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Indicators for sustainable energy development: An initiative by the International Atomic Energy Agency

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Abstract

Since 1999, the International Atomic Energy Agency (IAEA) has been leading a multinational, multi-agency effort to develop a set of energy indicators useful for measuring progress on sustainable development at the national level. This effort has included the identification of major relevant energy indicators, the development of a framework for implementation and the testing of the applicability of this tool in a number of countries. To achieve these goals, the IAEA has worked closely with other international organizations, leaders in energy and environmental statistics and analysis including the United Nations Department of Economic and Social Affairs (DESA), the International Energy Agency (IEA), Eurostat and the European Environment Agency (EEA). Also, the IAEA completed a three-year coordinated research project for the implementation and testing of the original set of indicators in seven countries — Brazil, Cuba, Lithuania, Mexico, the Russian Federation, the Slovak Republic and Thailand. This article provides an overview of the IAEA programme on Indicators for Sustainable Energy Development (ISED) and highlights its experiences and accomplishments.

Keywords: Energy indicators; Sustainable development; Energy statistics; Energy policy; International Atomic Energy Agency.

1. Introduction

The provision of adequate and reliable energy services at an affordable cost, in a secure and environmentally benign manner and in conformity with social and economic development needs is an essential element of sustainable development. Energy is vital for eradicating poverty, improving human welfare and raising living standards (UNDP *et al.*, 2000). However, most current patterns of energy supply and use are considered unsustainable (UN, 2001). Many areas of the world have no reliable and secure energy supplies, hence no energy services, which limits economic development, while in other areas environmental degradation from energy production and use inhibits sustainable development.

Adequate and affordable energy services have been critical to economic development and for the transition from subsistence agricultural economies to modern industrial and service-oriented societies. Energy is central to improved social and economic well-being and is indispensable to most industrial and commercial wealth generation. But however essential it may be for development, energy is only a means to an end. The end is a sustainable economy and a clean environment, high living standards, prosperity and good health.

Key energy issues were discussed in 2001 at the ninth session of the Commission on Sustainable Development (CSD-9). In 2002, at the World Summit on Sustainable Development (WSSD) held in Johannesburg, South Africa (UN, 2002), the international community reaffirmed that access to energy is important to the Millennium Development Goal of halving the proportion of people living in poverty by 2015 (UN, 2000). The WSSD agreed to facilitate access for the poor to reliable and affordable energy services in the context of broader national policies to foster sustainable development. The summit also called for changes in unsustainable patterns of energy production and use.

It is therefore important for policy makers to understand the implications and impacts of different energy programmes, alternative policies, strategies and plans in shaping development within their countries and on the feasibility of making this development sustainable over time. Indicators, when properly analysed and interpreted, can be useful tools for communicating data relating to energy and

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sustainable development issues to policy makers and to the public, and for promoting institutional dialogue. They provide a way to structure and clarify statistical data to give better insight into the factors that affect energy, environment, economics and social well-being and into how these factors might be influenced and trends improved. Indicators can also be used to monitor progress of past policies or to provide a reality check on strategies for future sustainable development. This cannot be done, however, without critical analysis of the underlying causal and driving factors.

The emphasis of the indicators discussed in this article is on national self-examination rather than international benchmarking. The interpretation will depend on the state of development of each country, the nature of its economy, its geography, the availability of indigenous energy resources, etc. Critical analysis of underlying conditions is therefore essential. Nonetheless, changes in the value of each indicator over time, properly analysed, can help to quantify progress toward selected development goals within a country.

2. Background

In response to decisions taken by the United Nations Commission on Sustainable Development (CSD) and to Chapter 40 of Agenda 21, the United Nations Department of Economic and Social Affairs (DESA) began working in 1995 to produce an overall set of indicators for sustainable development (ISD). This effort concluded with a package of 58 ISD, of which only three were energy related — annual energy consumption per capita, intensity of energy use and share of consumption of renewable energy resources (UNDESA, 2001). In order to complement the effort of the Commission on Sustainable Development and to provide a higher resolution of energy, the International Atomic Energy Agency (IAEA) started a long-term programme on indicators for sustainable energy development (ISED) in 1999 in cooperation with various international organizations, including the International Energy Agency (IEA) and DESA, and some Member States of the IAEA. The project was conceived to:

- Fill the need for a consistent set of energy indicators;
- Assist countries in the energy and statistical capacity building necessary to promote energy sustainability; and
- To supplement the work on general indicators being undertaken by the UN Commission on Sustainable Development.

