average annual GDP growth rate was assumed to be 5.9% during the study period, as projected by the National Institute for Economic Research, [6].

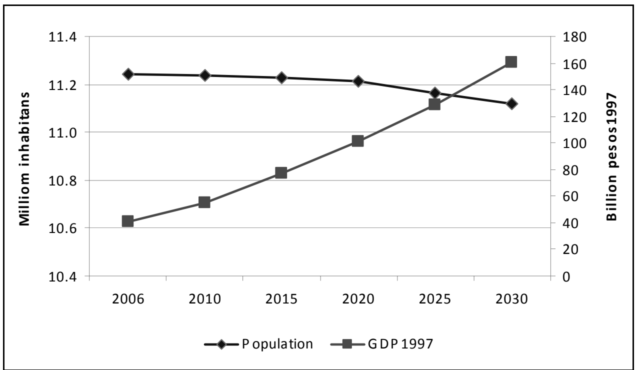

FIGURE 1 - Population and GDP$_{1997}$ grow

2.2 Base year data

2006 was selected as the base year, for the study. In that year the total primary energy supply was 10.9 million ton of oil equivalent (Mtoe) of which 52% was imported. Moreover, final energy use was 5.9 Mtoe. Fossil fuels made up 66% of the total, electricity 19% and renewable sources 15%. Table 1 shows the total primary energy supply (TPES) and the total final energy use, respectively.

TABLE 1 - Total primary energy supply (TPES) and total final energy use, 2006

TPES (Mtoe)	**10 .9**
Primary energy	5.3
Imports	5.6
Final energy use (Mtoe)	**5.9**
Fossil fuels	3.9
Renewable sources	1.1
electricity	0.9

Source: Author's elaboration from National Statistical Yearbook 2007[7]

The total installed capacity of oil refineries in 2006 was 2.9 million tons of crude and 2.047 Mtoe of petroleum products were produced in that year.

The total installed electricity generation capacity was 5177 MW, of which fossil sources accounted for 90% and renewables 10%. The electricity generation was 16469 GWh, and renewable sources (wind, bagasse and hydro) constituted 3% of the total. The electricity transmission and distribution losses were 6.7% and 12.3% respectively, and total losses equalled 17.8%. Table 2 shows the total installed electricity generation capacity and generation by sources.

TABLE 2 - Total electricity installed capacity and generation by sources, 2006

Total electricity installed capacity, MW	**5177**
fossil	4659.3
renewable	517.7
Total electricity generation, GWh	**16469**
fossil	15974.9
renewable	494.1

National Statistical Yearbook 2007

Main mitigation options

According IEA´s statistics, CO_2 emissions from fuel combustion for Cuba in 2009 were 26.84 Mt CO_2 [8]. It represented 2.75 % and 0.09% of the total Latin America and global emissions respectively. Although Cuba has no international commitment to reduce the GHG emissions (no Annex 1 country) and its GHG emissions are insignificant in the global context, some mitigation strategies, have been developed as part of the so called “Energy Revolution” (a deep transformation of the Cuban energy system). These address key issues such as energy efficiency, use of renewal energies sources, increased oil and gas production and improved electricity service availability.

The main mitigation options considered in the study were:

1. Increase of energy efficiency, mainly in the industrial and service sectors.
2. Investment in renewable energy:
   a. Introduction of solar energy for thermal purposes by 2010, reaching a share of 20% and 30% in 2030 in residential and services sector respectively.
   b. Introduction of more efficient bagasse power plants (100 kWh per ton of sugarcane crushed).
   c. Introduction of biomass gasification
   d. Use of wind energy up to its maximum potential (1 200 MW of installed capacity).
   e. Use of hydropower up to its maximum potential (360 MW of installed capacity).
3. Switch to fuels with lower carbon content, by increasing the use of natural gas for electricity generation, together with the installation of more efficient technologies.
4. Introduction of the Nuclear Energy (modular reactor (PBMR) 220MW), as a candidate plant from 2020

2.3 Energy demand projections

In Figure 2 the demand projections for the Business as usual (BAU) and the mitigation (MIT) scenarios are shown. In the mitigation scenario the demand is lower than in the base scenario from 2010 due the increased use of solar energy for thermal purpose in the residential and services sectors, the substitution of fossil fuels by electricity for cooking and lower energy intensities in the industrial and service sectors. By the end of the study period

the energy demand in the mitigation scenario is 4% lower than in the BAU scenario.

