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Energy Policy 34 (2006) 3317–3326

ENERGY POLICY

www.elsevier.com/locate/enpol

Market penetration rates of new energy technologies

Peter Lund*

Advanced Energy Systems, Helsinki University of Technology, P.O. Box 2200, FIN-02015 TKK, Espoo, Finland

Available online 10 August 2005

Abstract

The market penetration rates of 11 different new energy technologies were studied covering energy production and end-use technologies. The penetration rates were determined by fitting observed market data to an epidemical diffusion model. The analyses show that the exponential penetration rates of new energy technologies may vary from 4 up to over 40%/yr. The corresponding take-over times from a 1% to 50% share of the estimated market potential may vary from less than 10 to 70 years. The lower rate is often associated with larger energy impacts. Short take-over times less than 25 years seem to be mainly associated with end-use technologies. Public policies and subsides have an important effect on the penetration. Some technologies penetrate fast without major support explained by technology maturity and competitive prices, e.g. compact fluorescent lamps show a 24.2%/yr growth rate globally. The penetration rates determined exhibit some uncertainty as penetration has not always proceeded close to saturation. The study indicates a decreasing penetration rate with increasing time or market share. If the market history is short, a temporally decreasing functional form for the penetration rate coefficient could be used to anticipate the probable behavior.

Keywords: Technology diffusion; Penetration rate; New energy technologies

1. Introduction

The inertia of energy systems against changes is large, among others because of the long investment cycles of energy infrastructures or production plants. Energy is a basic commodity for which reason the price often dominates the competition over innovative features. Earlier studies have shown that the build up of present primary energy sources on a global scale from an embryonic to a significant market position took about a century (Shell International, 2001; Davis, 2001). On the other hand, new renewable energy sources have shown remarkably high market growth rates during the recent years (International Energy Agency, 2004a). Moving across the whole energy chain brings forward end-use and consumer products, which affect the total energy demand through their specific energy consumption. Here the capital turnover times are much shorter than in the energy production end, which could result in faster energy impacts through the energy-saving features.

Traditionally, energy system modeling has shed light on the above questions through scenarios on the energy future. The underlying methodology is often based on forecasting the cost development of new technologies and consequent penetration based on their cost competitiveness (European Commission, 2003). Technology learning or experience curves that describe the decrease of unit costs with increasing production volumes have proved to be useful aids for macro models (Wene, 2002). Statistical models of technology adoption or technology diffusion models are examples of approaches in which the penetration is mathematically described as a diffusion process resembling epidemic growth. Diffusion theory is a well-established field of science and the literature on diffusion of different technologies is ample. Logistic diffusion curves have been previously applied to modeling of changes in the global energy system (Häfele, 1981). Energy efficiency indicators or energy intensity

*Tel.: +358 9 4513218; fax: +358 9 4513195.
E-mail address: peter.lund@tkk.fi.

0301-4215/$ - see front matter
doi:10.1016/j.enpol.2005.07.002

coefficients are a way to describe the development in energy use (Schipper and Meyers, 1992) and indirectly the diffusion of more efficient end-use technologies. These can also be applied even on the level of a single appliance (Enerdata, 2004). The number of patents has been used to describe diffusion of environmentally responsive technology (Lanjouw and Mody, 1996).

The main objective here is to investigate how fast different new energy technologies penetrate to the market. In present approach, a diffusion model is applied to long-term real market data of 11 different technologies to reveal penetration rates and to enable comparison of these. The 20 data sets used in this study cover different geographical scope from single countries to global data, technologies with varying market maturity, and also a few established reference cases or benchmarks (nuclear energy, oil) for comparison. Both energy production and energy end-use technologies are considered.

2. Methodology

When estimating and comparing the market shares of new technologies over time it is most important to use a commensurable and reliable metrics as technologies are in practice in different stages of development. For example, near saturation or at high market shares, the yearly market growth rate can be expected to decrease whereas a technology just entering the market may reach huge yearly growths as the initial volumes are very low. Therefore just using year to year growth rates as an indicator may give a misleading signal of the penetration.

Diffusion modeling is often used for describing technology changes. In present study, a diffusion model is applied to measured market data using then the fitted diffusion parameters to describe the penetration. The diffusion theory describes per se the penetration or adoption of a new technology on the market and therefore contains a proper methodological basis for our purpose (Geroski, 2000). Diffusion research is very vast; both in terms of models, cases studied and disciplines involved (Stoneman, 1995). Often the resulting models used resemble S-shaped curves (Davies, 1979). Classics in the field are for example Mansfield's or Rogers' works (Rogers, 1995). Rogers classified the users of the new technology into groups according to their readiness to adopt and use the new technology. The decision making process of using a new technology would depend among others on information and past experience which would lead to a S-shaped diffusion (epidemic theory). Mansfield relates diffusion to the uncertainty and risks surrounded around new technologies. Another class of statistical adoption models is the hazard models, which focus on transition probabilities, where the sequence of choices made in the past affects every choice decision.

2.1. Diffusion model

The diffusion process can be presented mathematically in a quite simple way. Assume that the number of users or products of the new technology on the market at time t is $V(t)$. Then the remaining potential for the new technology is $V^* - V(t)$, where V^* is the total potential of the new technology. If the adoption rate of the new technology is β then during an infinitesimal time interval $\mathrm{d}t$ the usage will increase by $\mathrm{d}V$ equal to

$$\mathrm{d}V = \beta \frac{V}{V^*}(V^* - V)\,\mathrm{d}t. \quad (1)$$

Denoting $f(t) = V(t)/V^*$ in Eq. (1), where $f(t)$ is the market share or share of potential realized, Eq. (1) can be rewritten in the form

$$\mathrm{d}f = \beta f(1-f)\,\mathrm{d}t. \quad (2)$$

Assuming that β is constant, e.g. using an average value, Eq. (2) can be solved by integration yielding the well-known logistic time curve

$$f(t) = \frac{1}{1 + a_0\,\mathrm{e}^{-\beta(t-t_0)}}, \quad (3)$$

where the coefficient a_0 is

$$a_0 = \frac{1 - f(t_0)}{f(t_0)}. \quad (4)$$

Clearly $f(t_0)$ need to be >0 which means that the model explains diffusion after some number of early users has already entered the market.

The above equation can be conveniently rewritten into a compact form

$$f(t) = \frac{1}{1 + \mathrm{e}^{-\beta t + \alpha}}, \quad (5)$$

where α represents the integration constant. Comparing Eqs. (4) and (5) shows that α is equal to $\beta t_0 + \ln(a_0)$.

The temporal increase of the market share is obtained from Eq. (5) by differentiating:

$$\frac{\mathrm{d}f}{\mathrm{d}t} = f' = -\beta \times \mathrm{e}^{-\beta t + \alpha} \times \frac{1}{(1 + \mathrm{e}^{-\beta t + \alpha})^2}. \quad (6)$$

f' has a well-known inflexion point and maximum at $t = \alpha/\beta$ which we denote $t_{50\%}$. The market share f at $t_{50\%}$ is 1/2, or 50% of the potential, and $f' = \beta/4$.

The relative market growth rate can be written as

$$\frac{\mathrm{d}f/\mathrm{d}t}{f} = -\frac{\beta}{1 + \mathrm{e}^{\beta t - \alpha}}. \quad (7)$$

Eq. (7) decreases as a function of time ($\rightarrow 0$ when $t \rightarrow \infty$). When the market fraction is high, the natural relative market growth rate is lower than for a technology just entering the market. Therefore, using e.g. the annual market growth rate for comparing different technologies would not give a true picture of the penetration.