Exploring past energy changes and their implications for the pace of penetration of new energy technologies

P.D. Lund*  
Helsinki University of Technology, TKK, P.O. Box 4100, FIN-02015 TKK (Espoo), Finland

Abstract

Possible growth paths for new electricity generation technologies are investigated on the basis of an empirical analysis of past penetration rates. Finding and understanding high market penetration scenarios is relevant to formulating climate change mitigation strategies. The analysis shows that under favorable growth conditions, photovoltaics and wind could produce 15% and 25%, respectively, of world electricity by 2050. Under the same assumptions nuclear power could increase to 41% of world electricity. But it is unlikely that all three technology paths could be realized up to these values simultaneously and therefore the penetration rates presented here should be considered as indicative only. The results show that under positive conditions, an embryonic technology could move as a preferred option into a mainstream energy source within half a century. The introduction of growth constraints reflecting, e.g., severe economic, technical, or political limitations could reduce the above numbers by a factor of up to 2–3. The results indicate a decline in the relative year-to-year growth of new technologies when they have higher market shares. A comparison of the results with other short-term and long-term technology scenarios shows satisfactory agreement.

© 2009 Elsevier Ltd. All rights reserved.

1. Introduction

Massive introduction of clean and sustainable energy sources will be necessary to meet the challenges of mitigating climate change. According to the UN IPCC, 50–60% of the global energy system needs to be changed in half a century [1]. In industrialized countries even more radical levels may be needed. A recent suggestion by Sir Nicholas Stern that yearly CO₂ emissions should be limited to 2 tons CO₂/capita by 2050 would mean an 80% reduction from the present level for the European Union [2]. Limiting the rise of CO₂ to a level that keeps climate change moderate would, in practice, require zero-emission power production and near zero-emission transport.

Such CO₂ emission stabilization targets would require the massive introduction of clean technologies onto the market, along with energy being used more efficiently than today. There is a range of scenarios envisioning how this could be accomplished employing different technology options [1,3–5]. Under the present trend, though, fossil fuels will dominate far into the future.

From a historical perspective the global energy system displays considerable inertia. Research in the late 1970s at the International Institute of Applied System Analysis (IIASA) showed that it had taken from 50 up to 100 years to witness radical changes in the market shares of energy sources on a global scale [6]. In the short term the energy system looks almost static. The time frame for reducing emissions radically (ca. 40–50 years) is thus challenging compared to the historical pace of energy change.

A most relevant question is, indeed, how fast new energy technologies could be introduced on a large scale. In this paper, this is approached through investigating the energy changes of comparable time intervals in the past, and interconnecting the dynamics of change of an individual energy technology to the global energy system. Finding upper limits for the growth of energy technologies empirically is of particular interest here, but so is how practical limitations such as resource constraints could affect this growth. Instead of modeling energy systems, an approach focusing on the industrial capacity and the volume growth of energy technologies was chosen. On the basis of empirical observations on the changes in market share of energy sources and the above analytical frame, the future penetration paths of new energy technologies are outlined.

Modeling changes in the energy system and making future predictions can be based on several different approaches, such as the following:

1. energy systems modeling in which the market shares are determined on the basis of the interaction of the demand and
market share of a new technology is negligible, in spite of any
energy technologies to meet the energy demand, given the
which uses cost optimization to identify least-cost mixes of
greenhouse gas emissions [17]. Electricity production is one of the
mainly on power production, which represents close to 30% of all
specific volume or capacity growth estimation. The study focuses
penetration of new energy technologies is based on a technology-
detailed analysis of socioeconomic and system aspects of elec-
tricity systems [15,16].

2. Methodology for modeling energy change

2.1. General observations

The diffusion of a new technology has distinctive phases,
starting with a slow market entry, followed by a growth phase
and finally ending in market saturation [18]. At the beginning
the market share of a new technology is negligible, in spite of any
yearly capacity growth rate. When entering higher market shares
that are important for the relevance of the energy, the growth rates
are expected to decrease as a result of different limitations on
physical and financial resources, infrastructure, etc. Fig. 1
demonstrates the above observation on a global scale, based on data from
Over the past 40 years the observed yearly variations in the
volume changes of the different energy sources have ranged from
a few percent per year up to percentages countable in tens. New
energy sources show high growth rates, whereas traditional energy
sources with high market shares tend to grow much more slowly
and in a manner closer to the average growth of the energy
demand.

2.2. Analytical framework

The above observations were used as a basis to define the
relationships between the changes in volume (ΔV) and market
shares (fi) of energy technologies.

There are different methods available to describe market
penetration and changes in market shares. In sophisticated energy
system and equilibrium models [7–14,20] the effects of supply- and
demand-side factors on market penetration can be considered
during details such as the cost of the new technology, the cost-
supply curves, the market structure, etc. In this paper and in clas-
tical technology diffusion models, penetration is described in
a simpler way, through parameterization. On the other hand, if
favorable or almost ideal growth conditions are assumed, as in this
paper, several critical factors, such as the cost and supply issues, can
be overcome. The literature on diffusion models is vast and
comprehensive reviews can be found, e.g. in [21–23]. The mathe-
matical models used for diffusion typically yield an S-shaped
penetration curve, which may be either symmetric or asymmetric
around the inflection point. These models are capable of describing
both adoption and substitution processes for the new technology.

Diffusion models have been successfully applied in many tech-
nology fields [24] and in energy as well [25,26]. Marchetti and
Nakicenovic [27] used a two-parameter S-shaped logistic substi-
tution model to study changes in the global energy system and
predict the future market shares of energy sources.

In the classical diffusion model, the diffusion results from the
spread of information, which originates from analogies in the
epidemic theories of diffusion. These types of models overlook
several important factors that affect diffusion. In more sophisti-
cated diffusion models, such as the probit or hazard models, a range
of different factors influencing the underlying decision-making
process of the diffusion can be taken into account better, for
example the cost of adopting the new technology [33]. Rose and

Fig. 1. Year-to-year volume (ΔV) changes in global primary energy. The percentage in
brackets in the legend are the present world market shares of energy sources (fi).
دریافت فوری متن کامل مقاله

امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات