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Assessing rural energy sustainability in developing countries

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ABSTRACT

Providing sustainable energy access is one of the most critical global challenges. This paper introduces a method for evaluating the status and progress of rural household energy sustainability in developing countries using a new composite indicator, the energy sustainability index (ESI). The ESI combines 13 techno-economic, environmental and social indicators of sustainability using principal component analysis (PCA). We apply the ESI to China, India, South Africa, Sri-Lanka, Bangladesh and Ghana between 1990 and 2010. The analysis suggests that South Africa's rural energy sustainability index is highest followed by China, Sri Lanka, India, Bangladesh and Ghana respectively. All the countries' rural energy sustainability has improved relatively over time except Ghana's. Improvements result mainly from increasing rural electricity use and increasing access to clean and efficient cooking fuels.

Introduction

There is an urgent need to provide access to reliable and clean cooking energy to 2.8 billion and electricity to 1.2 billion people in the world (World Bank, 2013). Sustainable energy is defined as energy that is reliable, affordable, and accessible and that meets economic, social and environmental needs within the overall developmental context of society, but with equitable distribution in meeting those needs (Davidson, 2002; ICSU, 2007). Providing sustainable energy has been a priority for governments throughout the world particularly since the UN Conference on Environment and Development held in Rio 1992, and the signature of the United Nations Framework Convention on Climate Change (Carrera and Mack, 2010). However, providing sustainable rural energy access remains one of the central political challenges for many developing countries (Mainali and Silveira, 2013).

Various bilateral and multilateral agencies started adopting sustainability criteria in their development models after the publication of the Brundtland (1987) report. The UN-CSD (1996) developed more than 130 indicators including the four primary dimensions of sustainable development—social, economic, environmental, and institutional. Further, in 2001 (revised in 2007), a comprehensive report was published on key sustainable development themes and sub-themes with guidelines on developing indicators of sustainable development at the national level (UN, 2001; UNDESA, 2007). These large sets of indicators provided insights on sustainable development issues, but were difficult to combine into measurable and quantifiable sustainability indicators (Kemmler and Spreng, 2007). Several studies have assessed energy sustainability using different sets of indicators and different approaches (Mainali, 2014). Energy sustainability can be evaluated in terms of a more general sustainability index, which could be useful to inform policymakers, investors, and analysts about energy situations (Afgan et al., 2005; Brown and Sovacool, 2007; Doukas et al., 2012; Ediger et al., 2007; WEC. World Energy Trilemma, 2012). However, there is no single commonly accepted method for assessing and combining all dimensions of sustainability (Ilskog, 2008; Mata et al., 2011). The IAEA (2005) presents a comprehensive list of thirty energy indicators for sustainable development (EISD). Some of these indicators are broad in nature, and hard to quantify (Ugwu and Haupt, 2007). International Energy Agency (IEA) developed the Energy Development Index (EDI) for 80 different countries, to assist policymakers in following progress made towards modern energy access provision WEO. World Energy Outlook (2012). However, this index only provides a snapshot at a country level and does not cover technical and environmental aspects of sustainability. The EDI analyzes data at the national level and comprises indicators related mainly to access to clean cooking fuels, and electricity at the household level and access to energy for community services and productive uses. The WEC. World Energy Trilemma (2012) presents an energy sustainability index ($ESI_{National}$) covering indicators related to energy equity, security and environmental sustainability at an aggregated national level. Information and assessments of rural energy sustainability are thus limited (Doukas et al., 2012). There is typically a significant imbalance in socio-economic development between rural and urban areas. The majority of rural populations living in developing countries are energy poor[1]. Thus, there is a need for

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[1] The energy poor are defined as those who lack access to adequate, reliable, affordable clean energy carriers and technologies for meeting energy needs mainly for cooking and those enabled by electricity to assist in human development (Pachauri and Rao, 2013).

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analyzing rural energy separately, using indicators that can provide sufficient insight into the sustainability of rural energy development.

This paper introduces a method for evaluating the status and progress of rural household energy sustainability in developing countries using a new composite indicator, the energy sustainability index (ESI). Thirteen indicators (techno-economic, environmental and social) appropriately designed to capture rural energy sustainability have been combined using principal component analysis (PCA) to construct the ESI. We apply the analysis to six different countries including the fast developing countries China, India, South Africa, and other developing countries Sri-Lanka, Bangladesh and Ghana.

The rest of the paper is organized as follows: Section 2 highlights the profiles of the six countries assessed. Section 3 discusses the methodology adopted in the study, theoretical framework, indicators selection and data sources used for the analysis. Section 4 presents an evaluation of the selected indicators for all the countries under assessment. Results and discussions are presented in the fifth section after performing multivariate analysis to estimate an ESI. The analysis is further extended by presenting the results of a sensitivity and decomposition analysis. Conclusions are drawn in the final section. This paper contributes towards answering the broader question: 'how can we provide sustainable energy access to a large population in developing countries?' The study should help policy makers and planners in the studied countries to better appreciate the sustainability performance of rural energy.