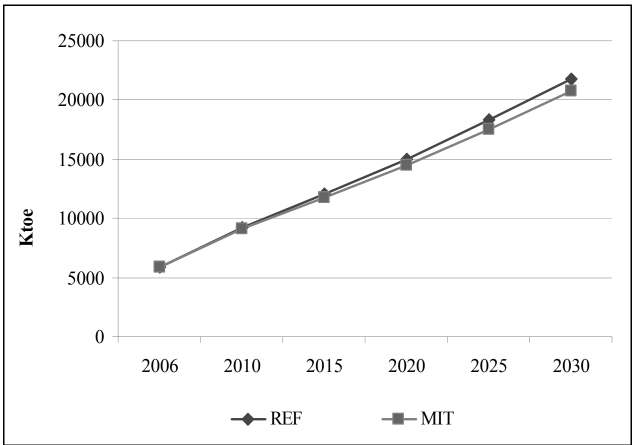

FIGURE 2 - Energy demand projection

2.4 Electricity supply projections: installed capacity and generation

In Figure 3 and Figure 4 the total installed capacity and electricity generation in both scenarios during the study period are shown. In the mitigation scenario the share of renewable energy is greater than in the reference scenario. This includes increased use of wind energy and hydropower and higher efficiency in the use of biomass due to the introduction of new bagasse power plants.

In addition to the increase in the use of renewal energy, the introduction of nuclear power from 2025 onwards, result in a decrease in the share of fossil fuel electricity generation from 97 % in reference scenario to 81% in mitigation scenario by 2030. In the MIT scenario, the installed electricity capacity mix in 2030 will be: 62% fossil fuels, 20% wind, 8% biomass, 6% hydro and 4% nuclear.

2.5 Climate observations and future trends

Although most small island states have very low GHG emissions, they are highly vulnerable to the impacts of climate change. In addition, they often have little capacity to adapt. The climate regimes of small islands are quite variable, generally characterised by large seasonal variability in precipitation and small seasonal temperature differences in low-latitude islands. In the tropics, hurricanes and other extreme climate and weather events cause considerable losses to life and property [1].

According to the IPCC Fourth Assessment Report (4-AR) [1], the global mean temperature has increased by around 0.6 ^{0}C during the past century. Over the same period the mean sea level rose by about 2 mm/yr. The rate of increase in air temperature in the Caribbean area exceeded the global average. The Third Assessment Report (TAR) also found that much of the rainfall variability appeared to be closely related to El Niño-Southern Oscil-

