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SPECIAL ISSUE PAPER

Assessing the socio-economic effects of power outages ad hoc

An application of BLACKOUT-SIMULATOR.com covering 266 European regions, 9 economic sectors and households separately

Michael Schmidthaler · Johannes Reichl

Abstract This contribution presents the methodology and the application possibilities of blackout-simulator.com, a recent software development for the ad-hoc simulation of user specified power outages in Europe. This tool draws upon a novel econometric modeling approach including businesses' production data as well as data from a willingness-to-pay (WTP) survey covering more than 8300 households. Making use of these inputs, blackout-simulator.com allows elaborated economic assessments of the value of electricity supply security. Households' WTP to avoid power outages is elicited via a stated preference (SP) approach. Power outages at any user-defined time and duration in all of the European countries (at the NUTS II specification level) can be assessed for durations from 1 to 48 hours. Such analyses can serve as essential inputs especially in the discussions on necessary investments for maintaining and upgrading transmission and distribution infrastructures. This tool thus provides a rationale for electricity supply security enhancing investments and energy policy decisions. Illustrating the capabilities of blackout-simulator.com, the blackout of September 28th 2003 in Italy, is assessed in this contribution. Damages to society are found to exceed 1.15 billion Euros, which corresponds to almost 0.1 percent of the annual Italian GDP.

Keywords Power outage assessment tool · Electricity supply security · Blackout analysis software

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1 Introduction

Securing an uninterrupted electricity supply is essential for any advanced economy to function economically, socially and politically. Europe has enjoyed a high degree of electricity supply security (ESS) during the last few decades. However, the need for action to ensure sufficient levels of ESS in the future is increasing, mainly because electricity production and distribution are currently undergoing significant restructuring.

While developing the necessary measures to secure the electricity grid and future supply is primarily a challenge for the engineering disciplines, it is the task of economic research to support the development of a system of incentives to counterbalance possible market failures and therefore enable the implementation of societally optimal measures. One central prerequisite for developing an efficient regulatory system is the ability to quantify the value of electricity supply security. As supply security constitutes a non-market good, which can be purchased only in combination with the physical product (electricity), the value of supply security cannot be determined directly. That is why usually the failure of electricity supply, and in particular the cost of power outages, is used to assess supply security's value [1–3]. Economic valuations of reliability are required for instance in discussions regarding necessary investments for maintaining and upgrading transmission and distribution infrastructures.

2 Methodology

The economic literature provides a clear distinction of cost categories associated with power outages. Losses due to outages are typically classified into three categories [4]:

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- Direct costs
- Indirect costs
- Long-term costs of macroeconomic relevance

In the public eye, direct economic losses are usually at the top of the list [5–7]. They are a direct result of the failure, e.g. repair costs for defective electrical infrastructure facilities. However, direct economic losses are usually limited and subordinate to indirect economic losses. These indirect costs also arise in direct connection with the outage, yet they belong to that part of the total losses resulting from the absence of electricity supply in the aftermath of the failure. Examples are the loss of productive activity, or lost value added. Through multiplier effects and due to the marked dependence of some industries on the flawless functioning of other economic sectors, these indirect costs make up a significant proportion of the total costs [8]. The analysis of the damages inflicted on businesses (non-households) in the case of power interruptions in this study relies on two different methods.

On the one hand, production data on the gross value added of businesses, industry and public administration were incorporated as a central indicator of economic activity. This is because economic activity is in most cases very closely connected to electricity supply.

The second part of the assessment of non-households is based on a comparison of typical damages per unit (kWh) of electricity not supplied in certain industries and sectors. This value-of-lost-load (VoLL) approach allows the quantification of damages for every unit of electricity not supplied for different sectors and EU regions (at the province level). The VoLL values were regressed on the characteristics of the outage under scrutiny. The influencing factors were then incorporated into the model to assess a broad variety of power outages which are not restricted to the characteristics of the original power outage settings.

Finally, the economic losses of individual non-households were clustered to make it possible to form complete aggregates of sectors or regions. The utilization of control variables for holidays, weekends and after work hours is paramount. This accounts for the fact that for example a grocery's daily value added is considerably higher on workdays than on public holidays. However, damages occur on holidays as well and also cause adverse effects resulting from a lack of cooling and security appliances. This is accounted for in the model as well.

On the other hand, for a comprehensive analysis of households, it is necessary to represent non-monetary effects as well as material losses. Thus, the results of an household-level survey with an unprecedented representativity covering over 8300 households in every EU member state (as of 2012) was incorporated inot the model. Drawing upon this data base it is possible to econometrically evaluate European households' WTP to avoid power cuts. The econometric assessments which yielded the inputs for blackout-simulator.com are state-of-the-art in the economic science [7].

