Applied Energy 212 (2018) 1282–1294

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Modeling of quality of life in terms of energy and electricity consumption

Reza Nadimi*, Koji Tokimatsu

Department of Transdisciplinary Science and Engineering, School of Environment and Society, Tokyo Institute of Technology, 4259 Nagatsuta-cho, Midori-ku, Yokohama 226-8503, Japan

HIGHLIGHTS

- Extracting linear quality of life indicator in terms of six variables.
- Fitting a sigmoid function to the quality of life data against energy consumption.
- Inferring the pre-developing countries part in lower plateau of the fitted sigmoid function.

ARTICLE INFO

Keywords:
Energy consumption
Electricity consumption
Quality of life
Factor analysis
Technological change

ABSTRACT

Some scholars have addressed the relationship between the Human Development Index (HDI) and energy consumption in terms of the semi-logarithmic or hyperbolic function. One of the results from this relationship is to divide the world countries into two categories, developed and developing countries. This classification considers pre-developing countries and developing countries into one category (developing) while the proportion of people with fundamental energy needs in the former is far higher than in the latter. The objective of this paper is to allocate a separate class for pre-developing which their fundamental energy needs have not completely satisfied. The methodology of the study is divided into two parts. Initially, based on the longitudinal data (112 country's data during the period of 2005–2013), a linear Quality of Life (QoL) indicator is proposed in terms of six variables. Then an S-shape (sigmoid) curve is fitted to the QoL indicator data against energy consumption (total primary energy supply as a proxy) per capita (ECpc) and electricity consumption per capita (Elcpc) data. Three types of countries, developed, developing, and pre-developing are identified based on the sigmoid function. The results of the proposed model demonstrate that the "pre-developing" category has different QoL and ECpc as compared to developing and developed classes. Another result of the paper shows the entry of new technologies has influenced the QoL and Elcpc to a greater extent in developing countries than in developed countries. One-way analysis of variance is a method to shed light on the latter consequence. In the case of pre-developing countries, the pertinent analysis shows an insignificant impact. This paper concludes the new classification of countries appropriately addresses variation of QoL against ECpc in each class.

1. Introduction

The direct influence of consumer activities in energy consumption equals to 43% of the total energy consumption (Chapter 21, [1]). Several investigations have been conducted to highlight the individual well-being, his role, and lifestyles in energy use reduction [2–6]. Different investigations have been also carried out on the well-being of society in terms of energy or electricity consumption.

The utility level and energy consumption in residential areas were studied by Liu and Yin [7]. The individual diurnal demand for goods in terms of mobile and non-mobile goods was scrutinized. Mobile goods consisted of all goods that demand energy consumption via either vehicle trips or public trips. Non-mobile goods consisted energy services in the residential and commercial sectors such as heating, cooling, cooking. A utility function was defined in terms of non-mobility and mobility goods, in which the level of QoL was described by the maximum utility. To determine the utility function, a constant elasticity of substitution function was defined to measures the substitution elasticity between types of goods as well as the trip types. A nested optimization problem was introduced based on the utility function with which the need of non-mobility goods, and the demand of the transport trip were optimized. The maximum utility level was considered as a QoL indicator that was convertible into a linear function. Therefore, the greater the amount of energy consumption, the higher is the achievable QoL.

* Corresponding author.
E-mail address: nadimi.r.aa@m.titech.ac.jp (R. Nadimi).

https://doi.org/10.1016/j.apenergy.2018.01.006
Received 29 October 2017; Received in revised form 25 December 2017; Accepted 2 January 2018

Nomenclature

ECpc	energy consumption per capita
Elcpc	electricity consumption per capita
EROI	energy return on investment
$EROI_{SOC}$	societal well-being of EROI
FA	factor analysis
GDP	gross domestic product
GEA	global energy assessment
GNI	gross national income
HDI	human development index
IHR	infant health rate
IMR	infant mortality rate
IWA	improved water access
LEB	life expectancy at birth
LEI	lambert energy index
MYS	mean years of schooling
PPP	purchasing power parity
QoL	quality of life

The relationship between societal well-being and energy quality was investigated by Lambert et al. [8]. The achievement of a higher GDP was attributed to the increasing EROI; a higher GDP resulted in a higher energy quality and societal well-being. Therefore, the $EROI_{SOC}$ for a society was defined as the ratio of energy return to society per energy investment. A multiple regression analysis was performed to establish a linear relationship between the social QoL indicators and $EROI_{SOC}$ as well as the energy per capita. Finally, a nonlinear LEI was introduced in terms of the $EROI_{SOC}$, average energy availability, and energy income distribution. Based on the investigation of Lambert et al., each QoL variable was separately taken into account against LEI, rather than concurrently. For example, HDI [9] as a QoL indicator was formulated by a natural logarithm function in terms of LEI plus a constant value.