The project was devised to include two phases. In the first phase (1999–2001), an original set of 41 ISED was identified and the conceptual framework to classify and implement these indicators was developed and tested in 15 countries (Argentina, Bulgaria, China, Croatia, Cuba, Germany, the Netherlands, Indonesia, Lithuania, Mexico, Pakistan, the Russian Federation, the Slovak Republic, Turkey and the USA). Major themes and subthemes and systematic cross-linkages among indicators were defined to establish causality. The results of the first phase were presented at CSD-9 in April 2001 (IAEA/IEA, 2001). In 2002, the ISED/IAEA project was classified as a Type II Partnership of the WSSD and was officially registered as such with the CSD. (Since then the terminology related to partnerships has been changed and the project is now called a WSSD partnership.)

The second phase started in 2002 with a three-year coordinated research project to implement the original set of ISED in seven countries. The countries were selected on the basis of proposals submitted by experts from statistical and energy research organisations interested in the evaluation of their countries' energy policies in accordance with their sustainable development objectives. The research teams worked on the evaluation of their countries' statistical capabilities and on the implementation of the particular subsets of the ISED most relevant to their energy priorities. The relevant indicators were used to analyse current energy policies and potential future energy strategies. This implementation project concluded in 2005 with final reports from participating countries summarizing findings and lessons learned. The results of this activity are summarized in the country case study articles contained in this issue of the *Natural Resources Forum*.

The second phase also included a parallel effort coordinated with other international organizations and agencies involved in the development of energy indicators, for further refining the original indicator set. The final set of energy indicators resulting from this effort, which builds on the cumulative experience of these agencies, was published in 2005 in a joint interagency report on methodologies and guidelines (IAEA *et al.*, 2005).

The main criterion driving the selection and refinement process of the energy indicators was their ability to address the most important energy-related issues of interest to countries worldwide. Furthermore, the indicators were selected, defined and classified to help countries assess effective energy policies for action on sustainable development. They were devised as a help to guide the implementation of various actions urged at the WSSD, namely to:

- Integrate energy into socio-economic programmes;
- Combine more renewable energy, energy efficiency and advanced energy technologies to meet the growing need for energy services;
- Increase the share of renewable energy options;
- Reduce the flaring and venting of gas;
- Establish domestic programmes on energy efficiency;
- Improve the functioning and transparency of information in energy markets;
- Reduce market distortions; and
- Assist developing countries in their domestic efforts to provide energy services to all sectors of their populations.

The selection criteria also included considerations about data availability, in particular in developing countries, and the feasibility of collecting additional data deemed essential to the establishment of important indicators.

3. First phase. Definition: Indicators for sustainable energy development (ISED) — the original set

The original ISED, developed under the aegis of the CSD, considered the economic, social, environmental and institutional dimensions of sustainable development. During the first phase of the ISED project, the IAEA, in cooperation with DESA, the IEA and a number of Member States, worked on the identification of important issues within each of these main dimensions of sustainable development, with the final objective of defining a set of energy indicators applicable worldwide and commensurate with the CSD approach.

3.1. Economic dimension

Economic ISED measure how the use and production patterns of energy, as well as the quality of energy services, affect progress in economic development and how the status of the energy sector and its trends in a country might improve the chances for economic development to be sustainable in the long run. All sectors of an economy — residential, industrial, commercial, transport, service and agriculture — require energy. These energy services in turn foster economic and social development at the local level by raising productivity and facilitating local income generation. Availability of energy affects jobs, productivity and development. Electricity is the dominant form of modern energy for telecommunications, information technology, manufacturing and services. Therefore, main factors of indicators in the economic dimension include energy use, production and supply; energy supply efficiency and end-use energy intensity; energy pricing, taxation and subsidies; energy security; and energy diversity. A difficulty with economic ISED lies in their interpretation, and specifically in maintaining a clear focus on income generation trends in economic growth and natural resource exploitation.

