IJEEP
INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY
EJ EconJournals
ISSN: 2146-4553

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2022, 12(1), 460-468.

EJ EconJournals

Japan's Low-growth Economy from the Viewpoint of Energy Quality

Yuka Nakajima[1], Jun Matsushima[2]*

[1]Department of Systems Innovation, Faculty of Engineering, The University of Tokyo (Presently Ministry of Economy, Trade and Industry), Tokyo, Japan, [2]Department of Environment Systems, Graduate School of Frontier Sciences, The University of Tokyo, Tokyo, Japan. *Email: jun-matsushima@edu.k.u-tokyo.ac.jp

Received: 16 September 2021 **Accepted:** 13 December 2021 **DOI:** https://doi.org/10.32479/ijeep.12521

ABSTRACT

To investigate the possible cause of Japan's low-growth economy, we analyze the correlation between the quality of energy and economic production such as real gross domestic product (GDP) and energy intensity over the 52-year period from 1965 to 2017. Corrections are made for the quality of energy using two approaches—a physical-based quality correction (i.e., transformity) and an economics-based quality correction. We find that energy quality affects economic production, and that real GDP correlates with quality-corrected final energy consumption. We imply that economic inactivity due to the decline in energy acquisition capacity represented by the decline in societal-scale Energy Return on Investment may be directly linked to the low economy growth. We also find that the energy intensity decreases as the quality of energy used improves, and that regardless of quality correction, the energy intensity decreases as the electrification rate increases. Finally, we conclude that the quantity and quality of energy are closely related to the performance of the Japanese economy and point out the importance of energy quality in Japan—a country that has a low energy self-sufficiency rate in an era when the supply of energy is being depleted.

Keywords: Low-growth Economy, Energy Quality, Energy Return on Investment, Economic Production
JEL Classifications: O530, Q430

1. INTRODUCTION

The Japanese economy has suffered through a prolonged period of slow economic growth since the bursting of the bubble economy in the early 1990s. The country's economic growth rate, which averaged 9.1% during the country's postwar era of rapid economic growth, fell to an average of 4.2% over the years from 1974 to 1990. The average annual rate fell even further—to only 1.0% from 1991 through 2018. What began as Japan's "lost decade," then turned into the "lost 20 years," has now lasted nearly 30 years. No consensus has yet to be reached on the causes behind the lost decades, attracting many studies from the viewpoint of microeconomics and macroeconomics. Hayashi and Prescott (2002) examined the Japanese economy in the 1990s, and found that the problem is not a breakdown of the financial system. They pointed out the importance of total factor productivity (TFP), which is considered as an indicator showing the contribution of technological progress to economic growth. Muto et al. (2016) mentioned that malfunction of financial intermediation causes a lower TFP. Fukao et al. (2015) pointed out that Japan has been suffering from a large negative GDP gap since the 1970s. They also mentioned that the declining trend in private investment from the 1970s is due not only to temporary financial factors such as banks' non-performing loans, firms' damaged balance sheets, and deflation, but also structural factors such as the slowdown in the growth of the working age population and the decline in TFP growth.

In its efforts to escape this extended period of low economic growth, the Japanese government has instituted a broad range of economic measures, including classical Keynesian policies, largely without success. Kameda (2014) mentioned that the Japanese government has spent a considerable amount of money (almost 350 trillion Japanese yen) to counteract the severe recessions that have recurred since the early 1990s, and that the effects of these expenditures have diminished since around the 1990s. Notably, however, Japan is not the only country suffering from an economic downturn. Developed countries are entering an era of low economic growth across the board (e.g. Martin and Islar, 2021; Goodstadt, 2014). Juknys et al. (2018) mentioned that the percentage gross domestic product (GDP) growth rate in the old Organization for Economic Co-operation and Development countries has decreased approximately 2–3 times over the last 50 years, and the largest reduction of GDP growth rate was observed in Japan.

Meanwhile, there has been an intensifying trend to incorporate the perspective of energy into economics. Systems ecologist Howard T. Odum, known as the progenitor of qualitative energy assessment, first advanced the concept of "net energy" in the 1970s, defining it as the energy obtained from an energy source minus the energy used in its acquisition and concentration (the energy investment, or energy cost). He essentially transformed energy quality from a strictly qualitative expression to a quantitative one. From his observation of the ecosystem, Odum (1971) pointed out that various work capacities can be achieved by various forms of energy and that it is inappropriate to make a simple comparison based on calorific value. According to Odum (1973), while energy is measured in calories and power generation capacity, it has quality characteristics that cannot be measured in calories. Moreover, the work that energy can do to satisfy human needs depends both on the quantity and quality of the energy, and if there is a difference in the quality of energy, higher-quality energy can be measured in terms of the lower energy that it takes to obtain it. Odum (1973) mentioned that the amount of work can be evaluated by aligning it with energy. Hall (1986) proposed the energy return on investment (EROI) as a way to quantitatively express net energy and proceeded with a net energy analysis based on Odum's ideology.

It should be noted that there is a large time lag between the advent of the concept of energy and the beginning of the consideration of energy in the field of economics. As economics evolved, the economy was gradually separated from nature, and the role of energy in economic production has characteristically not been considered (Hall and Klitgaard, 2011). In many economic models, the economic process is portrayed as a closed system centered on money. However, in reality, the human economy is not so defined. As can be seen from the first oil crisis in 1973, energy is directly linked to the economy of a society. The closed economic model that was accepted in the era when energy was available cheaply and without limit is no longer suitable for modern times. Several studies have pointed out the societal importance of net energy. Cottrell (1955) mentions that the energy available to humans limits what they can do and influences what they will do. White (1959) provides a profound understanding of the relationship between technology, ecology, and culture in the development of civilizations, and pointed out the importance of a society's ability to exploit energy as an indicator of progress. Odum (1971) warned that there may be a long period of leveling energy budgets and cautioned that the expanding economy may be gone and that citizens will sense this process as inflation. Odum (1973) proposed that the true value of an energy source is the net energy to sustain a society.

