Chapter 20
Data Envelopment Analysis Approach to Compare the Environmental Efficiency of Energy Utilization

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ABSTRACT
Due to increasing financial and environmental concerns, governmental rules, regulations and incentives, alternative energy sources are expected to grow at a faster pace than conventional sources of energy. However, the current body of research providing comparative decision-making models for conventional and alternative energy sources is limited. Furthermore, existing literature also falls short in offering a unifying model that benchmarks the technical efficiencies of countries in terms of their energy usage in relation to environmental impact. This paper proposes two sets of Data Envelopment Analysis (DEA) models to calculate and rank the technical efficiencies of (i) conventional and alternative energy sources for the United States, and (ii) energy usage of selected countries depending on various criteria. The first set of DEA models considers both the economics of energy sources and additional environmental criteria such as CO₂ emissions and damage cost. The second set evaluates the relative technical efficiencies of the top 25 petroleum consuming countries in the world in terms of the environment. Numerical examples are also included to demonstrate the functionality of the proposed models.

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INTRODUCTION

Energy is defined as the capacity for doing work, as measured by the capability of accomplishing work (potential energy) or the conversion of this capability into motion (kinetic energy) (EIA, 2008a), and its demand is proportional to the need for products and services. Today, for the first time in history, there are more people living in urban than rural areas (Bettencourt, Lobo, Helbing, Kuhnert, & West, 2007; Crane & Kinzig, 2005; Marshall, 2007; UN, 2004), therefore contributing to significant increases in demand for energy in the U.S. and around the world. Currently, approximately 85 percent of this demand is supplied by energy obtained from fossil fuels (Figure 1). However, increasing scarcity and cost of nonrenewable fossil fuels are most likely to force the U.S. and other energy-importing nations to either reduce energy dependency and/or obtain alternative means of energy production and conversion (Rosentrater & Kongar, 2007).

Where energy conversion is concerned, low-technology usually implies low efficiency and high pollution, whereas high-technology often implies higher efficiency and relatively lower environmental impacts. Thus, conversion technology is a critical link between the supply of energy services and access, affordability, and environmental compatibility (Mallon, 2006). Therefore, when deciding on energy alternatives to implement or pursue, methods for assessing environmentally-relevant factors are needed which take economic, technical, and especially ecological criteria into account simultaneously (Geldermann & Rentz, 2005).

Energy conversion alternatives can be mainly classified as renewable or non-renewable. Renewability, or non-renewability, is distinguished based on the energy storage or cycling time involved. Depletable resources include fossil fuels, which are non-renewable since the rate of their utilization far exceeds the rate at which they are formed. The major categories of renewable energy technologies

Figure 1. U.S. Energy Consumption by Energy Source, 2007 (Quadrillion (1 x 10^15) Btu) (EIA, 2008f). (All categories sum to 100%)
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