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A Comparative Analysis of the Impacts and Resilience of the Electricity Supply Industry against COVID-19 Restrictions in the United Kingdom, Malawi, and Uganda

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Abstract: In response to COVID-19, most countries implemented mitigative and suppressive measures to stem its spread. This study analysed their impacts on the operations, investments, and policies within the electricity supply industry (ESI) for the United Kingdom, Malawi, and Uganda. It further assessed ESI's resilience capacities (*prevention*, *absorption*, *adaptation*, *recovery*, and *transformation*) and ultimately quantified resilience using SDG 7 targets. The study observed that in 2020, the UK had 143 days of lockdowns compared to 74 for Uganda and none for Malawi. The UK's annual demand fell by 4.8% while Uganda and Malawi's increased by 0.5% and 2.8%, respectively. During lockdowns, the UK lost 28% of its demand compared to 5.5% for Malawi and 24% for Uganda. It took the UK 8 months to recover its demand, which was correspondingly twice and four times longer than Uganda and Malawi. The degeneration in the level of system operations in the UK did not significantly affect electricity access and reliability contrary to Uganda and Malawi, whose impacts on their development commitments could span for years. This study underscores the necessity of evaluating resilience with respect to local development commitments. Moreover, several measures were proposed to enhance resilience mainly through actions meant to ensure business continuity.

Keywords: resilience; electricity; pandemic; COVID-19; lockdown; extreme events; high impact low probability

Citation: Mujjuni, F.; Chivunga, J.N.; Betts, T.; Lin, Z.; Blanchard, R. A Comparative Analysis of the Impacts and Resilience of the Electricity Supply Industry against COVID-19 Restrictions in the United Kingdom, Malawi, and Uganda. *Sustainability* **2022**, *14*, 9481. https://doi.org/10.3390/su14159481

Academic Editor: Alberto-Jesus Perea-Moreno

Received: 21 June 2022
Accepted: 26 July 2022
Published: 2 August 2022

1. Introduction

At the time of writing this paper, March 2022, the world had been grappling with the COVID-19 pandemic for 25 months. To reduce its contraction and subsequent transmission, as well as to ensure that medical facilities are not overwhelmed with high numbers of patients, many governments instituted response measures aimed at restricting peoples' interactions. The measures remained in place for several months and in many instances, they were retriggered following a rise in the infection or mortality rate. These mitigative (i.e., social distancing) and suppressive (i.e., suspension of all non-essential work) measures commonly referred to as non-pharmaceutical interventions (NPIs), although helped in reducing the spread of the virus, had significant socio-economic impacts and affected the operations of critical systems such as the electricity supply industry (ESI).

Given the unique role of ESIs as a key enabler for service delivery and their high dependence on and integration with other critical infrastructure systems (CISs), the drawback on their operations was expected [1]. According to a study by the United Nations [2], countries under full lockdown experienced an average of 25% decrease in energy demand [3]. Several studies reported drastic changes in energy consumption patterns with domestic consumption overtaking both commercial and industrial consumption [1,3–5] and changes in load profiles [3,6,7]. Even after the restrictions were eased or completely removed, domestic consumption remained relatively high due to increased numbers of people working from their homes [8,9]. In several countries, there was an increase in electricity generated from renewable resources of 8–13% [4,10] and subsequently a 9% reduction of CO_2 emissions associated with electricity generation [6].

To assess the impact of COVID-19 on ESI, most studies [3,6–8,11,12] premised their findings on the effects of NPIs given their wider implications on demand, generation, utility operations and electricity markets. A number of studies [6,8,13] were focused on analysing changes within supply and demand, whereas Skarvelis-Kazakos et al. [1] and Norouzi et al. [14] developed deductive models that could generically be applied to quantify electricity systems impacts under extreme events. As a proxy for measuring the impact of the pandemic on the quality of life, several studies [13–15] employed econometric models to either quantify electricity prices or surpluses for utilities and consumers. Most of these studies were either system centric [1,7,15], were focused on the global north [8], Refs. [10,12–14,16] or were conducted in a highly revolving setting with circumstantial or insufficient data [3,5,13,17].

