Energy xxx (2014) 1–9

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Stated preferences based estimation of power interruption costs in private households: An example from Germany

Aaron J. Praktiknjo

Department of Energy-Systems, Technical University of Berlin, Berlin, Germany

ARTICLE INFO

Article history:
Received 21 October 2013
Received in revised form
18 March 2014
Accepted 21 March 2014
Available online xxx

Keywords:
Power interruption costs
Value of lost load
Stated preferences
Households
Supply security
Renewables

ABSTRACT

Concerns regarding supply security are increasingly raised in reaction to the transition of the German energy system toward a renewable and nuclear-free system called "Energiewende". The goal of this work is to contribute to a measurability of supply security by quantifying the consequences of power interruptions monetarily. The focus lies within the investigation of power interruption costs in private households. An online survey with 859 participants in 2011 is used to gather the necessary data. Based on this data, a two-staged bottom-up regression model was estimated to describe interruption costs for durations of 15 min, 1 h, 4 h, 1 day and 4 days. Finally, micro-data from 55,000 households were used to perform Monte Carlo simulations to increase the representativeness of the estimations. The frequency distributions of the estimated interruption costs indicate potentials for load-shedding measures. Such measures could be an economically viable contribution to a successful integration of large shares of renewable fluctuating generation like wind or solar power.

1. Introduction

In his Review on the Economics of Climate Change, Stern [1] quantified the consequences of a climate change monetarily and created a measurability between the following two goals of energy policy: environmental sustainability and affordability. Stern's argument is that the consequences of non-action are more expensive than costs of action to protect the environment.

In reaction to this argument, the German electricity system is engaging in a very fundamental transition called "Energiewende" from fossil toward a renewable supply. The goals of the government are to increase the shares of renewables to 35 percent by 2020, to 50 percent by 2030, to 65 percent by 2040, and finally to 80 percent by 2050. In addition to these efforts to integrate renewables, as well as following the events of the nuclear catastrophe in the Japanese prefecture of Fukushima, the German government has decided to completely phase out nuclear energies by the year of 2022.

Facing the government's ambitious plans, more and more concerns regarding the security of supply are being expressed, see Ref. [2]. One of the greatest challenges of the German energy transition for the electricity supply lies in growing temporal discrepancies between electricity consumption and generation. Most of the renewable electricity is currently, and probably will be in the future, generated from fluctuating generators like wind or photovoltaic power plants. In 2013, 53.1 percent of the renewable electricity originated in these two types of power plants (a share of 12.4 percent of the total power generation in 2013), see Fig. 1 and Ref. [3]. The power generation is thus mostly independent from the actual demand and instead dependent on uncontrollable meteorological factors. In order to cover the demand even in times with low wind and sun, one of three options is to reduce demand by shedding load, aside from continuing to use conventional power plants and the operation of storage systems. The shedding of load seems to be an interesting possibility because of the following factors: conventional power plants are struggling more and more with decreasing full load hours and shrinking contribution margins, making it more difficult to cover fixed costs; and storage systems are still very expensive and dependent on arbitrage possibilities. However, in order to estimate these economic potentials, fundamental knowledge of supply security and interruption costs is necessary, see also Refs. [4,5].

The goal of this study is to contribute to a measurability of supply security by quantifying the consequences of power interruptions monetarily. In this work, we focus on interruption costs in private households. In contrast to companies, private households do not use electricity with the intention to generate monetary profit. Rather, private household use electricity to facilitate everyday tasks, to gain additional comfort or to pursue leisure activities, see Ref. [6]. For further references on interruption costs in companies, see Ref. [7].

E-mail address: aaron.j.praktiknjo@tu-berlin.de.

http://dx.doi.org/10.1016/j.energy.2014.03.089
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Nomenclature

Δt	Duration of a power interruption
$y_{\Delta t}$	Power interruption costs of a household for a duration of Δt in Euro
$p^{y}_{\Delta t}$	Probability that a household has costs for a power interruption with a duration of Δt
n_{hh}	Size of the household
w_{hh}	Monthly household income in Euro per month
bt_{dummy}	Dummy variable whether or not a household is living in a freestanding or duplex family house
$u_{\Delta t}$	Regression residual for a duration of Δt
$VOLL_{\Delta t}$	Value of lost load for an interruption duration of Δt
I	Surveyed individual
c_i	Share of area of inconvenience i for Individual I

To enable a better understanding of this topic, this work starts in Section 2 by giving a short overview of the assumptions and theoretical fundamentals. I present data that was used as input parameters for the models to estimate interruption costs in Section 3. These models are presented in Section 4. The results of the estimations are shown in Section 5. I interpret and discuss the results' implications in Section 6 and conclude this work in Section 7.