In this context, Cleveland et al. (1984) found that energy use and economic activity in the United States are related both over time and across sectors, which is different from previous economic models. Cleveland et al. (1984) argued that the correlation between fuel use and economic production, the contribution of energy to labor productivity improvement, and the determinants of price level changes are the balance between money supply and energy supply. They proved their three hypotheses by analyzing data for the period from 1890 to 1982. More specifically, the correlation between fuel use and economic production was analyzed by correcting energy consumption based on energy quality. As a result, energy intensity, defined as final energy consumption (E)/GDP, was shown to have declined, not because of technological innovation, but because of the improved quality of the energy used.

Many studies have attempted to investigate the linkage between energy consumption and economic growth. Kraft and Kraft (1978) first indicated the presence of a strong statistical relationship between gross energy inputs and gross national product (GNP). Furthermore, their tests for causality implied that while the level of economic activity may influence the consumption of energy, the level of gross energy consumption has no causal influence on economic activity. Sorrell (2010) pointed out that the contribution of energy to productivity improvements and economic growth has been greatly underestimated. Sarwar et al. (2018) mentioned that there are some controversies about the causality energy consumption and economic growth. Akinlo (2008) classifies the results from previous studies into three groups: (i) unidirectional causality from energy consumption to economic growth, or vice versa; (ii) bidirectional causality, and (iii) no causality. There is no consensus about the direction of causation in this relationship (Borozan, 2013). Focusing on the case of Japan, some studies (e.g. Soytas and Sari, 2013; Narayan et al. 2010; Warr et al., 2010) indicate causality running from energy consumption to GDP, while other (e.g. Lee, 2006; Narayan and Prasad, 2008) indicate negative or not causality relation from energy consumption to GDP. Court (2018) showed the aggregate primary-to-useful exergy conversion efficiency of the USA (1900–2010), UK (1900–2010), Austria (1900–2012), Japan (1900–2000), and the world (1900–2014) by compiling the results from Warr et al. (2010), Brockway et al. (2014), De Stercke (2014), and Eisenmenger et al. (2017). The gains in the efficiency of primary-to-useful exergy conversions were rather slow from 1900 to 1945 and then increased considerably up to the 1970s. Since then, gains in the aggregate efficiencies of primary-to-useful exergy conversion have stagnated for the whole world and declined for Japan. Court (2018) also mentioned that the periods of highest rate of primary to-useful efficiency growth around from 1950 to 1970 correspond to the periods of highest economic growth.

Japan is a developed country with a number of social problems, including a declining birthrate and an aging population, "karoshi" (working to death) and a serious budget deficit. Inarguably, the continued sluggishness of the Japanese economy represents an enormous impediment. The question of how this can be remedied is thus a crucial one. From the perspective of supporting modern civilization, fossil fuel resources are the most important of all global commodities, and their production and distribution are extremely crucial issues. According to the International Energy Agency (IEA), energy demand will increase by 1.3% each year until 2040, and fossil fuels will have to account for 74% of final demand in 2040. On the other hand, Gagnon (2009) asserts that the decline in the acquisition performance of fossil fuels from the natural world exceeds the effect of technological innovation.

In this paper, we investigate the possible cause of the low economic growth in Japan by analyzing the correlation between the quality of energy and economic output such as real GDP and energy intensity over the 52-year period from 1965 to 2017. Corrections are made for the quality of energy based on two approaches: a physical-based quality correction (i.e., transformity [Odum, 1988]) and an economics-based quality correction.

2. METHODOLOGY

Using data from 1965 to 2017, we examined, analyzed and compared energy quality, economic production such as real GDP and energy intensity. The quality of energy was proposed using a physical quality correction value determined from transformity (an outline is provided below) and a quality correction value determined from economic impact. Energy was weighted based on its physical and economic quality. The correction using the value of transformity is called E1. This is weighted energy from a physical viewpoint. Transformity is the amount of energy input required to produce a certain amount of energy output represented as Emergy input/Energy output, and has changed slightly over time. "Energy" is the total amount of energy consumed, including solar energy, in direct and indirect conversions to produce a product or service. Energy weighted from an economic point of view is referred to as E2. With regard to energy quality correction by E1, we used the transformity value of Rydberg (2016), which is slightly different from that used in Cleveland et al. (1984). Further, in E1, oil and natural gas are treated equally in Cleveland et al. (1984); however, here, they are more accurately corrected as different values as shown in Table 1.

Table 1: Transformity values used for E1

Oil	1.3
Natural gas	1.2
Coal	1.0
Grid power supply (natural gas, nuclear power, hydropower, wind power, solar power, geothermal power)	4.3

With regard to energy quality correction by E2, we determined weighting coefficients from multiple regression analyses of real GDP and each of the energy resources. First, a regression analysis was conducted, with energy intensity (E/GDP) as the dependent variable and the three elements of %PETRO (defined as ratio of total oil and natural gas to primary energy supply), %ELEC (defined as ratio of total hydropower, nuclear power, and new energy to primary energy supply), and %PCE (defined as percentage of household sector in final energy consumption) as the independent variables. Equation (1) shows the regression model.

$$E / GDP = \alpha - \beta_1 (\%PETRO) + \beta_2 (\%PCE) - \beta_3 (\%ELEC) \quad (1)$$

Multiplying Equation (1) by GDP gives:

$$E_R = \gamma + \delta_1 (\text{oil \& gas}) + \delta_2 (\text{coal}) + \delta_3 (\text{hydro, nuclear power \& renewable energy}) \quad (2)$$

Next, we moved the negative terms on the right-hand side of Equation (2) to the left side and labeled the result E_R. This left on the right-hand side only those factors having a positive economic impact. A second multiple regression analysis was then conducted, with E_R as the dependent variable and % (oil and gas), % (coal), % (hydro, nuclear power and renewable energy) as the independent variables (Equation (3)), and the estimated regression coefficients were determined.

$$E_R = \gamma + \delta_1 (\text{oil \& gas}) + \delta_2 (\text{coal}) + \delta_3 (\text{hydro, nuclear power \& renewable energy}) \quad (3)$$

The regression coefficients δ_1, δ_2, δ_3 were then used as the correction coefficients in E2 (Table 2).

