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Interactions among energy consumption, economic development and greenhouse gas emissions in Japan after World War II

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ABSTRACT

The long-term dynamic changes in the triad, energy consumption, economic development, and Greenhouse gas (GHG) emissions, in Japan after World War II were quantified, and the interactions among them were analyzed based on an integrated suite of energy, emergy and economic indices. The results quantitatively showed that two different energy strategy periods, one before 1973 using new sources of higher quality energy and one after 1973 focused on improving the efficiency of energy generation methods, could explain the linear increase in national economic development in Japan over the 66 years from 1946 to 2011. Japan benefited both ecologically and economically from importing fossil fuels, which accounted for 8.7% of the nominal GDP of Japan averaged over the entire study period. The total environmental impacts of GHG (i.e., CO_2, CH_4 and N_2O) emissions measured by emergy decreased after 1997, and since 2009 they have remained lower than 76% of the emissions in 1990, even though no decrease in the global warming impact based on the weight of CO_2 was observed. Emergy methods and Energy Systems models revealed aspects of the complicated interactions among energy consumption, economic development, and the potential environmental impact of GHG emissions which formerly had not been recognized.

Contents

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1. Introduction

Energy consumption is not only recognized as one of the basic driving forces for social and economic development, but it is also a main source of greenhouse gas (GHG) emissions. Consequently, the relationships among energy consumption, economic development and environmental problems related to GHG emissions, have been the subject of long-term debate focused on reducing environmental problems without harming the economy. Many analyses have been performed at all scales of organization to try to answer this question [1–6], with special concern for identifying the causal relationships that may exist among them. Three main hypotheses [7], including the growth hypothesis, which assumes a unidirectional relationship from energy consumption to economic growth, or vice versa; the feedback hypothesis, which assumes a bidirectional relationship or feedback loop between energy consumption and economic growth; and the neutrality hypothesis, which assumes no causal relationship exists between the two, have been explored for many different countries during many different periods [7,8]. No definitive agreement among researchers has been achieved about the direction of the relationship between energy consumption and economic growth, although most studies validated the positive effects of energy consumption on the growth of GDP and CO_2 emission [7–9]. Furthermore, even after clarification of the casual relationships, constructing successful management strategies still has proved to be difficult, due to the lack of uniform models and evaluation tools that can quantify the three different aspects of the problem in the same terms to promote the development of unified methods of ecological-economic optimization. Some scientists tried to solve this “apples and oranges” problem by combining different methods and results through employing a suite of weighting factors [10–14]. However, those weighting factors can be somewhat subjective and the combinations are accompanied by fundamental theoretical conflicts that need to be solved in a uniform manner [15,16].

Available energy (i.e., exergy) or energy with the potential to do work is not only one of the main driving forces and causes of economic development and GHG emissions, but it is also the common essential factor for the creation of all items and actions, because all actions are necessarily accompanied by the transformation or conversion of energy potentials [17–20]. Thus, the past use of available energy can be used as a measure to quantify the ecological/economic production processes for all assets [21]. The above valuation process is called emergy evaluation, and it is an environmental assessment methodology that was developed by H. T. Odum and his colleagues. This method defines “emergy” as a common denominator measure for quantifying all kinds of energy, material and information storages and flows in equivalent units (e.g. solar equivalent joules that have been used in the past, or solar emjoules, sej). Defined as the available energy of one kind previously used up directly and indirectly to make a service or product, emergy is a thermodynamically defined quantity based on energy hierarchy theory and the maximum empower principle [21–26]. Over the past 30 years, Energy Systems Theory and emergy evaluation methods have been applied widely to address ecological economic issues on all scales [27–34], including national systems [35–41]. However, only a few emergy studies have been done to explore the ecological economic dynamics of national systems over a long period of time [42,43], and consequently the general emergy-based long-term trends of the triad, national energy consumption, economic development and environmental impacts, and the interactions among them scarcely have been explored. In past emergy analyses, potential environmental impacts were generally evaluated using the Environmental Loading Ratio, i.e., the ratio of the purchased and nonrenewable emergy use to the renewable emergy use, due to a lack of widely applicable emergy per unit coefficients (e.g., emergy per unit of available energy or mass) also called the Unit Emergy Values, UEVs, for specific pollutants. Recently, several studies have provided UEVs for GHG pollutants [16,44–46]. Furthermore, the potential for unfair international exchange from an emergy perspective and its effects on national economies have seldom been systematically quantified [47,48], although it is clearly becoming much more important as economic globalization increases.

An additional reason for studying Japan is that it may be an ideal microcosm for the world. Over the long-term both systems are undergoing intensified development; however, Japan has been leading the way. Therefore, both systems are trapped in a difficult triad of contradictions generated by the need to balance energy consumption and the benefits of economic development with the negative effects of pollutant emissions on the local and global ecosystems. The interactions of this triad are particularly intense in Japan, since it is the third-largest economy in the world, as measured by nominal GDP, and it has developed quickly from the wreckage left by World War II (WWII). Over this time Japan has passed through a period of rapid development known as the ‘post-war economic miracle’, which extended from the 1960s to the end of the 1980s, followed in 1990 by the wandering or ‘lost decades’, a period that started with the bursting of the Japanese asset price bubble triggered by a collapse in land and stock prices [49–52] (Fig. 1). Furthermore, Japanese economic development has occurred despite an extreme shortage of domestic energy sources [53],

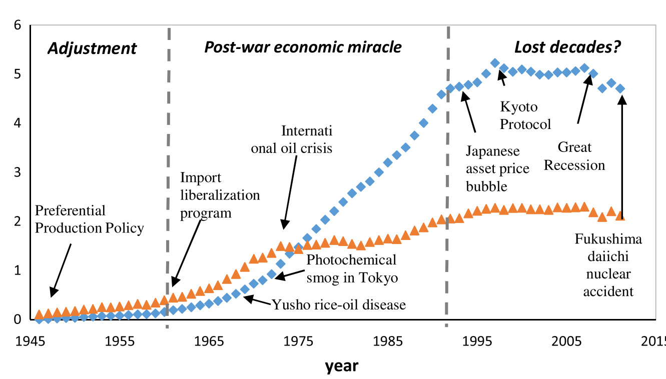

Fig. 1. Temporal patterns of ecological economic development in Japan.