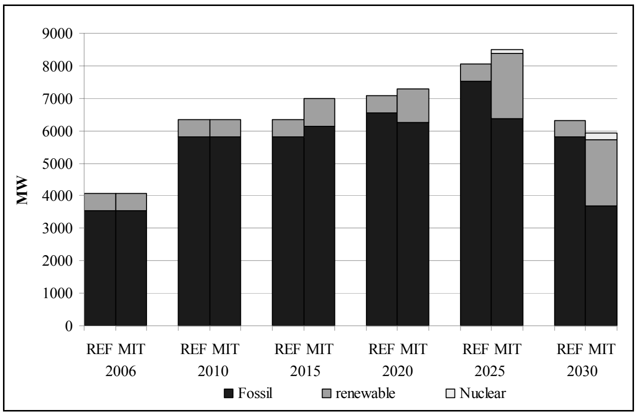

FIGURE 3 - Electricity Installed Capacity by scenario

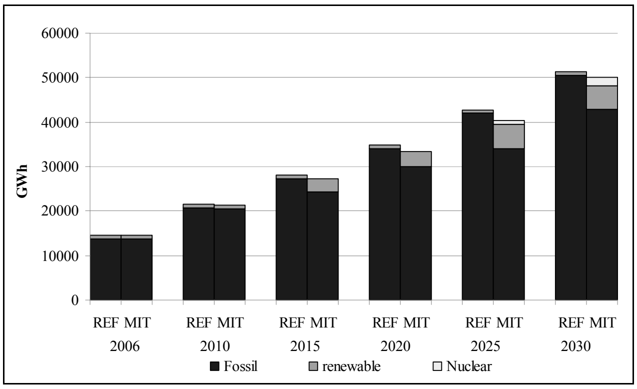

FIGURE 4 - Electricity Generation by scenario

TABLE 3 - Climatic projection for the Caribbean area

	Climate observed trends	Climate future trends[1]
Temperature	Increased from 0 to 0.5°C per decade since 1971 to 2004. The percentage of days with very warm maximum or minimum temperatures has increased considerably since the 1950s, while the percentage of days with cold temperatures has decreased.	Increase from 0,8 ^{0}C to 2,5 ^{0}C in 2050 and from 0,9 ^{0}C to 4 ^{0}C in 2070
Precipitation	The maximum number of consecutive dry days is decreasing and the number of heavy rainfall events is increasing.	Variation Range from -36.3% to 34.2% in 2050 and from -49,3% to 28,9% in 2070
Sea level rise	On average, the mean relative sea-level rise was 1 mm/yr during the last century.	Rise of 35 cm during the century
Extreme events	The number of storms, reaching the highest categories, has increased since 1970, along with increases in the Power Dissipation Index due to increases in their intensity and duration.	Increase in the frequency from 5% to 10% during the century

[1]The projected variations are related to the 1961-1990 period, and have been updated in the IPCC 4-AR[1]
Source: IPCC Fourth Assessment Report [1] and ECLAC 2010[10]

lation (ENSO) events, combined with seasonal and decadal changes in the convergence zones.

Table 3 shows the observed climate trends andprojection to 2100 based on different emissions scenarios (A2 and B2)[9].

The following is expected for the region:

- Increased frequency of extreme climatic events such as tropical hurricanes.
- Increase in annual rainfall
- Increased duration of droughts

3 VULNERABILITY OF ENERGY SYSTEM TO THE CLIMATE CHANGE

In order to adapt to climate change it is important to know how the energy sector may be impacted. For example:

- The increment of temperature and hot waves, reduce the efficiency of thermoelectric power production.
- Droughts reduce hydropower generation and biomass production.
- Changes in cloud cover influence solar energy production.
- Changes in wind direction, frequency, and strength affect wind power production, either adversely or positively.
- The occurrence of extreme events associated with tropical storms may cause damage to energy infrastructure.
- Coastal structures are influenced by sea level rise, and with a higher sea level, the need for adaptation options will often require extra energy supply.

Table 4 shows an analysis of the expected vulnerabilities of the energy systems, considered in the country supply energy projections.

4 INTEGRATED ASSESSMENT MODELS

Integrated assessment is an interdisciplinary process which combines, interprets, and communicates knowledge from diverse scientific disciplines in an effort to investigate and understand causal relationships within and between complicated systems. There is a current development of methods and tools to improve the assessments. However, the current energy models are not sufficient to undertake comprehensive analysis that incorporates climate sensitivity. Efforts are underway in Cuba for the use of IAMs to 1) assess the economic impact of climate change and, 2) improve energy supply projections based on the climate change adaptation from a CLEW (Climate, land, energy and water) approach.