Given that pandemics are high-impact low-probability (HILP) events commonly cited as drivers of both resilience conceptualization and operationalization [18,19], previous studies did not assess the impacts of NPIs with respect to ESI's resilience capacities. To this effect, the two closest studies were identified. One explored resilience capacities but for an abstract electric utility [1] while the other [10] analysed the general impact of government fiscal bailouts on corporations but not explicitly for ESI actors. It is also not well understood in previous studies how countries with significantly varying economic statuses were impacted by the pandemic and how their performances could be objectively compared.

Therefore, this study aimed to analyse, quantify, and compare the impacts of COVID-19 NPIs on the resilience of ESI systems for Malawi, Uganda, and the United Kingdom. In particular, the study undertook an assessment of the impacts of NPIs on ESIs' operations, investments, and policies. Second, the study assessed and quantified the countries' ESI preparedness, response and adaptation by considering five resilience capacities i.e., *prevention*, *absorption*, *adaptation*, *recovery*, and *transformation*. Ultimately, the study assessed how NPIs affected the realization of key development commitments derived from sustainable development goal 7 (SDG7) targets, and proposed measures to bolster current ESI systems to future pandemics. The main study's contribution to the existing literature is the comparative analysis of ESI resilience of low-income countries, Malawi and Uganda, with a high-income one, the UK, in the context of varied severity of instituted pandemic restrictions. In addition, the study presents a conceptual framework from which systemic impacts of extreme events on infrastructure systems can be linked to macro development indicators.

Following the introduction, Section 2 presents the methods of the study in which a conceptual framework of the study is presented, and Section 3 details the results and associated discussion in relation to NPI's impacts on ESI systems and their consequences on development outcomes. In Section 4, the conclusions and implications of the study are drawn.

2. Methods

This study follows the premises of previous studies [18,19] that have argued for resilience as primarily a means of attaining and sustaining local development commitments. That is, resilience capacities and qualities are assessed to the extent that they enable development targets of a particular community rather than them being simply desirable properties of the system perceived to be an end in themselves. Subsequently, the resilience analysis process followed a multi-phased conceptual framework (shown in Figure 1) in which the nature of threat was first characterized, the impacts on the ESI's performance quantified, resilience capacities evaluated, and lastly, the quantitative changes in key development performance indicators were ascertained. In this schema, the ESI is deemed resilient not only by its strength to withstand the threat or by its capacity to adapt but ultimately by how the system continues to support local development goals. As such, a slightly altered definition of resilience by Ciapessoni et al. [20] was adopted by reckoning resilience as the system's ability to limit the extent, severity, and duration of the consequences of an extreme event.

