TOWARDS INTERNATIONAL E-STAT FOR MONITORING THE SOCIO-ECONOMIC ACTIVITIES ACROSS THE GLOBE

Aki-Hiro Sato, Ken Umeno

Department of Applied Mathematics and Physics, Graduate School of Informatics, Kyoto University

ABSTRACT

We investigate relationship between annual electric power consumption per capita and gross domestic production (GDP) per capita for 131 countries. We found that the relationship can be fitted with a power-law function. We examine the relationship for 47 prefectures in Japan. Furthermore, we investigate values of annual electric power production reported by four international organizations. We collected the data from U.S. Energy Information Administration (EIA), Statistics by International Energy Agency (IEA), OECD Factbook (Economic, Environmental and Social Statistics), and United Nations (UN) Energy Statistics Yearbook. We found that the data structure, values, and unit depend on the organizations. This implies that it is further necessary to establish data standards and an organization to collect, store, and distribute the data on socio-economic systems.

Index Terms— Electrical power consumption data, macro statistics, gross domestic product (GDP), data inconsistency

1. INTRODUCTION

Sustainability is the important issue in the current world. The fundamental idea of sustainability was proposed by R. Buckminster Fuller in Operating Manual for Spaceship Earth [1]. He proposed the concept that Earth is similar to a spaceship flying through space. The spaceship has a finite amount of resources and the resources cannot be resupplied.

More recently, Brundtland Commission proposed the concept of sustainable development in 1987. It contains two key concepts; “needs” and “limited resources” in developing countries. After that, the concept of sustainable production emerged at the United Nations Conference on Environment and Development in 1992. The conference concluded that especially in industrialized countries, the major cause for the continued deterioration of the global environment is the unsustainable pattern of consumption and production.

Fig. 1 shows a conceptual illustration of a human society. The energy injection and substantial inflow/outflow are mandatory in order to maintain our society. Human resources and social organizations should be resupplied from the next generation to maintain our socio-economic systems. Therefore, sustainability of our society may be classified into several categories: Energy sustainability, substantial sustain-

![Fig. 1. The conceptual illustration of society consisting of many elements.](image)

To implement their framework in actual situations, we need data on human activities. Information and Communications Technology (ICT) is expected to contribute for constructing sustainable society for the next generation. In principle, ICT enables us to communicate with one another via computer networks. In the computer network, large amounts of data on human activities can be accumulated. These circumstances prepare emergence of data-centric social sciences at this time. This has also a potential for reconstructing our social structure from data.
Our society consists of six billion individuals and various types of mechanical and electrical equipments. Each element has the associated geometric information, several properties and states. According to M.F. Goodchild, every human is able to act as an intelligent sensor, and in that sense, the earth's surface is currently occupied by more than six billion sensors. We can extract information from an amount of data, construct knowledge from lots of information, and hopefully establish wisdom from several pieces of knowledge. Specifically, researchers in the fields of sociology, economics, informatics, and physics are focusing on these frontiers and have launched data-centric social sciences in order to understand the complexity of socio-economic systems.

D. Weinberger suggests a potential and a limitation of big-data to predict and understand our society. He focuses on an European large-scale research project called FuturICT (http://www.futurict.eu). In this big research project, large-scale sensor networks, data analysis platforms, and computer simulation environments will be constructed. Data-centric investigation in socio-econo-techno-environmental sciences will be established. This project is expected to provide us with technological, scientific, and commercial outcomes to our society.

Measuring properties and states of social elements provides large amounts of data on socio-economic activities. The number of elements consisting of our society is enormous and information generated from our society exceeds our individual's cognitive capacity. In fact, it is difficult to grasp states of our social environment, thus it is necessary to understand state of our society from more precisely and accurately in order to construct sustainable community.

In this article, we focus on data on electrical power consumption as energy consumption. The energy production and consumption is one of useful quantities to measure socio-economic activity. The socio-economic systems are constructed by many mechanical and electronic equipments driven by electricity or oils. Therefore, it is reasonable to infer that socio-economic activities are proportional to gross energy consumption in a society. The relationship between annual energy consumption and annual gross domestic product (GDP) has been largely studied in the context of designing efficient energy conservation policies. The pioneering study by Kraft and Kraft reported that causality runs from GNP to energy consumption using data on gross energy inputs and gross national product (GNP) for the USA. More recently Narayan et al. study Granger causality between electricity consumption and real GDP for 93 countries. They reported that in the six most industrialized nations increasing electricity consumption may reduce GDP.

