A NEW APPROACH TO MEASURING LOW CARBON ENERGY INNOVATION IN DEVELOPING COUNTRIES

Binu Parthan,

REEEP and IEE Graz University of Technology, VIC D1732, Wagramerstrasse 5, Vienna, A-1400, Austria and Inffeldgasse, 18, Graz, A-8010 – Austria –Tel:+43 1-26026-3209, Fax: +43-1-213-463678 E-mail: bp@reeep.org

Udo Bachhiesl

Graz University of Technology, Inffeldgasse, 18, Graz, A-8010 – Austria, Tel: +43 316 873 7909 Fax: +43 316 873 7910 E-mail: bachhiesl@TUGraz.at

ABSTRACT

The paper examines the existing approaches to measuring low-carbon energy technology innovation in the context of developing countries. Based on an appreciation of the limitations of the current approaches, the authors develop a new approach to measuring low carbon energy innovation titled Low-Carbon Energy Innovation (LEI) Index. The LEI Index is then calculated for 81 developing countries and the results are presented. The paper also draws conclusions from the LEI Index rankings of developing countries.

1. MEASURING TECHNOLOGY INNOVATION

Measuring technology innovation is difficult as it does not have a defined physical presence or a price definition. This has led efforts to measure energy innovation to generally resort to indirect measurement methods. A number of approaches to measure technological innovation and technical capability at the country level have been developed as an input to public policies on technology promotion and innovation. Businesses are also using these measurements and rankings to guide business decisions and business processes. The various approaches generally consider factors that influence innovation of technologies. Some of the main factors and indicators that are considered as part of methodologies to measure technical innovation or technological capability are reviewed below:

- **Patents** are considered to be a good indicator of national innovative capacity and the data on patents is available relatively easily compared on data on research and development efforts. However the quality of patents and the procedures for patenting vary significantly across countries. There is a tendency to rely on the patents granted by the UN Patent Trademark Office (USPTO) than national patent offices and agencies of individual countries.
- **R&D expenditures** are another indicator of technology innovation as it is measured in monetary values and therefore can be compared across countries.

However this indicator is available only for a small number of countries and availability is a problem for a large number of developing countries.

- **Scientific Publications** are also an output indicator which is associated with the public R&D expenditure input. The limitation of this indicator is similar to patents in that the quality and the sectoral distribution of publications vary across countries. Also since the vast majority of the journals monitored by the Institute for Scientific Information are in English, English speaking countries have an advantage.
- **Royalties and Licence Fees** are in indicator which denotes the creation and acquisition of technology. However the royalties and licence fee payment figures can be biased by the financial transactions between different branches, subsidiaries of companies which do not always represent royalties and licence fees;
- **Infrastructure indicators** are also used in certain methodologies to rate technology innovation and diffusion and specific indicators such as number of research institutions in the country, electricity consumption, internet access, telephone lines etc. have been used.
- **Trade indicators** such as exports of non-primary exports, medium and high-technology exports, manufactured exports per capita can be used as indicators of technological capability. However the limitation of the trade related indicators is that they do not take into account the size of the economy and smaller economies tend to be more open to trade than larger ones.
- **Human resources** are another set of indicators as the human capital is one of the most important drivers of technological innovation. Human resource indicators that are commonly used are the tertiary enrolment, number of scientists and engineers, literacy rate etc.
- **Economic indicators** are used by some methodologies to indicate competitiveness and indicators such as the performance of the manufacturing industry, level of national public institutions etc. have been used.

2. CURRENT APPROACHES

There have been a number of approaches to measure technological capabilities at the country level. Four of these indices that are relevant to energy innovation have been considered and are elaborated below.

