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Reducing energy demand: A review of issues, challenges and approaches

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ABSTRACT

Most commentators expect improved energy efficiency and reduced energy demand to provide the dominant contribution to tackling global climate change. But at the global level, the correlation between increased wealth and increased energy consumption is very strong and the impact of policies to reduce energy demand is both limited and contested. Different academic disciplines approach energy demand reduction in different ways: emphasising some mechanisms and neglecting others, being more or less optimistic about the potential for reducing energy demand and providing insights that are more or less useful for policymakers. This article provides an overview of the main issues and challenges associated with energy demand reduction, summarises how this challenge is 'framed' by key academic disciplines, indicates how these can provide complementary insights for policymakers and argues that a 'socio-technical' perspective can provide a deeper understanding of the nature of this challenge and the processes through which it can be achieved. The article integrates ideas from the natural sciences, economics, psychology, innovation studies and sociology but does not give equal weight to each. It argues that reducing energy demand will prove more difficult than is commonly assumed and current approaches will be insufficient to deliver the transformation required.

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1. Introduction

Improving energy efficiency and reducing energy demand are widely considered as the most promising, fastest, cheapest and safest means to mitigate climate change. Many opportunities appear to be cost-effective at current energy prices and can deliver additional benefits such as improved energy security, reduced fuel poverty and increased economic productivity. Reflecting this, the International Energy Agency (IEA) and other bodies are placing increasing priority on reducing energy demand, the European Commission has proposed long-term targets for energy demand reduction and countries throughout the world are introducing a range of policies to deliver those reductions.

But previous attempts at reducing energy demand have not always been successful. Frequently, the assumptions on which policy interventions are based do not adequately reflect either the challenges

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involved or the factors shaping individual and organisational decision-making. Moreover, the complexity of economic systems can lead to unintended and unanticipated consequences from those interventions that may undermine the original aims. Policies are usually informed to varying degrees by ideas from academic research, but different academic disciplines approach the challenge of reducing energy demand in different ways—emphasising some mechanisms and neglecting others, preferring some methodological approaches and sources of evidence over others, and providing competing recommendations. In turn, different disciplines are more or less optimistic about the potential for reducing energy demand and provide insights that are more or less useful for policymakers.

The aim of this article is to provide an overview of the issues associated with energy demand reduction, to summarise the 'framings' of this challenge by the academic communities that are most influential in this area and to argue that a 'sociotechnical' perspective can offer additional insights. The article integrates ideas from the natural sciences, economics, psychology, innovation studies and sociology but does not give equal weight to each—for example, it does not discuss the application of social practice theory to energy demand [1]. The aim is not to provide a comprehensive review of the literature, but instead to highlight key issues and challenges, to indicate how different approaches can provide complementary insights and to suggest a way forward. In doing so, it is hoped that the article will help improve understanding between different disciplinary perspectives.

The article is structured as follows. Section 2 begins by exploring the close link between energy demand and the scale of physical and human systems, while Section 3 examines the complex and contested relationship between energy consumption and economic growth. Section 4 summarises the multiple interpretations of improved energy efficiency and shows why the relationship between this and reduced energy demand is far from straightforward. Sections 5 and 6 summarise the key insights into the determinants of energy demand provided by orthodox and behavioural economics, social psychology and innovation studies and argues that each of these can inform the design of energy efficiency policy. However, current approaches seem unlikely to deliver the scale and speed of reductions in energy demand that are likely to be required to mitigate climate change. Section 7 argues that these more radical demand reductions imply fundamental changes in the 'sociotechnical systems' that provide energy services, and briefly discusses how such changes may come about. Section 8 concludes.

