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Assessing the sustainability of the UK society using thermodynamic concepts: Part 1

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ABSTRACT

This paper provides a concise overview of the influence of human activity within the UK society on resource consumption and the subsequent effects on the environment. The concept of the Multi Scale Integrated Analysis of Societal Metabolism (MSIASM) is applied in order to elucidate the evolution of the UK economy for the period between 1981 and 2004. Our findings highlight the transition to a service-based economy and the disproportionate increase of energy demand when compared to the overall population increase. Emergy synthesis is applied in order to understand the production and consumption patterns and the environmental support required to sustain human activity within the UK for the year 2004. Generally speaking the UK society greatly benefits from its significant natural resources with 44.3% of the total emergy used coming from home sources and 29.1% from locally renewable sources. Interestingly enough, despite its significant natural resources, the UK economy, seems to be a net emergy importer by 638.5×10^{21} seJ. Furthermore, the current economic activity is believed to have a significant impact in the environment despite the relatively low environmental load ratio of 2.44.

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1. Introduction

There has been considerable discussion over the past 20 years about the concept of sustainable development and its assessment. Since the onset of this debate, a large number of tools have been designed in order to capture the progress towards sustainability in a quantitative manner. A family of such techniques that has gained some acceptance amongst academics is based on thermodynamic concepts and accounts for the consumption and transformation of energy flows within a system. Methodologies that have embraced this viewpoint can be traced before the 1970s but it was the two oil crises and the accompanying concern for the need to conserve energy in industrialised nations [1] that gave a boost to their development and use. Thermodynamic accounting frameworks are generally able to capture the resource use (in the broadest sense) within a society. Whether such methodologies actually represent thermodynamic limits in a physical sense or are just a weak

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analogy or metaphor is still open to debate [2] the fact remains that they can significantly contribute to the current discussions about sustainable development. Central to all these methodologies, albeit not explicitly stated, is a common concern over resource depletion and environmental degradation [1]. The different aspects of sustainable development that can be elucidated by such tools have been discussed elsewhere in greater depth [3].

Despite the large number of sustainability assessment methodologies based on thermodynamic concepts found in the literature, in very few cases have these techniques been applied jointly on the same system. This two-part study bridges that gap by reporting on the application of four such methodologies for assessing the sustainability of the UK for the year 2004. Given that each technique illuminates certain aspects of a complex system's metabolism, integration of their findings is expected to assess more comprehensively the current production/consumption patterns and offer advice to policy makers for facilitating a shift towards sustainability. The different frameworks employed in the first part include Multi Scale Integrated Analysis of Societal Metabolism (MSIASM) and emergy synthesis (EmS) while exergy (EA) and extended exergy analysis (EEA) are employed in the second part.

Despite certain methodological differences all these techniques share several similarities. Based on the distinction between "upstream" and "downstream" impact assessment methodologies [4], all these techniques can fit into the "upstream" category given that they seem in a way to quantify the amount of resources (in the broadest sense) used to sustain human activity within a nation for a given year. Furthermore all these methodologies are in a sense biophysical sustainability accounting frameworks that are based on a "*cost of production*" theory of value rather than a "*subjective preference theory of value*" as in conventional economic analysis: refer to [5] for a distinction between the two terms and to [6] for their relevance to sustainability assessments. Furthermore, it has been claimed [7] that a theory of value based on energy can satisfy the criteria for a "*cost of production*" theory of value given that energy can be considered the "only" scarce factor of production because:

- it is ubiquitous;
- it is a property of all of the commodities produced in human and natural systems;
- its essential property cannot be substituted for.

It is worth mentioning here the similarities between the "*cost of production*" theory of value with what H.T. Odum designated as a donor-side point of valuation [8]. As a result all the biophysical tools utilized in our study fail to take into consideration human preferences and they have been criticized on these grounds in the past, e.g. [9]. However their relevance and importance for assessing the progress towards sustainability has been discussed elsewhere in the literature, e.g. [10,11]. We believe that our analysis can provide valuable information for better understanding a nation's metabolism through the utilisation of a variety of different tools based on thermodynamic concepts. MSIAM provides information on the exosomatic energy consumed in order to support human activity within various productive and "non-productive" sectors of the society. Its highly aggregated format can provide a quick snapshot of past and current trends and give hints on the sustainability of the current development path. EmS essentially quantifies the environmental support required to produce all the inputs that are consumed by the society while the total emergy consumed is an indication of its total appropriation of environmental services [4]. Finally EA and EEA make use of the concept of efficiency which has a more direct relationship with the market logic while at the same time it considers the qualitative differences between the different energy forms [4]. To better appreciate the insights relevant to sustainable development that can be provided by applying these different methodologies the reader is referenced to the introductory and methodology sections of our study and the referenced literature.

We should note that we do not view our sustainability assessment as comprehensive in the sense that it excludes human preferences (tools that employ a "subjective preference" theory of value) and does not adequately captures the consequences of a system's emissions (only "upstream" methods used). For a comprehensive sustainability assessment the inclusion of tools that are not based on thermodynamics is essential but we consider that this falls outside the scope of our study which is to highlight how tools based on thermodynamics can provide information relevant to the sustainability of a system.

The system under consideration is the United Kingdom of Great Britain and Northern Ireland (UK thereafter) for the year 2004. The 14 overseas territories as well as the territories of Jersey, Guernsey and of the Isle of Man have been excluded from our analysis.

The UK is an island nation situated in the North West of Europe having land borders only with the Republic of Ireland while it is surrounded by the Atlantic Ocean, the North Sea, the Irish Sea and the English Channel. With a population of just over 60 million the UK is both one of the most populous and one of the most densely populated European countries. It is also one of the major economies in the world, currently having the second highest gross domestic product (GDP) in Europe and the fifth highest in the world [12,13]. From a traditionally industrial nation the UK has been transformed from the 1950s onwards to a nation where the service sector spearheads the economy.

Interestingly enough the UK has significant fossil fuel reserves with their exploitation becoming economically feasible only during the 1980s as a result of the rising prices of fossil fuels initiated by the two oil crises. It is ranked amongst the 10 largest oil producing nations worldwide and together with Norway and Russia is the only European nation endowed with significant such resources. Furthermore the UK is one of the five largest producers of natural gas worldwide. Most of the oil and natural gas reserves are located offshore in the North Sea region and in order to tap these offshore fossil fuel resources the UK has claimed an extended continental shelf in the areas north and west of Scotland. The continental shelf is an important source of renewable emergy contributing significantly to a nation's wealth by providing important services such as climate mitigation, fisheries, solubilisation of nutrients from coastline, etc. However in cases such as the UK where extensive continental shelves are claimed for exploration, inclusion of the whole area of the continental shelf would overestimate the contribution of the renewable emergy sources sending misleading messages on the sustainability of the UK. In our EmS calculations we considered the continental shelf as the area of the continental margin which is between the shoreline the point where the depth of the superjacent water is approximately 200 m.

2. Methodology

2.1. MSIASM

The Multi Scale Integrated Analysis of Societal Metabolism (MSIASM) was introduced in [14–16]. The theoretical foundations of MSIASM are based on concepts popularised by Alfred Lotka and Nicholas Georgescu-Roegen [17]. In more detail MSIASM can be viewed as an operationalisation of Georgescu-Roegen bioeconomic approach that combines data on flows (exosomatic energy, GDP, food production, etc.) and funds (human time, land use, etc.) associated with the system under study (the UK in our case) [17]. Given that in this series of papers our analysis is focused on different energy accounting frameworks and the insights that they