However, a relationship of individual activities between electrical power consumption and economic productivity is not clarified. One of aims in this article is to elucidate the relationship between electrical power consumption per capita and GDP per capita.

Another aim in this article is to show data inconsistency among organizations which report energy statistics. We further propose the necessity of data management to understand our social states more accurately. To construct rigorous database of socio-economic systems, we need to consider both rules of data collection and roles of organizations.

This article is organized as follows. In Sec. we show the relationship between annual electrical power consumption per capita and GDP per capita. Sec. shows an example of the data inconsistency in energy consumption among organizations reporting energy statistics. In Sec. we propose the data integrity for electric power and an authentication of real unified data. Sec. is devoted to conclusions.

2. RELATIONSHIP BETWEEN ENERGY CONSUMPTION AND SOCIO-ECONOMIC ACTIVITY

Energy production and consumption are deeply related to human activities in our society. This fact can be partially confirmed from the relationship between annual electrical power consumption per capita and annual GDP per capita.

2.1. Relationship for 131 countries

The table shows the annual electrical power consumption per capita and GDP per capita in 2009 for 131 countries. The data were downloaded from the databank of the world bank (http://data.worldbank.org).

The figure shows double logarithmic scatter plots between annual electric power consumption per capita and GDP per capita.

1The countries included in the data are ALB (Albania), DZA (Algeria), AGO (Angola), ARG (Argentina), ARM (Armenia), AUS (Australia), AUT (Austria), AZE (Azerbaijan), BHR (Bahrain), BGD (Bangladesh), BLR (Belarus), BEL (Belgium), BEN (Benin), BOL (Bolivia), BIH (Bosnia and Herzegovina), BWA (Botswana), BRA (Brazil), BRN (Brunei Darussalam), BGR (Bulgaria), KHM (Cambodia), CMR (Cameroon), CAN (Canada), CHL (Chile), CHN (China), COL (Colombia), COD (Congo Dem. Rep.), COG (Congo Rep.), CRI (Costa Rica), CIV (Cote d’Ivoire), HRV (Croatia), CYP (Cyprus), CZE (Czech Republic), DNK (Denmark), DOM (Dominican Republic), ECU (Ecuador), EGY (Egypt Arab Rep.), SLV (El Salvador), ERI (Eritrea), EST (Estonia), ETH (Ethiopia), FIN (Finland), FRA (France), GAB (Gabon), GEO (Georgia), DEU (Germany), GHA (Ghana), GRC (Greece), GTM (Guatemala), HTI (Haiti), HND (Honduras), HKG (Hong Kong SAR China), HUN (Hungary), ISL (Iceland), IND (India), IDN (Indonesia), IRQ (Iraq), IRL (Ireland), ISR (Israel), ITA (Italy), JAM (Jamaica), JPN (Japan), JOR (Jordan), KAZ (Kazakhstan), KEN (Kenya), KOR (Korea Rep.), KWT (Kuwait), KGZ (Kyrgyz Republic), LVA (Latvia), LIB (Libyan), LBY (Libya), LITU (Lithuania), LUX (Luxembourg), MKD (Macedonia FYR), MYS (Malaysia), MLT (Malta), MEX (Mexico), MDA (Moldova), MNG (Mongolia), MAR (Morocco), MOZ (Mozambique), NAM (Namibia), NPL (Nepal), NLD (Netherlands), NZL (New Zealand), NIC (Nicaragua), NGI (Nigeria), NOR (Norway), OMN (Oman), PAK (Pakistan), PAN (Panama), PRY (Paraguay), PER (Peru), PHL (Philippines), POL (Poland), PRT (Portugal), QAT (Qatar), ROU (Romania), RUS (Russian Federation), SAU (Saudi Arabia), SEN (Senegal), SRB (Serbia), SGP (Singapore), SVK (Slovak Republic), SVN (Slovenia), ZAF (South Africa), ESB (Spain), LKA (Sri Lanka), SDN (Sudan), SWE (Sweden), CHE (Switzerland), SYR (Syrian Arab Republic), TJK (Tajikistan), TZA (Tanzania), THA (Thailand), TGO (Togo), TTO (Trinidad and Tobago), TUN (Tunisia), TUR (Turkey), TKM (Turkmenistan), UKR (Ukraine), ARE (United Arab Emirates), GBR (United Kingdom), USA (United States), URY (Uruguay), UZB (Uzbekistan), VEN (Venezuela RB), VNM (Vietnam), YEM (Yemen Rep.), ZMB (Zambia), and ZWE (Zimbabwe).
capita. From this graph, it is found that there is a monotonically increasing tendency of GDP per capita according to the annual electric power consumption per capita. This means that industrialized countries use annual electrical power more than developing countries. The annual electrical power consumption per capita and the GDP per capita show a positive correlation. We assume that the GDP per capita and the annual electrical power consumption per capita follows a power-law relation:

\[
\log y = a \log x + \log C,
\]

where \( y \) is denoted as the GDP per capita, \( x \) the annual electrical power consumption per capita. We obtain \( C = 7.6975 \) and \( a = 0.8808 \) with the least-squared method.

Fig. 2 shows the double logarithmic plots between annual electric power consumption per capita and GDP per capita. A solid line represents a fitting curve.

2.2. Relationship for 47 prefectures in Japan

Furthermore, the annual electric power consumption data on each prefecture in Japan is available from the agency for natural resources and energy of Japanese Ministry of Economy, Trade and Industry (http://www.enecho.meti.go.jp). The population data on each prefecture in Japan can be also downloaded from a homepage of Statistics Bureau of Ministry of International Affairs and Communications (http://www.stat.go.jp). The data of GDP for each Prefecture in Japan are provided by Cabinet Office (http://www.esri.cao.go.jp/en/sna/memu.html). This is called National Accounts of Japan, which is data aggregated from each prefecture. These data in 2009 were downloaded from these official sites.

The table shows the annual electrical power consumption per capita and GDP per capita for 47 prefectures of Japan.

\[1\]Japan consists of 47 prefectures; Hokkaido, Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima, Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo, Kanagawa, Niigata, Toyama, Ishikawa, Fukui, Yamanashi, Nagano, Gifu, Shizuoka, Aichi, Mie, Shiga, Kyoto, Osaka, Hyogo, Nara, Wakayama, Tottori, Shimane, Okayama, Hiroshima, Yamaguchi, Tokushima, Kagawa, Ehime, Kochi, Fukuoka, Saga, Nagasaki, Kumamoto, Okita, Miyazaki, Kagoshima, and Okinawa.

Fig. 3 shows annual power consumption per capita for each prefecture. The annual power consumption per capita in Japan ranges from 3.1 MWh to 7.7 MWh. The highest consumption per capita is in Fukui, and the lowest is 3.1 in Nara. Fig. 4 shows GDP per capita for each prefecture. The GDP per capita in Japan ranges from 250 million JPY to 650 million JPY. The highest is in Tokyo, and the lowest is in Nara.

Fig. 5 shows the double logarithmic plots between annual electric power consumption per capita and GDP per capita of each prefecture in Japan. In the case of Japan, the annual electrical power consumption per capita ranges from 3 MWh to 8 MWh. In fact, Tokyo is an outliers, but annual GDP per capita in other prefectures shows increasing tendency in terms of annual electrical power consumption per capita. This differences may be created from a difference of human behavior. Specifically, the situation of Tokyo is different from other prefectures. This is related to a mechanism of incomes by people in Tokyo. The number of headquarters of various kinds of organizations such as companies, institutions, etc. in Tokyo is larger than other prefectures comparing with its electrical power consumption level. This implies that domestic productions in Tokyo are given by branches and factories located in other prefectures. However, a slope between the annual electrical power consumption per capita and GDP per capita is less than the international relationship shown in Fig. 2. We also obtained \( C = 191.42 \) and \( a = 0.378 \) with the least squared method. The power law exponent \( a \) in the whole Japan is less than those in the whole world.