2. Theoretical background on the estimation of interruption costs

This section gives a brief overview over the assumptions and theoretical fundamentals regarding the willingness to pay (WTP) and the willingness to accept (WTA), log–log regression models, as well as binary discrete choice decision models. In order to improve the understanding of the conducted steps, the theoretical framework and the used assumptions shall be presented below.

2.1. Willingness to pay and willingness to accept

If a consumer's supply with a certain good is being interrupted, the quantity of this good's consumption decreases. This is also the case for electrical power interruptions. According to Ref. [8] the utility of goods is equal to its ability to satisfy needs of an economic decision maker. If the consumer is forced to reduce the consumption of a demanded good, its utility decreases. In order to monetarily quantify the utility loss caused by the forced reduction of consumed quantity, there are three different available empirical practices based on stated preferences: direct surveys and surveys on willingness to pay and willingness to accept. For reasons described by Sullivan and Keane [9], the two last approaches are particularly suitable for obtaining costs figures for reductions in private households. These shall be explained in the following. The first approach is the analysis of the maximum amount of money an individual would be willing to pay (WTP) to avoid the reductions. The second one is to figure out the minimum amount of money an individual would be willing to accept (WTA) as a compensation for the unavailability of the good.

Early studies in the field of economics suggested that WTA and WTP should be identical in theory, see Ref. [10,11]. However, empirical studies often reveal large disparities between WTA and WTP with WTA being higher than WTP. This means that interviewed individuals often mentioned a very high amount, which they would require as compensation payment, while at the same time the amount they would pay for avoidance, is significantly lower.

Hanemann [12] derives a theory from the Slutsky equation, which originates in the field of microeconomics, to explain these differences in WTA and WTP. The Slutsky equation describes demand changes due to price changes by means of an income effect and a substitution effect. It is suggested that the disparities in WTA and WTP can also be explained by means of an income effect, but more importantly with the help of a substitution effect, see Hanemann [12]. In the following, the consequences of income and substitution effects on the disparities between WTA and WTP will be shortly explained.

- Income effect

  The pure income effect reflects the impact of a change in the purchasing power (due to changes in income or prices) on consumers' behavior. The income elasticity provides a relative quantification of this effect. According to Hanemann [12], the disparity between WTA and WTP increases with an increase in income elasticity.

- Substitution effect

  The substitution effect describes the effect that relative price changes between several goods have on the demand of these goods. This effect is described by the elasticity of substitution (also called Allen–Uzawa elasticity). A low elasticity of substitution means that the product under investigation is difficult to substitute by other goods. The lower the (Allen–Uzawa) elasticity of substitution is, the greater is the disparity between the WTA and WTP.

According to Hanemann [12], the substitution effect has a far greater influence on disparities between WTA and WTP than the income effect. He concludes that this disparity indicates that all other available goods are rather imperfect substitutes for the considered good. For further details on microeconomic theory and the Slutsky equation see Varian [13].

Assumption

> The greater the difference is between willingness to accept (WTA) andwillingness to pay (WTP) regarding the scarcity of a good, the more difficult it isfor affected consumers to substitute the scarce good with other goods.

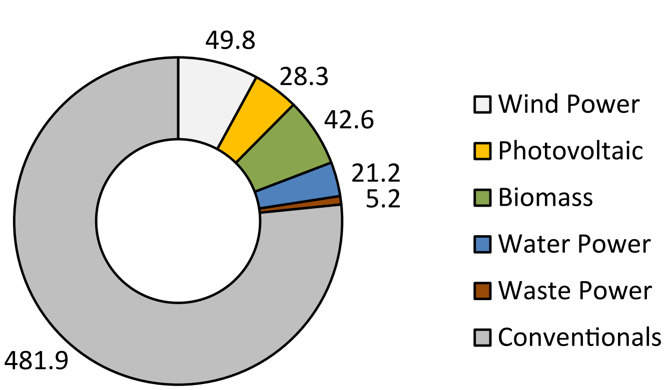

Fig. 1. Estimated power generation in 2013 in TWh.