3.2. Social dimension

ISED in the social dimension measure the impact that available energy services may have on social well-being. Availability of energy services has implications in terms of poverty, employment opportunities, education, community development and culture, demographic transition, indoor pollution and health, as well as gender- and age-related implications. Social ISED describe issues related to accessibility, affordability and disparity in energy supply and demand. In rich countries, modern energy services (lighting, heating, cooking, etc.) are almost universally available. The energy is clean, safe, reliable and affordable. In poor countries, up to six hours a day may be required to collect wood and dung for cooking and heating, and this task is usually done by women. In areas where coal, charcoal, paraffin or kerosene are commercially available, these fuels take up a large portion of the monthly household income. Inadequate equipment and ventilation means that the burning of these fuels inside the house takes a toll on human health and contributes to disease and even death through air pollution and fires. A major difficulty in the development of social ISED is the lack of relevant or adequate data (especially time-series) in developing countries.

3.3. Environmental dimension

The production, distribution and use of energy creates pressures on the environment in the household, workplace and city, and at the national, regional and global levels. Therefore, energy indicators are useful for evaluating impacts of energy systems in all these areas. Environmental ISED measure the impact of energy systems on the overall environment, and in particular the determination of positive or negative trends in land, waters (fresh and marine), and air quality. Such environmental impacts vary depending on how energy is produced and used, and on related energy regulatory actions and pricing structures. Gaseous emissions and particulates from the burning of fossil fuels pollute the atmosphere, cause poor local air quality and regional acidification. Large hydropower dams flood land and may cause silting of rivers. Both the fossil and nuclear fuel cycles, as well as geothermal production, emit some radiation and generate wastes of different levels of toxicity. Wind turbines can spoil a pristine countryside. And gathering firewood may lead to deforestation and desertification. Main issues related to the environmental dimension include global climate change, air pollution, water pollution, wastes, land degradation and deforestation.

3.4. Institutional dimension

Institutional indicators assess the availability and adequacy of the institutional framework necessary to support an effective and efficient energy system. Institutional indicators are useful for linking and addressing the response actions and policy measures designed to influence trends in the social, economic and environmental dimensions. For example, institutional indicators might help to measure not only the existence but also the effectiveness of a national sustainable energy development strategy or plan, energy statistical capacity and analytical capabilities, or the adequacy and effectiveness of investments in capacity building, education or research and development. Institutional indicators could also help to monitor progress towards appropriate and effective legislative, regulatory and enforcement measures to foster efficient energy systems.

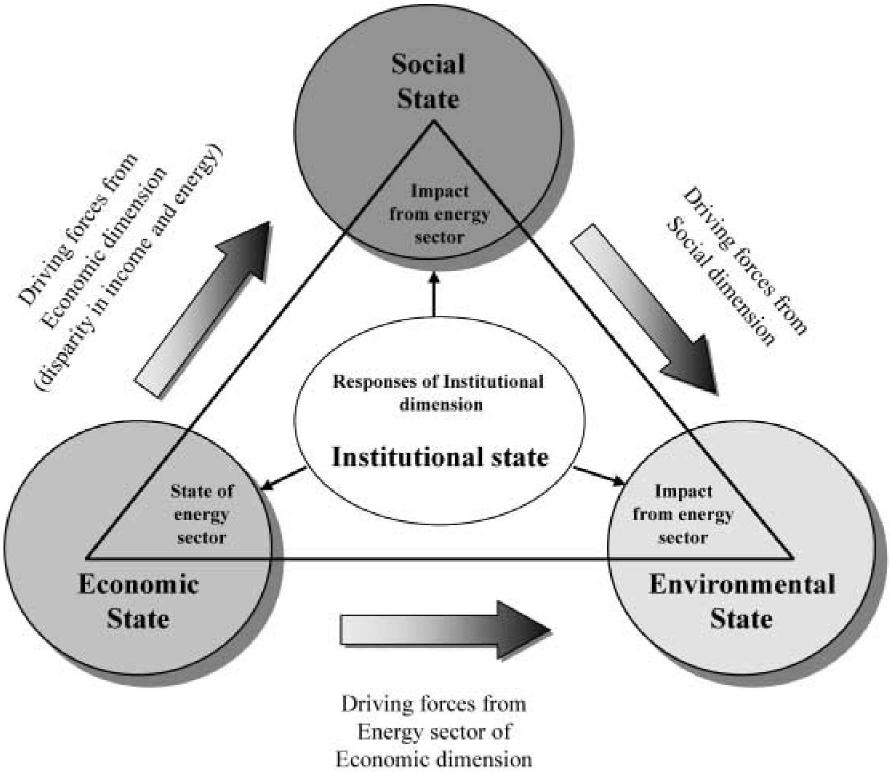

Figure 1. Interrelationship among sustainability dimensions of the energy system.
Source: IAEA/IEA (2001).

