Universidade do Minho
Escola de Economia e Gestão e Ciência Política

Maria Carolina Albuquerque Faria Ferreira Carmo

Recommendations on the Response to the Power Outage at Lusíadas Braga Hospital

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Work done under the guidance of

Maria Manuela Pereira Alves Azevedo

Nazaré Glória Gonçalves do Rego

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Recommendations on the Response to the Power Outage at Lusíadas Braga Hospital

ABSTRACT

A year ago, on the 28th of April 2025, the Iberian blackout caused widespread disruption across Portugal, affecting not only the electricity supply but also telecommunications, transport, fuel logistics, and digital systems. In this context, Lusíadas Braga Hospital experienced significant operational challenges, making it a relevant case for examining hospital resilience during prolonged power outages.

This work analyses the impact of the blackout on the hospital and identifies measures to improve its response to future similar events. Over the course of 3 months, the hospital's normal functioning, as well as how it functioned on the day of the blackout, were analysed. A mixed-methods approach was adopted, combining operational data on hospital activity with qualitative evidence from staff interviews and a risk matrix assessment.

The findings show that the hospital demonstrated important initial resilience. Backup generators activated automatically, critical services were maintained and essential operations continued during the event. However, the blackout also exposed vulnerabilities that extended beyond electricity loss itself. The most significant difficulties were linked to fuel resupply, dependence on centralised information systems, and the breakdown of telecommunications, all of which limited the hospital's ability to sustain normal activity. Quantitative analysis showed significant reductions in appointments, walk-in activity and exams performed on the day of the blackout when compared to data collected from March to May 2025.

We concluded that resilience in this context depends not only on backup power, but also on the capacity to operate when communications, logistics and digital systems are disrupted at the same time. The main recommendations are to secure a priority fuel supply agreement, improve access to essential patient information during system outages, strengthen communication resilience and clarify staff contingency procedures. These measures would improve the hospital's preparedness and support safer continuity of care during future prolonged outages.

Keywords: healthcare continuity; hospital resilience; Iberian blackout.

Recomendações na Resposta ao Apagão no Hospital Lusíadas Braga

RESUMO

Há um ano, a 28 de abril de 2025, o apagão ibérico causou uma disrupção generalizada em Portugal, afetando não só o fornecimento de eletricidade, mas também as telecomunicações, os transportes, a logística de combustíveis e os sistemas digitais. Neste contexto, o Hospital Lusíadas Braga enfrentou desafios operacionais significativos, tornando-se um caso relevante para o estudo da resiliência hospitalar durante falhas prolongadas de energia.

Este trabalho analisa o impacto do apagão no hospital e identifica medidas para melhorar a sua resposta a futuros eventos semelhantes. Ao longo de três meses, foram analisados o funcionamento normal do hospital, bem como o seu desempenho no dia do apagão. Foi adotada uma abordagem de métodos mistos, combinando dados operacionais da atividade hospitalar com evidência qualitativa proveniente de entrevistas a profissionais e de uma avaliação através de uma matriz de risco.

Os resultados mostram que o hospital demonstrou uma importante resiliência inicial. Os geradores de emergência foram ativados automaticamente, os serviços críticos foram mantidos e as operações essenciais continuaram durante o evento. No entanto, o apagão revelou também vulnerabilidades que foram além da própria perda de eletricidade. As dificuldades mais significativas estiveram associadas ao reabastecimento de combustível, à dependência de sistemas de informação centralizados e à falha das telecomunicações, fatores que limitaram a capacidade do hospital de manter a sua atividade normal. A análise quantitativa evidenciou reduções significativas no número de consultas, atendimentos sem marcação e exames realizados no dia do apagão, quando comparados com os dados recolhidos entre março e maio de 2025.

Conclui-se que a resiliência neste contexto depende não só da existência de fontes de energia de reserva, mas também da capacidade de operar quando as comunicações, a logística e os sistemas digitais são simultaneamente afetados. As principais recomendações incluem a garantia de um acordo prioritário de fornecimento de combustível, a melhoria do acesso à informação essencial dos doentes durante falhas dos sistemas, o reforço da resiliência das comunicações e a clarificação dos procedimentos de contingência para os profissionais. Estas medidas contribuirão para melhorar a preparação do hospital e assegurar uma continuidade de cuidados mais segura durante futuras falhas prolongadas.

Palavras-chave: continuidade dos cuidados de saúde; resiliência hospitalar; apagão ibérico.

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LIST OF ABREVIATIONS AND ACRONYMS

CSHU – Common Services of Hospital Use

ICU – Intensive Care Units

IESNSP – Integrated Emergency and Security Networks System of Portugal

IMT – Institute for Mobility and Transport

LHU – Local Health Units

NCA – National Communications Authority

NHS – National Health Services

NIME – National Institute for Medical Emergencies

1. INTRODUCTION

On the 28th of April 2025, at 11:33, a massive power outage struck the Iberian Peninsula, leaving millions without electricity and in uncertainty for several hours. In Braga, electricity began to be progressively reestablished around 21:00. The Portuguese National Electric Networks reported that they were able to fully reestablish the function of all the National Electricity Transmission Network substations by 23:30 (REN, 2025), meaning that the country experienced nearly 12 hours without a regular power supply.

The restoration efforts started with the hydroelectric plant of Castelo de Bode, in Santarem, and the natural gas plant of Tapada do Outeiro, in Porto, which are currently the only plants in Portugal with black start capacity. Black start capacity refers to the ability to restart the power station without access to the public electric network (Lagoa, 2025). With the help of the Spanish power station of Aldeadávila and the Tavira - Puebla de Guzmán tie-line, which allowed for synchronous connection with the continental European region, they were able to finish reconnecting all the stations in Portugal, with Divor substation being the last to be connected at 23:22 (ICS Investigation Expert Panel, 2025).

The European Network of Transmission System Operators for Electricity (ENTSO-E) has assigned an expert panel to investigate the causes behind the incident. They have created a website that is constantly being updated as more information is uncovered (ENTSO-E, 2026). A factual report of the incident was published on the 3rd of October 2025 (ICS Investigation Expert Panel, 2025) and the final report was released on the 20th of March 2026 (ICS Investigation Expert Panel, 2026).

The blackout not only impacted the electrical systems but aslo had a major impact on all national telecommunication networks, which gradually went down as the blackout went unresolved. In Braga, the Vodafone mobile phone network went down for most of the users while the data network remained on for another 2 hours. According to OOKLA (Kehoe, 2025), at the peak, almost 70% of all Vodafone's Portuguese users had no service, meaning that they were not able to make calls, text or use mobile data. In contrast, MEO had less then 20% of its users with no services at its peak (Kehoe, 2025).

During this period, Lusíadas Braga Hospital faced significant operational challenges. The hospital's main building, which provides consultations, diagnostic exams, and surgical services, as well as the hospital's inpatient unit, which at the time was operating in the building of the former Clínica Médica de Santa Tecla, were both affected by the power outage.

Through this work, it was possible to examine how the hospital responded to the power outage and to formulate recommendations aimed at enhancing preparedness for comparable events in the future.

2. RESEARCH AIMS AND QUESTION

This work aims to analyse the impact of the power outage on the 28th of April 2025 on Lusíadas Braga Hospital's activities and propose implementable changes to strengthen its preparedness for future prolonged power outages.

The central research question guiding this study is:

What measures can Lusíadas Braga Hospital implement to strengthen its preparedness and continuity of care during prolonged power outages and associated disruptions in fuel supply, communications and digital systems?

In addressing, we aim to identify the hospital's existing vulnerabilities and the specific operational, clinical and infrastructural challenges that emerged during the blackout.

Through these aims, the research will contribute to a deeper understanding of how Lusíadas Braga Hospital can mitigate the risks associated with power failures, safeguard patient safety and maintain continuity of services under adverse conditions.

3. LUSÍADAS BRAGA HOSPITAL

Founded in 1998, Lusíadas Saúde is one of the main private healthcare groups in Portugal, distinguished by its commitment to clinical excellence, innovation, and high-quality patient care. It has a nationwide presence supported by a growing network of hospitals and clinics, which integrates the expertise of over 7,000 healthcare professionals dedicated to delivering advanced medical services with a strong focus on rigour, quality and patient safety. In December 2022, Lusíadas Saúde became part of Vivalto Santé, one of Europe's largest private healthcare providers, further reinforcing its international position and capacity to respond to evolving healthcare challenges. Currently, Lusíadas Saúde has 17 different unite locations in the north, centre and south of Portugal (Figure 1).

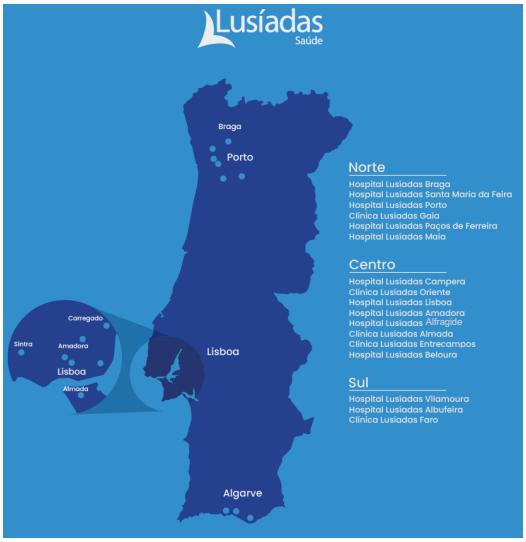


Figure 1 – Locations of the different Lusíadas Saude Units. Adapted from (Lusíadas, 2026).



Figure 2 – Photo of the main building of Lusíadas Braga Hospital. Located in Rua da Escola de Enfermagem 4700, 4700-000 Braga.

Among its key institutions, Lusíadas Braga Hospital has emerged as a reference centre in the northern region of Portugal. Officially inaugurated on 2nd of November 2020, the hospital operates from the historic premises of the former Hospital de São Marcos (Figure 2), through a partnership with Santa Casa da Misericórdia de Braga, and integrates the experience and expertise of the former Clínica Médica de Santa Tecla staff. Since its opening, the hospital has established itself as a benchmark in combining state-of-the-art medical technologies with patient-centred care, contributing significantly to the development of healthcare in the region.