2.1. Technology Achievement Index

The Technology Achievement Index (TAI) was published by the UNDP in the 2001 Human Development Report. The TAI is an eight-factor measure of technological innovation. The objective of the index is to capture technological achievements of a country in four dimensions:

- Creating new technology which is measured by the number of patents granted to residents per capita and by receipts of royalties and licence fees from abroad per capita;
- Diffusing new innovations which is measured by the number of internet hosts per capita and the share of high-technology and medium-technology exports in total goods exports
- Diffusing existing technologies which is measured by telephones (landlines and mobile phones) per capita and electricity consumption per capita
- Human skills measured by the mean years of schooling in the population aged 15 and older and the gross tertiary science enrolment ratio**.**

The UNDP has grouped countries into four groups based on the TAI as 1) leaders, who have a TAI of more than 0.5, 2) potential leaders who have a TAI of 0.35 to 0.49, 3) dynamic adopters who have a TAI between 0.2 to 0.34 and finally 4) marginalised countries who have a TAI of less than 0.2. The information content, validity and results of the TAI and the Human Development Index (HDI) were quite similar and the added value of TAI was questioned (Arcelus, 2005). It appears that UNDP has since discontinued the assessment of TAI.

2.2. Knowledge Economy Index

The World Bank Institute has developed the knowledge assessment methodology which relies on twelve indicators that have been grouped into four classes. These indicators are shown in table 1.

Table 1: Components of the Knowledge Economy Index[1]

Class of indicator	**Type**	**Indicators**
Economic and Institutional Regime	Input	Tariff and non-tariff barriers Regulatory Quality Rule of Law
Education and skill of population	Input	Adult literacy rate Gross secondary enrollment rate Gross tertiary enrollment rate
Information Infrastructure	Input	Telephones per 1000 people Computers per 1000 people Internet users per 1000 people
Innovation System	Output	Royalty payments and receipts Technical journal articles per million

[1] Source: World Bank Institute (2008)

Class of indicator	Type	Indicators
		people Patents granted to nationals by the USPTO per million people

The KEI measures a country ability to generate, adopt and diffuse knowledge and considers the economic and institutional regime, education and skills, ICT infrastructure and the innovation system. World Bank uses the index to track the relative performance of the countries in two points of time to see the relative effect of development investments.

2.3. UNCTAD Innovation Capability Index

The UN Commission on Trade and Development (UNCTAD) in its World Investment report 2005 introduced the UNCTAD Innovation Capability Index (UNICI). The UNICI consists of two sub-indices the Technological Activity Index (TAI) and the Human Capital Index (HCI). The components of the UNICI are shown in table 2.

Table 2: Components of the UNCTAD Innovation Capability Index[2]

Class of indicator	Weight	Indicators
Technological Activity Index	Equal	R&D personnel per million population US patents granted per million population Scientific publications per million population
Human Capital Index	1	Literacy rate as % of population
	2	Secondary school enrolment as % age group
	3	Tertiary enrolment as % of age group
UNCTAD Innovation Capability Index	Equal	Technological Activity Index Human Capital Index

The UNICI divides the countries into three groups high, medium and low on the basis of their innovation capabilities. The UNICI is based entirely on quantitative variables and applies weights for the human capital index depending upon the level of education with the logic that higher levels of education are considered more important for technical and managerial innovation.

2.4. Competitive Industrial Performance Index

UNIDO’s Competitive Industrial Performance (CIP) Index captures the ability of countries to manufacture and export competitively. The CIP was established in 2002

[2] Source: UNCTAD (2005)

and has been published by UNIDO on an annual basis thereafter. CIP index uses four main dimensions of industrial competitiveness which are shown in table 3.

Table 3: Components of the Competitive Industrial Performance Index[3]

Indicator	**Description**
Industrial Capacity	Manufacturing value added per capita
Manufactured Export Capacity	Manufactured Exports per capita
Industrialisation Intensity	Measured as the average of two indicators: The share of manufacturing in GDP and The share of medium and high technology activities in the Manufacturing Value Added
Export quality	Measured as the average of two indicators: The share of manufactured exports in total exports and The share of medium and high technology exports in total exports

The emphasis by UNIDO is on manufactured goods and their exports and does not consider the innovation system, human resource etc. which are a key determinant of the outputs of industrialization and manufacturing.

