An Environmental Impact Tool to Assess National Energy Scenarios

R. Taviv, A.C. Brent and H. Fortuin

***Abstract*—**The Long-range Energy and Alternatives Planning (LEAP) energy planning system has been developed for South Africa, for the 2005 base year and a limited number of plausible future scenarios that may have significant implications (negative or positive) in terms of environmental impacts. The system quantifies the national energy demand for the domestic, commercial, transport, industry and agriculture sectors, the supply of electricity and liquid fuels, and the resulting emissions. The South African National Energy Research Institute (SANERI) identified the need to develop an environmental assessment tool, based on the LEAP energy planning system, to provide decision-makers and stakeholders with the necessary understanding of the environmental impacts associated with different energy scenarios. A comprehensive analysis of indicators that are used internationally and in South Africa was done and the available data was accessed to select a reasonable number of indicators that could be utilized in energy planning. A consultative process was followed to determine the needs of different stakeholders on the required indicators and also the most suitable form of reporting. This paper demonstrates the application of Energy Environmental Sustainability Indicators (EESIs) as part of the developed tool, which assists with the identification of the environmental consequences of energy generation and use scenarios and thereby promotes sustainability, since environmental considerations can then be integrated into the preparation and adoption of policies, plans, programs and projects. Recommendations are made to refine the tool further for South Africa.

***Keywords*—**Energy modeling; LEAP; environmental impact; environmental indicators, energy sector emissions, sustainable development, South Africa.

I. Introduction

ENERGY is deeply intertwined with the three pillars of sustainable development – the economy, the environment and social issues. While certain forms of energy production and consumption can diminish environmental sustainability, energy is crucial for economic development. Energy services also contribute to meeting basic needs such as food and shelter, and to social development by improving education and public health. A major concern for policy makers, however, is whether the energy sector of a country is on a sustainable path. One issue that contributes to this concern is that of the volatile prices of fossil fuels. Another is that a significant fraction of human impacts on the environment is due to energy generation and use, e.g. fossil fuel combustion is the largest global contributor to emissions of carbon dioxide and other pollutants. Many indicators have been reported to measure sustainability, and specifically the environmental impacts of the energy sector. The study summarized in this paper suggests a group of indicators, referred to as Energy Environmental Sustainability Indicators (EESIs), which can be incorporated into widely-used energy models, such as the Long-range Energy and Alternatives Planning (LEAP) system, to serve as an environmental assessment tool for the evaluation of energy scenarios at national level.

II. Energy Sector In South Africa

South Africa, with a large endowment of coal, has an electricity production system that is highly carbon intensive. It produces two-thirds of Africa's electricity, approximately 90% of which is generated from coal. Low energy costs and an abundance of mineral deposits in South Africa have contributed to the country's high energy input per GDP. Both GHG emissions per capita and GHG emissions per unit of GDP in South Africa, are nearly double that of the world average [1].

South Africa has comprehensive energy policies and strategies that are described in many reports and papers, e.g. [1] and [2]. However, the main limitation of the existing strategies is that so far only one target relevant to the environmental impacts has been set. This is the target of 10 000 GWh (0.8 Mtoe) renewable energy contribution to the final energy consumption by 2013 [3]. Calculations show [1] that the total demand was already 58 Mtoe in 2005, so this renewable energy target is very low.

The production and use of energy in South Africa has significant local, national and international environmental impacts. In addition to GHG emissions, the combustion of coal and other fossil fuels releases large quantities of particulates, oxides of sulphur and nitrogen, and other pollutants. According to the State of the Environment report [4], "coal use is a primary source of air pollution and creates enormous solid waste-streams. …Liquid fuels, used in the transport sector, are the second largest source of pollution and greenhouse gas generation."

Thus, measures that may limit emissions, due to environmental concerns, will have profound implications for the energy sector and the country at large. Policy- and other decision-makers need a clear understanding of the trade-offs and investments that are required to shift the national economy into a "greener", "meaner" (efficient) and "cleaner" mode. An enhanced LEAP system is a means to assist decision-makers with such understanding.

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Financial support from the South African National Energy Research Institute (SANERI) is gratefully acknowledged.