On the 28th of April 2025, the hospital was still in the process of transitioning all the services into the main building and, as such, the inpatient unit and physiotherapy unit were still located at the former installations of Clinica Santa Tecla.

Currently, the hospital has a 24-hour walk-in service, a paediatric walk-In service open from 08:00 to 22:00, an inpatient unit, medical appointments, small surgeries, as well as a wide range of exams

available. It has several specialities for the patients' needs, ranging from, but not limited to: surgery and anaesthesiology; psychiatry/psychology and neurology; nephrology and urology; cardiology; pneumology; genecology/obstetrics; dermatology; gastroenterology; endocrinology; orthopaedics and physical therapy; clinical analysis; etc. The patients can book appointments and exams in person at the reception, through the call centre or through the maisLusiadas application. The hospital also has a dental unit, but it is managed by HeyDoc, a subsidiary under Lusíadas Saúde Group, and as such will not be addressed in this work.

The hospital has recently expanded and consists of 45 consultation rooms, 4 operating theatres and 18 inpatient beds. There are even more expectations of expansion for the future, with the intention of opening a maternity unit.

4. LITERATURE REVIEW

4.1. Effect of the Power Outage on the Portuguese Health System

After the blackout, public hospitals had their generators automatically activated. Several hospitals such as Hospital de Santa Maria in Lisbon (Lusa, 2025) and Hospital de São João in Oporto (SIC Notícias, 2025a), among several others, declared minimal services to ensure the distribution of energy to essential areas such as operating block for emergency surgeries and the Intensive Care Units (ICU) and to insuring the continuance of essential, urgent and inevitable clinical services (Rádio Renascença, 2025). There were reports of vaccines being transported to hospitals from health centres, since not every health centre had a backup generator (Carmo & Pereira, 2025).

Some hospitals prepared rooms for patients with home ventilators that needed to charge them (Alves & Pereira, 2025). Unfortunately, there was 1 reported death that was directly connected to the blackout, and that was of a 78 years old woman who needed to be connected to a ventilator 24h. The call for assistance for 112 was made when the battery was thought to have reach 50%, information that was later revealed to be wrong, and when the emergency services arrived, the patient had already passed, in the son's account, about 10 mins after the call was made (SIC Notícias, 2025c).

According to a report from RTP, there was no common contingency plan between all the Local Health Units (LHU) and each one dealt with the situation as they saw fit, accentuated by the compromise in the communication between hospitals (RTP Notícias, 2025a). In the interview, the president of the Portuguese Association of Hospital Administrators, Xavier Barreto, gave to RTP, he called for a more extreme blackout simulation to be carried out and for a common contingency plan to be made that integrates all the LHUs (RTP Notícias, 2025a). The chairman of the Order of Nurses, Luís Filipe Barreira, pointed out the shortages of fuel reserves for the generators, the need for updated contingency plans, the need for regular simulations and the difficulty in ensuring meals for patients in certain hospital units, calling for the necessity to strengthen the preparation of the Portuguese health system for emergency situations (Barreira, 2025).

The National Institute for Medical Emergencies (NIME) activated the contingency plan and maintained both its telecommunications and informatics systems, functional with energy provided by a generator that automatically turned on following the blackout (INEM, 2025), with no reported interruptions of its operations at the headquarters. However, due to the compromise of the telecommunications networks, both mobile and fixed, the National Communications Authority confirms there was a negative impact on the access to emergency services, as well as communication between

emergency services, authorities and civil protection agents (República Portuguesa, 2025a). The access to the emergency number, 112, through landlines was extremely compromised, while access to the emergency number on mobile was only possible if the mobile phone was able to connect to at least one mobile network (República Portuguesa, 2025a), which was not always possible.

The National Authority for Emergency and Civil Protection is in charge of managing the civil protection alert messages sent to the population, through collaboration with the telecommunications operators. At 17:15, the process to send the alert message was started, with them being scheduled to be sent from 18:00 to 24:00. It read "Power restoration is being done gradually. With everyone's serenity, we guarantee the essential services and the normalisation of the situation in the next hours.". Unfortunately, the delivery success rate was bellow 50%, when it normally reaches 95%, a number brought about due to the lack of network coverage, battery on mobile devices, the operators' network antennas running out of power and the overload of the operators' SMS centres. It should be noted that alert messages are not given priority over other SMS traffic (Espírito Santo, 2025).

One of the major telecommunication systems that failed during the blackout was the Integrated Emergency and Security Networks System of Portugal (IESNSP), the Government's emergency communication network. According to a report done by SIC 2025 (SIC Notícias, 2025b), around 75.2% of the of the IESNSP antenna network had failures in transitions, while 74 were reported to have completely run out of battery, which is not surprising considering that they have an autonomy of around 6 hours. An investment of around 4 million euros was made to change the batteries of 554 antennas from September 2024 until the end of 2025, which would have given them an autonomy of 10 to 22 hours, but on the day of the blackout only 160 batteries had been changed. There were reports of ambulances having to travel to a nearby firefighter station to be able to contact the Urgent Patient Guidance Centre, since they have no communication options, no phone or IESNSP, and would have remained inoperable otherwise. Unlike some Firefighter stations that still have a redundant communication network, the strategic Civil Protection Services network, which uses radios and a predetermined channel to communicate, the NIME system had only one communication option: telephones.

The breakdown of communication also hampered the logistics of fuel distribution, with Alfredo da Costa Maternity being the most extreme case, as it was less than 1 hour away from running out of fuel for its generators (Nunes, 2025).

4.2. Public Policies and Reforms

At the time of the occurrence, the government declared an energy crisis (Presidência do Conselho de Ministros, 2025), which is clearly defined within the decree-law nº 114/2001 of the 7th of April. The emergency crisis state allows for the priority use of the Strategic Network of Refuelling Stations, which is managed by the National Entity for the Energy Sector and currently consists of 26 stations with exclusive government use and another 343 non-exclusive stations with a pre-determined amount of fuel to be used exclusively by priority vehicles/institutions (ENSE, 2026). These priority vehicles/institutions include (Presidência do Conselho de Ministros, 2025): the armed forces and the security forces and services; civil protection services and agents, prison services, and justice infrastructure; emergency medical services, hospitals and health units, and services for transporting medicines and medical devices; public or private entities that provide essential public services in the areas of energy, electronic communications, postal services, drinking water, wastewater, waste collection and urban cleaning, public passenger transport, publication of the official gazette, air navigation, and the transport of reagents and sludge; and entities within the national scientific and technological system that provide services lacking vital resources.

At the core of the government's response was the presentation of a plan comprising thirty-one measures (RTP Notícias, 2025b) that is to be supported by approximately 400 million euros of public and private investment, which is a considerable amount. A main element of this plan is the increase in the number of powerplants with black-start capacity, which are vital for restoring power to the grid in the event of a total system failure. The power plants of Tapada do Outeiro and Castelo de Bode are going to be joined by facilities at Baixo Sabor and Alqueva (República Portuguesa, 2025b). On the other hand, the modernization of grid control and operational systems is being allocated an investment of 137 million

Definition of Energy Crisis (Decree-Law nº 114/2001 of the 7th of April):

1 – A situation of energy crisis is characterized by the occurrence of difficulties in the utilization or distribution of energy that makes necessary the use of extraordinary measures destined to guaranty the essential energy supply for national defence, functioning of the State, priority sectors of the economy and for the satisfaction of the population's fundamental necessities.

2 – The difficulties referred in the previous point can result from events caused by the action of humans or nature, within the Country or outside, namely in member countries of international organizations to which Portugal integrates.

3 – The forecast of circumstances that can cause, with a high degree of probability, the aforementioned difficulties are encompassed within the situation of crisis.

euros. They have allocated 25 million euros to enhance the resilience of critical infrastructures such as hospitals, water services and municipal facilities. At the European level, Portugal is intensifying cooperation with Spain and with European institutions in order to expand interconnections and thereby enhance security of supply. Beyond energy generation and grid management, the blackout exposed serious fragilities in the telecommunications and transport sectors. The National Civil Aviation Authority, the National Communications Authority (NCA), and the Institute for Mobility and Transport (IMT) delivered reports to the government which analysed the impacts of the blackout and formulated policy recommendations (República Portuguesa, 2025a). In telecommunications, NCA emphasised the urgent need to establish minimum autonomy standards for backup systems, including batteries and generators, and to diversify the technological base of these systems by incorporating renewable and satellite-based solutions. Proposals were also made to ensure redundancy in the routing of emergency calls to the 112 system, to introduce special SIM or eSIM cards for public authorities and to expand the use of public warning technologies such as Cell Broadcast. They also recommended the development of real-time monitoring systems to provide transparency regarding the resilience of telecommunications networks during crises.

The transport sector's report highlighted the vulnerability of operators and infrastructure to energy loss. IMT recommended the definition of minimum energy autonomy requirements for public transport operators, the establishment of priority fuel access for essential services and maintenance vehicles and the implementation of on-board power storage systems in rail and metro networks to allow the safe evacuation of passengers in the event of power loss. These measures were proposed alongside requests for systematic contingency planning and the regular conduct of joint simulation exercises to test coordination under blackout conditions.

The health sector also became a focal point of post-blackout reform, following the death of a patient dependent on home ventilation equipment. The General Inspectorate of Health Activities concluded that the lack of emergency preparedness, caregiver training and communication protocols contributed directly to the fatality. Its recommendations included the establishment of stricter technical norms for home-based medical care, the mandatory training of caregivers in emergency protocols, the creation of registries of vulnerable patients dependent on electricity and reinforced oversight of equipment suppliers and healthcare providers (SIC Notícias, 2025c).

Although the government has committed to substantial investment and initiated significant reforms, many proposals remain at the recommendation stage. These include the revision of sectoral contracts to impose binding obligations for energy resilience, the codification of minimum backup autonomy times

across critical infrastructures and the prioritisation of electricity restoration for hospitals, telecommunications networks and other essential services. Equally, the institutionalisation of regular simulation exercises and contingency planning has been recommended but not yet uniformly implemented across all sectors.