Indicators in this dimension are the most difficult to define for two reasons. First, they tend to address issues that are, by nature, difficult to measure in quantitative terms. Many of these issues relate to the future and need dynamic analysis based on projections of energy production, use and investment. Second, the variables measured by institutional indicators tend to be structural or policy responses to sustainable development needs.

In practice, the four dimensions are interrelated. Figure 1 is a simplified illustration of the interrelationship among these various sustainability dimensions of the energy system. The environmental state associated with the energy system is affected by driving forces originating from the economic and social dimensions. The social state of the energy system is, in turn, influenced by certain driving forces originating from the economic dimension. The institutional dimension can affect all the other three dimensions — social, economic and environmental — through corrective policies that influence the sustainability of the whole energy system.

The effort to identify and categorise ISED went through several iterations. A provisional list of ISED was discussed at an international workshop in 1999 (IAEA, 1999). The list was later subject to informal testing in 15 countries by volunteer groups of energy system analysts. The list of ISED resulting from the first phase of the project is shown in Table 1. The indicators in bold were considered most significant from the point of view of sustainable energy development and were viewed as the core set of ISED.

These ISED were then categorized into a conceptual scheme for identifying cross-linkages among various indicators across all four dimensions of sustainable development (IAEA/IEA, 2001). The initial ISED framework was consonant with the driving force, state and response (DSR) framework devised by the CSD for the original ISD, even though the CSD later replaced its framework with a system of more tractable and more easily defined themes and subthemes.

The driving force indicators were further split into two subcategories: direct and indirect driving forces. This allowed a distinction to be made between those factors having a direct influence on the state indicators (direct driving forces) and those that affect the state indicators indirectly (indirect driving forces) by influencing one or more of the direct driving forces.

Table 2 classifies each of these 41 ISED either as an indirect or direct driving force or a state indicator. There are 15 indirect driving force indicators, 14 direct driving force indicators and 12 state indicators. Again, the core ISED are shown in bold.

4. Second phase. Implementation

For the implementation part of the second phase, in 2002 the IAEA started a three-year coordinated research project entitled descriptively ‘Historical evolution of indicators of sustainable energy development and the use of this

Table 1. Original set of indicators for sustainable energy development (ISED)

1. Population: total; urban
2. GDP per capita
3. **End-use energy prices with and without tax/subsidy**
4. Shares of sectors in GDP value added
5. Distance travelled per capita: total, by urban public transport mode
6. Freight transport activity: total, by mode
7. Floor area per capita
8. Manufacturing value added by selected energy intensive industries
9. **Energy intensity: manufacturing, transportation, agriculture, commercial and public services, residential sector**
10. Final energy intensity of selected energy intensive products
11. **Energy mix: final energy, electricity generation, and primary energy supply**
12. **Energy supply efficiency: fossil fuel efficiency for electricity generation**
13. Status of deployment of pollution abatement technologies: extent of use, average performance
14. **Energy use per unit of GDP**
15. **Expenditure on energy sector: total investments, environmental control, hydrocarbon exploration and development, R&D, net energy import expenses**
16. **Energy use per capita**
17. **Indigenous energy production**
18. **Net energy import dependence**
19. Income inequality
20. **Ratio of daily disposable income/private consumption per capita of 20% poorest population to the prices of electricity and major household fuels**
21. **Fraction of disposal income spent on fuels (total population, 20% poorest)**
22. **Fraction of households: heavily dependent on non-commercial energy; without electricity**
23. **Quantities of air pollutant emissions (SO_2, NO_x, particulates, CO, VOC)**
24. **Ambient concentration of pollutants in urban areas: SO_2, NO_x, suspended particulates, CO, ozone**
25. Land area where acidification exceeds critical load
26. **Quantities of greenhouse gas emissions**
27. Radionuclides in atmospheric radioactive discharges
28. Discharges into water basins: waste/storm water, radionuclides, oil into coastal waters
29. **Generation of solid waste**
30. **Accumulated quantity of solid wastes to be managed**
31. **Generation of radioactive waste**
32. **Quantity of accumulated radioactive wastes awaiting disposal**
33. **Land area taken up by energy facilities and infrastructure**
34. **Fatalities due to accidents with breakdown by fuel chains**
35. **Fraction of technically exploitable capability of hydropower currently not in use**
36. **Proven recoverable fossil fuel reserves**
37. Life time of proven fossil fuel reserves
38. Proven uranium reserves
39. Life time of proven uranium reserves
40. **Intensity of use of forest resources as fuelwood**
41. Rate of deforestation

