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Abstract: Colombia has relied for long on a generous endowment of fossil fuels (oil, coal and gas) and hydropower to meet domestic energy needs and also to contribute substantially to the balance of trade in international markets. But this situation is about to change due to the announced loss of self-sufficiency in oil (forecasted by 2010-2011) unless a dramatic last minute change in proven reserves occurs. Likewise, Colombia's hydro potential (the largest energy source for power generation in the country) is facing difficulties to add further representation within the generation mix. These difficulties include increasing environmental and social costs associated with large hydro projects and the likely impacts of climate change and climate variability (drastic increases in surface temperature in the Andes and increases in intensity and frequency of ENSO -El Niño/Southern Oscillation- signals driving prolonged periods of drought). On the other hand, the country is richly endowed with wind and solar energy, resources that still have to participate more significantly in the national energy mix. Optimization of the nation's energy options, however, is not a trivial exercise. Decreasing reserves of natural gas, dwindling oil resources and vulnerable hydropower generation due to climate variability will likely force the power sector to increasingly seek alternative options to the current power mix. In this sense, National University of Colombia and CIEMAT have been planning a project in order to build a new model tool for energy planning. This tool will be developed by integrating environmental and social constraints as well as renewable energy sources (RES) (according to the current Colombian National Power Plan 2006 – 2025). This RES integration will be made using geographical information systems (GIS) technology. In this paper, the project is presented, as well as the state of the project, the basis of the model, the software to be used and the designed platform.

Keywords: sustainable energy, Environmental Decision Support Systems, renewable energy, geographical information systems, multi-criteria decision analysis.

1. INTRODUCTION

Colombia's primary energy supply is equivalent to 74 MMTOE/year. About half is produced by hydropower and the balance is obtained by fossil fuels (oil, coal and gas), 70% of which is imported. The energy demand makes up by large and growing requirements by the transport sector, followed by industry and the domestic sector. The annual electricity consumption is 49 GWh and the average electricity consumption per capita is 1113 kWh/yr (although this consumption is rising, between 1999 and 2004 decreased). CO2 emissions are 56 MMT (1.26 t CO2/capita), or less than half of world's average. Colombia's energy intensiveness is 0.1 TOE/ thousand -2000 US$PPP [WORLD-BANK, 2006] (see Table 1). This is equivalent to 10.1 dollars of product (GDP) generated per unit of energy use (2000 PPP$/kg oil equivalent), a high rate that shows Colombia's efficiency in energy use compared to a 6.2 for the Latin American and Caribbean region and 5.2 for high income countries [WORLD-BANK, 2006].

Table 1. Colombia Energy Balance. (Source: Ministerio de Minas, 2006 and others. Elaborated by authors).

Energy Source for electricity power generation	Generation GWh (2005)
Hydropower	39,576.1
Thermal	9519.4
Renewables	49.48
Exports	1,757
Imports	36.9

Colombia is particularly vulnerable to the impacts of climate change. The first national communication (NC 1) to the United Nations Framework Convention on Climate Change [UNFCCC, 2005] indicates the high vulnerability of Colombia to expected impacts from climate change [IDEAM, 2001] identifying health, high mountain habitats, and insular and coastal regions as the topics of primary concern. More recently, studies commissioned as part of the preparation of the second communication have confirmed and indicated in more detail trends and impacts in these areas. These vulnerabilities find echo in the findings of the Intergovernmental Panel on Climate Change (IPCC). The energy sector in Colombia is also vulnerable to the ongoing climate modifications associated with global warming. Major vulnerabilities related to the energy sector are described below:

- Coastal energy infrastructure is vulnerable to extreme weather events and coastal flooding potential, major power plants are located in coastal zones that may become susceptible to floods with projected sea level rise and changes in storm surges.

- Hydropower potential is vulnerable to changes in precipitations and warm temperatures leading to high ratios of evaporation. Ecosystem changes driven by warming temperatures are anticipated to negatively affect water retention rates, increase pace of sedimentation and reduce runoffs.

- Rapid glacier retreat will affect water regulation in the Andes and thus reliability of dependent installed hydropower capacity.

- Biggest intensity and frequency of ENSO signals will reduce rainfall and affect the share of hydropower.

In summary, decreasing reserves of natural gas, dwindling oil reserves, vulnerable hydropower generation due to weather variability (El Niño(a) events) and climate change (temperature and precipitation changes), will force the power sector to increasingly seek alternative options to the current power mix. In this sense, several options are included like increasing the hydropower generation with additional safety margins to cope with climate considerations, increasing the use of coal or alternatively, increasing the reliance on clean non-conventional energy sources; or a combination of some of the previous ones.

This situation makes advisable the development of a new energy model that integrates not only the purely technician-economic variables but also social and environmental aspects [WORLD-BANK, 1992]. This model should be developed from a perspective that will lead to cope with the necessities of most possible Colombian territory.