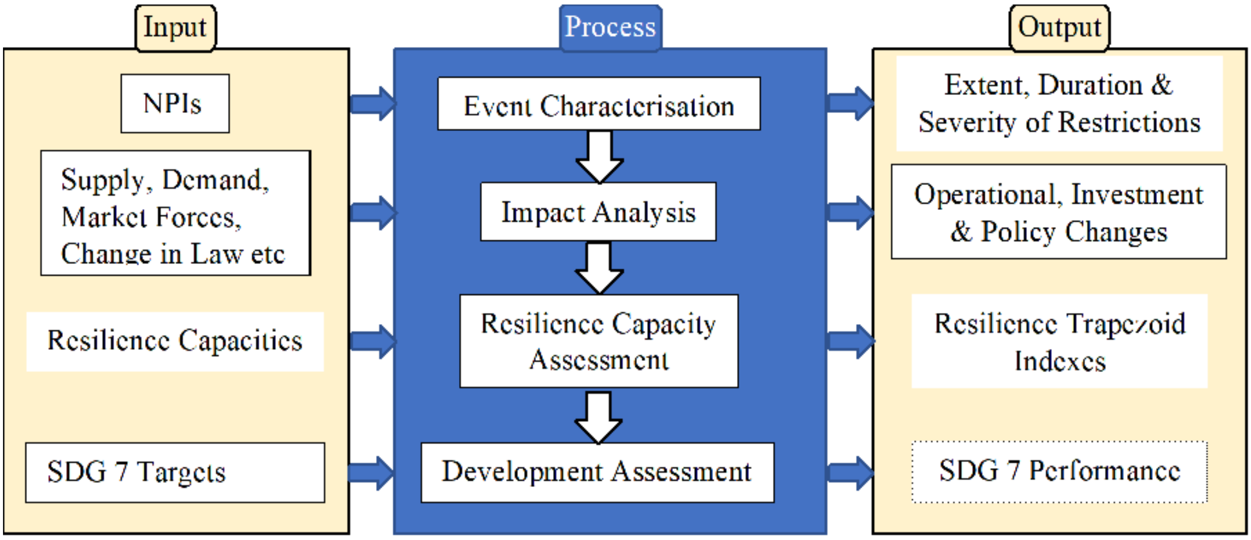

Figure 1. Research methodology conceptual framework.

The study assessed the extent of government restrictions, their duration and severity to draw probable causalities. The impacts of the restrictions on the ESI were grouped into three broad categories: operational, investment and policy. The operational elements include the assessment of the power systems demand and supply changes as well the attendant electricity market dynamics and industry's technical response capabilities. The impact on investments were evaluated by the flow and access to capital, number of developed or commissioned projects, or infrastructure assets added to the power system. The study also investigated whether government regulations to combat COVID-19 impinged on the existing laws regulating the ESI and whether new policies that have a direct bearing on the operations and development of power system infrastructure were enacted.

Resilience capacities are phased time-dependent responses of the system to an extreme event. The five capacities selected in this study were proposed by others [18,19,21]. The *prevention* capacity was assessed by the government's readiness to deal with pandemics as spelt out within existing policies and strategies. The *absorption*, *adaptation*, and *recovery* capacities were evaluated using the "*resilience trapezoid*" framework proposed by Panteli et al. [22] by how low the demand fell, how long the system stayed in a degenerated state, and the rate of recovery, respectively. The *transformation* capacity was quantified by the change in the electricity generation mix, whereas the consequences of NPIs were evaluated by changes within the selected sustainable development goal 7 (SDG 7) indicators [18]. The consequences were broadly classified into access to electricity, modern renewables within the country's final electricity consumption mix, and energy intensity [23].

Although it is preferable to evaluate access to electricity as a continuum of services as proposed by the Energy Sector Management Assistance Program [24], this study adopted the earlier binary method which quantifies it as proportion of the households with electricity supply. The continuum method is a six-tier framework premised on measuring electricity access based on a combination of seven attributes, namely: *capacity*, *availability*, *reliability*, *quality*, *affordability*, *formality*, and *health and safety*. Given their similarity with the SDG7 targets, this study quantified the seven attributes individually at the macro scale to evaluate consequences resulting from the pandemic restrictions. Relative to the business-as-usual case in 2019, the 2020 *capacity* was computed as the change of the per-capita installed generation capacity whilst *availability* was evaluated from the aggregated annual number of transmission system outage hours due to planned maintenance and faults. *Reliability* was quantified as energy not supplied resulting from transmission systems forced outages.

Quality was quantified as the aggregated number of voltage and frequency excursions on the transmission system while *affordability* (A) was calculated as in Equation (1).

$$A = \frac{T_d \times Q_a}{I_a} \tag{1}$$

where T_d is the annual average domestic tariff, Q_a is the average annual domestic consumption and I_a is the average annual domestic income.

The *formality* indicator was computed as the proportion of customers connected with either prepaid or smart metering services, whereas the *health and safety* attribute was quantified by number of injured victims and fatalities caused directly by utility components' malfunctioning, damages, or accidents. The study also assessed the growth of *modern renewables* within the generation capacity mix as well as tracking each country's energy efficiency by quantifying the *energy intensity* computed as the ratio of the country's total annual electricity generation to its gross domestic product.

The data used throughout the study were obtained from the individual country statistical bodies [25,26], electricity regulatory agencies [27], government energy, business and planning departments [4,28–32], peer-reviewed research [5,7,9,33], grey research [17,34], utilities [35,36], and government official statements [37,38]. Most of the raw data were aggregated on a monthly, quarterly, or an annual basis and unless stated explicitly, the remarked parametric changes contrasts metrics in two calendar years: 2019 (prior to NPIs) and 2020 (during or post NPIs).