The relationship among the QoL variables, ECpc, and the population growth was explored by Pasten and Santamarina [10]. Non-linear QoL functions were developed in terms of some variables, but a number of these variables were removed for simplicity. Then, a linear QoL function was calculated based on variables such as the LEB and MYS. This function was used to measure the global QoL. In other words, the global QoL was defined as the ratio of the summation of the QoL value of each country multiplied by its population to total population of all countries. Moreover, an energy-efficient growth formula was defined based on the QoL changes per variation of energy consumption rate to measure the life-oriented energy efficient growth.

The interactions of QoL indicators with both energy and electricity consumption were separately investigated by Mazure [11] in industrial nations based on panel data and cross-sectional data. The investigation relied on the correlation analysis distinctly for each QoL variable. According to Mazur, developed countries did not demonstrate any evidence that strongly emphasizes the promotion of QoL, despite their high per capita energy consumption.

The correlation analysis was separately applied by Alam et al. [12] to determine the relationship between Elcpc and physical QoL variables, which included life expectancy at one year of age, literacy rate, and IMR. Their analysis showed a positive correlation between life expectancy at age one and Elcpc as well as literacy rate and Elcpc. In contrast, the relationship between IMR and electrical energy consumption per capita was negative. Regression analysis was used to combine the results of correlation analysis in a function between Elcpc and physical QoL indicator. Where the physical QoL indicator was a function of the three mentioned variables.

The relation between lifestyle and energy consumption was also considered in other studies. An energy consumption research based upon the income within each country was conducted by Usama Almulali [13]. The results from his study demonstrated that energy consumption improves the QoL for 70% of the countries, regardless of the difference to the income among the countries. Moreover, his investigation revealed that a higher QoL demanded higher energy consumption. The impact of income level, occupation type, family pattern, and electric appliance usage on energy consumption in residential areas was investigated by Sukarno et al. [14] in Indonesia. According to their study, the increase in family income resulted into an increase in the ownership of power equipment and energy consumption. In addition, their results emphasized the positive relationship between the energy consumption, and the amount of time spent by the household. Their findings showed cooking activities consume a higher energy compared with cooling, lighting, and entertainment. Moreover, the impact of family size on the usage of electrical appliances was investigated and showed that energy consumption in the large families (> 6) is higher than the small families.

An energy saving study was conducted by Thøgersen [15] to identify and determine the house-related lifestyle in Denmark. His proposed model relied upon five components of the house-related lifestyle: acquisition motives, quality aspects, home improvement, ways of shopping, and living conditions. Factor analysis method was applied for each of these components to reduce the dimensions of the underlying segments from 71 to 16 factors in 10 European countries. The results from the paper demonstrated that by controlling differences among diverse lifestyles, the following items did not influence energy saving: country of residence, and interaction between a residence of a country and his lifestyle.

These studies have proposed either a nonlinear QoL indicator or few variables used to form linear QoL indicator. Complexity due to nonlinearity and reflect incomplete information due to the inclusion of few variables are two disadvantages of such indicators. For instance, inclusion the IWA variable in the QoL indicator reflects the influence of water access in human development as well as its impact on energy consumption. Study on human development variation against energy consumption in the world is one of the HDI applications [16,17]. Analysis and results of such studies have been summarized based on developed and developing countries. While analysis of human energy needs shows energy consumption, and its services fulfill the fundamental energy needs,[1] then switches the basic energy needs[2] of peoples, and finally, it is used to establish the productivity,[3] and recreation [18].

However, classification of the world countries into developed and developing is insufficient to address the human energy needs properly. According to this classification, countries like Brazil, Russia, China, and South Africa being in the same group (developing class) with countries like Zimbabwe, Togo, Haiti, Sudan, Senegal, Ethiopia, and Mozambique. The former set of countries are being industrialized with focus on energy for productivity. The latter set specify countries with a higher rate of poverty, which need to address fundamental energy needs and associated energy policies to poverty reduction.

The first contribution of the current paper is to outline a linear QoL indicator in terms of six variables. For example, the HDI is a famous indicator [9], which is a nonlinear indicator with three direct variables, income, education, and life expectancy index.

The second contribution of the current paper concentrates on the “developing class” obtained by the HDI model against energy consumption. It divides the “developing class” into two separate categories

[1] Fundamental energy needs contains cooking, heating, cooling, and lighting, which is required for human survival.

[2] The basic needs consists energy for cooking, heating, lighting, cooling, and energy services for educational and health centers as well as income generation [22].

[3] Productive uses of energy makes sure that energy access translates into employment, additional income and ultimately better living conditions for entrepreneurs, employees and their families [62].