TABLE 4 -Vulnerability of energy system to the climate change

Energy System	**Climate Impacts**
Solar energy	The use of solar energy in Cuba is foreseen mainly for thermal purposes. In the energy projection it is expected to reach a share of 20 % and 30% in 2030 in residential and services sector respectively. Solar energy for thermal purpose is extremely vulnerable to hurricanes and tropical storms as these can damage solar equipment.
Wind Power	An increase in the use of wind energy is expected in both energy supply projections. In the mitigation scenario wind energy was limited to its maximum estimated potential (1 200 MW of installed capacity). Wind energy is vulnerable to the change in the wind patterns and to the occurrence of hurricanes and tropical storm due the damage they may inflict on wind power generators.
Hydro Power	An increase in the use of hydropower is expected. In the mitigation scenario hydropower was limited to its maximum estimated potential (360 MW of installed capacity). The hydropower generation potentials are seriously affected by the drought, also temperature increment increases reservoirs evaporation. The occurrence of hurricanes and tropical storm might damage to the facilities.
Biomass Power	The biomass production is expected to increase with the introduction of more efficient bagasse power plants (100 kwh per tonne of sugar crushed) The biomass potential is affected by the drought and temperature increment, with negative impacts on crop, cycle efficiency and cooling water availability. Also, it is affected by the occurrence of hurricanes and tropical storm that may damage facilities.
Fossil fuels	The increase in temperature, reduce the thermal power production efficiency because of higher cooling water temperature. Fossil fuel facilities including oil and gas productions are affected by increasing sea levels because most of the facilities are located in coastal areas; also, they are affected by the occurrence of hurricanes and tropical storm that may cause physical damage.
Nuclear Power	The increase in temperature, reduce the nuclear power plant efficiency because of higher cooling water temperature.
Electricity transmission and distribution network	The power transmission system can suffer severe damage from hurricanes and tropical storms. Other impacts are associated with the stress due to temperature increases and associated demand growth.

4.1 Economic impact of climate change

Modelling the monetary impacts of climate change globally is very challenging since it requires quantitative analysis of a very broad range of environmental, economic and social issues. However, this type of modelling, though limited, provides a useful tool [11].

There are several IAMs, with differences in scope and level of detail. The parameters used in the models as input data are calibrated according to the results of numerous economic and scientific research studies conducted. These models often rely on the results of the previous studies.

PAGE2002 [12], RICE [13] and FUND [14] are considered among the most used and well known IAMs. In fact, these models have been used and referenced in important studies like the Third Assessment Report (TAR) of the IPCC (International Panel on Climate Change), the Stern Review [15] and the ExternE project [16]. A detailed comparison of these models was included in a reference document published on the CEPAL web page [17].

So far, in all IAMs, the input and outputs are given on a regional and global level. The estimated costs (the costs of the damage generated by climate change, adaptation costs and reduction of emissions costs) are subtracted from the projected GDP.

The interpretation of results is important. The projections obtained illustrate the risks involved, even though the uncertainties are high. The modelling of long time horizons and diverse regions raise ethical questions regarding inter-regional and inter-generational equity. For instance, if low weight is given to the future effects through the use of elevated discount rates, the estimated costs will be low and consequently, no actions will be taken to stop climate change.

The majority of the models use a global warming of 2–3 °C as starting point. In this range of temperatures, the cost of climate change varies between 0% and 3% of GDP. The poorest countries will suffer the highest costs.

If no actions are taken (BAU scenario) the temperature increase may exceed 2–3 °C by the end of this century. This increases the probability of additional impacts like abrupt and large scale changes in climate. Estimating these impacts is very difficult.

With a global warming of 5–6 °C, the models that include this impact (i.e. PAGE2002 and DICE/RICE) suggest losses between 5% and 10% of the global GDP, and even higher losses in poor countries. These costs may be increased by:

- Costs due to social and political instabilities
- Possible amplified feedback in the climate system
- Disproportional load of climatic change, affecting the poorest regions to a greater extend

Under these conditions, the level of uncertainty is high, raising the possibility of highly elevated losses.

The IAMs have been created from the perspective of developed countries and therefore reflect their priorities. We find the regional and global characteristics to be among the main difficulties in adopting IAMs. The regions in each model are set differently and countries are grouped by geographic regions or according to their socioeconomic characteristics. The regional definitions also differ from model to model. Some experts support the idea of disaggregating the regions in the models, but it must not be forgotten that regardless of how regions are defined, climate change has global effects. It depends not only on the region under analysis, but also of the interaction among regions. Emissions from developed countries, for instance, have impacts world-wide; however, the emissions from the Caribbean region are negligible when compared with other regions.