Source: IAEA/IEA, 2001.

information for designing guidelines for future energy strategies in conformity with the objectives of sustainable development'. The project was conducted with research organizations from Brazil, Cuba, Lithuania, Mexico, the Russian Federation, the Slovak Republic and Thailand. The main objective was to test and demonstrate the broad applicability of the original set of ISED and to prepare country case studies summarizing the experiences, lessons learned and problems encountered. Experts in each country were asked to implement the ISED in the context of their own national energy system. The ultimate goal of this activity was to explore, test and demonstrate the usefulness of the ISED for assessing specific policies and trends related to sustainable development.

Participating country teams were asked to perform the following specific tasks:

- Review the energy system in their country and summarize current status, main issues, trends, policies in place and future plans for expansion and improvement.
- Review the energy and environmental statistical capability of their country to determine its strengths and weaknesses and the extent to which the ISED package could be incorporated.
- Select a number of energy-related priority areas or main issues for assessment with the ISED.
- Compile the necessary time series to develop the relevant ISED for assessing these specific priority areas.
- Implement the relevant ISED using time-series data to evaluate the current situation, past trends and expected future developments.
- Define additional indicators that may be unique to a particular country or required to assess priority areas.

Table 2. ISED classified according to indirect and direct driving forces and state

Indirect driving force	Direct driving force	State
1. Population: total; urban	**14. Energy use per unit of GDP**	**16. Energy use per capita**
2. GDP per capita	**15. Expenditure on energy sector: total investments, environmental control, hydrocarbon exploration & development, R&D, net energy import expenses**	**17. Indigenous energy production**
3. End-use energy prices with and without tax/subsidy	**21. Fraction of disposal income spent on fuels (total population, 20% poorest)**	**18. Net energy import dependence**
4. Shares of sectors in GDP value added	**23. Quantities of air pollutant emissions (SO_2, NO_x, particulates, CO, VOC)**	22. Fraction of households: heavily dependent on non-commercial energy; without electricity
5. Distance traveled per capita: total, by urban public transport mode	**26. Quantities of greenhouse gas emissions**	24. Ambient concentration of pollutants in urban areas: SO_2, NO_x, suspended particulates, CO, ozone
6. Freight transport activity: total, by mode	27. Radionuclides in atmospheric radioactive discharges	25. Land area where acidification exceeds critical load
7. Floor area per capita	28. Discharges into water basins: waste/storm water, radionuclides, oil into coastal waters	**30. Accumulated quantity of solid wastes to be managed**
8. Manufacturing value added by selected energy intensive industries	**29. Generation of solid waste**	**32. Quantity of accumulated radioactive wastes awaiting disposal**
9. Energy intensity: manufacturing, transportation, agriculture, commercial & public services, residential sector	**31. Generation of radioactive waste**	**34. Fatalities due to accidents with breakdown by fuel chains**
10. Final energy intensity of selected energy intensive products	**33. Land area taken up by energy facilities and infrastructure**	37. Life time of proven fossil fuel reserves
11. Energy mix: final energy, electricity generation, and primary energy supply	**35. Fraction of technically exploitable capability of hydropower currently not in use**	39. Life time of proven uranium reserves
12. Energy supply efficiency: fossil fuel efficiency for electricity generation	**36. Proven recoverable fossil fuel reserves**	41. Rate of deforestation
13. Status of deployment of pollution abatement technologies: extent of use, average performance	38. Proven uranium reserves	
19. Income inequality	**40. Intensity of use of forest resources as fuelwood**	
20. Ratio of daily disposable income/private consumption per capita of 20% poorest population to the prices of electricity and major household fuels		

Source: IAEA/IEA, 2001.

- Assess the effectiveness of existing policies in achieving specific goals that move the country towards a more sustainable energy future.
- Formulate potential policies and strategies that could help further achieve the specified sustainable development goals with respect to energy and the environment, and assess the potential success of these response actions using the ISED framework.
- Provide a critique of the ISED, their ease of use, their applicability to current policy needs, their consonance with national statistical resources, and their utility as policy and energy system analysis tools.