III. Development of a South African LEAP model

A LEAP system was developed and populated to model energy scenarios as a group of responses affecting the major demand sectors: industry, mining, transport, residential, commercial and agriculture [5]. The demands under each scenario were balanced with plausible sources of energy production and transformation. The input and assumptions for energy demand and supply were defined from an extensive literature review, data collection and consultation with a range of stakeholders. Three scenarios were modeled using the LEAP system. The first is a reference scenario, which is a projection of historical data (business as usual), overlaid with interventions based on policy measures that are already in place. It was used as a baseline for comparison with the other scenarios. The other two scenarios were selected to represent major implications for the environment in South Africa and to reflect one of the most significant international drivers (oil depletion scenario) and the potential national choice (low carbon development path). The study period was 2005 to 2030 [5].

IV. Methodology to develop a LEAP-based environmental assessment tool

The study commenced with a review of existing sustainability indicators. The selection of appropriate indicators was done through extensive stakeholder participation. First, the indicators selected by researchers were distributed using a questionnaire to a wide range of experts, nationally and internationally. The replies were analyzed and presented at a workshop with national stakeholders. The workshop helped to refine and validate the selection of sustainability indicators and to suggest ways of presenting indicators that will be easily understood and appealing to the target audience. The stakeholders' contribution was analyzed and further work was done to define the most appropriate indicators. The developed LEAP system was modified to include the proposed indicators and the required additional data for their calculations. The indicators were then tested and the reporting capabilities of LEAP software were utilized to prepare the most suitable way to present the tool outputs.

V. Development of EESIs

A. Overview of Existing Sustainability Indicators

Environmental sustainability refers to the long term maintenance of valued environmental resources in an evolving human context. Extensive literature is available on this subject and detailed information relevant to environmental sustainability indicators for the energy sector can be found elsewhere [1].

The Environmental Sustainability Index (ESI) is a comprehensive and appropriate aggregation that "provides a gauge of a society's natural resource endowments and environmental history, pollution stocks and flows, and resource extraction rates as well as institutional mechanisms and abilities to change future pollution and resource use trajectories." [6]. The ESI includes 76 variables combined into 21 indicators that represent 5 dimensions of sustainability: Environmental Systems; Reducing Environmental Stresses; Reducing Human Vulnerability; Social and Institutional Capacity; and Global Stewardship. The ESI requires extensive data collection and processing. Its main objective is to provide international benchmarking, rather than compare different development options. The ESI is also too complex and data intensive for local scale energy planning. Only some of the variables used for the calculations of the ESIs are relevant to the energy sector and could be utilized for the EESIs.

The Energy Indicators for Sustainable Development (EISDs) are based on the Indicators of Sustainable Development developed by Agenda 21 and the United Nations Commission on Sustainable Development [7]. They include 30 indicators and each one is calculated from at least 2 or more variables. The EISDs also require extensive data collection. The full EISD data collection and analysis were performed for only seven countries and sufficient data are not available for South Africa.

HELIO International's Sustainable Energy Watch (SEW) suggests a very simple set of 8 indicators [8] that measure the environmental, social, economic and technological dimensions of energy policies. These indicators are specifically designed for performance assessment and some suggestions on sustainability targets for each indicator are provided. In 2006 they were applied to 17 countries, including South Africa [8] and [9]. The main limitation of SEW indicators is that they are based on targets that have not been agreed upon by the participating countries and are not required by any legislation, strategies or international obligations. However, they were all deemed relevant for this study and some of them were incorporated into the EESI sub-group.

102 national core environmental indicators for eight different themes were selected by the South African Department of Environmental Affairs and Tourism (DEAT) in 2002 [10]. However, there are no quantifiable targets and only two of these indicators are relevant to the energy sector, namely, CO_2 emissions, and energy use by households. A shorter and simpler version of 16 indicators based on the ESIs ([6] was proposed as Headline indicators [11]. The Headline indicators were described and quantified, but still only two of them, namely, GHG emissions and energy use, are relevant for the energy sector.

Reference [12] suggested eight Sustainable Development Indicators for South Africa. These are: SO_2/Total Primary Energy Supply (TPES); TPES/GDP; CO_2/GDP, CO_2/TPES, Renewable share in power generation; Investment in new power plants; Per capita electricity use; and Household electricity access. A comparison between South Africa, Brazil, India and China was provided using web or radar diagrams. This selection was used as a basis for this study and it was modified through the methodology described above.

