Chapter 4
Methods to assess the economic value of cybersecurity

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ABSTRACT
This chapter of the Quaderno IRCrES on *Cybersecurity and data protection in the electricity sector: state-of-the-art of the literature and evaluation methods* focuses on demonstrating the suitability of the Cost-Benefit Analysis (CBA) approach for assessing the value of cybersecurity in electrical infrastructures, from the perspective of citizens. Given the absence of market data for such non-market goods, we argue for the validity of Stated Preferences methods, particularly discrete choice experiments. We review the existing literature applying CBA methods to cybersecurity before narrowing our focus to works evaluating the economic valuation of electricity service continuity. This body of work is largely composed of case studies focused on specific countries or environments and discusses the relative merits of willingness to pay versus willingness to accept. Despite a growing interest in the economic implications of service interruptions, our review reveals a consequential gap: the absence of studies examining power outages caused by cyberattacks on critical electricity infrastructures. This highlights an urgent need for further research at the intersection of cybersecurity and energy system resilience.

KEYWORDS: Cybersecurity, electricity continuity, cost-benefit analysis, stated preferences methods, discrete choice experiments.

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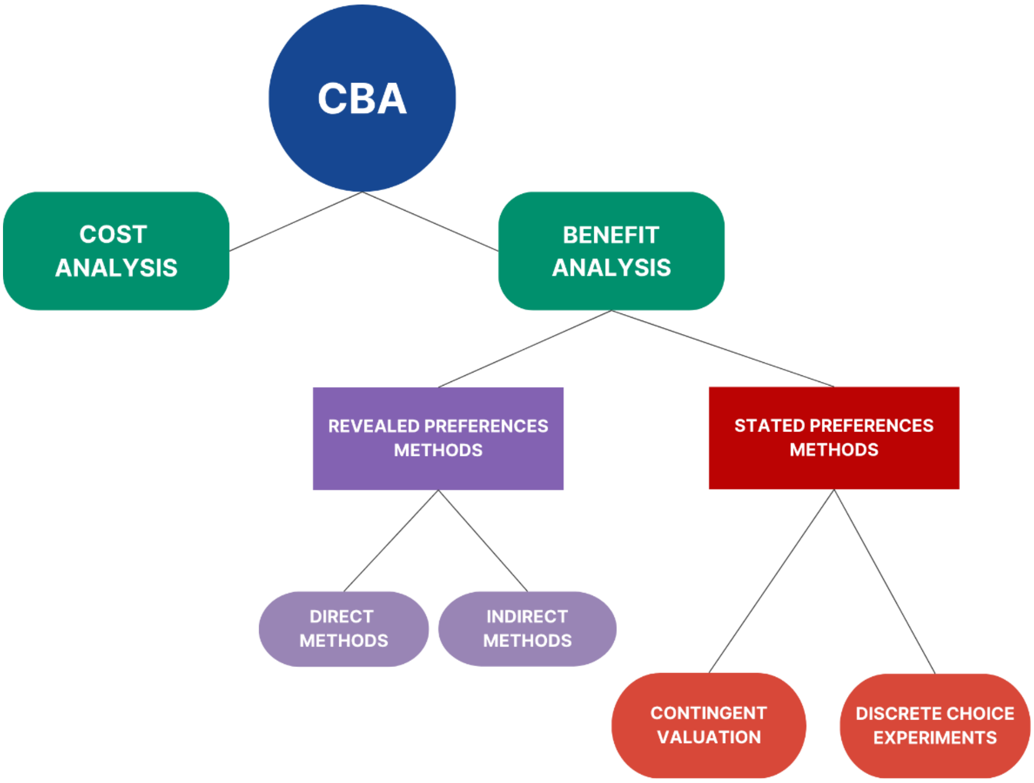
1 INTRODUCTION

Cost-benefit analysis (CBA) methodologies aim to evaluate the economic value of non-market goods, such as security. Furthermore, these methods analytically compare the costs and benefits related to a project. To this end, CBA makes it easier to make and justify investment or regulatory decisions by providing an estimate of the economic impacts before implementation begins. Boardman, Greenberg, Vining & Weiner (2018) define CBA as a "policy assessment method that quantifies in monetary terms the value of all consequences of a policy to all members of society" with the purpose of "social decision making […] or, more technically, to improve allocative efficiency" (p. 2).

The analysis of the value of cybersecurity in electrical infrastructures for citizens falls within the scope of CBA because it allows for the estimation of the benefit of investing in measures to increase control over digital resources. In this framework, to better clarify the different methodologies, we have summarized in Figure 1 the methodological options available for evaluating benefits and costs, and how the different methods are related to each other.

Figure 1. Framework of the different methods for evaluating non-market goods under a Cost Benefit Analysis



Source: Own elaboration.

When the benefit of an investment is a market product or service, the prices set in the market can be used as a reference. However, when the benefit is a non-market product, as is the case with security, estimates based on non-market valuation methods are required. In some cases, the preferences of citizens or target users can be inferred from their behaviour regarding different products or services that may reveal preferences for the good in question (Revealed Preferences methods). If this is not possible, the data to estimate the value must be derived from statements made by individuals (Stated Preferences (SP) methods).

The quality of the estimate depends largely on how these statements are obtained. With contingent valuation (CV), individuals are asked to directly state a value (e.g., “what is the maximum amount you would be willing to pay for...”). One may investigate either the willingness to pay (WTP) for a certain good or the willingness to accept (WTA) compensation if one were to be deprived of it. Contingent valuation is usually based on a detailed set of questions presenting different scenarios. The structure can be simple, with a single set of mutually exclusive questions, or it can include multiple layers of questions to better define different scenarios (e.g., one layer might be the duration of a blackout, another its timing, and so on).

It should be emphasized that it is very difficult to provide well-founded answers by expressing a monetary value for aspects/goods/services for which one has no direct experience. The choice experiment approach partially addresses this difficulty by asking respondents to imagine possible real-life situations described in precise scenarios, where a monetary value is usually presented as an attribute among those defining the scenarios. The economic value of the non-market good will be elicited, through econometric models, by combining responses on the acceptance or rejection of different scenarios.

Applications of the described methods can be found in the literature. For example, to understand the value of cybersecurity for consumers, Blythe, Johnson & Manning (2020) investigate the WTP for secure "Internet of Things" devices. The authors use CV to assess the extent to which consumers value the security of various internet-connected products. They confirmed previous findings (Nguyen, Rosoff & John, 2017; Rowe & Wood, 2013) that customers are willing to pay for safer products and services.

Moreover, over time, several studies have focused on analysing the costs and benefits related to personal data breaches, showing how CBA methodologies can be applied to the context of cybersecurity (Wottrich, Van Reijmersdal & Smit, 2018; Winegar & Sunstein, 2019; Yamaguchi, Oshima, Saso & Aoki, 2020; Paliński, 2022).

A further justification for using cost-benefit analysis to evaluate cybersecurity lies in its importance within regulatory frameworks. For example, Gordon, Loeb & Zhou (2020) argue that current regulatory frameworks, which aim to maximize cybersecurity investments in organizations, lack specificity and clear guidelines. This, in turn, leads to a loss of effectiveness in assessing cybersecurity risks within organizations. The authors therefore propose integrating the Gordon-Loeb model (Gordon & Loeb, 2002) into the NIST (National Institute for Standards and Technology) framework. They use the Gordon-Loeb model as a basis for deriving a cost-effective level of spending on cybersecurity activities. The Gordon-Loeb model has indeed been widely recognized in the literature as the leading model for cybersecurity investment (Haapamäki & Sihvonen, 2019). Consequently, following this evaluation, organizations would be able to select the most accurate level of security within the NIST framework, corresponding to the rigor and sophistication of their risk management process.