3. EXAMPLE OF DATA INCONSISTENCY

According to data quality management model, six control dimensions of data quality are proposed; (1) completeness, (2) accuracy, (3) duplicates, (4) consistency, (5) integrity, and (6) conformity. The completeness is that key data items needed are defined in the data structure. The accuracy implies that
Table 1. Electrical power production of several typical countries by five international organizations with the confidence in 2009.

| Country        | Electrical power production in 2009 |
|----------------|------------------------------------|
| United States  |                                    |
| EIA            | 3,950,331,600,000 [kWh]            |
| UN             | 4,188,214 [GWh]                    |
| OECD           | 4,165.4 [TWh]                      |
| Worldbank      | 4,165,394,000,000 [kWh]            |
| Germany        |                                    |
| EIA            | 594,685,400,000 [kWh]              |
| UN             | 637,232 [GWh]                      |
| OECD           | 631.2 [TWh]                        |
| Worldbank      | 631,211,000,000 [kWh]              |
| Japan          |                                    |
| EIA            | 984,799,000,000 [kWh]              |
| UN             | 1,047,919 [GWh]                    |
| OECD           | 1,071.3 [TWh]                      |
| Worldbank      | 1,040,983,000,000 [kWh]            |
| China          |                                    |
| EIA            | 3,445,716,000,000 [kWh]            |
| UN             | 3,714,950 [GWh]                    |
| OECD           | 3,695.9 [TWh]                      |
| Worldbank      | 3,695,928,000,000 [kWh]            |

We found that data inconsistency of energy statistics by several international organizations with the confidence. Tab. 1 shows electrical power productions reported by several international organizations such as U.S. Energy Information Administration (EIA), Energy Statistics Yearbook of United Nations Statistics Division (UN), OECD Factbook 2011-2012: Economic, Environmental and Social Statistics, and Databank of Worldbank.

According to U.S. EIA, the annual electricity production of the United States of America is estimated as 3,950,331,600,000 kWh. UN reports that the annual electricity production of the United States of America in 2009 is 4,188,214 GWh. OECD factbook reports the annual electricity generation of the United States of America in 2009 was 4165.4 TWh. UN Energy Statistics Yearbook reports that the annual electricity generation of the United States of America in 2009 was 4,188,214 GWh. The Worldbank databank reports it was 4,165,394,000,000 [kWh]. The same tendency is confirmed in other countries.

We found that the unit of the annual electricity generation is not common. The EIA uses kWh, UN GWh, OECD TWh, and Worldbank kWh. The values reported by EIA, UN, and OECD are not same. OECD and Worldbank showed the same value. This means that the statistics are not unique (The values depend on the associations which report data). Each association does not seem to communicate with each other and adjust their reports.

It is apparent that the inconsistency in the annual electricity generation is owing to a lack of the coordination agency which is responsible for standardization and coordination about the annual electricity generation. Furthermore, frequency of updating the data is not so fast. Normally the data is delayed for one or two years.

4. TOWARDS POWER DATA INTEGRITY

In the case of Japan, Statistics Bureau of the Japanese Ministry of Internal Affairs and Communication collect macro data of Japan and share them in a website called E-stat. We suggest that we need the standard of macro data in socio-economic systems and organize several international organizations of socio-economic data. Accurate data of electricity generation is the key ingredient...
for building smart community and society with ICT based smart grids for sustainable development. Thus, the data integrity for electric power and an authentication of real unified data (standardization of electric power) is vitally important.

A simple solution for avoiding the inconsistency is to build an international institution which is responsible for data consistency (integrity) in electricity generation and their publications, which is comparable to building an international root certificate authority (CA) organization. However, it is not so practical and very hard to build a new agency. On the other hands, International Telecommunication Union (ITU) has already issued the recommendation for standardization about data integrity such as the trusted time source standardization ITU-R TF. 1876 [8]) for time stamp authority by ITU-R which is important for data integrity.

Furthermore, recent technologies on the smart grids have been intensively developed. Specifically, automated meter reading (AMR) and smart meters have been launched [9][10]. ICT may assist automated matching of electrical power demand and supply. Such an automated matching system is called a central energy management system, which can be also useful to measure electrical power generation and consumption in real time. However, we need to carefully consider balancing consumer privacy concerns with novel applications of power data to our society [11]. To do so, we need several regulations for organizations handling power data.

Furthermore, ITU-T Recommendation C. 2 [12] refers to collection and publication of official service information for service providers in the field of telecommunication. Since smart grid services are of an emerging field, it has not been defined as telecommunication service providers yet. However, the smart grid service uses telecommunication infrastructure in order to transmit power data and collect them for commercial purposes. We can define the smart grid service as one of telecommunication services. Thus, we will make them observe ITU-T Recommendation C. 2.

Therefore, we propose that ITU plays a leading role for the standardization for establishing electric power data integrity with time stamping, which is the main conclusion of our paper.