B. Selected EESIs

Usually three dimensions of sustainability are addressed: environment, economic and social issues. Since this study focused on the energy sector, and as energy security is a critical issue for South Africa, this component was added (see Table I). It is recognized that water use, water and soil pollution (especially from mining), waste generation and effects on ecosystems are all very important in the evaluation of environmental impacts. However, to keep this group simple only atmospheric impacts were quantified.

TABLE I
PROPOSED EES INDICATORS

1.Environmental impacts	2. Energy security	3. Economic sustainability	4. Social sustainability
1.1 Air pollutant emissions	2.1 Coal mined for energy sector	3.1 Import dependence	4.1 Electrified low income households
1.2 Total GHG emissions	2.2 Renewable energy as a share of total electricity generated	3.2 Energy productivity	4.2 Clean fuel use in low income households
1.3 GHG emissions per capita	2.3 Nuclear energy as a share of total electricity generated		

1) *Indicators of Environmental Impacts*

Indicator 1.1 Air pollutant emissions (SO_2; NO_x; particulates; CO; VOC) from energy systems represent the emissions for all of the listed pollutants. In the LEAP system the calculated emissions are proportional to the amount of fuel used. Therefore, one of them, SO_2, which is used most commonly, was selected to represent the rest of the pollutants. Ambient air pollution is a more appropriate factor to determine environmental impacts, and emissions are an indirect measure of environmental impact, but they are more suitable for scenario comparison. The changes in SO_2 emissions and other environmental indicators are shown in Fig. 1.

Indicator 1.2 Total GHG emissions expressed in Mt of CO_2 eq is the most commonly used indicator. GHG, or sometimes CO_2 emissions, are reported in practically all indicator groups. The existing data for South Africa is outdated (based on the national inventories of 1990 and 1994), but the results of the new inventory should be available by the end of 2009.

Indicator 1.3 GHG emissions per capita is also produced by many databases and used for international comparison. The LEAP system also calculates GHG emissions/GDP as some studies prefer it [12]. However, the changes in GHG/GDP are proportional to the changes in the energy productivity indicator 3.2. So to simplify the EESIs, the GHG/capita was adopted as an EES indicator.

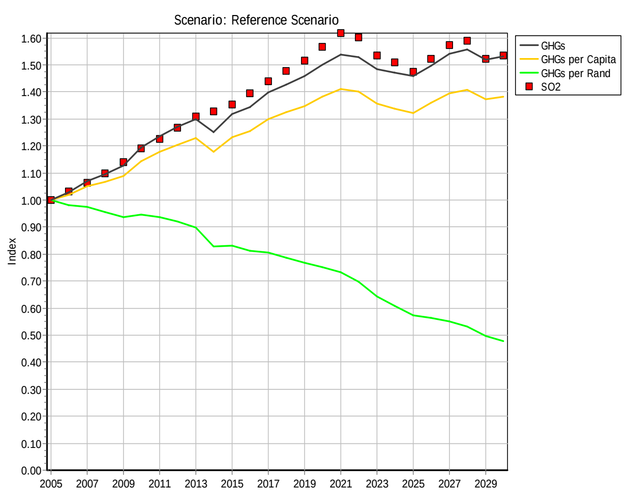

Fig. 1 Environmental indicators indexed by base year

2) *Indicators of Energy Security*

Indicator 2.1 Coal consumed by the energy sector can be used to quantify change in the use of coal for energy as compared to the total amount of coal mined or as a fraction of total coal reserve, to judge the sustainability of coal use. As explained in the detailed report [1] it is also an indirect measure of the environmental impact on land and water. Therefore it is a very useful indicator for the analysis of energy scenarios.