3 Estimation results and application of blackout-simulator.com

Bringing together these efforts from high-level research, the recent software development blackout-simulator.com provides a tool for placing a value on the non-market good of electricity supply security for all member states of the European Union. Using this comprehensive approach to calculate the monetary value of a reliable supply of electricity for every NUTS 2 region a fairly fine-mesh quantification of all economic sectors is possible. As a result, not just particularly vulnerable sectors (such as the semiconductor industry, papermaking or data-generating processes), but all sectors of the economy as per NACE 2008 nomenclature are modelled. The tool allows a wide range of possible blackout scenarios, lasting from 1–48 h and covers many different conceivable outages for most of the EU provinces (266 in total). It is thus possible for the first time to assess every subsector of the European economy as well as households province by province as regards their degree of dependence on a reliable supply of electricity. Due to increasing efforts to include quality parameters into the network regulation, knowledge of opportunity costs is relevant for regulatory purposes as well [9]. The costs due to damage to or the destruction of electricity infrastructure have for comparability reasons not been included into the model, as the model simulates the resulting blackout, independently of what caused it.

3.1 Userfriendly specification of outage characteristics

Blackout-simulator.com allows the intuitive selection of various properties of power outages. Users can choose dimension, affected areas, duration and time of occurance (also for past and future scenarios). Several indicators of the economic impact of the assessed power outage can be calculated. Economic loss and electricity shortfall due to the outage are used as key indicators. For non-households, the amount of energy not supplied is derived from synthetic load profiles of the relevant sectors. Thus, an indicator for the total damage per sector, for households and for the amount (GWh) of energy not supplied is provided. This allows the calculation of the damage per unit of electricity not supplied (VoLL). To get more specific results, blackout-simulator.com allows the download of custom-made results tables (in csv format) as well as a detailed pdf report with further elaborations on the societal and economic effects.

Table 1 Power outage in Italy on September 28th, 2003

Outage characteristics	Case study power outage in Italy on September 28th, 2003 Specified by user, checked by the system
Date of start of outage	28 September 2003
Start time of outage	03:00 am
Duration in hours	3–16 depending on the region
Provinces affected	Italy (except Sardinia)
Public holiday	Yes (Sunday)
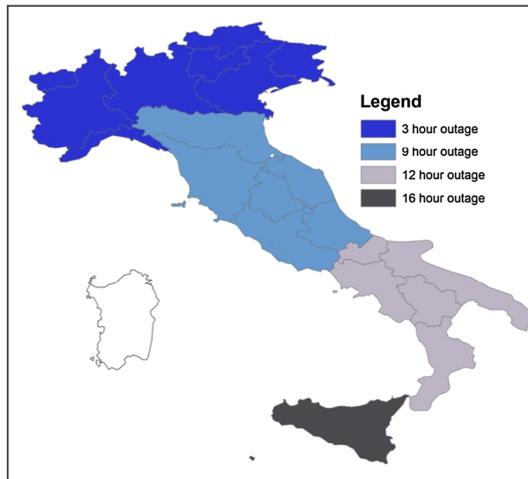
Fig. 1 Extent and affected periods of power outage in Italy on September 28th, 2003 lasting between 3 and 16 h

3.2 Assessment of the 2003 Italian power outage

As an example of the functionalities of blackout-simulator. com, a prominent power outage, namely the large-scale supply interruption which occurred in Italy on September 28th, 2003, is investigated in the following. Table 1 presents the summary of this power outage which affected over 55 million (m) persons. This power outage was among the largest recent interruptions in Europe and lasted for 3 h in the North, for 9 h in the center, for 12 h in the South of Italy and for 16 h in Sicily.

Figure 1 depicts these characteristics graphically. The chain of restoration is highly relevant. In this case, the whole of Italy except Sardinia was affected. Due to different circumstances with regards to restoration activities, the blackout is specified according to the actual outage durations in the affected areas which lasted between 3 and 16 h depending on the region. The economic assessment of the losses and effects due to this outage are presented in Table 2.

In total, the macroeconomic damage of this power outage amounted to €1182 m. Differences between economic sectors are presented in Table 2. This table summarizes 9 sectors into 3 categegories: agriculture (primary sector, I), production of goods (II) and services (III). For households, the WTP to avoid this power outage in their respective region was calculated to be € 43 m in the north (3 h), € 98 m in the center, € 94 m in the south and € 49 m in Sicily.

Figure 2 presents the visualization in blackout-simulator. com taking into account the chain of restoration, which can be specified by the duration of the power outage in any of the relevant areas.

When comparing the results with evidence in the literature, a specifically introduced board of Italian experts and scientists [10] concluded that the same Italian outage caused approximately € 640 m in damages. It was found to be associated with for a loss of load of 160 GWh. This report only takes into account non-households' damages, while here, the entire country was accounted for. However, in terms of damage and energy loss estimation, this board of scientists' analysis diverges very little from the independently calculated damages and the amount of energy not supplied using blackout-simulator.com. The opportunities of this tool however are much greater than the assessment of one power outage, as it can also be utilized for future projections and is available to the broad public.

