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Energy policy planning near grid parity using a price-driven technology penetration model

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ABSTRACT

Here we analyze the importance of the price differences between energy technologies for their market penetration. A price-conditioned technology diffusion model was shown to adequately describe the market take-up of solar and wind penetration and natural gas (shale gas) with respect to the (subsidized) price. Because of the simplifications made to the energy system and the economic framework the results are indicative only and limited to less complicated policy cases. The model was used to investigate the effects of public support on the market shares of renewable electricity technologies. The results indicate that a dynamic support structure for new energy technologies may be necessary as their market share increases. At market entry "oversubsidizing" may be necessary, but, when the share grows beyond a certain percentage, cutting down on subsidies will be necessary to avoid the overheating of the market, which could otherwise lead to exponential growth and a huge need for financial support. If the aim is a swift transition to sustainable energy, a price ratio of around 1:3 (new:old) or higher may be necessary in industrialized countries, but in emerging economies, a lower ratio of 1:2 could apply. When the new technology passes the grid parity landmark by 30%, the natural (non-subsidized) penetration rate could settle at 1% of the total market per year, but with more ambitious policy goals some support may be necessary even then.

1. Introduction

The grand challenges in energy and climate call for major changes in the energy system to replace carbon-intensive energy sources with clean energy options, such as renewable energy. The magnitude of the change that is necessary is huge: global carbon emissions need to be more than halved by 2050 [1]. As energy is a commodity, the cost of energy sources often determines their market shares, meaning that the more costly new and clean energy sources need public support to gain market share. As a matter of fact, energy policies and policy measures often 'manipulate' the differences in energy prices through financial and fiscal or other measures to enhance diffusion [2,3] and to achieve the policy goals [4] motivated by, e.g., climate change mitigation, energy security, or industry competitiveness, among others.

Renewable energy technologies are the focus of the energy policy in many countries [5]. Recent progress in new renewable energy (RE) has been impressive in terms of both volumes and costs. For example, the installed capacity of wind power is reaching the 300 GW mark globally, and that of photovoltaics (PV) 100 GW_p, although this development has been driven by a generous public hand [6]. These technologies now represent around 3.5 and 0.5% of all electricity, respectively. In a recent market survey, the International Energy Agency foresaw that renewables will outstrip gas in the global power mix and provide twice as much as nuclear as early as by 2016 [5]. The IEA World Energy Outlook from 2012 forecasts a 30% share for RE electricity by 2035 [7,8]. Several countries have set very

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Nomenclature

a	replacement rate of existing power capacity (%/yr)
b	scalar parameter
C	cost
df_i	yearly change in market share
F	function
f_i	market share
K,L	parameters
p	innovation coefficient
P	probability
q	imitation coefficient
r	return rate on investment
t	time
x	multipler
X	marketing variables
V	volume or capacity
V_i	volume of capacity of the new technology
V'	volume of capacity of the existing technology
α	yearly power demand growth (%/yr)
β	net expansion rate of the new technology
η	efficiency
γ	empirical parameter values
σ	spread

Subscripts, superscripts

cost	cost
el	electricity
i	technology type
inv	investment
k	time step
mar	market
max	maximum
new	new technology
old	old or existing technology
op	operating, operational
0	variable value at $t = 0$
theor	theoretical

Abbreviations

BOS	balance of system
FiT	feed-in-tariff
LCOE	life-cycle cost of electricity
NG	natural gas
O&M	operation and maintenance
PV	photovoltaics
RE	renewable energy or renewable electricity
Y2Y	year-to-year

ambitious targets for future RE utilization, e.g., Denmark is aiming at 100% renewable energy in its energy production by 2050 [9] and Germany has an 80% RE electricity target [10]. The long-term scenarios by the IPCC [11,12], IEA [13], or Shell [14] also give a prominent role to RE in the global energy system. Theoretically, the resource base of renewable energy is enough to cover 100% of world energy demand [15,16].

At the same time, the price of new renewable technologies has gone down and it is approaching the grid parity (or cost parity) limit, reducing the importance of public subsidies. This has also resulted in uncertainty and instability in the public support schemes. For example, in Germany, Italy, and Spain the feed-in-tariff (FiT) support to PV has been cut, and in Greece it has even been done retrospectively. The RE business is also undergoing a very turbulent phase, where company margins are shrinking, bankruptcies are common, and trade wars are looming [17]. This is quite typical when the markets consolidate, which is a common phase in technology development.

The erosion of costs, growing volumes, turbulent business, and high future expectations make the energy policy planning of renewable energy demanding. Intuitively, one might think that once new energy technologies are cheaper than traditional energy, that would be enough for their market breakthrough. On the other hand, one could reason that the price difference may affect the pace of the adoption of the new technology. The vintage of technology, capital cycles, and technology characteristics (e.g. base versus peak load plants) also play an important role in this context. Clearly, energy policies still play a role as they influence and stimulate penetration through adjusting the price factors. Indirectly, these policies could also influence the competitiveness and global positioning of domestic RE industries and labor markets in RE, among others [18,19].

Motivated by the inherent importance of price as articulated above, we focus here on investigating the role of cost or price factors in the penetration and adoption of new energy technologies. Technical limitations or energy system integration issues, while also are important, are not considered as such here, but indirectly these could be incorporated into the methodology through a price component. We aim at gaining a better understanding of how price and price differences affect the adoption of the new energy technologies, and through this also to build a link to energy policy planning.

The market penetration of new technologies and energy has been described through different models [20–22], including energy technology specific models [23–27]. The influence of the price on market penetration has been investigated, in particular in the consumer goods segment, and models that include marketing mix variables have been reported. For example, the well-known Bass imitation/innovation diffusion model has been modified to include product price as an exogenous variable [28]. More sophisticated models that include multiple variables that relate to multiply price or economics have also been proposed [29], e.g., for household appliance ownership forecasting [29–31]. The price could affect the size of the market potential of a new technology or new product, but in particular the rate of adoption [32,33]. Bottomley et al. [33] concluded, however, that including the price in diffusion models would not markedly improve their predictive validity, but could provide support for decision making when evaluating

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