The reforms launched after April 2025 represent a decisive shift in Portuguese policy towards greater systemic resilience. They combine substantial financial commitments in the energy sector with regulatory and procedural reforms in telecommunications, transport, and healthcare. Having said that, the effectiveness of these measures will depend on their translation from policy recommendations into enforceable standards, as well as on continuous coordination between public authorities, private operators and local communities. The blackout has become both a catalyst for accelerated investment and a test of the government's capacity to integrate resilience planning into the management of critical infrastructure.

4.3. Other Cases of Power Outages in Hospitals

There is limited literature on the impact of power outages on hospitals and their operational response. The causes of such outages vary widely, ranging from extreme weather events and armed conflict to failures within the electrical grid itself. Their impact is highly variable and context-dependent, often shaped by country- or region-specific factors, including differences in power grid infrastructure, resilience measures, and operational protocols.

If we look at the frequency of reported incidents where a Portuguese hospital experiences a blackout, we can see that it is not a rare scenario, but it is extremely uncommon, and in most cases, the problem is localised and resolved within a few hours. The news surrounding the incidents are normally vague, and refers mostly to the fact that it happened, sometimes why and for how long, but they rarely mention how it had an impact on the hospital's services themselves or operational constraints.

One of the most recent cases of regional blackouts that lasted several days was the case in the district of Leiria. Depression Kristin, which started around the early hours of the 27th of January 2026, knocked down several very high voltage poles (REN, 2026). Álvaro Santos Almeida, Chief Executive of the National Health Services (NHS), stated that the NHS was completely prepared for any necessities originated due to the blackout in the region of Leiria (Lusa, 2026), on the other had there are reports (Schreck, 2026) that some medical centres are closed, others working under major constraints, some generators were failing, mainly Alvaiázere, while the hospital of Leiria, that suffered structural damages,

is being maintained using power supplied by generators. There are reports that 15 people have already been hospitalised due to carbon monoxide poisoning from at-home generator use (Schreck, 2026).

On the 3rd of February, the Government published a report (Lima, 2026) regarding how the situation was dealt with. They stated that they were able to mobilise more than 2500 health professionals, that the NHS director board assured that there was proper operational connection in terms of the limited communications, the replenishment of essential consumables and the prevention of potential stock ruptures and that the Civil Protection unit prioritised the clearing of the Hospital of Leiria access points, fuel resupply and other logistical needs. Measures were implemented to ensure the transport of patients to other, less affected, ULSs to be able to guarantee urgent care necessities. All patients undergoing home respiratory treatments were identified and contacted, and patients were directed to go to the firehouse or emergency care departments whenever administration of oxygen was required. With the coordination between Shared Services of the Ministry of Health and the Health Information Network operator the were able to restore communications at the hospitals of Leiria, Pombal and Alcobaça, as well as at the Long-Term Psychiatric Inpatient Unit on the 29th of January. The Common Services of Hospital Use (CSHU) focused on the rehabilitation of the physical infrastructure of the Leiria LHU, including the repair of damaged roofing, clearance of circulation routes, replacement of window frames and glass, and repair of equipment. CSHU also supported the Institute of Social Security by organising and delivering bottled water, hot meals, and bedding kits for residents of care homes, without compromising the hospitals' operational capacity. Paper-based death certification was also activated in areas affected by power outages, in coordination with the National Institute of Legal Medicine and Forensic Sciences, to ensure proper management and, where necessary, the transfer of bodies to areas with better operational conditions.

Whole-country and large-scale blackouts are also rare, but there is a lot more information available compared to regional blackouts in Portugal. They have occurred all over the globe, from Europe to North America, Latin America and Asia. They normally happen either from severe technical cascades in fragile systems or from large disturbances that overwhelm even interconnected grids. The triggers vary but the operational pattern is similar: abrupt system separation, collapse of frequency or voltage control and gradual staged restoration over hours or, in some cases, days.

One of the most significant prolonged European examples was the Italian blackout on the 28th of September 2003 (BBC News, 2003). According to the final report (UCTE, 2004) done by the Union for the Co-ordination of Transmission of Electricity, the blackout was triggered by failures on cross-border transmission lines with Switzerland and the event evolved into a near-complete collapse of the Italian electricity system. There was a progressive restoration of the transmission grid from the North to the

South of the country, with final customer resupply taking over eighteen hours. The Italian case is important because it shows how dependency on interconnected imports can amplify vulnerabilities rather than mitigate them, much like what happened in Portugal and its dependency on Spain. Unfortunately, the only reports found detailing the impact of the blackout on Italian hospitals and their response state that generators were used and that a liver transplant was successfully finished at the Molinette hospital in Turin due to their use (Il Post, 2025). This shows a clear gap in the scientific literature, even after such an impactful event happened and is a topic that should be further explored.

Another important case that happened in a developed country was the 2003 blackout in the USA and Canada, which happened just a month before the one in Italy, on the 14th of August 2003. The blackout was due to a bug in the system that failed to notify the control room of the need to redistribute load when power lines in Cleveland came into contact with trees and caused the plant to shut down. The failure to notify and mitigate the situation then caused a cascade of blackouts that affected more than 40 million Americans and 10 million Canadians (The National, 2003), which at the time made it the world's second-largest blackout in history, region-wise. The blackout started just after 16:10 EDT, and although in some regions the power was restored after a few hours, according to the Michigan State report (Michigan Public Service Commission, 2003), full power was only restored on the 16th of August 2003 at 06:30 EDT. When it comes to how a major blackout affected public health, this scenario is one of the ones that has been the most studied in scientific literature.

The William Beaumont Hospital in Michigan was one case that was without an external power supply for 38 hours. According to the report done by Jeff Brown (2004), the hospital's disaster plan was able to anticipate needs such as extra staffing, the lack of computers and the transport of laboratory specimens, but they were not able to anticipate, and had to deal with, the loss of elevators, pharmacy dispensary service, control of environmental temperatures and external water supply. According to an article that looked at 4 different hospitals (Klein et al., 2005), policies such as just-in-time inventory work very well for day-to-day operation of the hospitals, but are detrimental to them in emergency scenarios and don't allow for the recommended 48 - 72 hours of self-sufficiency hospitals should have.

More than 15 years later, Venezuela experienced one of the most severe examples of a nationwide power failure (Valderrama & Polanco, 2019). Starting on the 7th of March of 2019, several recurring blackouts left much of the country without electricity for at least 10 days of the month of March. The blackouts caused serious disruptions to water supply, communications, transport, healthcare and economic activity (Pons & Ellsworth, 2019). Although the report varies when it comes to the specific duration and location of the blackouts, it was obvious that restoration efforts were uneven and widely

ineffective. The events were attributed to the lack of proper infrastructure, maintenance and expert manpower. The Venezuelan case is especially important because it demonstrates the social consequences of extended grid failure when restoration capacity is weak and infrastructure resilience is limited. To note that, even though it was not on the same scale, on the 30th of August 2024, most of Venezuela experienced another blackout that lasted up to 20 hours in the most affected areas (Flores, 2024). The chaos from the Venezuelan blackouts of March 2019 was exacerbated by the fact that many public hospital generators were either damaged or idle for lack of fuel, while dialysis, intensive care, and other essential services were severely disrupted. NBC news (Gutierrez & Ramos, 2019) has cited that the Venezuelan NGO Doctors for Health, Dr. Julio Castro, has attributed at least 48 hospital deaths to the first major blackout of March 2019.

In South Asia, Pakistan is a notable example of continuous near-national and national grid collapse. One of the most impactful cases was the blackout on the 23rd of January that was caused by an unusual fluctuation in voltage in the south of the country that triggered a cascade of powerplant failure that resulted with nearly 220 million people being plunged into darkness and took over 12 hours to be resolved in the major cities, while more rural regions were reported to have been without power for longer (Ahmadani & Kamran, 2023). According to the Electricity Minister Khurram Dastgir Khan, the bigger hospitals had emergency generators, but smaller hospitals had to do everything manually, so getting an appointment would take some time (Hussain, 2023). Hospitals such as Pakistan Institute of Medical Sciences were reported to have to switch off their operating theatres, while others like Jinnah Postgraduate Medical Centre stated they were not affected and that their backups would allow them to work for 5 days uninterrupted (Hussain, 2023).

When looking at the reports, we can clearly see that hospitals are rarely affected by nationwide blackouts in a uniform manner. Rather, the severity of impact depends on three closely related factors: (i) the duration of the outage, (ii) the reliability of emergency generation and (iii) the resilience of associated support systems such as fuel supply, water, telecommunications and digital infrastructure. In the less severe cases, hospitals generally maintained life-preserving functions through backup generators, while elective activity and some non-critical services were stopped. In the more severe cases, however, the blackout exposed not only electrical vulnerability but also the fragility of broader hospital operating systems, particularly where generators were unavailable, damaged, under-fuelled or unable to sustain the full clinical load.

Taken together, these cases indicate that the principal hospital mitigation measures during nationwide blackouts are broadly recurrent: 1) activation of emergency generators; 2) prioritisation of

intensive care, emergency, and inpatient services; 3) suspension of routine consultations and elective surgery; 4) concentration or transfer of patients dependent on electrical equipment and 5) the use of manual procedures when digital systems and communications fail. At the same time, the comparative evidence also shows that generator availability alone is not sufficient. Hospital resilience depends equally on fuel logistics, maintenance, communications, water access and the capacity to sustain clinical operations under degraded conditions.

5. METHODOLOGY

5.1. Research Design

The internship at Lusíadas Braga Hospital lasted from October 2025 to until the end of December 2025, during which I had the opportunity to observe the day-to-day functioning of the hospital, as well as analyse the events of the 28th of April 2025.

To be able to reach our research objective of analysing the hospital's response to the blackout and to be able to identify actions to improve preparedness for future power outages, this study adopted a mixed-methods design (Figure 3) that combines the analysis of hospital-provided operational data with qualitative evidence gathered through a mix of informal and semi-structured interviews and analysis of a risk assessment.