We analyzed and compared changes in final energy consumption and real GDP using data for the years from 1965 to 2017. Final energy consumption was defined as the amount of energy ultimately used by consumers. Energy supply includes various types of energy sources such as crude oil, coal, and natural gas, which are eventually consumed through the power generation and energy conversion sectors (power plants, oil refineries, etc.) that transform these inputs into electricity and petroleum products. In contrast to the concept of primary energy supply, which encompasses all of the energy required in Japan and includes the loss that occurs in the power generation/conversion sectors, the concept of final energy consumption is defined as primary energy consumption minus power generation loss, loss during transportation, and self-consumption in the power generation/conversion sector. In this study, we analyzed how final energy consumption affects economic production. For final energy consumption, we used statistical data (Ministry of Economy, Trade and Industry 2017). For real GDP, we used data from the Cabinet Office National Accounts (GDP

Table 2: Correction coefficients in E2

Oil/natural gas	δ_1
Coal	δ_2
Grid power supply (nuclear power, hydropower, wind power, solar power, geothermal power)	δ_3

statistics) (Cabinet Office, 2018). In addition, since oil prices are considered to be closely related to energy consumption, oil prices were also compared. For oil prices, we used the spot prices (Crude Oil in Dollars per Barrel, Products in Dollars per Gallon) (Energy Information Administration US, 2020. Spot Prices 2020).

Equation (4), which is often used as general energy efficiency, was used for energy intensity.

$$\text{Energy intensity} (= E / GDP) \\ = \text{final energy consumption / real GDP} \quad (4)$$

In addition to the uncorrected values (hereinafter referred to as E/GDP(a)), the corrected values with two types of corrections, E1 and E2 (hereinafter referred to as E/GDP(b) and E/GDP(c), respectively), were investigated and the results compared. We also investigated the relationship between energy intensity and the electrification rate. Additionally, since energy intensity is considered to be affected by changes in the industrial structure, changes in the working population in primary, secondary, and tertiary industries were investigated using data from the Labor Force Survey of the Ministry of Internal Affairs and Communications (Statistics Bureau, Ministry of Internal Affairs and Communications, 2018).

Energy balance (i.e., EROI) was also used as an important comparative index. The EROI time series values were calculated following Liu and Matsushima (2019). EROI is the ratio of usable energy obtained to the energy used to obtain it. Different types of EROIs are defined on different system boundaries. For example, the system boundary for $EROI_{std}$, the standard EROI, is the mine mouth. $EROI_{pou}$ is EROI at the point of use and expands the calculation of $EROI_{std}$ to include the cost of refining and transporting the fuel during the refining process (Murphy and Hall 2010). On a society scale, it is necessary to consider all sorts of fuels. Since measuring such energy precisely is complicated, some approximating approaches have been proposed to express EROI on the societal scale. Hall et al. (1986) calculated the EROI of imported oil ($EROI_{io}$), which is the ratio of the energy value of the amount of fuel purchased per U.S. dollar relative to the amount of oil required to generate a U.S. dollar's worth of goods and services. Lambert et al. (2014) proposed a societal-scale EROI at the national level ($EROI_{soc}$) by extending the definition of $EROI_{io}$ to include all fuel sources, domestic and imported, that a nation uses. In order to include many countries and investigate the annual changes in the relationship between energy quality and quality of life, Liu and Matsushima (2019) modified the measure of $EROI_{soc}$ proposed by Lambert et al. (2014) using the method outlined below:

$$EROI_{soc} = \frac{GDP \times (\eta_1 P_1 + \eta_2 P_2 + \ldots + \eta_n P_n)}{E_T} \quad (5)$$

where E_T is the total EC in a year and η_n is the net contribution of energy n to the total annual EC for a society. $P_n = \frac{E_{Un}}{E_{Pn}}$ is the inverse of the price of energy (MJ/USD), and thus represents how much energy (MJ) a U.S. dollar can buy for a particular energy n.

GDP data were taken from the World Economic Outlook Database October 2017 Edition (IMF, 2017). The total EC was taken from the BP Statistical Review of World Energy June 2017 (BP, 2017). The direct price of energy was taken from the Electric Power Annual 2016 (EIA, 2017) and Renewable Power Generation Cost (levelized cost of electricity) (IRENA, 2017).

3. RESULTS

3.1. Energy Quality Correction

The green line in Figure 1 shows the results when the final energy consumption is corrected by E1. Two features are particularly notable: The increase in energy consumption since 1982 is greater after the E1 correction. On the other hand, since 2011, the decline in energy consumption after the E1 correction is conspicuous. As for E2 correction, multiple regression analysis based on our Equation (1) produced the results shown in Table 3 (multiple R = 0.8; standard error = 0.34). Multiplying both sides of the equation by GDP produces.

$$E = 6.73(GDP) - 18.62(\%PETRO)(GDP) \\ +197.34(\%PCE)(GDP) - 29.46(\%ELEC)(GDP) \quad (6)$$

Next, moving the terms with negative coefficients, (%PETRO) (GDP) and (%ELEC) (GDP), to the left-hand side gives.

Table 3: Results of multiple regression analysis (Equation (1))

Model	Regression coefficient	Standard error	t	P-value	Standardized partial regression coefficient
Intercept	2.08	1.11	1.87	0.067	6.73
% PETRO	−4.90	1.31	−3.74	0.00048	−18.62
% ELEC	21.87	3.11	7.03	5.9E-09	197.34
% PCE	−6.03	1.68	−3.58	0.00079	−29.46

Figure 1: Annual changes in real gross domestic product (black dotted line), crude oil price (black solid line), final energy consumption (uncorrected: blue line; corrected by E1: green line; corrected by E2: red line), and societal-scale energy return on investment (red dotted line)