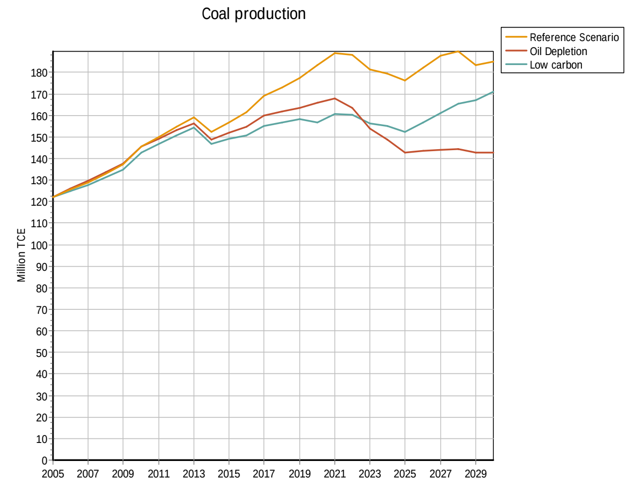

Fig. 2 Projected coal consumed by energy sector in South Africa

Indicator 2.2 Renewable energy as a share of total electricity generated represents renewable energy used in electricity production, including local and imported hydro (supply sector). The low carbon scenario, based on a previous study [13], assumes a very ambitious shift towards wind and solar power generation (see Fig. 3). This indicator excludes the reduction in electricity demand as a result of increased usage of solar energy for domestic water heating, and biomass use in the domestic sector (assuming that it is sustainable). A large proportion of the rural population in South Africa is still using wood, which causes indoor pollution. This problem is addressed in indicator 4.2.

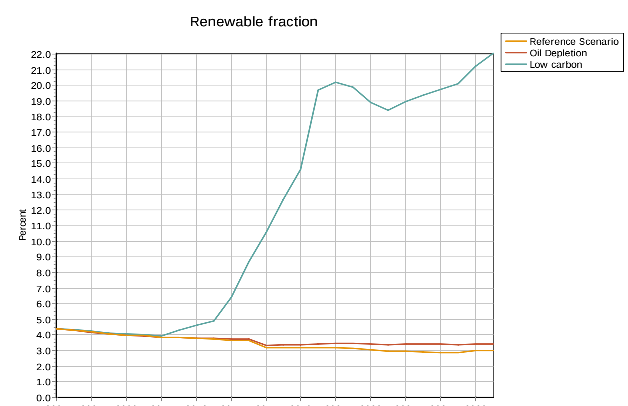

Fig. 3: Projected renewable fraction of electricity generation

3) *Indicators of Economic Sustainability*

Indicator 3.1 Import dependence represents the ratio between the energy of imported fuels and the total primary energy supply. It is also linked to energy security, as it quantifies how dependant South Africa is on imported fossil fuels.

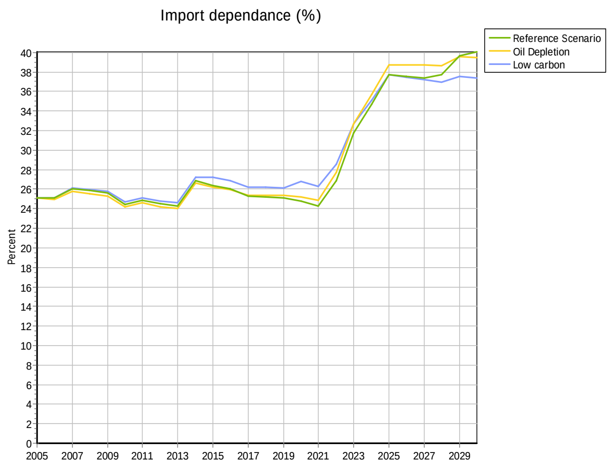

Fig. 4 Percentage of imported energy

This indicator is a critical measure for South Africa especially with the recent volatility in oil prices, which has impact on the national balance of payments and therefore affects the economic sustainability. Although South Africa has a relatively low import dependence (about 25%), with an expected growing need for liquid fuels this dependence may grow significantly with time and there is not much variation between scenarios.

Indicator 3.2 Energy productivity is expressed as total energy consumption per GDP. It represents the level of economic activity per unit of energy consumed. It is a widely used indicator reported by many international organizations and therefore useful for international benchmarking. However, the comparison is complicated by variability in definitions (some countries only account for commercial energy, others aggregate sectors, etc.), variation in reporting of GDP, and the conversion of national into other currencies (e.g. Rand into USD or Euros), amongst others. This indicator was expressed in MJ/GDP in Euro in the LEAP system and the results are presented in Table II below.