3. Results and Discussion

3.1. Characterising the Disruption

In 2020, Malawi experienced two waves of COVID-19, with the highest peak infection rate of about 220 cases daily in July [39]. The government announced a lockdown slated to start on 18 April 2020 in which all educational facilities were to be closed, a night-time curfew instated, public gatherings restricted to 50 people, and a ban on international passenger flights and public transport [5]. The government restrictions were met with an injunction from the country's High Court and eventually were overturned on 10 September [33]. Stringent restrictions, however, had been implemented in Uganda in March with the first lockdown lasting 7 weeks. Following the rise of daily cases to 1900 in June, another full lockdown of 7 weeks was announced. Similarly, the UK announced its first full lockdown in March which was eased in May and completely relaxed in June. A second full lockdown was announced in November which lasted for 4 weeks. A summary of when lockdowns came into place and how long they lasted can be seen in Figure 2. In relation to the UK, the indicated dates in Figure 2 are those which were binding upon all constituent countries.

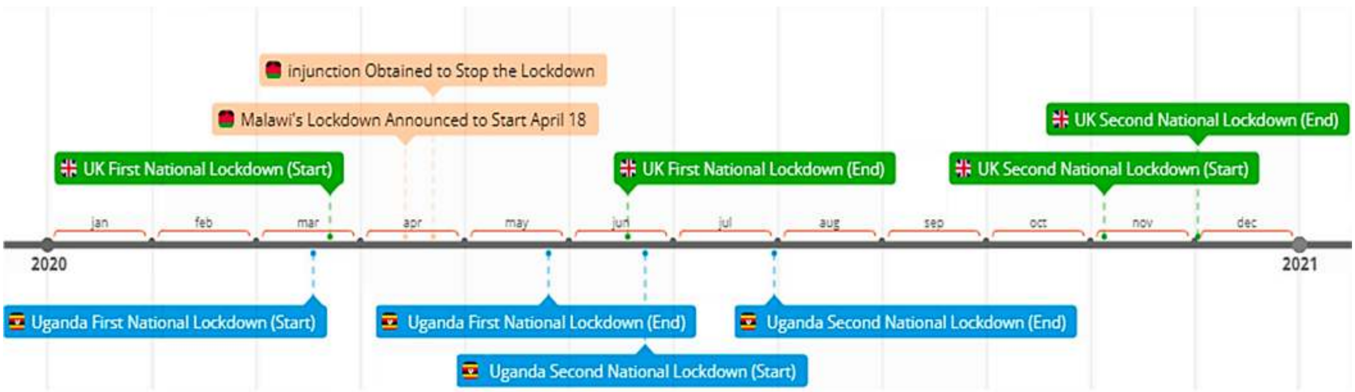

Figure 2. National lockdowns timeline.

Within the considered year for this study (2020), Malawi did not go into a lockdown, although there was an imposition of less stringent NPIs such as social distancing and a ban on non-essential international flights which had considerable impacts on the ESI's operations [5,33]. Given Malawi's landlocked status and the fact that all but one of its neighbours (Tanzania) implemented national lockdowns, there were observed disruptions in both electricity energy trade and supply chain for the necessary equipment and personnel [5]. The four different countries within the UK had different severity (partial or full, and regional or national) and durations of lockdowns. In 2020, Scotland's full lockdowns lasted a total of 195 days, 130 days for England, 129 days for Wales and 116 days for Northern Ireland [40]. In total, Uganda had 74 days of total lockdown in 2020 [37,38]. On the account of the duration of total lockdowns, which is a period in which all movement and gathering of people deemed "non-essential" was outlawed, the UK had the most severe restrictions followed by Uganda.

The responses to the pandemic were both a cause and a "victim" of reduced level of service of the ESI: a cause given that the restrictions affected the frequency, duration, quality, and effectiveness of service delivery from electricity sector players and a "victim" because pitfalls within the ESI impinged upon the operations of other CISs in responding to the pandemic. For example, electricity is critical in the production of hospital amenities and operations of hospital equipment, and yet strict adherence to NPIs meant reduced levels of service and response to power systems emergencies. Beyond the health sector, electricity is necessary for digitalization, monetary transactions, and communication systems, which are key enablers of response and recovery actions during pandemics.