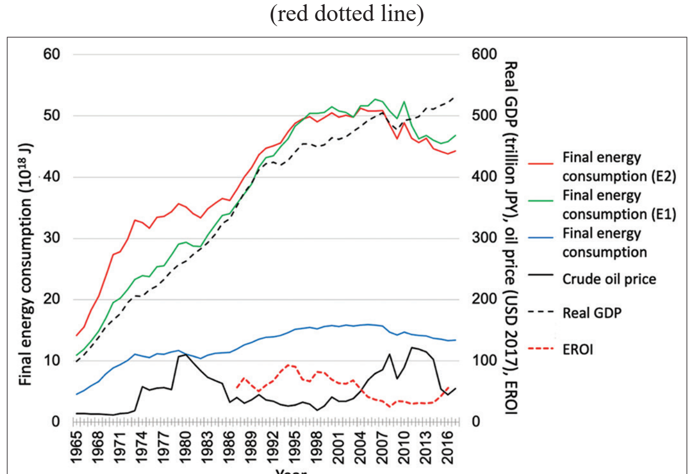


Table 4: Results of multiple regression analysis

Model	Coefficient	Standard error	t	P-value	Standard partial regression coefficient
Intercept	−202,888.0	440,120.8	−0.46	0.65	−54,635,267.2
% (Oil and gas)	203,284.5	439,914.3	0.46	0.65	54,716,253.2
% (Coal)	205,524.3	440,154.5	0.47	0.64	55,349,334.5
% (Hydro nuclear power and renew.energ)	240,822.3	440,919.9	0.55	0.59	64,968,142.3

$$E + 18.62(\%PETRO)(GDP) + 29.46(\%ELEC)(GDP) = 6.73(GDP) + 197.34(\%PCE)(GDP) \quad (7)$$

We labeled the collective left-hand side as and conducted a second multiple regression analysis, treating E_R as the dependent variable and % (oil and gas), % (coal), % (hydro, nuclear power and renewable energy) as the independent variables. The results are shown in Table 4 (multiple R = 0.7; standard error = 1634.39). Adjusting these ratios so that $\delta_1 = 1.00$, the values for γ, δ_1, δ_2, δ_3 in equation (3) are as shown below in Table 5. Correspondingly, the parameters used for E2 correction are shown in Table 6. The red line in Figure 1 shows the results obtained when E2 correction was applied to final energy consumption.

Table 5: Results of multiple regression analysis (Equation (2))

γ	−0.99
δ_1	1.00
δ_2	1.01
δ_3	1.18

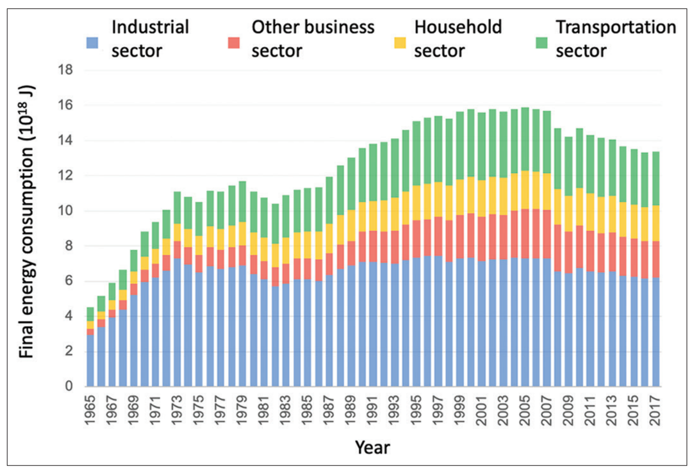
Table 6: Parameters used for E2 correction

Oil/natural gas	1.00
Coal	1.01
Grid power supply (nuclear power, hydropower, wind power, solar power, geothermal power)	1.18

3.2. Energy Use and Economic Production

Figure 2 shows the annual changes in final energy consumption by sector (industrial, other business, household, transportation). Three features are of particular note here: (1) final energy consumption, which was 4.55 (10^{18} J) in 1965, tripled to 15.9 (10^{18} J) in 2005, and shows an overall increase; (2) economic growth was sluggish in the 1970s, primarily due to the global oil crisis; and (3) after peaking in 2005, final energy consumption has continued to decline at a moderate rate. With regard to the transition of each sector, four points merit special mention: (1) the industrial sector continued to grow rapidly from 1965 to 1972, but has remained virtually flat since then; (2) the transportation sector continued to grow moderately from 1965 to 1999, peaking in the early 2000s and then leveling off or declining; (3) the household sector continued to grow moderately until 1990 and has been flat since then; and (4) the other business sector showed growth until 2006, but peaked in 2006 and has since been declining.

Figure 2: Annual changes in final energy consumption by sector (industrial: blue; other business: red; household: yellow; transportation: green)



With respect to changes in real GDP (black dotted line in Figure 1) and final energy consumption without any correction (blue line in Figure 1), it is apparent that, as a whole, both final energy consumption and real GDP are increasing. From 1965 to 1985, real GDP increased, while final energy consumption was nearly flat. From 1986 to 2001, final energy consumption and GDP moved in a similar way. Since 2001, however, correlation between the two is no longer evident. Especially since 2008, real GDP has risen, while final energy consumption has declined. The black solid line in Figure 1 shows the annual changes in oil prices. As indicated, there was a substantial oil price surge in the 1970s, when there were two oil crises, and in the 2000s. Taken together, the implication is that high oil prices affect the relationship between real GDP and final energy consumption. In other words, high oil prices affect the economy of the society in Japan.

The correlation between final energy consumption without correction and real GDP is shown in (Figure 3a), where a linear correlation is evident (R = 0.92). (Figure 3b) shows a graph of the correlation obtained by conducting a linear regression analysis for the E1 correction. Overall, the correlation is stronger (R = 0.97) than in the case without correction. (Figure 3c) shows the results for the E2 correction. The overall correlation here (R = 0.94) was higher than in the case without correction, but lower than that for the E1 case.