3. LIMITATIONS WITH EXISTING APPROACHES

The existing approaches to measuring technology innovation and low-carbon technology innovation evaluate the environment at the country level. These indicators are useful in national and global public policy issues and to see how countries with comparable socio-economic characteristics perform with respect to technology innovation and diffusion. These indices and measurement approaches are also helpful in assessing the progress between two points in time of a country in response to public policy interventions. The limitations of the existing measurement approaches in the context of low-carbon energy innovation in developing countries are:

- Most measurement approaches consider all types of technologies as similar and environments required for technology innovation are also considered the same. The exceptions have been the TAI and the KEI both of which focuses on information and communication technologies;
- The role of innovation institutions are important in technology innovation and the characteristics of the institution which carries out energy research and

[3] Source: UNIDO (2009)

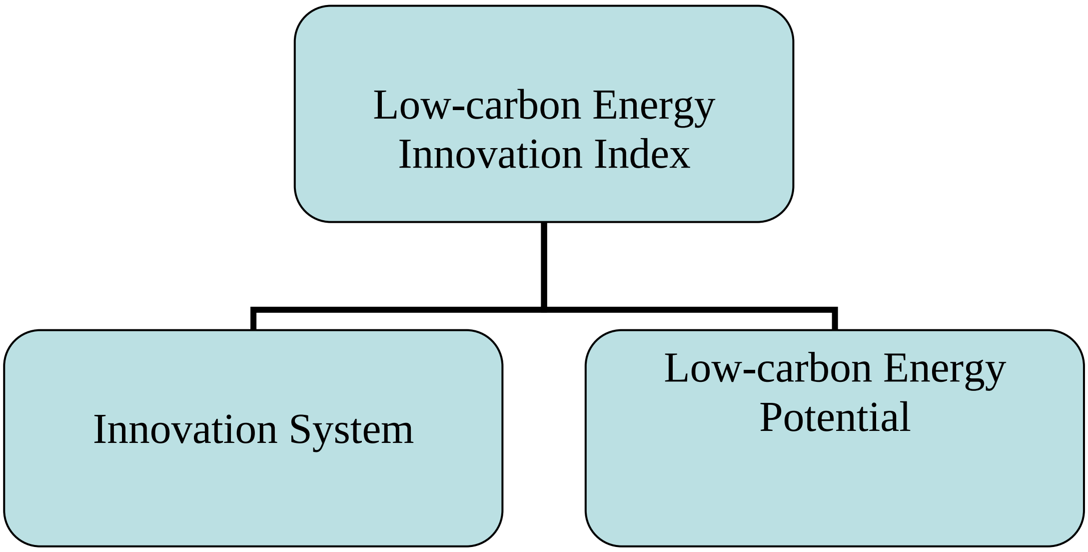
innovation is not adequately captured by the indices and measurement approaches;

- Most of the indices also do not capture the potential for application of the technology innovation within a country in the index. From the perspective of low-carbon energy technologies, the potential to apply the energy innovation in the country needs to be considered.
- Most of the indices and measurement approaches can be applied to all the countries – developing and developed countries. Such a universal approach often results in selection of indicators for which data is widely available in developed countries and where significant data gaps exist in developing countries.

4. LOW CARBON ENERGY INNOVATION INDEX

The Low-Carbon Energy Innovation Index (LEI) consists of two major components – the innovation system and the low-carbon energy potential which is shown in fig 1 below.

Fig 1: LEI Index



4.1. Components of LEI Index

The components of the LEI Index are shown in table 4.

Table 4: Components of the Low Carbon Energy Innovation Index (LEI)

Class of indicators	**Indicators**
Innovation system	Royalty payments and Receipts per million people (a1)

Class of indicators	Indicators
	Technical Journal Articles per Million People (a2) Patents granted to nationals by USPTO per million people (a3)
Low-Carbon Energy Potential	Energy Emissions Factor (b1) Emissions Per Capita (b2)

Each of the five indicators used in the LEI Index are explained below:

- **Royalty Payments and Receipts (US$ Millions/ million population) (a1)**: The royalty payments and receipts provide a good and reliable indicator of creation as well as acquisition of technology in an economy. These consider payments and receipts between residents in a developing country and non-residents for the use of intangible, non-produced, non-financial assets and property rights such as patents, copyrights, trademarks, industrial processes and franchises and for use through licensing agreements of produced originals or prototypes (World Bank Institute, 2008). The data for payments and receipts of royalties and licence fee are available from balance of payments statistics. Both the payments and receipts in US$ millions is added together and weighed by million population.
- **Technical Journal Articles (no/million population) (a2)**: This output indicator considers the scientific and engineering articles published in the technical fields of physics, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology and earth and space sciences. This indicator is also closely associated with public R&D expenditure inputs and is a reliable indicator. The number of articles published in a year in these technical fields is totalled up and are weighted by million populations.
- **Patents Granted by USPTO (no/million population) (a3):** The number of patents give a good indicator of national innovative capacity. This output indicator considers the patent documents granted to nationals of a developing country by US patents and Trademark office. This indicator considers utility patents, design patents, plant patents, reissue patents, defensive publications and statutory invention registrations. The number of patent documents in a year is weighted by million populations.
- **Energy Emissions Factor (tCO_2e/kWh) (b1):** This indicator reflects the Greenhouse Gas intensity of the energy sector in the country. The Energy emissions factor shows the tonnes of CO_2 equivalent of GHG emissions per unit of electricity and heat output. Countries that have a high GHG intensity for their energy supplies will score higher for this indicator and those countries

which have low GHG intensities for their energy supply will score lowly against this indicator. This indicator gives an indication for the potential to decarbonise the energy sector in a country using low-carbon energy technologies. The information for this indicator is available from IEA statistics and also from the UNFCCC national communications.

- **Emissions per Capita** (**tCO_2e/person) (b2):** This indicator is arrived at by sum of the emissions of GHG gases and emissions and emission reductions attributable to Land Use, Land Use Change and Forestry (LULUCF). A country which achieves a low emission per capita will have relatively low contributions to climate change per person and the countries with higher emissions per capita will be contributing more per capita to global climate change. Countries which have high emissions per capita will score high against this indicator and countries with low emissions per capita will score low. The indicator gives information about the industrialisation level and the GHG intensity of the economy and also the potential for low-carbon energy technologies. The information for this indicator is available from IEA statistics and UNFCCC national communications for GHG inventories and the population data is available from IMF's World Economic Outlook.

LEI Index uses a normalization process that most indices use so that indicators and variables that are measured in different units and scales are comparable. This process is done for all the five indicators that constitute LEI:

$$\textbf{Normalised (x) = 100* (1-Nh/Np)}$$

Where:

x = Actual data;
Nh = Number of countries with a higher value;
Np = Number of countries in the population

5. APPLICATION OF LEI INDEX

The Low-Carbon Energy Innovation Index is intended to be applied at the developing country level. This is primarily because these countries are developing their economies and planning investments in their energy infrastructure. These rankings indicate the potential and the capacity to carry out low-carbon energy technology innovation. A total of 81 developing countries for which data was available have been evaluated and the results are presented at table 5 below.

Table 5: Low-carbon Energy Innovation (LEI) Index

Country	**Low-Carbon Energy Potential**	**Innovation System**	**LEI Index**
United Arab Emirates	98.77	95.05	**100**
South Africa	87.65	97.53	**98.77**
Qatar	88.89	93.83	**97.53**
Trinidad & Tobago	90.12	90.12	**96.30**
Kuwait	97.53	77.78	**95.06**
Malaysia	79.01	96.30	**95.06**
Oman	96.30	76.54	**92.59**
Bahrain	100	67.90	**91.36**
Guyana	92.59	75.31	**91.36**
China	81.48	83.95	**88.89**
Botswana	95.06	62.96	**87.65**
Saudi Arabia	91.36	60.49	**86.42**
Jamaica	72.84	79.01	**86.42**
Jordan	64.20	86.42	**83.95**
Swaziland	83.95	66.67	**83.95**
Fiji	69.14	80.25	**81.48**
Mexico	60.49	88.89	**81.48**
Thailand	59.26	87.65	**79.01**
Argentina	45.68	100	**77.78**
Lebanon	71.60	71.60	**76.54**
Mauritius	86.42	54.32	**75.31**
Iran	67.90	72.84	**75.31**
Chile	40.74	98.77	**72.84**
Venezuela	49.38	85.19	**71.60**
Indonesia	82.72	46.91	**70.37**
Uruguay	46.91	82.72	**70.37**