CBA has also been widely applied in the context of cybersecurity risk management. For example, Kayode, Arome, Tolulope & Ajoke (2016) discuss cybersecurity strategies through the application of mathematical models implemented in a cost-benefit analysis. To make their estimates, the authors first interviewed individuals from academia, financial institutions, and internet service providers, asking questions about the advantages, disadvantages, and effectiveness of their security strategies. The authors claim that their application of CBA can automatically compare the projected amount with the allocated amount of the cybersecurity strategy in question. In their study, Algarni, Thayananthan & Malaiya (2021) also use mathematical models to estimate the cost of a breach and the probability of a data breach within 12 months. By estimating these two components of cybersecurity risks, the authors aim to improve data security solutions. Furthermore, Lee (2021) developed a cybersecurity risk management framework. In this framework, organized into four levels, cost-benefit analysis plays a central role. In particular, CBA is necessary within the “cyber risk assessment level” because it requires three steps: risk identification, risk quantification, and cybersecurity investment analysis.

Finally, as mentioned in previous sections, cyberattacks can have enormous consequences for society as a whole. These consequences are often not taken into account when constructing regulatory frameworks and policies. However, CBA addresses this aspect by providing a model of rationality. Indeed, as explained in the OECD (2018) guideline on CBA applied to environmental issues, CBA "forces the decision-maker to look at who the beneficiaries and losers are in both the spatial and temporal dimensions" (p. 32). In this way, CBA applied to the context of cybersecurity can provide a comprehensive and extended estimate of the economic value of cybersecurity.

To summarize, conducting studies on cybersecurity using a cost-benefit analysis methodology has proven effective and significant. More specifically, economic sciences argue that to assign an economic value to non-market goods through CBA, direct methods such as Stated Preferences can be used. These methodologies allow deriving the value of a non-directly monetizable good through studies conducted on a representative sample of a population. As described above, this also applies to cybersecurity analyses. To narrow the analysis and explain our methodological choices, the following section addresses a practical situation: a cyberattack leading to a blackout, to examine the economic value of cybersecurity attributed by energy consumers.

2 COST-BENEFIT ANALYSIS APPLIED TO THE CASE OF THE ELECTRIC SYSTEM

To demonstrate the value attributable to a good or service for which market information is unavailable, SP methodologies often use individuals' WTP for the good or service in question or their WTA compensation following a change in the provision of that good or service. Through the use of WTP or WTA, monetary values are derived from participants' responses to specific questions about real or hypothetical but realistic scenarios. In this way, SP methodologies contrast with revealed preference methodologies, which rely on actual purchasing behaviours. Specifically, WTP and WTA are tools evaluated through two types of survey methodologies. One is the CV method, which uses direct questions where participants must state their WTP or WTA for a non-market good. The second is the DCE method, which presents scenarios involving different characteristics of the good in question, where participants must choose between different options of acceptance or compensation.

The goal of this section is to narrow the literature analysis to themes closer to the specific research focus. Therefore, this section presents scientific articles that conduct cost-benefit analyses using stated preference methodologies related to the specific topic of security in the management of electrical systems. This literature overview shows that works on the topic are preferably represented by case studies specific to countries or environments.

Several studies relate to the economic evaluation of electricity service reliability in developing countries. The reason behind this high number of studies lies in the fact that these countries experience what can be characterized as a "double tragedy". In fact, these countries suffer from both low electricity access rates and frequent power outages, which are often persistent and severe. This situation, on the one hand, highlights how understanding the value of service continuity is fundamental in prioritizing the various types of infrastructure investments a country needs. On the other hand, it allows consulting panels of respondents who are fully aware of the impacts of service disruptions on their work and non-work activities. However, it should also be noted that in contexts where electricity supply is particularly unreliable, economic operators often equip themselves with emergency generators, the presence of which could reduce WTP but whose costs should be included in the overall CBA. Moreover, it should be emphasized that these results cannot be simply transferred to developed contexts. In fact, in markets with a high reliability of electricity provision, consumers show higher propension to buy electric devices with respect to other available technologies (e.g. for cooking or heating) and they depend more on continuity of supply.