Another important issue with respect to is how climate change affects rainfall patterns. None of the reviewed IAMs projects rainfall or impacts associated with changes in rainfall such as droughts and floods. These issues are of paramount importance for the region.

Nor are extreme weather events properly treated in most existing IAMs, but the latest science suggests that extreme events will increase in frequency and severity with climate change.

It is necessary to verify the impacts that are really important for the region and whether they can be assessed in the chosen models. If impacts are not included, it would be advantageous to find alternative ways to incorporate them into the analysis. In Cuba, studies linking the impact of climate change on ecosystems and crops have been conducted. However, to incorporate these impacts into the studies more information and knowledge about cause and effect relationship will be needed.

Moreover, taking into account that the importance of adaptation is much higher than the importance emissions mitigation in the region, it is necessary to improve the way to evaluate it. In order to support the decision making process with enough information, delay in implementation of adaptation measures will increase the costs of climate change.

Despite the limitations of these models for immediate application, each of their stages provides important information that can be used for multiple purposes. As part of the integrated modelling analysis, climate projections are needed. These can be obtained directly either from the IAMs assumptions or from regional or global climate model results, as those obtained from the PRECIS [18] and RegCM [19] models for Latin America and Europe, respectively. Climate projections are made for each of the emission scenarios provided. Using this information, it is possible to assess the energy technologies suitable for the projected climate depending on their availability in the country.

Furthermore, IAMs assess and quantify impacts on the energy sector and other sectors, for example agriculture. The energy demand projections may vary in different

climate scenarios and should be taken into account in the energy planning process.

From the adaptation point of view, the economic evaluations will allow quantifying the impacts and to carry out cost-benefit analysis of adaptation strategies.

4.2 CLEW (climate, land, energy and water) interaction approach

IAEA is launching efforts to develop methods and tools to assess the energy, water and food nexus. Most water, energy and land-use planning, decision and policy making occurs in separate and disconnected institutional entities. Likewise, the analytical tools used to support decision-making are equally fragmented, though undertaken routinely [20]. Common tools used for energy system analysis include, for example, MESSAGE, MARKAL [21], and LEAP [22] models. A commonly used model for water system planning is the Water Evaluation and Planning system (WEAP) [23], and for water scarcity and food security planning, the Global Policy Dialogue Model (PODIUM) [24] model is well established.

"However, these and other models, in one way or another, lack the components required to conduct an integrated policy assessment especially when it might be needed in a developing country policy context. Generally, they focus on one resource and ignore the interconnections with other resources, have overly simplified spatial representations, are long-term policy "research" rather than short-term applied "policy"/ decision support models, or analyse scenarios which are impractically long term..." [25].

"What is needed it is an integrated analysis tool which includes climate, land, energy and water aspects in an accessible and useful manner for analysts and planners in developing countries. Key improvements over existing approaches should include: finer geographical coverage, simplified data requirements, a medium-term temporal scope, multi-resource representation (including their interlinkages) and software accessible to developing country analysts. Such a tool would help decision makers assess different technological options with diverse benefits and disadvantages; estimate the impacts of different development scenarios; and analyse and evaluate policies..." [26].

It is likely to the net outcome of treating the three areas of the CLEW nexus comprehensively would lead to an improved allocation of resources, greater economic efficiency, lower environmental and health impacts and better economic development conditions. In short, overall increase in welfare [27]. To actually form constructive linkages across the boundaries that exist between the three areas, it will require strong political leadership, compelling visions, and significant cooperation. The vast gains in human welfare from improved provision of food, energy and water and the spectre of losing this access through short sighted policies that fail to recognise the complex interactions of these three issues suggest that the CLEW nexus must be prioritised both by the analytical policy support community and policy makers.