TABLE II
ENERGY PRODUCTIVITY (CONSUMPTION/GDP)

Units: MJ/Euro	2005	2010	2020	2030
Reference Scenario	36.43	34.32	27.43	21.73
Oil Depletion	36.43	33.76	27.96	25.02
Low Carbon	36.43	33.85	25.00	20.51

Indicator 3.3 Nuclear energy as a share of total electricity generated was added because South Africa is currently considering significant investments in nuclear energy. This investment will help to increase energy diversification and consequently improve energy security. Although nuclear energy is not really as sustainable as renewable sources, it could make a significant contribution to mitigation efforts in South Africa [13]. The aggressive nuclear development was planned for after 2020 (see Table IV). However, the escalating prices and economic decline compounded with the credit crunch have a negative impact on the massive capital availability required for nuclear power stations and are impeding these plans. For the time being, the plans for large-scale nuclear power plants are on hold.

TABLE III
PERCENTAGE OF NUCLEAR POWER IN THE ELECTRICITY GENERATION

Units: Percent	**2005**	**2010**	**2020**	**2030**
Reference Scenario	4.2	3.7	5.2	29.5
Oil Depletion	4.2	3.7	5.2	29.3
Low Carbon	4.2	3.7	4.4	23.7

4) *Indicators of Social Sustainability*

Indicator 4.1 Electrified low income households represents the fraction of low income households that have been connected to the national electricity supply grid. This indicator is most commonly used as a measure of success of national policies on energy access and it is also linked to the Millennium Development Goals (MDGs). The comparison with other developing countries shows that South Africa has not achieved such high electrification as China and Brazil, but has been more successful than India [12]. The LEAP results show that this indicator may increase from 0.72 to 0.8 by the end of the study period, with very little variation between scenarios [1].

Indicator 4.2 Clean fuel use in low income households represents the percentage of clean fuels, out of all fuels, used by low income households. The "dirty" fuels are wood and coal, while the rest of the fuels are considered clean. It is based on the assumption that dirty fuels are consumed using open fires or polluting stoves. The literature on indoor pollution caused by wood and coal in South Africa is abundant and this indicator was added to track the progress in addressing this problem. Indoor pollution could also be solved by using more effective stoves, which is much more cost effective than fuel switching. In this case the proposed indicator is not suitable to monitor change. The LEAP system could be extended to include different types of stoves and then the indicator could be changed to express the shift toward more efficient technologies. However, the proposed indicator is simple and still useful as a first level of assessment, as shown in Fig. 5.

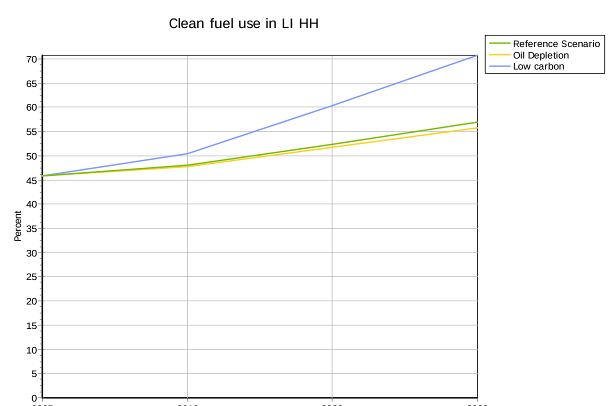

Fig. 5 Percentage of clean fuels used by low income households

C. *Performance Assessment Indicators*

As explained above, there are, as yet, no targets for sustainability indicators in South Africa and therefore no performance assessment could be done. However, a simplified sub-group of indicators is suggested to show, at a glance, the national performance in the three main dimensions of sustainability (environmental, social and economic).

This new sub-group of indicators for performance assessment consists of 3 indicators, which are based on the SEW indicators described above:

1.GHG emissions per capita (environmental dimension);

2.Electrification of low income households (social dimension); and

3. Energy productivity (economic dimension).

Although these indicators were calculated as part of the EESIs, the SEW indicators incorporate target values and convert the indicators into dimensionless values to allow for comparison. The methodology for the SEW indicator calculation is described elsewhere [8] and briefly summarized here.

Three variables are used to calculate each indicator with the definitions of these variables remaining the same for each indicator. The generic formula for target indicator I is written as:

$I = (X – Y) / (W – Y)$

Where:

X = the national value

Y = the ideal sustainability target value, and

W = the selected base value of the environmental, economic or social dimension.

All three values must be expressed in the same unit.

In the dimensionless format the ideal target sustainability for each indicator is zero.