In this context, the project has innovative characteristics that represent a strong difference with respect to other projects or initiatives, because the main goal is "to integrate" several approaches in order to claim a complete and integral vision of energy problem from geographic, environmental, social and technologic point of views

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Next, we will describe the main aspects of the project plan, indicating the initial hypothesis, the proposed work methodology, the contributions that are hoped to reach with the development of the project, as well as its current state.

2. HYPOTHESIS AND GOALS

The aim of the project is to design and build a methodology for energy and environmental planning in an integrated platform. It will include the evaluation of environmental impacts generated by energy production and use, the simulation of an energy matrix based on renewable energies and the required information for the decision-making in the design of energy and environmental policies in the medium and long term.

The guidelines will be based on international criteria about sustainable development. These lines will be developed applying different techniques of energy-cycle analysis, in order to get a global assessment at National scale [IAEA, 2005, UN_DESA, 2001, Vera, I., *et al.*, 2007].

Models are usually developed to address specific questions and therefore they are only suitable for the purpose they were designed for. Incorrect application of a model may result in significant misinterpretations. This fact cannot be ascribed to poor model functioning but, as the World Bank [WORLD-BANK, 1991] –among others– claims, the misuse could be responsibility of the model users. Our project will be based on two different types of models. On one hand, general purpose models (forecasting, exploring, backcasting), and on the other, more specific purpose ones (e.g., demand-supply analysis, environmental impact analysis, etc), which will be the most meaningful within our project.

3. METHODOLOGY

The methodology focuses on three main issues:

- The energy load and supply and the environmental impacts produced by the energetic activity, the renewable energy in the national energy matrix and the promotion of sustainable energetic resources.
- The integration of the renewable energy resources (RES) based on geographic information systems (GIS)[Dominguez, J., *et al.*, 2007].
- The sustainability of the energy process based on the environmental impact, externalities and Life Cycle Analysis (LCA) assessment [Lago, C., *et al.*, 2007] and the definition of a sustainable matrix [Smith, R., *et al.*, 2000].

The first issue focuses on the integrated planning models (load-supply) and its conception. This vision should include the definition of the requirements for the development of activities that are very intensive in terms of energy demand. The project includes the analysis of the different models that can be useful for the *formulation line* (a specific line of strategic planning in Colombia) and its application. Decision makers and analysts require a comprehensive analysis of different elements and components, many times at odds, that provide objectivity and truthful information to check the approach, correlation and the validity of the relationships among the same ones [Frangopoulos, C. A., *et al.*, 1997].

The second one is related to the integration of RES. GIS technology will be used in order to overcome the current supply-demand model [Dominguez, J. y Amador, J., 2007]. By means of the geographic analysis, we will build a strategic planning based on constraints, simulating scenarios of supply–request with different technological and available possibilities. The evaluation of resource potential (solar energy, wind and biomass) will be emphasized in order to improve the penetration of new energy sources. The result should be a technological mix, sustainable and hierarchical, build upon resources, potentials and technologies. The potential of renewable energy that can be introduced into the energy basket will be considered in the sustainable matrix along with the respective assessment of LCA and the up-to-the-minute models of planning with new scenarios.

Finally, we will build a sustainable matrix, in order to intersect the environmental impacts and the external costs or externalities associated with the energy production cycles. We will count on the compilation of the original information with the results of the LCA of the several energy alternatives and the available information of externalities' assessment in the development of the matrix [Lago, C.*, et al.*, 2007]. In addition, we will take into account sustainable indicators [IAEA, 2005, UN_DESA, 2001, Vera, I. y Langlois, L., 2007] for the comprehensive assessment of scenarios. The decision-making analysis, with an objective assessment, will be made for all the activities of the energy cycle. The matrix will be set up with variables, indicators, index and criteria, all of them delimited under the same technological, environmental, social, economic and cultural dimensions. The introduction of the energy consumption structure, can modify the composition of the energy structure creating sustainable scenarios [Smith, R.*, et al.*, 2000] and closing the cycle of the comprehensive model, this way will feedback the results of the matrix. The change of the energy structure shows alternatives and elements in order to develop a sustainable environmental energy policy new.

4. CONTRIBUTIONS

The result of the present research will be a simulation tool for energy and environmental planning. This tool will join GIS, externalities assessment, LCA and a *sustainable energy matrix*. In several aspects, this approach is innovative compared to the current sectorial visions. The integrate conception of the model, the inclusion of social and territorial aspects, the prospective vision based on local and renewable resources as well as environmental issues structured in a sustainable matrix, could convert this develop in a powerful tool for integral energy planning that contributes to the takeoff of clean energy in Colombia.

5. CURRENT STATE OF THE PROJECT

During last year, National University of Colombia (UNAL) and Centre of Energy, Environmental and Technological Researches (CIEMAT), have been planning a project about the viability of building a new model tool for energy planning, integrating environmental and social constraints (land use, resources competition, natural protected areas… in function of the different parameters of each technology) as well as using geographical information systems (GIS) technology in order to integrate renewable energy sources.