Country	Low-Carbon Energy Potential	Innovation System	LEI Index
India	62.96	65.43	**67.90**
Brazil	37.04	91.36	**67.90**
Mongolia	74.07	48.15	**65.43**
Panama	38.27	81.48	**64.20**
Algeria	65.43	51.85	**62.96**
Bolivia	75.31	41.98	**62.96**
Angola	61.73	53.09	**60.49**
Benin	76.54	37.04	**59.26**
Morocco	58.02	55.56	**59.26**
Mauritania	85.19	27.16	**56.79**
Tunisia	34.57	74.07	**55.56**
Djibouti	93.83	11.11	**54.32**
Costa Rica	9.88	92.59	**53.09**
Zimbabwe	50.62	50.62	**51.85**
Syria	54.32	45.68	**50.62**
Côte d’Ivoire	66.67	29.63	**49.38**
Egypt	27.16	69.14	**49.38**
Colombia	23.46	70.37	**46.91**
Cambodia	70.37	22.22	**45.68**
Sudan	77.78	13.58	**44.44**
Ecuador	29.63	61.73	**44.44**
Sierra Leone	80.25	9.88	**41.98**
Yemen	53.09	34.57	**40.74**
Peru	25.93	59.26	**39.51**
Nicaragua	56.79	23.46	**38.27**
Dominican Republic	39.51	40.74	**38.27**
Philippines	20.99	56.79	**35.80**

Country	**Low-Carbon Energy Potential**	**Innovation System**	**LEI Index**
Sri Lanka	13.58	64.20	**35.80**
Tanzania	51.85	24.69	**33.33**
Senegal	32.10	38.27	**32.10**
Namibia	24.69	43.21	**30.86**
Honduras	22.22	44.44	**29.63**
Eritrea	44.44	20.99	**28.40**
Kenya	7.41	58.02	**28.40**
Burkina Faso	48.15	12.35	**25.93**
Guatemala	43.21	17.28	**25.93**
Rwanda	55.56	1.23	**23.46**
Viet Nam	19.75	35.80	**22.22**
El Salvador	6.17	49.38	**22.22**
Madagascar	28.40	25.93	**19.75**
Pakistan	14.81	39.51	**19.75**
Cameroon	17.28	33.33	**17.28**
Laos	33.33	16.05	**16.05**
Zambia	30.86	18.52	**16.05**
Guinea	41.98	6.17	**13.58**
Nigeria	16.05	30.86	**12.35**
Nepal	11.11	28.40	**11.11**
Myanmar	35.80	2.47	**9.88**
Uganda	2.47	32.10	**8.64**
Ghana	8.64	19.75	**7.41**
Bangladesh	18.52	8.64	**6.17**
Malawi	12.35	14.81	**6.17**
Mozambique	3.70	9.88	**3.70**
Haiti	4.94	7.41	**2.47**
Ethiopia	1.23	3.70	**1.23**

6. CONCLUSIONS

The United Arab Emirates (UAE) tops the Low-Carbon Energy Innovation index, followed by South Africa, Qatar, Trinidad & Tobago and Kuwait which make up the top 5. It can be seen from the above table that Asian countries and especially countries in the middle-east have high Low-carbon Energy Innovation index scores. There are 7, 11 and 15 countries in the top 10, 20 and 30 respectively from Asia. Asian countries score highly on both the Low-carbon energy potential and Innovation system and seem to present the best opportunities for investments in low carbon energy technologies. South Africa is the only African country in the top 10 and there is no country from Latin America in the top 10. An interesting observation is the high LEI index scores by Caribbean Island nations such as Trinidad and Tobago and Guyana both of which figure in the top 10.

While there are notable exceptions, generally several countries in Africa score low in the LEI Index. Latin American countries have average scores which are higher than African countries. Asian countries have relatively high scores compared to the Latin American and African countries. The average score of Asian countries is 63.85, average for Latin America is 50.54 and that for Africa is 41.02. It can therefore be concluded that Asian countries offer the greatest potential for low carbon energy technology innovation followed by Latin America. Countries in Africa offer the lowest potential amongst the three continents for low-carbon energy technology innovation.

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