4.3 Energy adaptation options and policies in Cuba

In order to solve the current deficit in energy production (mainly in electricity generation) in the light of major transformations in the energy sector (Energy Revolution), the Cuban Government is evaluating ways to incorporate new sources and technologies and to expand the existing capabilities. Since 2005, more than 1596 MW of fuel oil and diesel engines have been commissioned to satisfy the electricity demand because of this policy. This was a response to the energy crisis in the 2003-2005 period, and forms part of the Decentralized Energy Program that was introduced. Additionally, the policy includes measures to reduce the vulnerability of the electricity transmission and distribution network to hurricanes and tropical storm.

During 2008 hurricane season three high category hurricanes impacted Cuba, although the damages to the electricity transmission and distribution network and energy facilities were high, the fuel oil and diesel engines did not suffer serious damage and its availability helped support essential activities for the human life in the most of the affected areas.

A demonstration project for the introduction of renewal energy, a wind park situated in the affected area, was severe damaged by the hurricanes. The electricity transmission and distribution network also suffered severe damage.

Although the Distributed Generation System based on diesel and fuel oil engines has a positive impact on the reliability of electricity supply, its operation has caused negative impacts through increased emissions of local air pollutants (SO_2 and NOx) [28]. Currently, its use has been limited to the hours of high electricity demand, mainly for those located closer to human settlements.

5 CONCLUSIONS

Because Cuba is a small island with low domestic emissions efforts should be focused on climate change adaptation. It is expected that climate variation in the Caribbean area will affect economic sectors.

For adaptation to climate change it is important to identify what the climate impacts on the energy sector might be, in order to foresee futures changes. A robust policy will favour an energy mix that limits impacts on energy supply.

Based on the Caribbean climate predictions, all energy sources considered in the country supply energy projections, are vulnerable to climate change (temperature increase) and extreme events (hurricanes and tropical storms).

IAMs are needed to improve the energy planning analysis take into account the effects of climate change and its interactions with other resources that usually are evaluated in an isolated manner.

ACKNOWLEDGEMENTS

We would like to thank the IAEA, especially the Planning and Economic Studies Section and Dr. H-H Rogner.

REFERENCES

[1] Mimura, N., L. Nurse, R.F. McLean, J. Agard, L. Briguglio, P. Lefale, R. Payet and G. Sem. (2007) Small islands. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 687-716.

[2] Meneses, E. et al, (2009) Final report on RESEARCH CONTRACT NUMBER: 13729 "Case study to assess options and mechanisms for GHG mitigation in Cuba". Submitted to International Atomic Energy Agency.

[3] IAEA (2002a) Model for Analysis of Energy Demand, User Manual, IAEA, Vienna

[4] IAEA (2002b). MESSAGE: Model for Energy Supply Strategy Alternatives and Their General Environmental Impacts, User Manual, IAEA, Vienna.

[5] CEPDE (Centro de Estudios de Población y Desarrollo) (2006) Cuba, Proyección de la Población, nivel nacional y provincial. Período 2007-2025. ONE, Habana.

[6] Somoza, J., García, A. (2002) Escenarios macroeconómicos a largo plazo del desarrollo energético y su impacto ambiental. Salida del proyecto ramal "Reconstrucción estadística y análisis prospectivo sobre el desarrollo energético cubano y su impacto ambiental", INIE.

[7] ONE (2007) Oficina Nacional de Estadísticas. Anuario Estadístico de Cuba 2007.

[8] IEA. (2011) Key World Energy Statistics 2011. http://www.iea.org/textbase/nppdf/free/2011/key_world_energy_stats.pdf

[9] IPCC (2000) Emissions Scenarios. Special Report of the Intergovernmental Panel on Climate Change [Nakicenovic, N. and R. Swart (eds.)].Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 599 pp.

[10] ECLAC (2010) América Latina y el Cambio Climático

[11] Stern, N. (2007) The Economics of Climate Change: The Stern Review, Cambridge: Cambridge University Press (http://www.hm-treasury.gov.uk/ independent reviews/stern_review_economics_climate_change/stern_review_report.cfm).