2. System scale and energy demand

2.1. *An understanding of energy demand must begin with the natural sciences*

Energy is a mysterious property of objects and systems that can be neither created nor destroyed, but can be transferred from one system to another and converted from one form to another. Since not all forms of energy are equally useful, a more relevant quantity is *exergy* or the availability to perform physical work. Exergy is a measure of both the quantity and quality of energy and, unlike energy, can be destroyed during conversion processes (e.g. in the conversion of electricity to low temperature heat). Energy – or more precisely, exergy – is of unique importance in nature because nothing functions without it. Complex physical systems such as organisms, ecosystems and human societies exist far from thermodynamic equilibrium and can only be maintained in this state by a constant throughput of high quality energy from outside the system—with larger and more complex systems requiring larger energy flows.

Biologists and ecologists have identified remarkably consistent and apparently universal relationships between the physical scale of systems and the size of these of energy flows, based upon quarter power exponents [2,3]. For example, the metabolic rate of organisms scales with the three-quarter power of mass over 27 of orders of magnitude, from the smallest microbes to the largest mammals [2,4]. There appear to be common principles underlying this universal relationship, linked to the evolutionary optimisation of the fractal-like branching networks that supply energy and materials to organic systems—such as the vascular system of plants and the circulatory system of mammals [4].

Since human societies rely upon analogous networks for distributing energy, water, food and other materials they may be subject to comparable constraints and hence exhibit comparable relationships between system scale and energy flows [5]. While drawing analogies between physical and human systems can be problematic, it is demonstrably the case that larger, wealthier, more populous and more complex societies require larger energy flows. Such societies evolved by accessing progressively larger energy flows and they cannot be sustained in the absence of those flows [6]. The massive increases in global population and wealth since the beginning of the 19th century have been associated with equally massive increases in energy consumption, derived largely from the 'energy surplus' provided by fossil fuels (i.e. the energy available from those fuels after subtracting the energy used to obtain them). Specifically, the sevenfold increase in global population since 1800 has been paralleled by a four-fold increase in per capita primary energy consumption (eight-fold in the industrialised world), leading to a 27-fold increase in global energy consumption [7].

The rate of growth of global primary energy consumption has been remarkably stable since 1850 (2.4%/year $\pm$0.08%) and shows no sign of slowing down [8]. Hence, if energy demand reduction is to be measured as a departure from this 150-year trend, there appears to be little sign of it yet at the global level. However, since primary energy consumption (E) has grown more slowly than gross domestic product (GDP) (Y), there has been a steady decline in global energy intensity (E/Y) and hence a steady increase in energy productivity (Y/E), with the precise trend depending upon how these variables are measured. Aggregate energy consumption is commonly expressed as the product of population (P), per capita wealth (Y/P) and energy intensity (E/Y), but many factors contribute to these aggregate ratios and more disaggregated breakdowns are required to understand their trends. The IEA [9] estimate that global energy intensity declined by 1.3%/year between 1990 and 2000, but this slowed to 0.4%/year after 2000 as a consequence of emerging economies (notably China) accounting for a larger proportion of global GDP. These economies are more energy intensive than the global average, but they are also reducing their energy intensity (and growing their economies) at a more rapid rate.

Regional trends in economic growth and energy consumption underpin this global picture and are consistent with it. For example, Brown et al. [10] examined 220 countries over 24 years and found that, on average, every 1% increase in per capita wealth was associated with a 0.76% increase in per capita energy consumption. As the authors observe, the closeness of this result to the three-quarter power relationship observed in natural systems may not be a coincidence. Similarly, Csereklyei et al. [11] analysed 99 countries over the period 1971–2010 and found a comparable elasticity of approximately 0.7—implying that energy intensity is lower in richer countries and that, on average, a 1% increase in per capita income is associated with a 0.3% decrease in per capita energy intensity. This result was derived from repeated cross-sectional analyses of national data and indicates that the per capita energy use associated with any given level of per capita income has not changed for four decades. The long-term decline in regional and global energy intensity is therefore due to countries getting richer rather than from producing particular levels of wealth with less energy. This in turn suggests that the technological changes that have reduced energy intensity are strongly correlated with the technological changes that have increased per capita wealth.