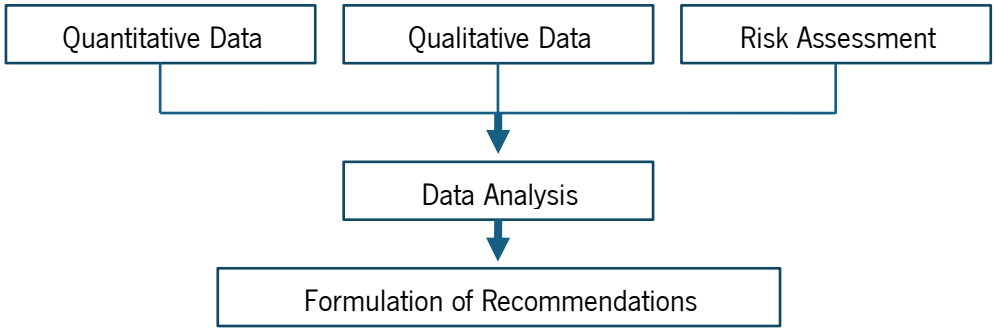


Figure 3 – Research Design

5.2. Quantitative Data

The quantitative data was provided by Lusíadas Braga Hospital. Using the hospital's own data collection software, the total number of appointments, surgeries, and exams performed in March, April and May of 2025 we extracted. The information extracted was divided into 3 different subsets: Mondays, Business Days and Every Day. All subsets do not include information from the day of the blackout. The subset Business Days did not include weekends. The data was also separated by weekday and violin graphs were produced to observe the distribution on the different days. Data from holidays were omitted from analyses within Business Days subset and violin graphs when not respecting usual hours of operation. The holidays excluded were the 4th of March, the 18th, 20th and 25th of April and the 1st of May.

The numbers observed on the day of the blackout were compared against the different subsets. The mean and standard deviation for each group were calculated. For each activity type, the observed value on 28th April was compared with the distribution of comparable days using a standardised score where z is equal to = (value on the 28th of April – mean of subset) / standard deviation. The corresponding lower-tail probabilities were used as exploratory indicators of whether activity was unusually low.

5.3. Qualitative Data

The qualitative data was collected through informal and semi-structured interviews. The semi-structured interview was audio-recorded, while the informal interviews were captured through field notes written during or immediately after the interaction. After spending some time observing the functioning of the hospital and speaking with the director, a list of key personnel (Table 1) was chosen to conduct interviews. The interviews allowed us to explore experiences that cannot be represented by operational records, such as the challenges of communication breakdowns, the effectiveness of decision-making processes and the strategies used to maintain patient care under difficult conditions. The questions and responses were used to delineate a timeline of events, as well as a descriptive overview of specific areas of importance. A summary of the interviews can be found in the appendix (Table A.1).

Table 1 – List of interviewed people and main topics approached.

Position	Interview Type	Main topics
Director of the Hospital	Semi – structured	• Communications • Fuel/Electricity Management
Head Nurse	Informal	• Communications • Patient Management
Head of Physiotherapy	informal	• Patient Management
Head of Maintenance	informal	• Fuel/Electricity Management • Water Management

5.4. Risk Matrix

A risk matrix assessment was conducted to analyse the main risks associated with hospital operations during the Iberian blackout. This technique is used in risk management as it enables the identification, comparison and prioritisation of risks and allows us to create targeted recommendations and define mitigating measures for similar future events.

Relevant adverse scenarios were identified and evaluated in relation to the severity of the consequences of the scenarios against how close they were to happening during the day observed or in a 72-hour long blackout. A five-point scale was used for both criteria (Table 2). Severity and occurrence were each classified from 1 to 5. The final risk score was obtained by multiplying the values from each parameter, producing a score between 1 and 25. Scores were then classified into risk levels to support interpretation and prioritisation of mitigation measures, where: 1 to 5 represents a low risk level; 6 to 10 represents a moderate risk level; 11 to 15 represents a high risk and 16 to 25 represents an extreme risk. This approach allowed the most significant vulnerabilities affecting service continuity, patient safety, and critical infrastructure to be systematically identified and compared.

Table 2 – Description of risk matrix scoring.

	Severity		Occurrence	
Score	**Term**	**Description**	**Term**	**Description**
1	Insignificant	Minimal disruption	Very unlikely	Scenario showed no meaningful signs of occurring
2	Minor	Limited-service disruption	Unlikely	Scenario was possible, but there were limited indications that it would occur
3	Moderate	Noticeable disruption	Possible	Scenario showed some warning signs of occurrence
4	Major	Serious disruption	Likely	Scenario came close to occurring
5	Catastrophic	Severe threat to patient safety or continuity	Imminent	Scenario was on the verge of occurring or partially occurred

5.5. Ethical Considerations

Ethical safeguards were given priority at all stages of the research. Since there was no collection, use or analysis of identifiable patient information, the risks relating to privacy and confidentiality were limited. The research was conducted using non-specific patient information, with specific attention to ensure that no patient could be identified. Interview participants will be given clear information about the purpose of the study, the voluntary nature of participation, and their right to withdraw at any stage.

6. THE IMPACT THE BLACKOUT HAD ON LUSÍADAS BRAGA HOSPITAL

6.1. Timeline of Events

To better understand the impact of the blackout on the hospital, a timeline of the events was delineated (Fig. X). At 11:33 a.m., right after the blackout, the hospital generators automatically kicked in, and everything continued as normal. Initially, there were expectations that the situation would be resolved quickly, so no steps were taken to mitigate the situation. About an hour later, the administration became aware of the dimension of the blackout and that it would be a difficult situation to resolve, city-wise. At round lunch time (13:00-14:00), there was a meeting with all the administrators of the different Lusíadas units, where they were informed, with information from the government, that not only was the situation critical, but the expectations were that it could take up to 3 days until the national electric grid was back in working conditions.

After the meeting, the main priority was to get fuel reserves for the generator, but by then the government had already declared an energy crisis state and obtained control of the Strategic Network of Refuelling Stations starting at 14:00 (Presidência do Conselho de Ministros, 2025). As Lusíadas Braga Hospital does not have an Intensive Care Unit and does not take in emergency patients it is not included in the government's priority supply list, as such, it was necessary for the administrators to arrange for their own fuel resupply, which they were able to secure, with a 500L supply of diesel that was delivered around 17:00. They also sent couriers to the gas pumps to see if they were able to get any fuel but by then most of the fuel stations were closed and the ones that were open were extremely chaotic.

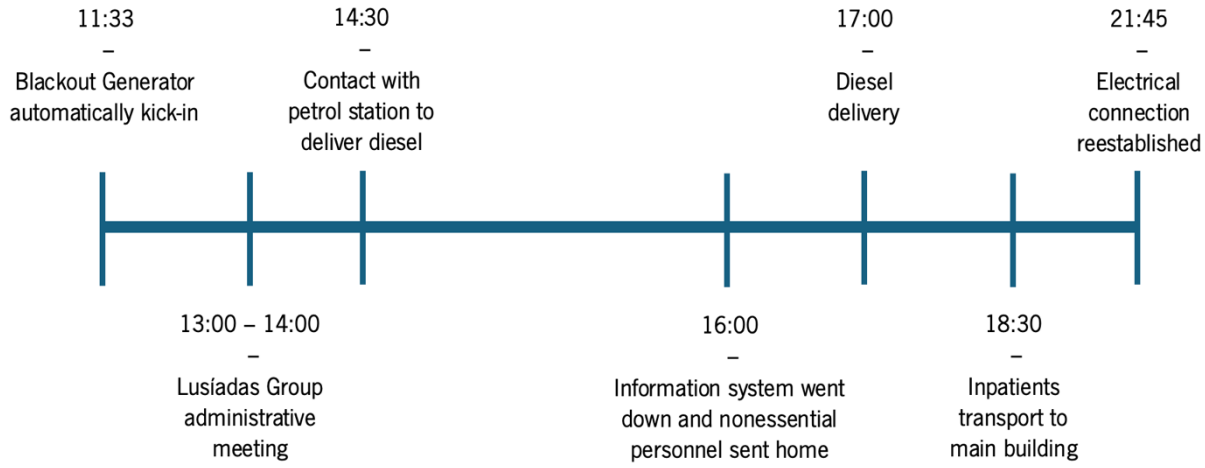


Figure 4 – Timeline of the main events on the day of the blackout.

At around 16:00, the informatics servers, which were located in Lusíadas Hospital Porto, went down due to an interruption in the energy supply to the system. As such, the hospital was not able to access patient information and history. A decision was then made to stop all programmed activity and send non-essential workers, such as general administration workers and receptionists, home.

Another priority was the transport of the hospitalised patients to the main building. The head nurse had to drive, at around 17:30/18:00, to the head office of their partners, Ambulâncias do Minho, to request the transport of a patient from the inpatient unit, which had no generators, to the main building of the hospital. The transport happened around 19:00.

At around 21:45, the power supply was restored, and on the next day, activity continued as normal.

6.2. Generators and Energy Management

When there is a loss of power from the power grid, all lights except for UPS systems go out and it takes around 45 seconds for the generators to turn on. At the time, when the expectation was for the blackout to last 3 days, the administration was informed that they were going to have enough fuel to last them 12 to 14 hours until they entered default at the current consumption.

There are two generators, each with a capacity of 1000L of fuel. Normally, each will be maintained at around 500L except in exceptional circumstances, since it is not recommended that the generators be maintained at full fuel capacity. They are topped up when they each reach 250L. At the time of the blackout, each generator had around 300L. With each generator at 500L, they can last about 24 hours if the hospital is working at full capacity, but with proper management and with the hospital functioning at minimum capacity, it can last for up to 3 days. At full capacity, they use around 50L per hour. The fuel is only used for the generators, as there is no other need for it in the hospital.

Tests are regularly conducted on the generators. The dry tests are conducted for 15 minutes every 15 days, and the most recent test carried out before the blackout was on the 14th of April. The full load tests are conducted every 3 months for 1 to 2 hours, with the previous one being conducted in March.