A series of articles addresses the problem of power outages in Ethiopia. The most recent is by Entele & Ayalew (2024). The authors conduct a CE study aimed at estimating the economic cost of power outages for manufacturing firms in Ethiopian cities. Consequently, they derive the WTP of small, medium, and large manufacturing firms using an econometric analysis performed through a mixed Logit model. In this way, they complement the work of other authors such as Carlsson, Demeke, Martinsson & Tesemma (2020) and Meles et al. (2021). Entele & Ayalew (2024), in fact, study the impact of power outages in areas outside the capital Addis Ababa, which has a specific energy supply situation. Their results show strong heterogeneity depending on the size of the firm and the industrial sector. However, both the costs of power outages and the WTP of firms to avoid outages are significant. Consequently, the authors argue for the importance of optimizing the diversification of electricity sources. For their part, Aweke & Navrud (2022) studied Ethiopian households in rural areas, who on average experienced 160 blackouts, lasting an average of four hours, per year. They found in their analysis that participants' WTP to avoid blackouts is worth about 32% of the annual electricity bill.

Some articles have focused on the impact of households' socioeconomic and demographic characteristics on WTP for improved energy services. Abdullah & Mariel (2010) and Osiolo (2017) conducted a choice experiment and a contingent valuation, respectively, based on the population of Kenya. The latter author examined WTP in the form of a "quality tax" on energy sources, namely firewood, charcoal, and electricity for households and businesses. The former author, on the other hand, studied WTP to avoid power outages for rural households. For their part, Taale & Kyeremeh (2016) studied WTP for reliable services using a CV method. These authors were able to clarify that households are willing to pay 44% more than the average monthly electricity bill for greater reliability. These three studies highlight two common socioeconomic characteristics that can influence WTP: household size and education level. Additionally, Abdullah & Mariel (2010) also emphasizes the effects of age, years of residence in the area, employment status, agricultural activities, and whether participants had a bank account. Taale & Kyeremeh (2016), on the other hand, found that notice period, business ownership, monthly income, and ownership of a separate meter (compared to households who share their meter) were significant.

Two papers focused on the impact of the timing of power outages on WTP. Nkosi & Dikgang (2018) and Alinsato (2015) use the same methodology for two studies based in South Africa and Benin, respectively, with results that are not very aligned (likely due to the different contexts of the two studies). This methodology involves a CV survey where WTP to avoid power outages is derived using a random parameter Tobit model. In the study by Nkosi & Dikgang (2018), WTP is higher when seeking to avoid power outages on weekdays and in winter, while in Alinsato (2015), the preference for service reliability is greater during the night and on weekends. However, both studies emphasize that WTP depends positively on the duration of the outage.

Other studies, conducted in Ghana (Amoah, Ferrini & Schaafsma, 2019), Nigeria (Oseni, 2017), Senegal (Deutschmann, Postepska & Sarr, 2021), Northern Cyprus (Ozbafli & Jenkins, 2015; 2016), and Nepal (Hashemi, 2021), use SP methods, assessing WTP for reliable electricity supply or WTP for quality improvement. All works show that households exhibit significant preferences for high-quality and reliable electricity service.

The economic evaluation of service reliability in the electricity sector has also been studied in developed nations. For example, Praktiknjo (2014) studied the monetary consequences of power outages for German households. To this end, he used both the estimation of outage costs using WTA and WTP methodologies and the derivation of VoLL (Value of Lost Load). In this way, the author found that residential consumers assign relatively high values to the security of supply, with the duration of the power outage having a significant impact on VoLL and the magnitude of outage costs.

Looking at other aspects of electricity reliability, Amador, González & Ramos-Real (2013) focused on WTP for three levels of service attributes: supply reliability, share of renewable energy, and availability of a complementary energy audit service. Their work is based on the residential market in the Canary Islands. Among other results, the article shows that respondents with a high level of education exhibit higher WTP for renewable energy, in line with their stated concern about greenhouse gas emissions.