The work flow chart of the model has already been defined (see figure 1), the framework of the integrated platform has been designed, the election of the software has been made and a preliminary draft of the sustainability matrix has been designed.

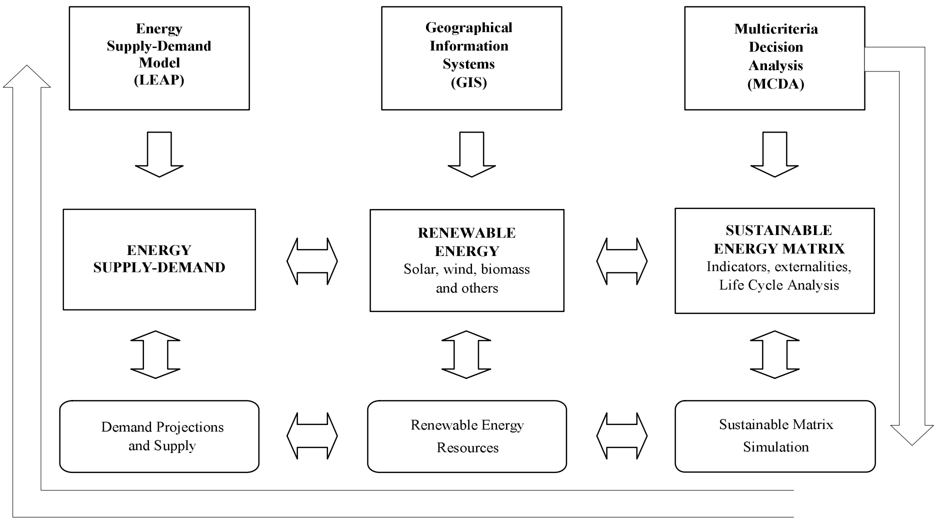

Figure 1. Flow chart of the designed model.

As we describe in the methodology section, the conception of the model is structured in three parts. These are: demand-supply models as LEAP, renewable energy integration based on GIS and sustainable matrix for LCA and externalities results. The entire model will be running until the feedback returns a sustainable energy mix, in order to define a sustainable energy supply. The model integrates some of the most important technologies in the evaluation of the energy system, environmental aspects and spatial analysis.

We will use the software LEAP for the supply-demand model, ARCGIS for GIS integration and, at the final step, software for the multi-criteria decision analysis (MCDA) in order to support the sustainable matrix.

The sustainability matrix will be defined according to the indicators included in the Energy Indicators for Sustainable Development (EISD) [IAEA/IEA, 2001] across to dimensions social, economic, technical and environmental. These four dimensions are further classified in themes and sub-themes. That some indicators can be classified in more than one dimension, theme or sub theme, given the numerous interlinkages among these categories. In addition, each indicator might represent a group of related indicators needed to assess a particular issue.

Table 2. Sustainability matrix example.

Theme/Sub-theme	**Energy indicator**	
General - Equity		
Accessibility		Share of households (or population) without electricity or commercial energy, or heavily dependent on non-commercial energy
Affordability		Share of household income spent on fuel and electricity
Disparities		Household energy use for each income group and corresponding

Theme/Sub-theme	**Energy indicator**	
		fuel mix
Overall use		Energy use per capita
Overall productivity		Energy use per unit of GDP
Supply efficiency		Efficiency of energy conversion and distribution
Production		Reserves-to-production ratio
End use	1.1	Industrial energy intensities
	1.2	Agricultural energy intensities
	1.3	Service/ commercial energy intensities
	1.4	Household energy intensities
	1.5	Transport energy intensities
Diversification (fuel mix)	2.1	Fuel shares in energy and electricity
	2.1	Non-carbon energy share in energy and electricity
	2.3	Renewable energy share in energy and electricity
Prices	3	End-use energy prices by fuel and by sector
Imports	4	Net energy import dependency
Strategic fuel stocks	5	Stocks of critical fuels per corresponding fuel consumption
Environmental Dimension	6	Other
Economic Dimension	7	Other

Theme/Sub-theme	**Energy indicator**	
Social Dimension	8	Other
Political and Institutional Dimension	9	Other

In our opinion, the first steps for the development of a solid project have been defined. In this sense, besides the aspects described previously, contacts with multiple agents potentially involved in the project have been made (energy corporations and governmental agencies in charge of necessary geographic information for the project).

6. CONCLUSION

According to the Colombian National Power Plan 2025, there should be available consistent and powerful tools for planning like the ones shown in this paper. These tools will ensure that the energy resources would meet the national request and would guarantee the sustainability of the energy sector in the long term.

The tool will provide enough elements for the formulation of coherent energy and environmental policies. These policies will be then based on a sustainable energy basket, which would not only meet society demands while improving its quality of live but also would promote the use of national resources minimising external energy dependence.

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