The surgical theatre is under an Uninterruptible Power Supply (UPS) system, and as such, there were no interruptions. The UPS system can last a maximum of 1 hour and has to be changed every 5 years. At the time of the blackout, a surgery was underway, but it concluded without a problem and the people involved were only informed of the blackout after the surgery was concluded.

There is an energy priority plan as part of the hospital safety measures, which defines the priority areas for the hospital, with the main ones being lifesaving: the operating block, the postoperative recovery units and the inpatient units. It details what should be turned off first in a sequential manner.

When the external power connection was reestablished, the system waited for 1 minute to ensure the connection is stable before disconnecting from the generators and reconnecting to the power grid, which takes 13 seconds.

The new inpatient and physiotherapy units on the floor of the building of Santa Casa de Misericordia are physically connected to the main hospital building and are incorporated within their electrical system, and as such, will use the same generator. There is the possibility, if needed, to connect that floor to the generator of the Santa Casa de Misericordia. They have also acquired a small building that used to be the outpatient clinic of the old São Marcos Hospital, which will have its own generator.

In terms of water use, during the blackout, the external water supply was disrupted, but since the 2 water deposits in the building were full, it did not generate any problems. The deposits, when full, can supply the hospital for about 3 days.

6.3. Staff Management and Communication

There was no preparation in terms of the shutdown of most of the communication services. As it was the first time there was a breakdown in all communications networks at the same time throughout the country, the situation could not be predicted, and the administration was not prepared for an external communication failure of that level. There were, though, pre-defined rules and protocols that made a difference in terms of the organisation of personnel, such as the guarantee of service continuity.

In terms of the safety protocol, all the scheduled activities are automatically non-priority. When it comes to the staff in charge of continuous activity, such as walk-in appointments, inpatient care and recovery room, they need to ensure that the service is not interrupted and, as such, they are not allowed to leave unless the staff who is supposed to replace them arrives.

One of the major hurdles when it comes to staff management was the fact that several of them had children and because of the lack of certainty on the continuation of services of school and day cares as well as the inability to communicate with the children and facilities when the services tend to end, around 16:00/17:00, it made it especially hard to plan if people needed to get their kids or not and who didn't.

The main communication network of the hospital is NOS. On the day of the blackout, NOS was one of the last telecommunication companies to lose communications, both fixed and mobile (Kehoe, 2025). The primary reason the hospital did not continue to work as normal was that the information systems went down in the Lusíadas Porto Hospital, and Braga is dependent on their information servers. When the servers went down, the decision was made to stop all scheduled activity and non-essential staff were sent home.

In the meantime, changes were also made internally to guarantee the ability to communicate internally, including the acquisition of portable radios, but when it comes to external communication, the responsibility falls under the civil protection unit to manage it. The hospital does not have a satellite phone, as the dimensions of the hospital do not justify the acquisition of one.

6.4. Patient Management

In April, both the inpatient care and the physiotherapy departments were located in the facilities of the Clinica Médica de Santa Tecla, which were not equipped with a backup generator. At the time of the blackout, several physiotherapy sessions were underway, and there were four patients hospitalised in the inpatient unit.

Due to the power outage, the physiotherapy sessions had to be concluded prematurely, as most therapies required electrical equipment, and the remaining sessions were cancelled. Of the four inpatients, two already had a planned discharge for that day. For one of the patients, their doctor went specifically to the unit to have them discharged. The remaining patient was not clinically stable for discharge, so they moved them to the postoperative recovery unit in the main building of the hospital, which at the time had one other patient. They remained overnight alongside the patient who had undergone surgery in the morning, before being transferred back to the inpatient unit the following morning, since normal operations had resumed. This process was complicated by the lack of telecommunications or internet in the inpatient unit. The head nurse had to make their way to the main building to try to make contact with their ambulance partners, Ambulâncias do Minho, but was not able to make contact due to failures in the communication systems. The nurse was able to search the internet for the address of their head office and had to physically go there to request the ambulance transport.

Before 16:00, all patients who had scheduled appointments and were able to make their way to the hospital were seen as long as their doctor was present. If the doctor was not present, then they were informed of such and, when possible, appointments were rebooked. After 16:00, only walk-in appointments were conducted since the informatics servers were down, access to patient history was lost and all scheduled activity was cancelled.

6.5. Services Impacted

6.5.1. Scheduled Appointments

On the 28th of April 2025, **187** scheduled appointments were performed. The mean number of scheduled appointments on Mondays, Business Days and Every Day were 503, 488 and 342, respectively, while the standard deviations were 68.3, 61.8 and 214, respectively (Table 3, Figure 5). The z-scores for each group were obtained, which were -4.63, -4.87 and -1.60, giving us the probability values of 1.81×10^{-6}, 5.52×10^{-7} and 0.235. In Figure 6, the distribution of scheduled appointments for each weekday can be seen, as well as where the number of appointments on the day of the blackout falls.

It can be observed that there was a significant reduction in the number of appointments due to the blackout when compared to the average number of appointments for Mondays and all Business Days for the months of March, April and May. On the other hand, there was no significant difference when taking into account Every Day, which was to be expected since on weekends, these do not follow the "normal" working hours and as a result, skew the averages down.

Table 3 – Data from scheduled appointments.

	Mondays	Business Days	Every Day
Mean	503	488	342
Standard Deviation	68.3	61.8	214
Z-Score	-4.63	-4.87	-0.72
p-Value	1.81×10^{-6}	5.52×10^{-7}	0.235

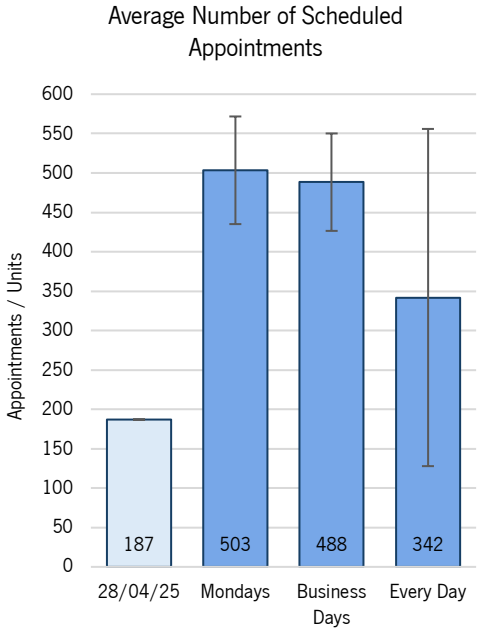


Figure 5 – Average number of scheduled appointments. Comparison between the subsets of Mondays, business days and of every day against the number of appointments on the 28th of April 2025.

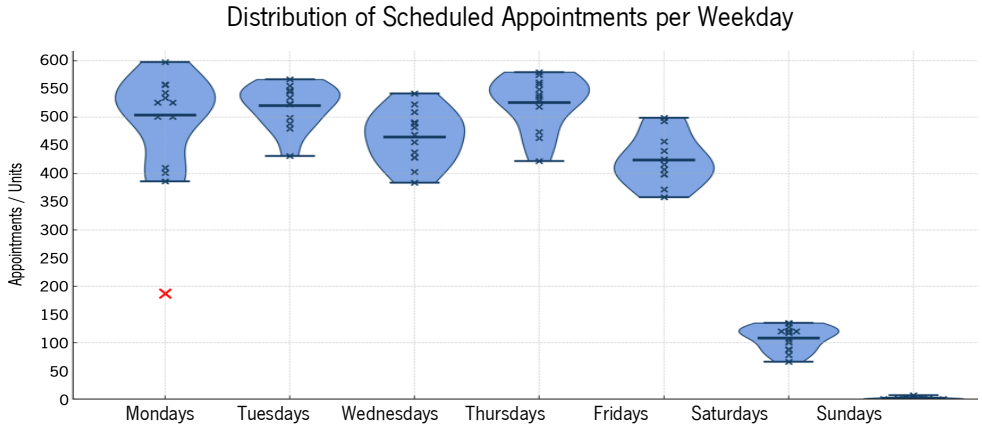


Figure 6 – Distribution of scheduled appointment on the different weekdays. The red X represents the number of appointments on the 28th of April of 2025.

6.5.2. Surgeries

On the 28th of April 2025, **14** surgeries were performed. The mean number of surgeries on Mondays, Business Days, and Every Day were 25.7, 22.2 and 16.3, respectively, while the standard deviations were 6.72, 5.46 and 9.93, respectively (Table 4, Figure 7). The z-scores for each group were obtained, which were –1.74, –1.50, and -0.23, giving us the probability values of 0.0413, 0.0673 and 0.407. In Figure 8, the distribution of surgeries for each weekday can be seen, as well as where the number of appointments on the day of the blackout falls.

These results do indicate that the number of surgeries performed during the blackout can be considered significantly lower than would be expected under typical Monday conditions, with a p-value under 0.05. On the other hand, when we compare the number of surgeries against Business Days and Every Day, it would not be considered significantly different. The p-value of Business Days was a lot closer to what would be considered significant, but fell above the 0.05 value, while for Every Day they were not, which was to be expected, as surgeries also do not have a "normal" working hours on weekends and holidays.

A reason that can explain why the number of surgeries was less impacted and a lot closer to not being considered significant is the fact that most surgeries are performed early in the morning, starting at 08:00. The reduction in surgeries was statistically weaker than for other services and should be interpreted with caution.

Table 4 – Data from surgeries.