Figure 4 shows the annual changes in the composition ratio of the primary energy supply. The proportion of oil increased significantly from 1965 to 1970. The oil ratio peaked in 1972 and then declined due to the oil crisis. From 1973, the proportion of nuclear power began to increase sharply; however, since the nuclear accident resulting from the huge earthquake on March 11, 2011, nuclear power has almost disappeared, and the proportion of fossil fuels, mainly natural gas, has increased. Figure 5 shows the annual change in the three energy intensities with various corrections, E/GDP (a) to E/GDP (c). As indicated, E/GDP (a) to E/GDP (c) decreased significantly from the time of the oil crises

Figure 3: (a) Cross plot and correlation of final energy consumption and real gross domestic product (GDP), (b) Cross plot and correlation of final energy consumption after energy quality correction by E1 and real GDP, (c) Cross plot and correlation of final energy consumption after energy quality correction by E2 and real GDP

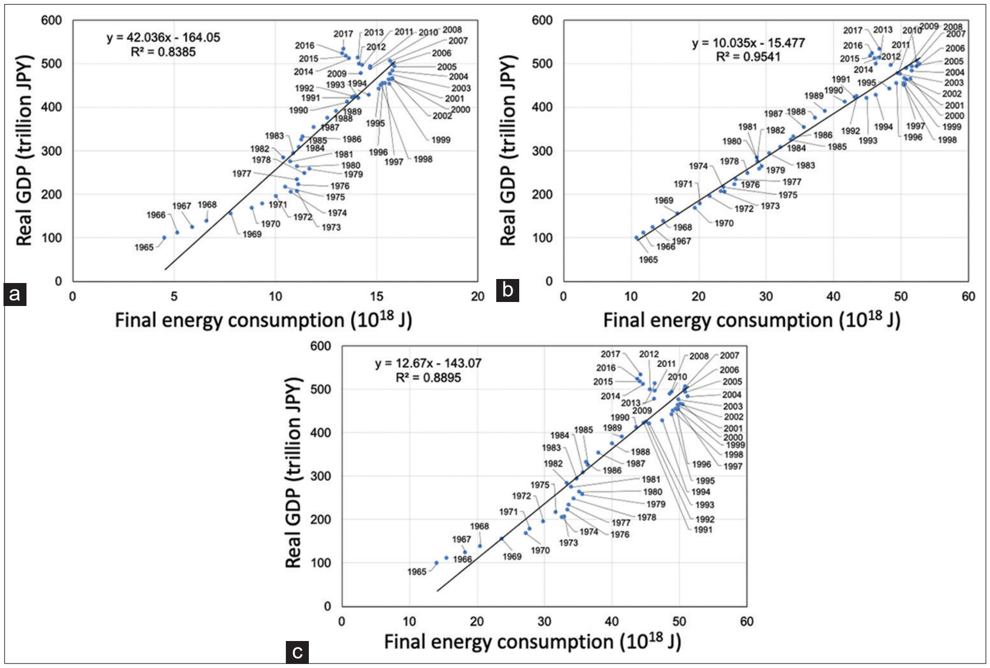
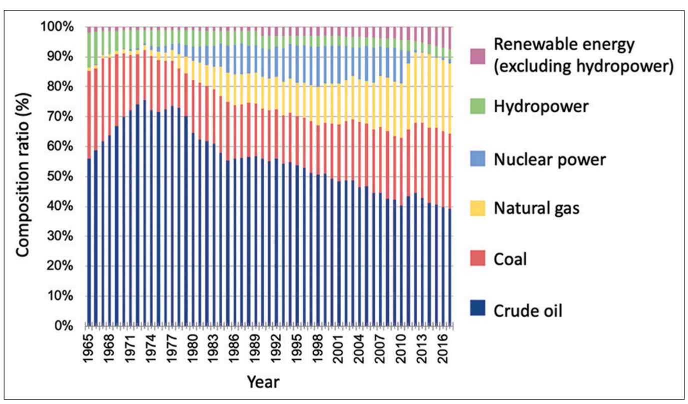


Figure 4: Annual changes in the composition ratio of the primary energy supply



in the 1970s to the early 1980s, then remained relatively flat until the latter half of the 2000s, when the Lehman shock occurred, after which the rate of decrease increased. The solid black circle in Figure 5 shows the annual change in the electrification rate. While E/GDP (a) to E/GDP (c) follow a general downward trend, the electrification rate increased through the beginning of 2000, then flattened.

Based on the survey data (Statistics Bureau, Ministry of Internal Affairs and Communications, 2018), Figure 6 shows the annual changes in the working population in primary, secondary, and tertiary industries. The overall working population continued to increase through the early 1990s but has remained level since that time. In the primary industries, the size of the working population declined sharply between 1965 and 1972 but has since followed a pattern of moderate decline. The size of the working population in secondary industries increased moderately or leveled off between 1965 and the early 1990s, after which time it continued to decline moderately. The ratio of the working population in primary industries decreased significantly from 1965 to 1972 and continued to decrease until 1995; it has continued to decline gradually since that point. Although the proportion of the working population in secondary industries has been declining, the rate of change is relatively small. The proportion of the working population in tertiary industries has continued to increase at an almost constant rate since 1965.

4. DISCUSSION

4.1. Energy Consumption and Real GDP

A comparison of the annual changes in final energy consumption without correction (blue line in Figure 1) and real GDP (black dotted line in Figure 1) from 1965 to 2017 shows a generally positive correlation between the two sets of values. In general, this relationship is often explained in terms of basic logic: when oil prices (black solid line in Figure 1) are low, both energy consumption and GDP increase. However, Figure 1 shows that, while the final energy consumption was nearly flat in the 1970s and 2000s, when oil prices were high, the real GDP was not always flat. The implication is that although oil prices have an effect, they are not the only factor. On the other hand, the societal-scale EROI (red dotted line in Figure 1) has declined since 1995. When the societal-scale EROI was high from late 1980s to early 2000s, Japan bought cheap energy and sold high-priced products. However, in the era of low societal-scale EROI from early 2000s, Japan has been buying high-cost energy and selling products at low price. This implies that the decline in energy acquisition capacity has led to economic inactivity in Japan.