Profiles of the countries under assessment

The typical energy end-uses considered for determining household energy access are cooking and lighting, which are treated as basic energy needs (Balachandra, 2011). The use and reliance on different types of fuels for meeting household energy demand depend upon geographical location, resource conditions and economic situation. The sustainability assessment in this paper has been made choosing developing countries in Asia and Sub-Saharan Africa as these are the regions where the energy access problem is more acute. Countries like Bangladesh, China, Ghana, India, Sri Lanka and South Africa were selected for the analysis based on data availability and with the intent of capturing a broad range of development and energy conditions.

Table 1 shows some key development indicators for these countries. They span a range of rural population sizes from 15 to 1300 million; urbanization rates of 27% to 64%; HDI from 0.47 to 0.66; and rural GDP (per cap) from $220 to $1363. The range of energy conditions in these six cases illustrates the extent of variation seen across developing countries (see Fig. 1).

By 2010, the dependency on biomass for energy ranged from around 90% in Bangladesh to around 30% in South Africa. The types of biomass used for cooking depend on geography, culture and climate conditions. Aside from wood and agricultural residues, which are used in all countries, coal use is common in China and South Africa; charcoal in Ghana, kerosene or paraffin in Ghana, South Africa, India; and dung in India. LPG (liquefied petroleum gas) is the modern form of cooking fuel used in all countries, but its use is very limited and mainly found among the richer population. Rural electrification rates in 2010 were as low as 27% in Ghana, but over 98% in China and 72% in Sri Lanka. Bangladesh and India have recently made modest improvements to increase rural electricity access to 42.5% and 47.5% respectively.

Methodology, theoretical framework, and data sources

Methodology for constructing composite indices

Composite indicators (CIs) are used to measure multi-dimensional concepts that cannot be captured by a single indicator, such as sustainability (EC, 2005). A composite indicator should be constructed on the basis of (i) a solid theoretical framework that can define the phenomenon being measured, (ii) a comprehensive process of construction (covering the selection of indicators and aggregation process) and, (iii) good quality of essential data (EC, 2005; OECD, 2008). The first step in the construction of CIs is to build a theoretical framework defining energy sustainability (see the Theoretical framework section). Then, a set of indicators that capture energy sustainability as defined within this theoretical framework are selected (see the Selection of indicators section) and quantified (see Evaluating the indicators section). Finally, overall progress towards sustainability is estimated in terms of a composite energy sustainability index (ESI). The ESI is generated by aggregating the above individual indicators using multivariate techniques, such as principal component analysis (PCA). EC (2005) and OECD (2008) guidelines have been referred in constructing the composite indicator in this study, paying attention to avoid the shortfalls typically associated with CIs.

The main advantage of PCA is that once patterns in a large number of interrelated data sets are recognized, the dimensionality of such data sets is reduced and compressed, without much loss of information (Helena et al., 2000; Jolliffe, 2003; Li et al., 2012). Besides, it is a non-parametric analysis and allocates weights on the basis of their statistical significance. This makes the analysis neutral and independent of the users (Ali, 2008). For this reason, a PCA technique has been applied in constructing the ESI in this study. However, PCA does not allow taking a-priori knowledge about the indicators/variables into account. This can be taken as the limitation of this technique. Besides, it is sensitive to the number of observations and works better with large sets of observations. The individual indicators that do not change with others may have minimum contribution to the whole (OECD, 2008). Also, PCA is sensitive to alterations in the basic data and updates (e.g. addition of country information as new observations) (EC, 2005). Details regarding PCA technique can be found in Appendix I and in Doukas et al. (2012).

Theoretical framework

The choice of an appropriate conceptual framework and corresponding indicators largely depends on the specific purpose of the analysis (Fiksel et al., 2012) i.e. how we define rural energy sustainability in this specific context. The framework offers a basis for the selection of indicators and their combination into a meaningful composite indicator under a fitness-for-purpose principle (EC, 2005; OECD, 2008). As mentioned earlier, sustainability is often linked with three pillars (economic, environmental and social) (IAEA, 2005; Mahat, 2004). Two additional dimensions (technical and institutional) are sometimes added when

Table 1
HDI, GDP and population trend of countries under study.

Description	Bangladesh	China	Ghana	India	Sri Lanka	South Africa
Human development index—2010	0.469	0.663	0.467	0.519	0.658	0.597
Human development rank—2010	129	89	130	119	91	110
Rural population in 1990 in million	89.59	817.87	10.29	638.54	13.60	19.04
Rural GDP per capita in 1990 (USD of 1990)	164	230	261	240	370	1343
Rural population in 2010 in million	118.45	739.20	15.50	803.59	15.01	17.21
Rural GDP per capita in 2010 (USD of 1990)	220	920	275	522	698	1363
Urbanization—2010	31%	45%	40%	30%	27%	64%

Source: IIASA, 2013; HDR, 2010.