Investigating the Coupling between Useful Exergy and GDP

Summary

The last decade has seen increasing interest in relating energy and the economy considering the useful exergy (useful work) metric. Here, we classify energy uses according to the three stages of the economic process in which energy is used: (1) production of capital goods; (2) production of other goods; (3) direct energy use by final consumers. High temperature heat uses are mostly associated to (1). The uses in (3) are not directly associated to the creation of economic value and vary significantly with income for the same country and with climate between different countries. We hypothesize that, if we remove the effects of (1) and (3), useful exergy intensity is roughly constant and equal between countries. We discuss the empirical basis for this result, analyse the implications regarding trends in primary energy and final energy intensities, and outline a research plan for further testing, analysis and interpretation of this hypothesis.

Extended Abstract

The last decade has seen increasing interest in analysing the relation between energy and the economy by focusing on the useful exergy (also called useful work) metric (Ayres *et al.*, 2003, 2005; Ayres & Warr, 2010; Warr *et al.*, 2010). Useful exergy (UE) looks at energy at the use stage (beyond the primary and final stages) and looks at exergy, i.e., the capacity of an energy flow to produce work (this changes the way heat and work are added up, reflecting the fact that, by the 2nd Law of Thermodynamics, work can be completely converted to heat, but heat cannot be completely converted to work).

Here, we introduce a distinction between three main types of energy uses, related to the three stages of the economic process in which energy is used: (1) energy used for the production of capital goods; (2) energy used for the production of other goods; (3) energy used directly by final consumers.

Given their qualitatively distinct characteristics, we expect these three types to have different relations with both economic activity and useful exergy required.

A standard division of useful exergy flows is in the following categories (predominantly of heat and mechanical work, with a few others): high temperature heat (HTH), medium temperature heat (MTH), low temperature heat (LTH), stationary mechanical drive (SMD), mobile mechanical drive (MMD), lighting, other electrical uses. HTH is closely associated with energy use type (1). Residential LTH and the passenger component of MMD are closely associated with energy use type (3).

High temperature heat uses are essentially for the iron, steel, and non-metallic mineral industries (cement, ceramics, glass and lime). Hence, their output is very much associated to investment, namely machinery and transportation vehicles (iron and steel). During industrialisation, this type of investment increases disproportionately to GDP.

Recent results lead us to hypothesise that energy type (2) intensity is approximately constant along time and between countries:

1. Serrenho *et al.* (2014b) find that UE/GDP is roughly constant for Portugal, 1856-2009, at a value of around 1 MJ/2010 €.
2. Serrenho *et al.* (2014a) find that for the EU15, in the period 1960-2009, UE/GDP is statistically constant along time and equal for all countries, after removing the effects of residential energy use (which is dominated by the latitudinal difference in countries regarding domestic heating requirements) and of high temperature uses (which reflects the very variable significance, along time and between countries, of heavy industry).

Regarding 1., machinery for industrialisation in Portugal was essentially imported, so industrialisation did not have a strong effect on increasing HTH uses. Also, Portugal has a mild climate and low income, so residential LTH use is not very significant.

Consider now the agriculture – industry – services transition. HTH is mostly significant in the middle of the period, so it is not relevant in comparing the initial and final UE/GDP values. This explains the fact that UE/GDP in the UK in 1700 and in 2010 are similar (Serrenho, 2013).

Supporting evidence comes also from the results of Kaufmann (1992), who was able to create a statistical model for primary energy/GDP in the post-war period in France, the Federal Republic of Germany, Japan and the United Kingdom just with four variables (Sorrell, 2007): (1) percentage share of different energy carriers in primary energy consumption; (2) fraction of GDP spent directly on energy by households; (3) fraction of production that originated in energy intensive manufacturing sectors; (4) primary energy prices. If we note that (1) and (4) are essentially explaining changes in primary energy intensity, we see that (2) and (3) are our explanatory factors.

We discuss the additional empirical basis for these results considering other useful exergy studies carried out until now, analyse the implications regarding trends in primary energy and final energy intensities, and set up a research plan for further testing, analysis and interpretation of this hypothesis.

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