In several countries, most scheduled maintenance works were suspended, and in contrast, utilities were required to implement business continuity plans to ensure that the systems were not unnecessarily disrupted [5,17]. The challenges presented by the pandemic on power systems can be summarized as the need of safeguarding public health, the necessity for business continuity for ESI actors, and increased stochasticity of electricity market dynamics.

3.2. Impacts of COVID-19 Restrictions on the Electricity Supply Industry

In this section, the impacts of COVID-19′s NPIs were assessed under three distinct classifications: operational, investment, and policy changes. The observed changes of the different parametric indicators were then discussed in light of their desirability within each country's development ambitions.

3.2.1. Operational Impacts

The impacts on the operations of the ESIs were considered in two ways: (i) the operation of the system's infrastructure which is primarily concerned with delivering sufficient and quality energy and (ii) the organizational operations focused on the business continuity of major sector players.

Demand and Supply

In Uganda, compared to 2019, the second quarter of 2020 saw a drop in demand of 11% [27] which was the first time that quarterly demand fell since 2015. Contrary to studies such as [1] that inferred a universal decrease in the overall annual demand, there was an increase of 0.5% for Uganda [41] and 2.8% for Malawi [42]. This contrasts with the UK which experienced an annual decrease of 4.6% [4] as seen in Figure 3A,B, although similar to Uganda, the demand share shifted from industrial and commercial customers to domestic consumption during lockdowns. Uganda's energy consumption growth (Figure 4A–C) was essentially due to recovery in industrial and commercial demand as well as fast-tracking of installation of prepaid metering units [41]. In Malawi, the domestic consumption rose by 8%, whereas industrial demand fell by 1% [42]. Similarly, the UK and Uganda domestic demand was up by 3.9% and 4.7%, respectively, whereas the corresponding industrial and commercial consumption fell by 9.3% and 0.4% [4,27]. There were changes in the daily demand profile during the first lockdown in the UK; other than the demand being significantly lower in comparison to the seasonal expectation, there were broader daily peaks, and mid-morning peaks were observed (Figure 3C,D), possibly arising from increased numbers of people working at home.