The X value varies over time, while the values W and Y are constant. Thus, once the difference (W-Y) has been calculated it can be kept as the denominator when calculating performance assessment indicators for the base and current years. The closer the resulting indicator is to zero, the better the sustainability performance.

The W and Y values suggested in application of this methodology for South Africa [9] have been accepted in this study. To calculate performance assessment indicator 1 (GHG emissions/capita) the world average value (1.13 t C/capita = 4.14 t CO_2/capita) was used for the W value, while the sustainability objective (Y) is assumed to be 30% of the world average value. Although the indicator used in this study is GHG emissions/capita rather than CO_2 emissions per capita the difference is very small, as more than 90% of the GHG emissions in the South African energy sector are contributed by CO_2. Therefore for now CO_2 values are acceptable.

To calculate performance assessment indicator 2 (Electrification of low income households) the maximum W value for Households with access to electricity is assumed to be zero, while objective (Y) is 100%.

To calculate performance assessment indicator 3 (Energy productivity) the world average value (10.64 MJ/Euro) expressed as Energy consumption/GDP was used for W. The sustainability objective (Y) is assumed to be 10% of the world average value [9].

These objectives are idealistic and therefore unrealistic, but internationally they are used in combination with qualitative analysis, which draws heavily on the energy expert's knowledge of national or local conditions. In this study the application of SEW methodology quantifies how far South Africa has to go to meet the ideal sustainability objective. It was demonstrated how SEW methodology can be applied to the LEAP system and how simple charts can be created to help in stakeholder discussions and energy planning analysis. These three performance assessment indicators were added to the LEAP system and the results are presented in Fig. 6.

The economic dimension shows that although South Africa is very far from the sustainability objective (which is represented by zero value) there is an improvement with time from about 3.7 to 2.1. The social dimension shows that electrification is already relatively close to the objective, but further changes with time are minimal. The environmental dimension is a cause for concern. The CO_2 emissions/capita starts from a high base of 2.8 and grows to 4. This simplified set of indicators describes the main characteristics of the energy sector in South Africa at present as well as its future projections.

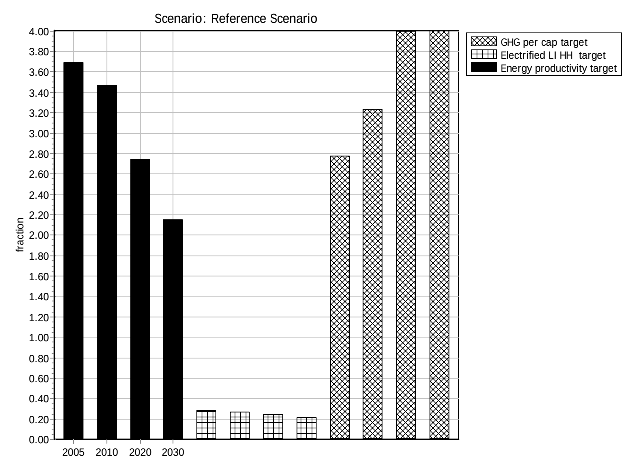

Fig. 6: Subset of performance assessment (SEW) indicators for selected years (Zero = sustainability objective)

VI. Conclusions

The main outcome of this study was the modification of the LEAP system to serve as an environmental assessment tool to provide decision makers and stakeholders with the necessary understanding of the environmental impacts associated with different energy scenarios. The application of the tool helps to identify environmental consequences of energy use and will promote sustainability, since environmental considerations can then be integrated into the preparation and adoption of policies, plans, programs and projects. The developed tool could help to frame public and policy debate by providing an aggregated metric of issues of severity expressed as Energy Environmental Sustainability Indicators (EESIs).

The LEAP system has been developed and populated with very detailed input data for the base year of 2005 and for a limited number of plausible future scenarios that may have significant implications (negative or positive) in terms of environmental impacts. The system quantified the national energy demand for the domestic, commercial, transport, industry and agriculture sectors, the supply of electricity and liquid fuels, and the resulting emissions, as well as 10 proposed EESIs and a sub-group of three performance assessment indicators. The system can be updated to include more accurate data or to change scenarios. Further indicators could be added for more in-depth analysis.