	Mondays	Business Days	Every Day
Mean	25.7	22.2	16.3
Standard Deviation	6.72	5.46	9.93
Z-Score	-1.74	-1.50	-0.23
p-Value	0.0413	0.0673	0.407

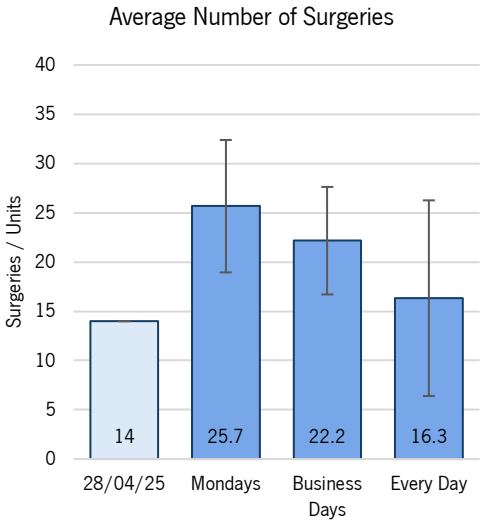


Figure 7 – Average number of surgeries performed. Comparison between the subsets of Mondays, business days and of every day against the number of appointments on the 28th of April 2025.

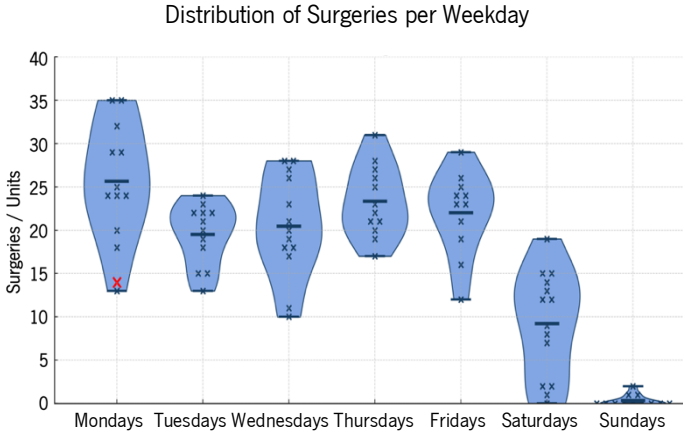


Figure 8 – Distribution of surgeries on the different weekdays. The red X represents the number of appointments on the 28th of April of 2025.

6.5.3. Walk-In Appointments

On the 28th of April 2025, **11** walk-in appointments were performed. The mean number of appointments on Mondays, Business Days and Every Day were 36.7, 30.8 and 29.62, respectively, while the standard deviations were 6.41, 6.52 and 6.61, respectively (Table 5, Figure 9). The z-scores for each group were obtained, which were -4.00, -3.04 and -2.82, giving us the probability values of 3.15×10^{-5}, 1.19×10^{-3} and 2.43×10^{-3}. In Figure 10, the distribution of walk-in appointments for each weekday can be seen, as well as where the number of appointments on the day of the blackout falls.

We included the data from the holiday for each data set since this service is open every day, including on holidays. The fact that the number of appointments on the day of the blackout was significantly lower in every subset, even with the continuity of the service, highlights the fact that external factors, like the reluctance of patients to travel to the hospital, had a major impact on the hospital's numbers.

Table 5 – Data from walk-in appointments.

	Mondays	Business Days	Every Day
Mean	36.7	30.8	29.6
Standard Deviation	6.41	6.52	6.61
Z-Score	-4.00	-3.04	-2.82
p-Value	3.15×10^{-5}	1.19×10^{-3}	2.43×10^{-3}

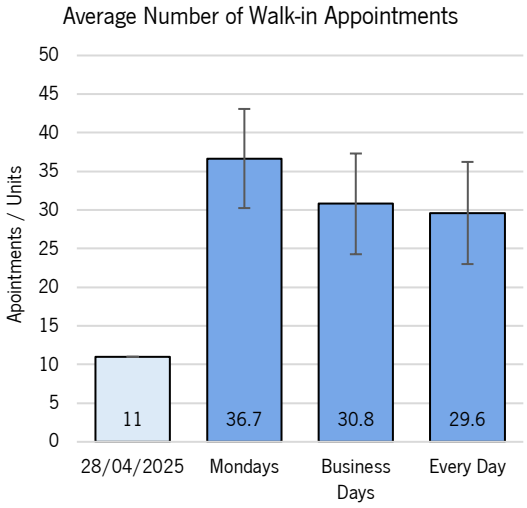


Figure 9 – Average number of walk-in appointments. Comparison between the subsets of Mondays, business days and of every day against the number of appointments on the 28th of April 2025.

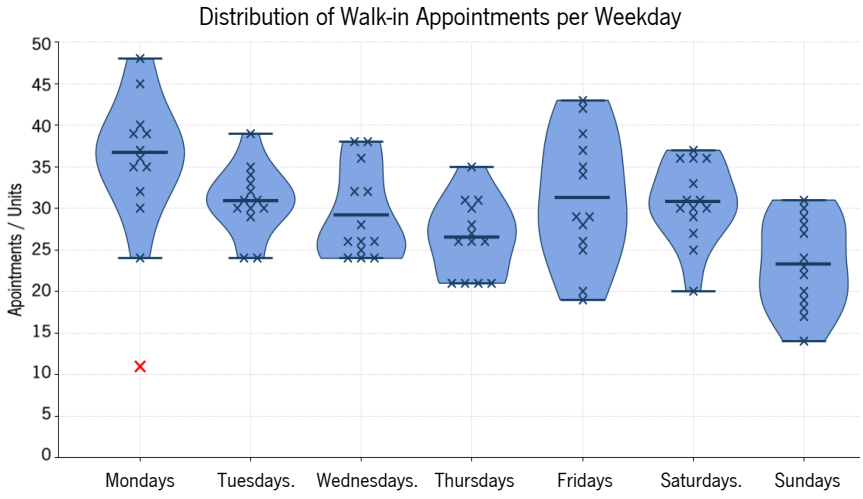


Figure 10 – Distribution of number of walk-in appointments performed on the different weekdays where the red X represents the number of Appointments on the 28th of April of 2025.

6.5.4. Exams

This section was divided between speciality exams, diagnostic imaging exams and clinical and anatomical pathology exams.

Table 6 – Data from the different exams.

	Specialist Exams			Imaging Exams			Pathology Exams		
	Mondays	Business Days	Every Day	Mondays	Business Days	Every Day	Mondays	Business Days	Every Day
Mean	190	213	170	189	190	140	581	533	436
Standard Deviation	35.3	39.0	77.7	37.2	38.3	80.7	98.1	90.3	199
Z-Score	-2.71	-3.06	-0.983	-3.54	-3.48	-1.03	-3.23	-2.98	-0.863
p-Value	$3.36x10^{-3}$	$1.12x10^{-3}$	0.163	$1.99x10^{-4}$	$2.52x10^{-4}$	0.153	$6.15x10^{-4}$	$1.46x10^{-3}$	0.194

On the 28th of April 2025, **94** specialist exams were performed. The mean number of specialist exams on Mondays, Business Days and Every Day were 190, 213 and 170, respectively, while the standard deviations were 35.3, 39.0 and 77.3, respectively (Table 6, Figure 11a). As such, we obtained the z-scores for each group, which were – 2.71, – 3.06 and – 0.983, giving us the probability values of $3.36x10^{-3}$, $1.12x10^{-3}$ and 0.163.

There was a significant decrease in the number of specialist exams when compared to Mondays and Business Days. Considering the significant disruption to scheduled appointments, it was expected that the exams linked to them would also be impacted. On the other hand, there was no significant difference when taking into account Every Day, which was to be expected since on weekends and holidays, these do not follow the "normal" working hours and as a result, skew the averages down.

On the 28th of April 2025, **57** imaging exams were performed. The mean number of imaging exams on Mondays, Business Days and Every Day were 189, 190 and 140, respectively, while the standard deviations were 37.2, 38.3 and 80.7, respectively (Table 6, Figure 11b). As such, we obtained the z-scores for each group, which were – 3.54, – 3.48 and – 1.03, giving us the probability values of $1.99x10^{-4}$, $2.52\ x10^{-4}$ and 0.153.

There was a significant decrease in the number of imaging exams when compared to Mondays and Business Days. Considering the fact that imaging machines require a large amount of energy and the uncertainty of patients about whether the exam may be available, it can be expected. On the other hand, there was no significant difference when taking into account Every Day, which was to be expected since on weekends and holidays, these do not follow the "normal" working hours and as a result, skew the averages down.

On the 28th of April 2025, **264** clinical and anatomical pathology exams were performed. The mean number of clinical and anatomical pathology exams on Mondays, Business Days, and Every Day were 581, 533 and 436, respectively, while the standard deviations were 98.1, 90.3 and 199, respectively (Table 6, Figure 11c). As such, we obtained the z-scores for each group, which were –3.23, –2.98 and -0.863, giving us the probability values of 6.15×10^{-4}, 1.46×10^{-3} and 0.194.

There was a significant decrease in the number of pathology exams when compared to Mondays and Business Days. These can be attributed to patient reluctance and uncertainty about whether they would be able to perform the exams and whether their samples would be safe. On the other hand, there was no significant difference when taking into account Every Day, which was to be expected since on weekends and holidays, these do not follow the "normal" working hours and as a result, skew the averages down.