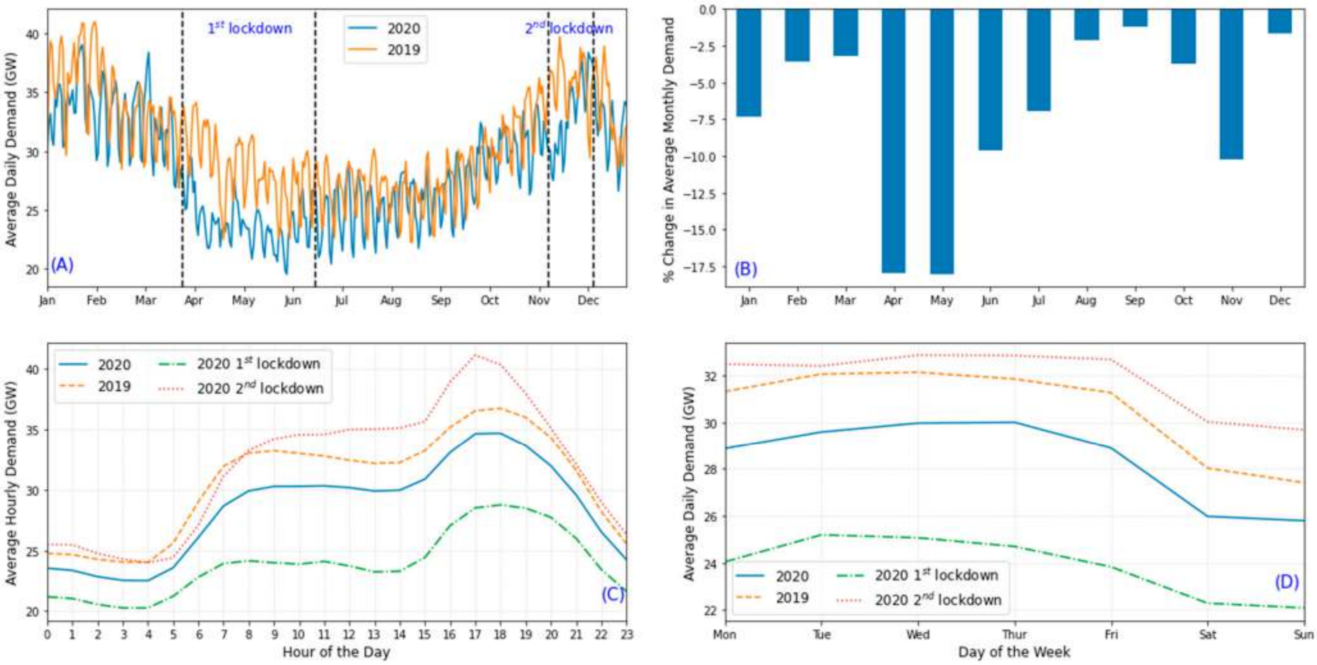

Figure 3. A comparison of 2019 and 2020 ESI performance in the United Kingdom: (**A**) Average daily demand with start and end duration of the national lockdowns represented; (**B**) The percentage change in average monthly connected load; (**C**) profile of the daily demand including demand profiles during the two lockdowns; (**D**) profile of average daily demand in a typical week.

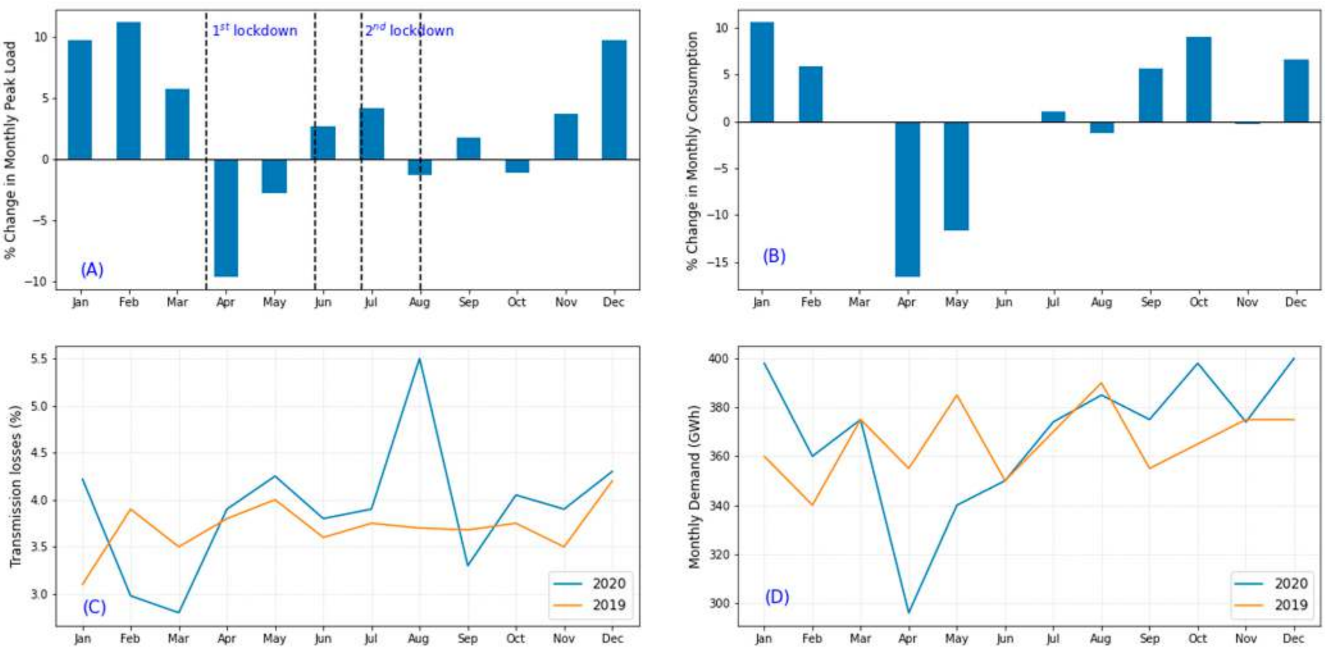

Figure 4. A comparison of Uganda's ESI performance for both 2019 and 2020: (**A**) change in monthly peak load with a demonstration of the spans of the two national lockdowns; (**B**) percentage change in total monthly electricity consumption; (**C**) profile of transmission losses; (**D**) total monthly consumption.