Participants were asked to prepare reports summarizing these tasks. This issue of the *Natural Resources Forum* includes a number of articles that summarize the experiences, findings and lessons learned from the implementation of the ISED in the participating countries. Their findings and critiques also contributed to the further refinement of the ISED.[1]

[1] It is important to note that the articles summarizing the country case studies and included in this issue of the *Natural Resources Forum* are based on the implementation of the original ISED set as listed in Table 1.

5. Second phase. Refinement: Energy indicators for sustainable development (EISD)

The second phase of the IAEA energy indicators programme also included a parallel effort to further refine the original ISED set. This effort was conducted with other international organizations and agencies involved in the development of energy indicators, including DESA, the IEA, Eurostat and the European Environment Agency (EEA). The final set of energy indicators resulting from this effort builds on the cumulative experience of these agencies and the inputs from the process of implementing the coordinated research project. It was published in 2005 in a joint interagency report on methodologies and guidelines (IAEA *et al.*, 2005). Based on practicality, data availability and results from 'learning by doing', the original set of 41 indicators was reduced to the 30 that constitute the current refined set of energy indicators. The original name 'Indicators for sustainable energy development (ISED)' was then modified to 'energy indicators for sustainable development (EISD)' to reflect the view held by some that 'sustainable energy development' refers only to renewable energy and not to the broader spectrum of energy choices. The name change was considered necessary to avoid future misunderstandings in discussions relevant to energy and sustainable development.

A number of indicators were redefined and merged; others were classified as auxiliary indicators. Notably, indicators for the institutional dimension were dropped, having been found to be difficult to define quantitatively or to chart over time in a meaningful way. Since these indicators focus primarily on response actions, the assessment of the adequacy of these measures has been left to a qualitative discussion. Furthermore, although the original indicators followed the driving force/state/response framework, the report on methodologies and guidelines uses the main approach of themes and subthemes currently used by the CSD.

The indicators in the EISD set are thus consistent with and supplementary to the CSD indicators as published by DESA in 2001 (UNDESA, 2001). Moreover, this interagency report reflects a consensus of leading experts on definitions, guidelines and methodologies. The 30 EISD are now classified according to the three major dimensions of sustainable development: social (4 indicators), economic (16 indicators) and environmental (10 indicators). Each group is divided into themes and subthemes. Table 3 lists the indicators of the EISD according to this scheme. The list also includes the basic components of each indicator. It is important to note that indicators can be classified in more than one dimension, theme or subtheme, given the numerous interlinkages among these categories.

This interagency report provides background on the dimensions, themes and frameworks used to define the indicators. It also provides guidelines on how to select and use the indicators and discusses their limitations, pitfalls and constraints to ensure meaningful analysis and to avoid basic statistical misinterpretations. Finally, the report contains methodology sheets for each of the 30 EISD, designed to assist users in the elaboration, construction and implementation of the indicators. The methodology sheets include complete descriptions of the indicators, principal and alternative definitions, the components of each indicator, the units in which they are measured, instructions on how to construct them, data concerns, key data sources, and linkages to other indicators. The report is intended for specialists in energy and the environment, including statisticians, analysts, policy makers and academics — in particular those involved in the development of energy and environmental indicators relevant to sustainable development.

Clearly, the organizational framework of energy indicators has evolved somewhat from CSD-9 (April–May 2001) to the publication of the report on guidelines and methodologies in 2005. These changes, described above, reflect refinements based on experience in applying the indicators over the past five years. The basic approach and the analytical concept, however, have not changed. The shift from the driving force/state/response framework to the themes and subthemes does not change the nature of the analysis, nor does it mean that causality and interrelationships among trends and factors are ignored. Such relationships are still the backbone of the indicator approach to sustainable development analysis. The adoption of the theme and subtheme approach, and the emphasis on institutional changes as responses, make it easier, at least in theory, for policy makers to target policies to influence trends in a more sustainable direction, and to gauge the success of these policies over time.

As it has evolved, the EISD set is intended as a reference point or basis upon which users can develop their own specific indicators. Users do not have to implement the full set, but can select those indicators that are relevant; nor are users limited to the proposed EISD, but can create other indicators that are appropriate for their case.

6. Using EISD for analysis

Generating indicators is only a beginning. As a structure for critical analysis, the EISD can be used to relate sustainable development goals and strategies to economic, environmental, or social factors and to policy analysis and monitoring. The IAEA has been using the EISD in three specific ways:

- To clarify statistical information;
- To monitor progress of past energy-related policies; and
- To provide a reality check on policy proposals.