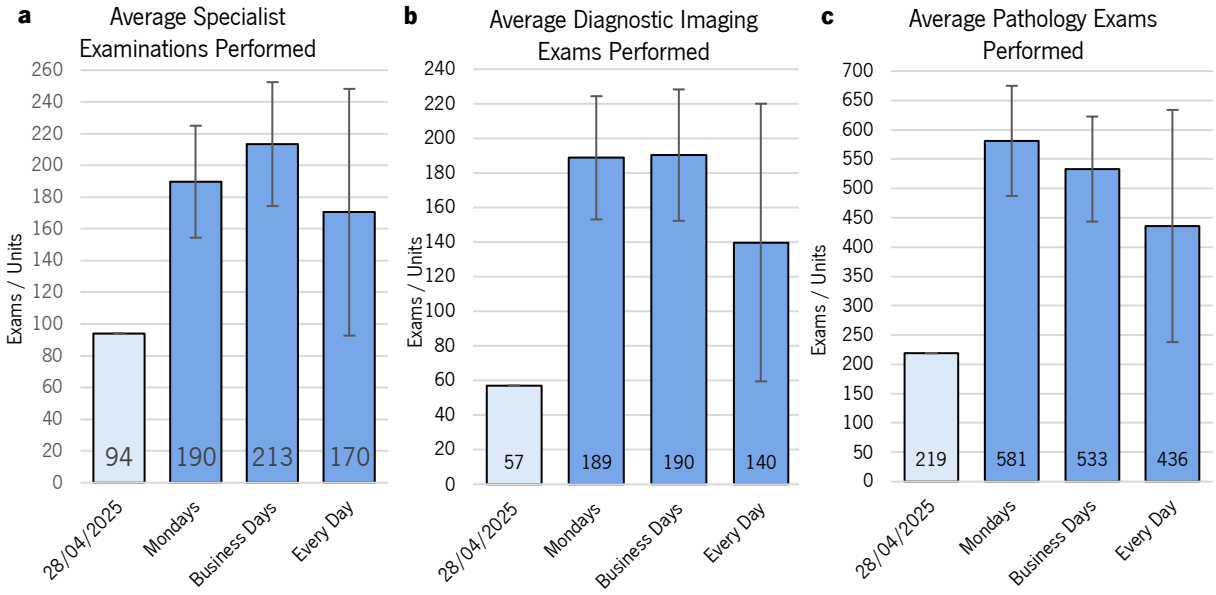


Figure 11 – Analyses of the number of exams. **A)** Average number of specialist exams performed on Mondays, business days and of every day against the number of appointments on the 28th of April of 2025; **B)** Average number of diagnostic imaging exams performed on Mondays, business days and of every day against the number of appointments on the 28th of April of 2025; **C)** Average number of pathology exams performed on Mondays, business days and of every day against the number of appointments on the 28th of April of 2025.

6.6. Risk assessment

Formulating effective recommendations for improvement depends on the systematic identification of areas of vulnerability, a task for which risk assessment provides a structured and appropriate framework.

6.6.1. Occurrence on the 25th of April 2025

Based on all the information acquired throughout the internship, we first looked at what actually happened on the day of the event and identified the following scenarios: running out of fuel; information system shutdown; lack of communications; lack of staff and generator failure. The scenarios were then analysed according to the risk matrix scoring (Table 2) and an overview can be seen in Table 7.

Scenario 1 (S1) - running out of fuel: When looking at what happened on the 28th of April 2025, this scenario had a possibility of happening if no interventions were done. If it had happened, it would have been catastrophic. The reason this scenario was given the rating of possible, 3, was due to the fact that if energy management and fuel resupply, the interventions, had not happened then the generators would have been left with low levels of fuel, if the blackout had lasted longer then it would have been catastrophic, 5, as the hospital would have been out of energy and the UPS systems only last a few hours, only the recovery would be operational and under constraints. Given this information, it is considered a high-risk scenario and measures should be implemented to prevent this.

Scenario 2 (S2) - information system shutdown: When looking at what happened on the 28th of April 2025, this scenario actually happened and therefore was imminent, 5, even though it was thought to be very unlikely to happen. Even though it happened, the severity of the scenario was minor. The reason this scenario was given the rating of minor, 2, was because it was only for a few hours, between 4 pm and 6 pm, and most of the important patient information about the inpatients on the recovery room was stored on the computer's hard drive but it was because of this disruption the scheduled activity was cancelled as general patient information is only stored on the servers. Given this information, it is considered a moderate-risk scenario and so attention and control should be given to it during the scenario.

Scenario 3 (S3) - lack of communications: When looking at what happened on the 28th of April 2025, this scenario actually happened and therefore was imminent, 5, but even though it was not expected, it could have been predicted given the duration of the backout. Even though it happened, the severity of the scenario was minor. The reason this scenario was given the rating of minor, 2, was because even though it disrupted administrative operations, it had no direct impact on the medical care provided. Given this information, it is considered a moderate-risk scenario and so attention and control should be given to it during the scenario.

Scenario 4 (S4) - lack of staff: When looking at what happened on the 28th of April 2025, this scenario was unlikely to happen. If it had happened, it would have been major. The reason this scenario was given the rating of unlikely, 2, was due to the policy of service continuity but it could have not been completely ruled out considering the uncertainly around childcare and transport but if there was indeed a shortage of staff it would have a major impact, 4, specially around shift change since it would put extra pressure on the staff that had already been working since the morning and it could even affect medical care. Given this information, it is considered a moderate-risk scenario and so attention and control should be given to it during the scenario.

Scenario 5 (S5) - generator failure: When looking at what happened on the 28th of April 2025, this scenario was very unlikely, 1, to happen given all the test, that had been conducted with frequency. If it had happened it would have been catastrophic, 5, for the same reason as in S1, except it could be harder to fix than resupplying with fuel. Given this information, it is considered a low-risk scenario and monitoring the scenario would be enough.

Following the assessment of risk across the identified scenarios, priority should be assigned to those with higher scores, particularly **S1**, while also implementing mitigation strategies for **S2**, **S3**, and **S4**. Although the complete elimination of risk would be ideal, this is rarely feasible or not cost-effective. Therefore, emphasis should be placed on managing these scenarios to reduce overall risk.

Table 7 – Risk assessment matrix analysis of the day of the blackout.

Scenario	Severity of Event	Occurrence on the 28th of April 2025	Score	Risk Level
S1 - Running out of Fuel	5	3	15	High
S2 - Information System Shutdown	2	5	10	Moderate
S3 - Lack of Communications	2	5	10	Moderate
S4 - Lack of Staff	4	2	8	Moderate
S5 - Generator Failure	5	1	5	Low

6.6.2. Prolonged 72-hour blackout

When the same scenarios are examined in the context of a prolonged blackout lasting 72 hours, as initially reported by the government, the impact of the blackout becomes significantly more pronounced.

Using the same scoring matrix (Table 2), the scenarios were analysed against the occurrence of a 72-hours whole country blackout. An overview can be seen in Table 8.

S1 - running out of fuel: When looking at what could happen if the blackout lasted 72-hours, there is an imminent possibility that the generators could run out of fuel, which would still be a catastrophic scenario, 5, as previously explained. The reason this scenario was given the rating of imminent, 5, was due to the fact that the 300L on each generator would not have been enough to last the 3 days without intervention and even under minimum energy consumption, more fuel would still be needed. Given this information, it is considered an extreme-risk scenario and immediate actions are required to mitigate the situation.

S2 - information system shutdown: When looking at what could happen if the blackout lasted 72-hours, the likelihood of the system going down is actually unlikely, 2, this is because of all the protections that are in place to prevent it from happening. The severity of the scenario still remains minor, 2, since most of the important patient information about the inpatients in the recovery room is stored on the computer's hard drive and protocols are in place for recording patient information when servers are down for the walk-in appointments. Given this information, it is considered a low-risk scenario and so monitoring the scenario would be enough.

S3 - lack of communications: When looking at what could happen if the blackout lasted 72-hours, this scenario would be imminent, 5, and at a larger scale than the one that happened since ever more operators' network antennas would run out of batteries. The severity of the scenario would be moderate, 3, since administration would have a hard time communicating with staff, as well as patients not being able to contact the hospital for information. Given this, the scenario can be considered a high-risk scenario and measures should be implemented to prevent this.

S4 - lack of staff: When looking at what could happen if the blackout lasted 72-hours, this scenario would be likely, 4, since shift rotation would need to happen while still under the constraints of the lack of communications, as well as the likely scenario of lack of public transports, making it hard to guarantee service continuity. If it did happen, the impact would still be major for the same reasons. Given this information, it is considered a moderate-risk scenario and so attention and control should be given to it during the scenario.

S5 - generator failure: When looking at what could happen if the blackout lasted 72-hours, this scenario rating would be increased to unlikely, 2, due to the fact that the generators would be running for a lot of hours, which increases the probability of something going wrong with them. If it did happen, it would have been catastrophic, 5, for the same reason as in S1. Given this information, it is considered a moderate-risk scenario and so attention and control should be given to it during the scenario.

Following the assessment of risk across the identified scenarios, priority should be assigned to those with extreme scores, with the focus still being **S1**, but this time **S4** would also have to be given a high priority, while also implementing mitigation strategies for **S3** and **S5**.

Table 8 – Risk assessment matrix analysis of a 72-hour blackout.

Scenario	Severity of Event	Occurrence on a 72-hour blackout	Score	Risk Level
S1 - Running out of Fuel	5	5	25	Extreme
S4 - Lack of Staff	4	4	16	Extreme
S3 - Lack of Communications	3	5	15	High
S5 - Generator Failure	5	2	10	Moderate
S2 - Information System Shutdown	2	2	4	Low

7. RECOMMENDATIONS ON POLICIES THAT INCREASE RESILIENCE

After being able to delineate what risks were presented and which ones should take priority on what to address first in both the scenario of the actual blackout and a 72-hour blackout, a series of recommendations to mitigate each scenario, as eliminating the risk is not feasible, as they are dependent on external factors.

When it comes to **S1**, fuel shortages, our recommendation would be to make a contract with a fuel supplier that is not included in the Strategic Network of Refuelling Stations, for the priority supply of fuel in case of an expected prolonged regional blackout, with prolonged being defined as an expectation of more than 12 hours. The contract should have actionable clauses that, in case of a complete communications breakdown, either fuel is to be delivered without further instructions if there is no contact with the hospital within 2 hours of the severity of the incident being identified, or someone is in charge of physically going towards the location of the fuel station to activate the contract.

This would be the best solution considering that, at least for now, Lusíadas Braga Hospital is not included within the priority refuelling list of the government due to a lack of emergency services. Not only that, but as could be observed, even if it was within the priority list, the government has shown itself that it can't always be the most reliable when it comes to such extreme situations where the whole country is in a crisis and in need of fuel for generators. With Lusíadas Braga Hospital's supply normally ranging from 500L to 1000L, it would give them an autonomy of 10 to 24 hours at full capacity, which can be extended with the decrease of services provided. The contract would allow for the mitigation of scenarios when the blackout lasts for more than half a day.