5. CONCLUSION

We investigated the relationship between electrical power consumption per capita and GDP per capita for 131 countries using the data reported by Worldbank. It was found that an increasing tendency of electrical power consumption per capita in terms of the GDP per capita. The comparison analysis among countries showed that the relation can be fitted with the power-law function. Furthermore, we examined the same relationship for 47 prefectures in Japan. The comparison analysis among 47 prefectures in Japan showed an increasing tendency slower than comparison among 131 countries. This may indicate that the relationship between energy consumption and economic activities strongly depends on life style and social organization in each country. Moreover, the data inconsistency of international electricity production was found among EIA, UN, OECD, and Worldbank. We propose an electrical power data integrity issue and suggest a solution that ITU plays a leading role for the standardization for building power data integrity and authentication with the standard time stamping procedure which was already standardized as ITU-R TF.1876.

6. REFERENCES

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## Table 2. The electrical power consumption per capita and GDP per capita for 131 countries in 2009. The data source is Databank of WorldBank.

| Country | Electricity per capita [kWh] | GDP per capita [JPY] |
|---------|-------------------------------|----------------------|
| AGB     | 202.4952052951              | 458.503395169        |
| ARG     | 795.769499428              | 292.978243531        |
| BRA     | 287.321028762              | 280.965309226        |
| CAN     | 274.344166999              | 258.52698191         |
| CZE     | 344.437899561              | 340.4289882          |
| DOM     | 319.945846195              | 315.7933534          |
| EGY     | 271.094552701              | 257.5137115          |
| ERI     | 157.518636441              | 154.2461809          |
| HUN     | 175.159352829              | 172.9601070          |
| IND     | 0.3949420856              | 0.385206927          |
| IRL     | 144.295049346              | 141.8085634          |
| ISL     | 19.604042724              | 19.419695286         |
| ITA     | 2.0351874053               | 2.024689524          |
| JPN     | 344.437899561              | 340.4289882          |
| KOR     | 320.053208304              | 317.7672873          |
| KWT     | 261.902578562              | 259.6802703          |
| MYS     | 186.669060986              | 184.0002592          |
| MZO     | 11.817709138               | 11.5085634          |
| MRT     | 24.334809436               | 24.063809436         |
| NLD     | 170.945830441              | 168.5137115          |
| NRU     | 11.817709138               | 11.5085634          |
| NOR     | 234.362597892              | 232.094552701        |
| NZL     | 218.432770289              | 216.065309226        |

## Table 3. The annual electrical power consumption for GDP per capita and 47 prefectures in Japan. The data source is E-stat of Statistics Bureau of the Japanese Ministry of Internal Affairs and Communications and the agency for national resources of energy and Japanese Ministry of Economy, Trade, Industry, and Alliance.

| Prefecture | Electricity per capita [kWh] | GDP per capita [JPY] |
|------------|------------------------------|----------------------|
| Hokkaido   | 3293.39025294               | 3278.879841          |
| Aomori     | 3093.96771138               | 3261.664782          |
| Iwate      | 3124.05941246               | 3197.689642          |
| Miyagi     | 2563.55347763               | 2409.896686          |
| Akita      | 3444.437899561              | 340.4289882          |
| Yamagata   | 319.945846195               | 315.7933534          |
| Fukushima  | 2734.344166999              | 258.52698191         |
| Ibaraki    | 143.430564895               | 143.7520352          |
| Tochigi     | 216.05303135                | 203.8222583          |
| Gunma      | 2006.05954002                | 200.4377824          |
| Saitama     | 1023.68075065               | 283.946364           |
| Chiba      | 1043.3655074                 | 308.9999908          |
| Osaka      | 840.34999277                 | 847.4320342          |
| Shiga       | 293.76185265                 | 354.676858           |
| Niigata    | 135.10336579                 | 354.676858           |
| Tochigi     | 216.05303135                | 203.8222583          |
| Gunma      | 2006.05954002                | 200.4377824          |
| Saitama     | 1023.68075065               | 283.946364           |
| Chiba      | 1043.3655074                 | 308.9999908          |
| Osaka      | 840.34999277                 | 847.4320342          |
| Shiga       | 293.76185265                 | 354.676858           |
| Niigata    | 135.10336579                 | 354.676858           |

## Notes
- The electrical power consumption per capita and GDP per capita data source is E-stat of Statistics Bureau of the Japanese Ministry of Internal Affairs and Communications.