



André Cabrera Serrenho (IST), Benjamin Warr (INSEAD), Robert U. Ayres (INSEAD), Tânia Sousa (IST), Tiago Domingos (IST)

Title: *Useful work accounting in Portugal from 1856 to 2009*

Abstract:

In this work we present a detailed methodology for useful work accounting. This methodology centers the analysis of energy (or exergy) accounting on final uses instead of energy sources, contrarily to traditional analysis. Because the diversity of end-use efficiencies depends on types of use, a useful work accounting shall focus its analysis in the uses, rather than in the energy sources or carriers. Therefore, as final energy (or exergy) uses and its efficiencies differ in their nature, grouping them in different categories allows the study of evolutions in the paradigms of energy uses and, consequently in efficiencies' structural changes. Besides as the methodology is based on energy data per energy source/carrier, the analysis also capture the structure of existing energy mixes.

We define 5 different categories of energy uses with similar efficiencies in order to study evolutions in the paradigm of energy uses and efficiencies' structural changes: heat, mechanical drive, light, other electric uses and muscle work.

We apply this methodology to account for useful work in Portugal from 1856 to 2009. Portuguese final exergy consumption and useful work dramatically increased since mid-19th century. However in this period structural changes in the mix of exergy final consumption took place. It is very visible the transitions from combustible renewables carriers, namely firewood, to coal and later to oil and electricity. Also, the share of food in the societal exergy inputs dramatically decreased with the massive use of high-density energy carriers. Food and feed products evolved from essential to not relevant in the Portuguese energetic context.

Types of energy use have also changed. In this context is more adequate to analyze the evolution of useful work share of each useful work category than analyze the share of exergy by type of use. Useful work shares by useful work categories are much more constant and influenced by structural changes in the demand for energy services. The structure of useful work categories changed in the analyzed period in Portugal. Such changes show a transformation of useful work needs. The economy evolved to a much

more dependency for mechanical drive services than in the past. Also, other electric uses and higher temperature heat uses gained importance. These changes take effect as a consequence of the industrialization of the country and mobility needs that drove to increases in the transport sector energy uses. Notwithstanding, these changes occur slowly and in very well defined historical periods.

Contrarily to the trends in energy and exergy intensity, useful work intensity varies no more than 20% above and below its 154-year average value since 1856 in Portugal. This result seems to confirm the assumption that useful work allows for an analysis closer to final uses, centered in types of exergy use and energy service provided rather than a quantitative description of the amount of energy resources used to the same result.

The constancy of useful work intensity enables further research concerning future GDP growth trends. The consistency of such result must be confirmed by running the presented methodology for other countries. If so, the consistency of previous results relating the strong relation between useful work and economic growth (Warr et al. 2010) may be confirmed and new insights on growth theory may be obtained.

Keywords: energy; useful work; efficiency; energy transitions.

References: WARR, B. AND AYRES, R.U. Evidence of causality between the quantity and quality of energy consumption and economic growth. *Energy*, 2010, 35 (4): pp. 1688-1693.