A scenario was analysed where the hospital was to be fully supplied using solar panels. It was quickly dismissed as not only would it require a substantial financial investment, but also physical space, as a lot more solar panels than the ones already installed, which cover half the rooftop, would be needed. Also, a whole floor would have to be used just to be able to house the batteries and inverters that would allow for the efficiency needed to have the hospital being fuelled solely by the panels. With the current number of panels installed on the roof of the building, a whole day of energy production would only be able to fuel the hospital for 2 hours.

When it comes to **S2**, if we were only taking into consideration the resilience of Lusíadas Braga Hospital, then it would make sense to have its own informatics systems servers within the hospital premises and control, which would also help mitigate unforeseen circumstances. That is not the scenario due to the fact that the hospital is part of a big group of health providers and, as such, it is a lot more

cost-effective and feasible to centralise big components like that. Mitigations are already in place to reduce the impact of a system breakdown, but it would still have an impact if it happened again, especially in the scheduled appoints that would lose patient history, as well as, the case of inpatients as the new infrastructure for the inpatient unit is still not ready within the main building and the patients are currently temporarily being housed in Clinica de São Lasaro that is across the street from the main building. For inpatients, we would recommend that a physical copy of not only patient medication, but a full patient history and lab be available to mitigate a scenario where both information systems and communications are down, at least until the inpatient unit in the main building is opened, where they would then have a digital copy saved to the computer of the unit and not just in the servers. It would not be feasible to save all patient information from Lusíadas Braga Hospital locally on the computers to mitigate against a blackout, due to the fact that the storage capacity of the computers would not be able to accommodate all the information.

When it comes to solutions to improve communications **S3**, it is a bit complicated, as having a satellite phone would not be feasible, as the hospital's dimensions would not justify it. The recommendation would be to have contacts with a variety of telecommunications providers, including MEO, to ensure that communications can stay open as long as possible. One of the actions that was already implemented was the acquisition of portable radios to facilitate communications within the building, between the administration and key individuals.

One of the hardest situations to mitigate would be **S4**, the lack of staff, which is also complicated by the uncertainties with communications, public transports and staff with underage children. Even though protocols are already in place to ensure continuation of services, clearer guidelines should be established to minimise disturbances and ambiguity in the situation. Guidelines should include staff dismissal priority for individuals with dependents as well as fixed scheduling of staff in cases of declared emergencies, so they know that if declared, they are the ones responsible for those shifts.

The hospital's Emergency Plans should be updated to take into account and help mitigate future blackouts. These measures would contribute to alleviating how the hospital is able to respond in the case of another prolonged regional blackout and help guarantee the ability to maintain the safe and continuous care of its patients.

8. DISCUSSION AND CONCLUSION

The situation the country experienced on the 28th of April 2025 was unprecedented and, as such, it was a real-life stress test on the resilience of Lusíadas Braga Hospital. Even though the main event was the loss of electricity by the whole country, we have observed that the main struggles experienced during this event were not caused by the lack of electricity itself but by the subsequent failures of the supporting systems, like telecommunications, which also increased the uncertainty the population was facing. This event cannot be looked at as an isolated electrical failure but as a multi-system disruption that exposed the interdependence between energy, communications, digital infrastructure, logistics and hospital service continuity.

Our analysis showed that, from the perspective of an isolated electrical failure, the hospital showed a high degree of resilience. Since the generators were fuelled and the performance tests were up to date, this allowed for their proper functioning. The ongoing surgery was protected by the UPS system, and essential services were maintained during all hours of the event. The water tanks were also full, which was also extremely important as clean water is essential for the proper functioning of the hospital and, due to lack of electricity, the external water supply was interrupted. The existence of an internal energy-priority plan also helps reduce the risk of any immediate infrastructural collapse. These show that the hospital had the capacity to absorb the initial brunt of the blackout. However, it also shows that technical backup systems alone are not enough to guarantee organisational resilience in a prolonged outage. By the end, the hospital was only able to remain operational in a reduced mode dependent on fuel availability, the response of the external supplier and the continued partial functioning of communication channels.

One of the main findings of this work is that the hospital's vulnerability was strongly shaped by factors outside its direct control, which would have been aggravated if the blackout had been due to factors such as extreme weather. The duration and severity of the disruption depended not only on internal preparedness, but also on the state of public infrastructure, the broader emergency context and the performance of telecommunications. This helps explain why a hospital that was technically capable of continuing under generator power was nevertheless forced to suspend most programmed activity. In practice, resilience was constrained by external systemic conditions rather than by the immediate failure of the hospital's own physical infrastructure. This is an important point because it suggests that hospital contingency planning for blackouts cannot be limited to internal engineering solutions, but it must also address dependencies on suppliers, network operators, transport, and digital systems.

The reduction in hospital activity witnessed on the day of the blackout reinforces this observation. Quantitative analysis showed significant decreases in scheduled appointments, walk-in appointments and exams when compared with typical Mondays and Business Days patterns. Surgeries were less severely affected, likely because many were scheduled earlier in the day and the operation already underway was able to conclude under protected power conditions. These findings indicate that the blackout had a similar impact across services. The fact that walk-in appointments, which remained operational as normal, also saw a significant decrease when compared to the daily average of the three months observed showed that the limitation was not internal but external, such as patient mobility and uncertainty.

The qualitative evidence complements these quantitative results by showing how disruption unfolded in operational terms. The hospital's principal weaknesses were located at the interfaces between systems. This can be seen in the need to transfer the remaining inpatient from the unit without generator support, the difficulty in contacting ambulance partners, the need for physical travel to arrange transport, and the eventual suspension of scheduled services after the loss of access to informational system servers in Porto. The blackout became significantly more difficult to manage once communication and information systems deteriorated. This finding is particularly relevant because it shifts the focus of resilience planning away from power supply alone and towards a broader concept of continuity under degraded conditions.

The risk matrix developed in this study supports this observation. Running out of fuel emerged as the most severe scenario because it threatened the continuity of all powered functions in the hospital. Yet information-system shutdown and communications loss were also shown to be highly relevant because, although less catastrophic in immediate clinical terms, they were effectively imminent during the observed event and had wide operational consequences. This points out the fact that sometimes the most dangerous scenarios are not always those with the highest severity, but those that combine significant consequences with a realistic probability of happening during prolonged outages. For the hospital, this means that resilience policy should prioritise not only catastrophic failure scenarios, such as total generator loss, but also highly plausible operational degradations, such as communications collapse, server inaccessibility and uncertainty in staffing.

As Lusíadas Braga Hospital's CEO stated, when talking about how the government dealt with public hospital´s emergency planning during the blackout of April 2025, "The hospitals were prepared to deal with catastrophes, but they were not prepared to the catastrophes.", meaning that the hospital themselves became the emergency the government was trying to mediate.

This finding must be interpreted within the study's limitations. Since this work analyses a single case of one private hospital, this limits the extent of information available and the conclusions can be generalised to all Portuguese hospitals. Public hospitals, hospitals with emergency departments or ICUs, and hospitals located in different infrastructural contexts face different vulnerabilities and operate under different constraints. The operational data used in the quantitative component can contain some inconsistencies related to how activity was entered, recorded or classified in the hospital systems. In the system, it was not possible to differentiate on whether the appointments and exams were classified as absences due to the doctors not being present or due to the patients not making their way towards the hospital. The small sample size and relatively high standard deviation in some cases limit the statistical robustness of the analysis, meaning that the results should be interpreted with caution rather than as definitive evidence and used as a groundwork for recommendations.

On the other hand, the qualitative material relies on interviews and retrospective accounts, which are valuable for reconstructing the event but remain subject to recall limitations and individual interpretation. Since this was an unprecedented event shaped by highly specific external circumstances, including nationwide telecommunications degradation and an energy crisis declaration, the exact configuration of risks observed here may not be replicated in future localised outages.

Nevertheless, these limitations do not diminish the value of the case, but they underline the importance of studying real disruption events and how they affect hospitals both locally and in a more interconnected perspective, especially when taking into consideration the lack of information available within the scientific literature.

Future research should expand on this case study by comparing the response of Lusíadas Braga Hospital with other private and public healthcare units affected by the same blackout. This would help identify whether the vulnerabilities observed in this study are specific to this hospital or reflect broader weaknesses across the Portuguese healthcare system, mainly fuel supply and communications breakdown. Further studies could also evaluate the effectiveness of blackout simulations and emergency drills in improving hospital preparedness, especially for prolonged scenarios lasting 48 to 72 hours. In addition, future research should examine the cost-effectiveness of different resilience measures, such as priority fuel supply agreements, local data backup systems, redundant communication channels and alternative energy sources.

This work provides an analysis of how one hospital experienced, managed, and adapted to an extreme infrastructure failure. In doing so, it contributes to a more realistic understanding of hospital resilience as something dynamic, context-dependent, and deeply influenced by interdependencies beyond the hospital walls.

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Grammarly and ChatGPT were used to support spelling, grammar, sentence structure, and academic phrasing. ChatGPT was also used to generate violin graphs using data and formatting specifications provided by the author. The author reviewed, edited, and approved all AI-assisted outputs and remains responsible for the dissertation's content, analysis and conclusions.

APPENDIX A – SUMMARY OF INTERVIEWS

Table A.1 – Summary of interviews performed.

Position	Interview Summary
Director of the Hospital	- Explained when communication disruption happened and new mitigation strategies already implemented. - Explained the concern surrounding staff management, including staff with children, as well as explain the continuity of care protocol in place. - Explained Emergency Plans in place to mitigate scenarios. - Explain the logistics behind fuel procurement and energy management. - Helped delineate timeline of events.
Head Nurse	- Explained how many people were in the surgical recovery room as well as in the inpatient unit. - Explained the logistics on how they were able to arrange for an ambulance. - Explained what patient records were available. - Helped delineate timeline of events.
Head of Physiotherapy	- Explained what happened on within the building on the day of the backout and how the physiotherapy services were impacted.
Head of Maintenance	- Explained how the generators normally worked and their past testing records. - Explained what happened in terms of fuel availability and energy management on the day of the blackout. - Explained water storage system and capacity. - Explained solar panel system in place and feasibility of use. - Helped delineate timeline of events.