Figure 5: Annual change in the electrification rate (solid black circles) and there energy intensities: E/gross domestic product (GDP) (a) (blue line) indicates the uncorrected final energy consumption, E/GDP (b) (green line) indicates E1 correction, E/GDP (c) (green line) indicates E1 correction

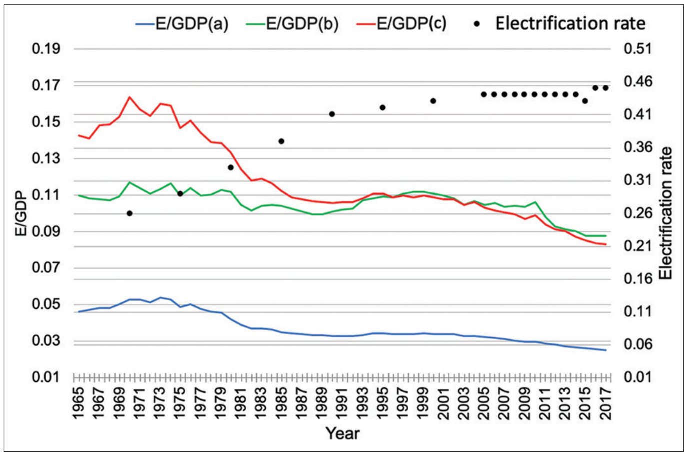
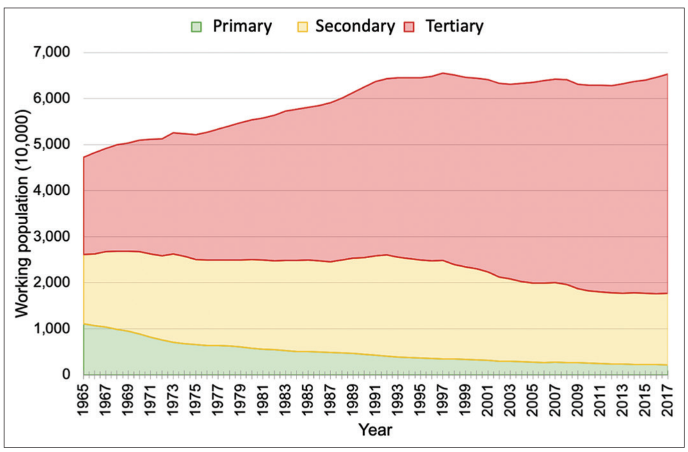


Figure 6: Annual changes in the working population in primary, secondary, and tertiary industries



Cleveland et al. (1984) investigated the rate of annual changes and the correlation between the final energy consumption and GNP, and concluded that the final energy consumption directly affects a country's economic production. By using both the single equation static cointegration analysis and the multivariate dynamic cointegration analysis, Stern (2000) mentioned that energy is significant in explaining GDP. Stern (2000) also pointed out that there is cointegration in a relationship including GDP, capital, labor, and energy. Our study shows that there is a positive correlation between the final energy consumption without correction and real GDP (Figure 3a), but that the annual changes in the trend were different between the 1970s and 2000s. Based on (Figure 3a), the correlation shifted below the trend line during the 1970s oil crisis and above the trend line from 2009 forward. It can be said that being on the lower side of the trend line indicates that less GDP is produced for the energy inputted, while being on the upper side indicates that more GDP is produced for the input energy.

Regarding the final energy consumption after the E1 correction (green line in Figure 1) and the real GDP (black dotted line in Figure 1), it is apparent that the correlation between the two is greatly increased after the correction, as shown in (Figure 3b). The amount of E1 quality-corrected energy during the period from 1965 to 2011 correlates more strongly with the real GDP. This means that the amount of energy corrected for quality from a physical point of view (i.e. with E1), rather than the amount of energy measured strictly in thermodynamic [J] units, is more closely related to the GDP.

In comparing results using the final energy consumption corrected with E2 correction (red line in Figure 1) and that with no correction (blue line in Figure 1), it is apparent that the correlation between the final energy consumption and the real GDP increases after the correction. Since E2 correction is weighted based on the economic influence of each energy type, it can be reasonably argued that the economic quality of energy affects the GDP. However, the correlation coefficient here is smaller than that produced when the quality correction is based on the physical point of view (i.e., with E1 correction).

4.2. Dividing into Four Distinct Periods Offers Additional Insights

4.2.1. 1965-1972

The latter half of the 1960s was an era known as the "Izanagi economy" in Japan, a period of great economic development centered on manufacturing. Along with the steel industry, the machinery industry, which includes general machinery, electrical machinery, and transportation machinery, grew to become the core of Japan's manufacturing industry, and capital investment was highly active (Yoshikawa and Miyagawa 2009). The increase in the uncorrected final energy consumption (blue line Figure 1) during this period exceeded the increase in the real GDP. In Figure 2, we can see that the energy consumption is growing rapidly during this period. The increase in oil consumption is particularly remarkable (Figure 2). On the other hand, the real GDP (black dotted line in Figure 1) is increasing at a somewhat slower pace. Notably, the rise in energy consumption after the energy quality corrections are made (E1: green line; E2: red line) is not as pronounced as it is in the case of the final energy consumption without quality correction (blue line in Figure 1). This tendency is particularly noticeable for the E1 correction. In fact, the final energy consumption after E1 correction is in line with the real GDP. Perhaps the most significant characteristic of E1 correction is that the correction value for the grid power supply is rather large and the correction value for oil, coal, and natural gas is relatively small. Therefore, in this era—when the proportion of oil and coal was high, as shown in Figure 4—energy consumption is corrected to a lesser degree than in other eras when corrected by the quality value based on transformity.

4.2.2. 1973-1986

Japan's period of rapid economic growth ended in the first half of the 1970s. It is thought that the reason that the final energy consumption remained generally flat during the years that followed is that oil prices continued to rise, especially during the oil crises of 1973 and 1979. Moreover, it has been said that the reason the real GDP continued to grow despite the stagnation of energy consumption is that technological innovation occurred in the wake of the oil crises, and energy conservation progressed (Yoshikawa and Miyagawa 2009). However, as is particularly noticeable in the case of E1 correction (green line in Figure 1), the amount of energy consumed increased when a correction for quality was made. In other words, it can be said that an improvement in the quality of the energy consumed led to a flattening of the apparent increase in energy consumption.