Some studies have chosen to use WTA as a measure of preferences regarding the reliability and quality of electricity service. Xu, Yang, Deng & Wang (2024) examined compensation (WTA) for energy rationing during peak hours in China, while Abrate, Bruno, Erbetta, Fraquelli & Lorite-Espejo (2016) studied WTA compensation for power outages in Italy. Tocock, Hatton MacDonald & Rose (2024), on the other hand, focused on WTA regarding lower cost increases in Australia. The similarities between the three articles lie in their methodologies, as all use a DCEs. However, their results differ. Xu et al. (2024) observe that participants’ preferences are for a higher level of compensation in summer and at night. As for Abrate et al. (2016), they note that VoLL is correlated with both the duration of the outage and various household characteristics. Finally, Tocock et al. (2024) conclude that households value electricity contracts that influence the pace of energy investments, making the compensation modelled for lower cost increases in cases where such features within a contract are reduced.

Woo et al. (2014) also employed WTA, but this time observing participants’ acceptance preferences in cases where they could pay a lower electricity bill in response to reduced reliability. This experiment was conducted in Hong Kong, where electricity supply is considered nearly flawless. The authors establish that participants are unwilling to accept a reduction in reliability, even in exchange for financial compensation.

Regarding the use of WTP, various articles have measured it in cases where power outages must be avoided. This is the case for Hensher, Shore & Train (2014) in Australia, Carlsson, Kataria, Lampi & Martinsson (2021) in Sweden, Morrissey, Plater & Dean (2018) in England, and Gorman & Callaway (2024) in the United States. Although they use similar methods, these works investigate different aspects of the problem. Gorman & Callaway (2024) examined the impact of advance notice of power outages on household WTP. Morrissey et al. (2018), on the other hand, characterized power outages using five attributes: duration; peak/off-peak hours; day of the week; winter/summer; price. Hensher et al. (2014) differentiated their work by studying the frequency and duration of power outages. Finally, Carlsson et al. (2021) compared past studies from 2004 and 2017 to investigate changes in WTP. It can be seen here that the variety of topics and aspects studied can be broad and detailed, while the conclusion remains fairly homogeneous across studies: deriving monetary values of electricity reliability allows for demonstrating significant preferences for avoiding power outages.

Finally, various setups and case studies have been implemented in Switzerland (Motz, 2021), Finland (Küfeoğlu & Lehtonen, 2015), Norway (Vennemo, Rosnes & Skulstad, 2022), Pennsylvania, USA (Baik, Davis & Morgan, 2018), and South Korea (Kim, Nam & Cho, 2015). A detailed analysis of each of these works would be too space consuming, but it is worth noting their added value in the research area of electricity system security management through the lens of SP methodologies.

To summarize, works using SP methodologies, particularly through the use of WTP and WTA, on the specific topic of security in the management of electrical systems are characterized by their particular geographic contexts. The diversity of characteristics of electrical systems, as well as socioeconomic contexts, can lead to very different results regarding the effect of conditioning variables (respondent characteristics) or the appreciation of specific aspects of service continuity.

This review shows that, despite a certain richness and variety of works on service continuity, there is an almost total lack of studies addressing the challenges of cybersecurity in ensuring the security of electrical systems. Indeed, no work to our knowledge refers to the specific case of power outages due to cyberattacks on critical electricity grid infrastructures, highlighting the need for further research and investigations.

3 FROM THEORY TO PRACTICE: METHODOLOGICAL ASPECTS RELATED TO THE IMPLEMENTATION OF A DATABASE FOR ANALYSING THE ECONOMIC VALUE OF CYBERSECURITY

The goal of this "Quaderno IRCrES" is to provide a review as complete as possible of the state of the art of economic research related to the various existing methods related to cybersecurity and data protection, with a particular focus on the electricity sector. More specifically, this chapter focuses on the acceptance of monetary compensation in the form of discounts on electricity bills, using the WTA method as a valuation tool. To carry out this estimation, we deem as the best option the use of a Choice Experiment (CE) method, that we practically apply in our experimental activity presented in the next chapter (Vallette d'Osia, Finardi & Ragazzi, 2025).