VII. Recommendations

The developed LEAP system needs to be verified to ensure that the results are consistent with other energy planning modeling results. Most of the emission factors used by the LEAP system still need to be verified against local data. The outcome of the GHG inventory project would be particularly useful for this verification. Furthermore, the target for the indicator CO_2 emissions/capita could be replaced by the target for GHG emissions/capita, which is more accurate for determining impact on global warming and is already incorporated into the LEAP system.

This study showed strong correlations between addressing air pollution and the mitigation of climate change. The cost effectiveness of this synergy should be further researched to suggest suitable implementation strategies. It is also suggested that another indicator be added to the economic sustainability group to quantify the costs of imports. This will allow for the tracking of the monetary impact of imports, which were particularly volatile during 2008. The indicator to monitor investments in new power plants as suggested in [12] could also be added.

The existing LEAP system is limited because it focuses only on South Africa. The system modeling should consider regional opportunities such as supporting regional development and the movement of energy across national boundaries. Further extension of the developed LEAP system with the proposed EES indicators to the Southern African Development Community (SADC) region could be a practical application of this study for regional benefit.

Acknowledgment

The authors thank all the workshop participants and the reviewers of the main report – Drs S Hietkamp and L Haywood from the CSIR, and A Trikam from the Energy Research Centre, Cape Town. The technical contribution and support from C Heaps, Director of SEI, Washington, US was most valuable.

References

[1] R. Taviv, A.C. Brent and H. Fortuin, “Energy Environmental Sustainability Indicators (EESI) for the quantification of impacts of energy futures in South Africa”, CSIR report to South African National Energy Research Institute (Draft), 2009

[2] H. Winkler, (Ed). *Energy policies for sustainable development in South Africa: Options for the future*. ISBN: 0- 620-36294-4. Cape Town, Energy Research Centre (ERC), 2006. online http://www.erc.uct.ac.za/publications/South%20Africa%20electricity.pdf

[3] Department of Minerals and Energy (DME), *White Paper on Renewable Energy*, November 2003. Pretoria, South Africa, 2003

[4] Department of Environmental Affairs and Tourism (DEAT), *State of the Environment Report*. Pretoria, South Africa, 2006. online http://soer.deat.gov.za/docport.aspx?m=97&d=13

[5] R. Taviv, A. Trikam, T. Lane, K. O’Kennedy, M. Mapako and A.C. Brent, “Population of the LEAP system to model energy futures in South Africa” Report prepared for the South African National Energy Research Institute project EPP 0607-074, 2008. online http://researchspace.csir.co.za/dspace/handle/10204/2378

[6] D.C. Esty, M. Levy, T. Srebotnjak and A. de Sherbinin. *2005 Environmental Sustainability Index: Benchmarking National Environmental Stewardship*. New Haven: Yale Center for Environmental Law & Policy, 2005

[7] International Atomic Energy Agency (IAEA), “Energy Indicators for Sustainable Development: Guidelines and Methodologies” ISBN 92-0-116204-9, 2005

[8] Helio-international “Overview of methodology for Sustainable Energy Watch (SEW) indicators”, 2006. http://www.helio-international.org/energywatch/methodology.cfm

[9] N Dlamini “Energy and Sustainable Development in the Republic of South Africa” by Helio-international, 2006. online http://www.helio-international.org/index.cfm#

[10] Department of Environmental Affairs and Tourism (DEAT), “National core set of environmental indicators phase 3: Selection of indicators atmosphere and climate.” Prepared for: The Directorate: Environmental Information and Reporting National Department of Environmental Affairs and Tourism. Specialist Report prepared by M. van der Merwe & E. Muller, March 2002

[11] Department of Environmental Affairs and Tourism (DEAT), “Provisional Environmental Headline Indicators”, 2006. online http://soer.deat.gov.za/indicator.aspx?m=445

[12] H. Winkler, P. Mukheibir, S. Mwakasonda, A. Garg and K. Halsneas, *Electricity Supply Options, Sustainable Development and Climate Change priorities,* UNEP Risoe Centre, ISBN: 978-87-550-3629-1. September 2007

[13] Scenario Building Team (SBT), *Long term mitigation scenarios: Technical summary.* Department of Environmental Affairs and Tourism (DEAT), Pretoria October 2007. online http://www.erc.uct.ac.za/Research/LTMS/LTMS-intro.htm