4.2.3. 1987-2003

Based on the level of uncorrected final energy consumption (blue line in Figure 1), energy consumption again increased with GDP growth in the 1990s. Increases in the household sector and the other business sector (tertiary industry) are particularly strong (Figure 2). The latter half of the 1980s was the era of the "bubble economy," an era in which the construction industry and the real estate industry contributed greatly to GDP growth (Yoshikawa and Miyagawa 2009), promoting the transition to tertiary industry and the rapid spread of home appliances in Japanese homes. The bubble economy ended in the early 1990s and was followed by the "Heisei recession." From 1987 to 2003, oil prices were relatively low, but both the real GDP and final energy consumption were slowing down.

4.2.4. 2004-2017

Uncorrected final energy consumption (blue line in Figure 1) has followed a downward trend after peaking in 2004. This is likely due to the rise of crude oil prices beginning in the early 2000s. Since 2008, when the Lehman crisis shook the world economy, energy consumption has declined at an increasing rate. On the other hand, the real GDP has continued to grow, albeit at a relatively slow rate.

4.3. Energy Intensity

Figure 5 shows the response of the energy intensity (E/GDP) to energy quality correction. From 1973 to 1986, the energy intensity peaked, and then began to decrease. Looking at the composition of the primary energy supply (Figure 4) during this period, one can see that this coincides with the period during which the amount of oil in primary energy decreased, and natural gas and nuclear power increased significantly. In other words, the increased quality of energy appears to have reduced the energy intensity. In general, the apparent energy efficiency is thought to increase through technological innovation; however, according to our analysis, it appears that the better the quality of the energy used, the lower the apparent energy efficiency. We also examined the relationship between changes in the industrial structure and in E/GDP. Figure 6 shows that the working population in tertiary industries is increasing steadily in terms of both size and proportion. Examining the transition of E/GDP shown in Figure 4, there appears to be no relationship between the increase in tertiary industries and E/GDP. Furthermore, in comparing E/GDP with the electrification rate in Figure 5, which is the ratio of the energy used for power generation in energy consumption, one can see that E/GDP decreases as the electrification rate increases.

Considerable attention has been paid to the electrification rate as it relates to both energy and environmental issues. Liddle (2012) indicated the importance of energy quality –primarily the shift toward the use of high quality electricity– by examining the role of energy quality in the five most energy intensive manufacturing sectors (iron and steel, non-ferrous metals, non-metallic minerals, chemicals, and pulp and paper). Sugiyama (2015) argues that it is desirable to promote decarbonization by increasing the electrification rate. According to this analysis, however, the merit of increasing the electrification rate is not only its environmental impact, but also the fact that it suppresses E/GDP. Based on the Agency for Natural Resources and Energy 2019 White Paper (Ministry of Economy, Trade and Industry 2017), Japan's electrification rate of 45% in 2017 is extremely high relative to the rest of the world. However, the 2011 Great East Japan Earthquake slowed the promotion of electrification ("Survey on the penetration rate of all-electric condominiums in 2011 and the first half of 2012" by the Institute of Real Estate Economics (Real Estate Economic Research Institute, 2011).

5. CONCLUSIONS

To investigate the possible causes of Japan's prolonged economic slowdown, we analyzed the Japanese economy from the perspectives of energy quality and examined the correlation between energy quality and economic production such as real GDP and energy intensity over the 52-year period from 1965 to 2017. Our findings can be summarized as follows:

Energy quality affects economic production. The real GDP and quality-corrected energy quantity are correlated. This implies that to increase the real GDP, it is important to either increase energy consumption or increase the amount of high-quality energy. Especially in Japan, where energy self-sufficiency rate is quite low, it is important to emphasize the quality of energy. We also found that the energy intensity decreases as the quality of energy used improves, and that regardless of quality correction, the energy intensity decreases as the electrification rate increases. Our results strongly suggest that the amount of quality-corrected energy, which represents the quality of energy, have a major impact on the Japanese economy. We need to consider not only the economic efficiency of energy but also its quality. Our study involved a cross-sectoral analysis of the real GDP and final energy consumption. However, we recognize that the impact of energy quality may differ for each industry. Accordingly, an analysis by industry sector should be conducted in the future.

REFERENCES

Akinlo, A.E. (2008), Energy consumption and economic growth: Evidence from 11 Sub-Sahara African countries. Energy economics, 30(5), 2391-2400.

Borozan, D. (2013), Exploring the relationship between energy consumption and GDP: Evidence from Croatia. Energy Policy, 59, 373-381.

BP (British Petroleum). (2017), BP Statistical Review of World Energy. London: British Petroleum.

Brockway, P.E., Barrett, J.R., Foxon, T.J., Steinberger, J.K. (2014), Divergence of trends in US and UK aggregate exergy efficiencies 1960-2010. Environmental Science and Technology, 48(16), 9874-9881.

Cabinet Office. (2017), National Accounts for 2017 (2008SNA, Benchmark Year=2011).

Cleveland, C.J., Costanza, R., Hall, C.A.S., Kaufmann, R. (1984), Energy and the US economy: A biophysical perspective. Science, 225(4665), 890-897.

Cottrell, F. (1955), Energy and Society: The Relation Between Energy, Social Change, and Economic Development. Bloomington: Author House.

Court, V. (2018), Energy capture, technological change, and economic growth: An evolutionary perspective. Biophysical Economics and Sustainability, 3, 1-27.

De Stercke, S. (2014), Dynamics of energy systems: A useful perspective. In: Technical Report, International Institute for Applied Systems Analysis (IR-14-013), Schloss Laxenburg, AT.

EIA (Energy Information Administration). (2017), Electric Power Annual 2016. Washington DC: Energy Information Administration.

Eisenmenger, N., Warr, B., Magerl, A. (2017), Trends in Austrian resource efficiency: An exergy and useful work analysis in comparison to material use, Co_2 emissions, and land use. Journal of Industrial Ecology, 21(5), 1250-1261.

Energy Information Administration US. (2020), 2020 Spot Prices (Crude oil in Dollars Per Barrel, Products in Dollars per gallon). Available from: https://www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm [Last accessed on 2020 Jan 07].

Fukao, K., Ikiuchi, K., Kim, Y., Kwon, H.U., Makino, T., Takazawa, M. (2015), Lessons from Japan's Secular Stagnation. RIETI Policy Discussion Paper No. 15-E-124.