[12] Hope, C. (2006) The Marginal Impact of CO2 from PAGE2002: An Integrated Assessment Model Incorporating the IPCC's Five Reasons for Concern, IAJ, The Integrated Assessment Journal, Bridging Sciences & Policy, Vol. 6, Iss. 1 pp. 19–56.

[13] Nordhaus, W., Bayer (1999) Roll the DICE Again: Economic Models of Global Warming, web 102599.wpd.

[14] Tol, R. (2003) Is the uncertainty about climate change too large for expected cost-benefit analysis?, Climatic Change 56, Kluwer Academic Publishers, pp. 265–289,

[15] Stern, N. (2007), The Economics of Climate Change: The Stern Review, Cambridge: Cambridge University Press (disponible online en (http://www.hm-treasury.gov.uk/ independent reviews/stern_review_economics_climate_change/stern_review_report.cfm).

[16] European Commission. (2005) Externalities of energy: Methodology 2005 update, (EUR 21951), Directorate-General XII, Science Research and Development, Office for Official Publications of the European Communities, L-2920 Luxembourg, F75272, Paris, Cedex 06, France

[17] Turtos, L. et al. (2008) Una introducción a los modelos integrados de valoración del cambio climático. http://magic.un.org.mx/mexico/cambioclimatico/ LeonorTurtos.pdf . April 2008

[18] Precis Model http://precis.insmet.cu/Precis-Caribe.htm

[19] The ICTP Regional Climate Model (RegCM) http://users.ictp.it/~pubregcm/RegCM3/

[20] Rogner, H-H. (2009) Climate, Land, Energy and Water Strategies. CSD 17. IAEA

[21] ETSAP (2011) MARKAL (Market Allocation) model of the ETSAP implementing agreement of the International Energy Agency

[22] SEI (2011) LEAP (Long Range Energy Alternatives Planning) model. Stockholm Environmental Institute

[23] WEAP (Water Evaluation and Planning) model. Stockholm Environmental Institute: http://www.seib.org/software/weap.html

[24] PODIUM model. International Water Management Institute http://podium.iwmi.org/podium/

[25] Rogner, H.H., Vessia, Ø., Howells, M., Aggarwal, P, Brent, N., Nguyen, M., Fischer, G., Purkey,D., Heaps, C. and Heng, L. (2011) Seeking CLEWS—climate-, land-,energy-, water-, strategies: A case study. Energy Policy, accepted.

[26] IAEA. (2009) Annex VI: Seeking Sustainable Climate Land Energy and Water (CLEW) strategies, Nuclear Technology Review 2009. http://www.iaea.org/Publications/Reports/ntr2009.pdf

[27] Bazilian, M., Rogner, H., Howells, M., Hermann, S., Arent, D., Gielen, D., Steduto, P., Mueller, A., Komor, P., Tol, R.S.J. and Yumkella, K.K. (2011) Considering the energy, water and food nexus: Towards an integrated modelling approach. Energy Policy 39 (12), 7896-7906

[28] Fonseca Rodriguez, Y.A., Turtós Carbonell, L., Meneses Ruiz, M., Capote Mastrapa, G. and de Jesus Rivero Oliva, J. (2012). Air quality study, comparison between the proposed and actual scenarios of generator sets in Havana, by using CALPUFF model. In: Khare, M. (ed.) Air Pollution _ Monitoring, Modelling, Health and Control . InTech – Open Access Publisher, pp. 123-146.

Received: December 05, 2011
Revised: June 11, 2012
Accepted: July 16, 2012

CORRESPONDING AUTHOR

Elieza Meneses Ruiz
Center for Information Management and Energy Development, CUBAENERGIA
Calle 20 No 4111 e/ 18-A y 47, Playa,
11300, Ciudad Habana
CUBA

Phone: (+537) 206 2065, 2027527
Fax: (+537) 206 2065, 204 1188
E-mail: emeneses@cubaenergia.cu

FEB/ Vol 22/ No 1/ 2013 – pages 74 - 80