DCEs, along with CV methods, as defined and illustrated above, are significant stated preference techniques for analysing individual preferences in the electrical industry.

In surveys conducted by the CV method, the structure is usually simple. In fact, a single set of mutually exclusive questions is used or, in order to further detail different scenarios, additional levels of questions (e.g., one level might be the duration of the blackout, another its time location, and so on).

In contrast, in DCE methods, respondents are offered a choice of several specific decision-making processes, where several alternative fixed options are displayed. A high number of scenarios are then assumed, combining attributes in different proportions. Since respondents can only accept or reject a scenario as a whole, the estimate of how each attribute impacts the economic value of the studied good or service is obtained by combining the responses from a large sample. Different types of cyber breaches are simulated in our scenarios, leading to outages of different durations. For this purpose, our research is inspired by the survey conducted in the ESSENCE (Emerging Security Standards to the EU power Network controls and other Critical Equipment) project, widely described in chapter 3[1] (Bruno & Erbetta, 2025); it adopts its approach while conducting a much larger experiment in terms of sample coverage and scenario attributes.

Supporting the use of a choice experiment method in our case stems from the idea that we believe it is difficult for individuals to attribute monetary values to their preferences in both cybersecurity and electric service interruptions. This problem is addressed by the DCEs because they allow respondents to immerse themselves in hypothetical scenarios without having to provide an exact value of what is difficult for them to monetize. In fact, DCEs are constructed so that respondents do not have to actively provide a monetary value to a nonmarket good or service. Instead, they must choose among discrete alternatives that are proposed to them.

As mentioned above, our research project employs the concept of WTA for the purpose of deriving acceptance of monetary compensation in the form of rebates on electricity bills in the event of a blackout caused by a cyberattack. The choice between WTA and WTP has been widely debated in the literature. Our position of using WTA also has to do with the difficulty of valuing a nonmarket good or service. We think it is more difficult for respondents to think about how much they would be willing to pay for reliable cybersecurity or uninterrupted electricity. In this we agree with what Abrate et al. (2016) say in their paper as they thoroughly explain the use of WTA in the context of a choice experiment to value power outages. We therefore find it simpler to evaluate disruption than the service that respondents benefit from on a daily basis.

To summarize, it seems more reliable to demand WTA compensation for a discontinuity or breach because respondents consider it fair and almost guaranteed to benefit from a cyber-secure electricity provider. Conversely, where electrical supply security or cyber security were not normally guaranteed, WTP would be an appropriate survey tool. The results of Grutters et al. (2008) support this idea. Indeed, their work makes it clear that the choice between WTP and WTA in a DCE must be made taking into account whether most respondents are potential beneficiaries or losers, depending on the cost attribute defined in the DCE (a payment or a discount). The paper also argues that the choice of a WTA experiment is in fact the best option in the case of potential

[1] See also https://essence.ceris.cnr.it/ (link visited July 2025).

losers, which is true in our case as respondents face scenarios in which they experience a cyberattack-induced blackout.

In addition, it is important in our case not only to look at the total change in blackout preferences caused by cyberattacks, which is usually done with CV surveys, but to retrieve the combinations of attribute levels that would be acceptable to respondents, justifying our choice for a DCE (OECD, 2018).

4 CONCLUSIONS

The present chapter goes deeper in adding specific topics to this Quaderno. After addressing the economic perspective of cybersecurity in the electricity sector, exploring the broader concept of digital sovereignty, and introducing relevant insights from the ESSENCE experience, this section turns to an analysis of the methodological approaches that can be used to disentangle the challenges involved in citizens' economic evaluation of these relevant topics. The concise but complete analysis, performed mostly by part of a literature review, of the methodologies that can shed light on these magnitudes, goes directly into the fifth chapter of this Quaderno (Vallette d'Osia et al. 2025), that is, a synthetic description of an experimental activity aimed at the direct evaluation of costs and benefits of cybersecurity.

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