Gagnon, N., Hall, C.A.S., Brinker, L. (2009), A preliminary investigation of energy return on energy investment for global oil and gas production. Energies, 2(3), 490-503.

Goodstadt, L.F. (2014), Poverty in the Midst of Affluence: How Hong Kong Mismanaged its Prosperity. Hong Kong: University Press.

Hall, C.A.S., Cleveland, C.J., Kaufmann, R.K. (1986), The Ecology of the Economic Process: Energy and Resource Quality. New York: John Wiley & Sons. p602.

Hall, C.A.S., Klitgaard, K.A. (2011), Energy and the Wealth of Nations. New York: Springer.

Hayashi, F., Prescott, E. (2002), The 1990s in Japan: A lost decade. Review of Economic Dynamics, 5(1), 206-235.

IMF (International Monetary Fund). (2017), World Economic Outlook Database October 2017 Edition. United States: International Monetary Fund.

International Energy Agency. (2019), World Energy Outlook. Paris, France: International Energy Agency.

IRENA (International Renewable Energy Agency). (2017), Renewable Power Generation Costs in 2017. United States: International Renewable Energy Agency.

Juknys, R., Liobikienė, G., Dagiliūtė, R. (2018), Deceleration of economic growth-The main course seeking sustainability in developed countries. Journal of Cleaner Production, 192, 1-8.

Kameda, K. (2014), What causes changes in the effects of fiscal policy? A case study of Japan. Japan and the World Economy, 31, 14-31.

Kanai, A. (2009), Karoshi (work to death) in Japan. Journal of Business Ethics, 84(2), 209.

Kraft, J., Kraft, A. (1978), On the relationship between energy and GNP. The Journal of Energy and Development, 3, 401-403.

Lambert, J.G., Hall, C.A.S., Balogh, S.B., Gupta, A., Arnold, M. (2014), Energy, EROI and quality of life. Energy Policy, 64, 153-167.

Lee, C.C. (2006), The causality relationship between energy consumption and GDP in G-11 countries revisited. Energy Policy, 34(9), 1086-1093.

Liddle, B. (2012), The importance of energy quality in energy intensive manufacturing: Evidence from panel cointegration and panel FMOLS. Energy Economics, 34(6), 1819-1825.

Liu, B., Matsushima, J. (2019), Annual changes in energy quality and quality of life: A cross-national study of 29 OECD and 37 non-OECD countries. Energy Reports, 5, 1354-1364.

Martin, M., Islar, M. (2021), The 'end of the world' vs. the 'end of the month': Understanding social resistance to sustainability transition agendas, a lesson from the Yellow Vests in France. Sustainability Science, 16(2), 601-614.

Ministry of Economy, Trade and Industry, Agency for Natural Resources and Energy. (2017), Energy White Paper. Japan: Agency for Natural Resources and Energy.

Ministry of Land, Infrastructure and Transport. (2020), Available from: https://www.mlit.go.jp/common/001142601.pdf [Last accessed on 2020 Jan 20].

Murphy, D.J., Hall, C.A.S. (2010), Year in review-EROI or energy return on (energy) invested. Annals of the New York Academy of Sciences, 1185(1), 102-118.

Muto, I., Sudo, N., Yoneyama, S. (2016), Productivity Slowdown in Japan's Lost Decades: How Much of It Can Be Attributed to Damaged Balance Sheets? Japan: Bank of Japan. p16-E-3.

Narayan, P.K., Narayan, S., Popp, S. (2010), A note on the long-run elasticities from the energy consumption-GDP relationship. Applied Energy, 87(3), 1054-1057.

Narayan, P.K., Prasad, A. (2008), Electricity consumption–real GDP causality nexus: Evidence from a bootstrapped causality test for 30 OECD countries. Energy Policy, 36(2), 910-918.

Odum, H.T. (1971), Environment, Power and Society. New York: John Wiley & Sons.

Odum, H.T. (1973), Energy, ecology and economics. AMBIO, 2, 220-227.

Odum, H.T. (1988), Self-organization, transformity, and information. Science, 242(4882), 1132-1139.

Real Estate Economic Research Institute. (2011), Survey of all-Electric Condominium Penetration Rates in 2011 and the First Half of 2012. Available from: https://www.fudousankeizai.co.jp/share/mansion/.105/md20121011.pdf [Last accessed on 2020 Jan 10].

Rydberg, T., Haden, A.C. (2006), Emergy evaluations of Denmark and Danish agriculture: Assessing the influence of changing resource availability on the organization of agriculture and society. Agriculture Ecosystems and Environment, 117(2-3), 145-158.

Sarwar, S., Waheed, R., Amir, M., Khalid, M. (2018), Role of energy on economy: The case of micro to macro level analysis. Economics Bulletin, 38(4), 1905-1926.

Sorrell, S. (2010), Energy, economic growth and environmental sustainability: Five propositions. Sustainability, 2(6), 1784-1809.

Soytas, U., Sari, R. (2003), Energy consumption and GDP: Causality relationship in G-7 countries and emerging markets. Energy Economics, 25(1), 33-37.

Statistics Bureau, Ministry of Internal Affairs and Communications. (2018), Labor Force Survey. Japan: Bank of Japan, Currency Statistics.

Stern, D.I. (2000), A multivariate co-integration analysis of the role of energy in the US macroeconomy. Energy Economics, 22(2), 267-283.

Sugiyama, H. (2020), What Should be the Power Consumption Rate of the Year. Available from: http://www.ieei.or.jp/2015/03/sugiyama150303 [Last accessed on 2020 Jan 05].

Warr, B., Ayres, R., Eisenmenger, N., Krausmann, F., Schandl, H. (2010), Energy use and economic development: A comparative analysis of useful work supply in Austria, Japan, the United Kingdom and the US during 100 years of economic growth. Ecological Economics, 69(10), 1904-1917.

White, L. (1959), The Evolution of Culture: The Development of Civilization to the Fall of Rome. New York: McGraw-Hill.

Yoshikawa, H., Miyagawa, S. (2009), Changes in Industrial Structure and Economic Growth in Postwar Japan, RIETI Discussion Paper.