4 Concluding remarks

Blackout-simulator.com offers an intuitive and detailed analysis tool for power outages in the European Union. It is easy to use while providing class-leading precision. Due to the growing public interest for scientific evidence on electric-

Table 2 Total losses across all regions, sectors and households (in million €) resulting from the blackout in Italy on September 28th 2003

Economic sector/affected region of Italy	Agriculture	Manufacturing	Services	Households	Total losses
North	5.3	136.7	60.8	43.1	245.8
Center	20.6	217.6	154.6	98.2	491.0
South	20.9	82.8	97.6	94.3	295.5
Sicily	12.4	33.7	54.6	49.5	150.1
Total	59.2	470.8	367.5	285	1182.4
% of GDP					0.083 %
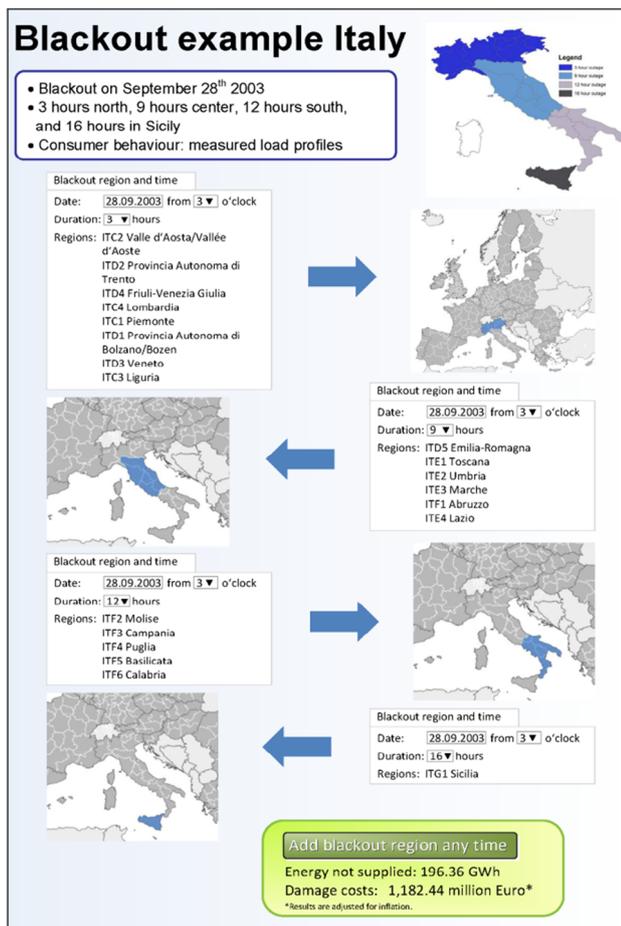
Fig. 2 Chain of power restoration after the supply interruption as selected in blackout-simulator.com

ity supply security and its socio-economic dimension, there is a need for more research that assigns a monetary value on "electricity supply security", particularly at the transnational level. Given that European markets for electricity are increasingly interlinked, and that interdependence across borders is more and more marked, assessing "supply security" uniformly throughout Europe has become a necessity as opposed to country-specific approaches. While the interaction of supply security with regulatory frameworks [9] is a highly relevant issue with regards to sustaining a, secure and affordable supply of electricity in the future, the ability to quantify benefits of concrete infrastructure projects is but one cornerstone of infrastructure implementation as various other hurdles are found to exist [11, 12].

The online assessment tool blackout-simulator.com can be used to elicit the costs of power outages to different private and business consumer groups ad hoc, thereby providing an essential economic input for policy decisions and is of great interest for businesses and utilities alike.

Serving a variety of interested users, quantitative assessments such as the value of lost load, the outage related dam-

age of each economic sector and households in every country of the EU at the NUTS 2 level, as well as of the energy not supplied can be conducted in a matter of minutes.

In the process of collecting the necessary data, an in-depth survey of over 8300 households' willingness-to-pay (WTP) to avoid power outages was conducted. Additionally, every economic sector according to the NACE nomenclature was accounted for.

In order to demonstrate the capabilities of blackout-simulator.com, the Italian power outage, which took place on September 28th 2003, was analyzed. This supply interruption lasted for three hours in the North of Italy and up to 16 hours in Sicily. It resulted in aggregated macroeconomic costs of € 1182 million (m) with 196 GWh of electrical energy not being supplied to customers. The majority of damages for this Italian power outage results from outage costs of agriculture, manufacturing and public administration. Households bear about 24 % of the total costs. The damage of all economic sectors in the affected regions of Italy was calculated at € 897 m. Households' willingness to pay to avoid this specific power cut was assessed at € 285 m.

Having easy-to-use assessment tools such as blackout-simulator.com helps the broader public understand the value of uninterrupted supply with electricity in much greater detail. This is necessary as it assists relevant decision makers in energy policy and industry in their choice to invest in modern infrastructure and protection technologies.

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