In all three cases, indicators are being combined with energy system modeling. This marriage of indicators and scenario modelling is now a current analytical focus.

One of the first IAEA uses of the EISD was in the context of a partnership initiative, led by the Agency, registered with the CSD for developing country profiles on sustainable energy development. Started in 2002, this project now includes four participating countries — Brazil, Cuba, South Africa and Romania — along with the IAEA and DESA. The main objective is to marry scenario projections of national energy demand and supply and related policies with a statistical analysis of past and future trends in selected sustainable development priorities, thus permitting policy makers to gauge whether the energy system is evolving in a desirable direction and how appropriate corrections can be made. These country energy profiles comprise quantitative and qualitative assessments of energy demand, supply, domestic resources, technology and trade, and scenarios of energy sector evolution under different policy and technology assumptions. The analysis is structured to address the most important energy issues and national priorities in the context of the major dimensions of sustainable development (economic, social and environmental). Historical trends and current status are assessed using the EISD tool. Future developments are explored using a scenario approach. The partnership initiative is thus an effective mechanism,

Table 3. List of energy indicators for sustainable development (EISD)

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
	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 tonne-km freight and by mode
	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

Table 3. ***Continued***

Economic				
Theme	*Subtheme*	*Energy indicator*		*Components*
		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, etc.) —Critical fuel consumption

Environmental				
Theme	*Subtheme*	*Energy indicator*		*Components*
Atmosphere	Climate change	ENV1	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

Source: IAEA *et al.* (2005).

at the national level, for evaluating the fulfilment of a country's Johannesburg Plan of Implementation.

More recently, a regional project entitled 'Tracing sustainable energy paths with nuclear power and other energy options' has begun involving 14 countries in the Asia and Pacific region. Using the same approach as for the national profiles, this project adds a regional dimension to the analysis. A spin-off benefit will be that the EISD framework will be integrated into the national statistical system of participating countries.

Work has also begun to establish links between the EISD and other sets of indicators that are being developed. This includes using the EISD in tandem with more specific indicators for nuclear technology innovation and development, with a special focus on indicators that satisfy three key criteria. First, technology development indicators should be consistent with and usable in conjunction with the EISD framework and, if applicable, with the modelling tools adopted to support in-depth analyses. Second, these indicators should help to interpret the impacts of technological change and development efforts and to trace the progress of nuclear energy technologies in achieving sustainable development goals. Third, the indicators should be adopted in the context of future scenarios to reflect key relevant social, economic and environmental goals (values, aspirations, development levels) to ensure consistency between technological aspirations and the socio-political context.

Finally, the IAEA is developing several different sets of indicators related to technology innovation. These indicators, coupled with the EISD set, and with technology-specific nuclear indicators, may help to define future requirements for energy services and the conditions for long-term development of specific energy technologies.

A major area of application for technology-oriented indicators is the IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO). The two main objectives of this project are to help ensure that nuclear energy is available to contribute to fulfilling energy needs in the 21st century in a sustainable manner, and to explore national and international actions required to achieve desired innovations in nuclear reactors and fuel cycles. Indicators can play an important role in assessing the economics, sustainability, environmental impacts, safety and other characteristics of innovative nuclear energy systems, and their user requirements. Such indicators would ideally be conceived and used both at a geopolitical level, where indicators can help design national, regional or sectoral strategies for sustainable energy development, and at the technology level, where indicators can provide a sustainability context on the one hand, and technology-specific characteristics on the other.

7. Conclusions

The IAEA has worked successfully in cooperation with national and international organizations to develop a worldwide set of recommended energy indicators for sustainable development. The ISED/EISD is an analytical tool designed for assessing energy systems and for measuring progress towards more sustainable energy futures. This tool is a starting point that can serve as a reference point for a more refined and complete set of energy indicators, for more coherent methodologies and guidelines for its implementation, and for the design of future scenarios.

The country case studies that follow this article illustrate the applicability and use of the ISED tool in the assessment of energy sectors and trends towards sustainable development at the national level. These articles also describe limitations and difficulties encountered in the implementation of the ISED analysis and in the interpretation of results.

Further development of energy indicators and their dissemination and implementation at the national and regional levels, as well as designing indicators for the assessment of advanced innovative technologies are continuous efforts at the IAEA. It is hoped that this work will result in an expanded analytical tool useful to energy experts and other stakeholders.

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