During the first lockdown in Uganda, the peak demand dropped by 20% in comparison to the month prior to the lockdown [27] as seen in Figure 4C. During 2020, Uganda's peak demand increased by 3.2% while that of the UK and Malawi reduced by 2.3% and 7.9%, respectively, compared to 2019 [4,27]. Possibly, due to the reduced peak demand, the UK's load factor reduced by 1% [29], whereas Malawi's increased by 0.3% [42], perhaps due to the increase in the average base load.

Both Uganda and Malawi are net exporters of electricity, whereas the UK is a net importer. In 2020, the UK and Malawi's net imports decreased by 27% [4] and 26% [42] (Figure 5C), respectively, compared to 2019. The exports in Malawi and Uganda were down by 1% [42] and 26% [27], respectively. Particularly in Uganda, the effects of lockdowns on demand were apparent when exports were analysed. Of the four countries to which Uganda exports electricity, three went into national lockdowns, and consequently, their energy imports from Uganda fell by 37% (Kenya), 12% (Rwanda) and 13% (DRC) [41]. However, the export to Tanzania, which did not implement any lockdowns, increased by 0.4% [27].

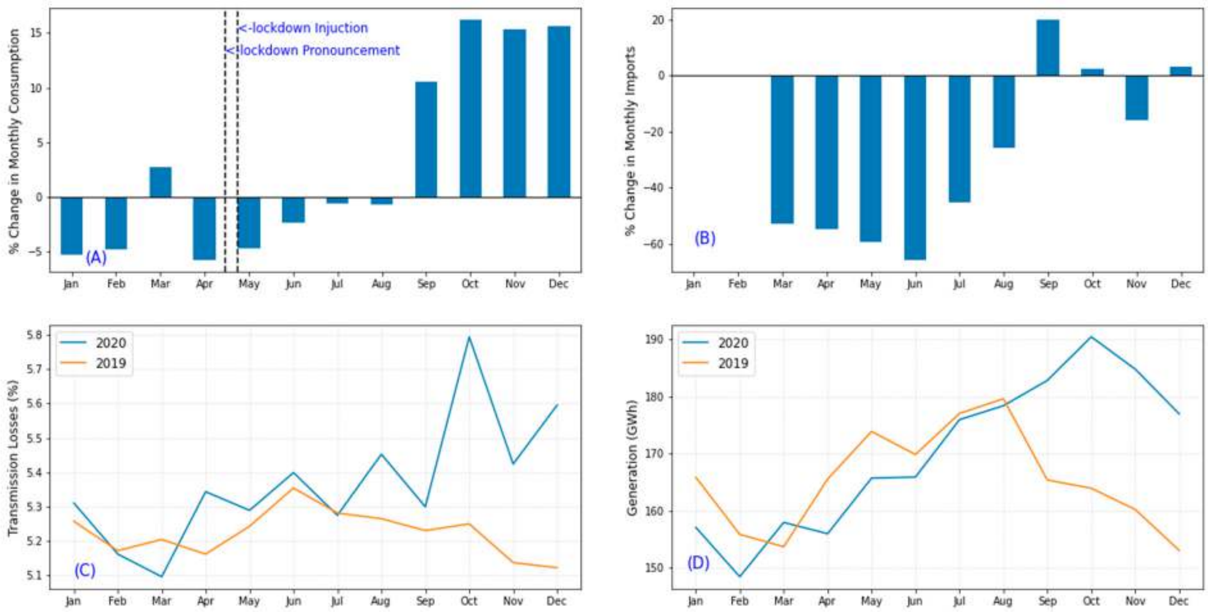

Figure 5. A comparison of Malawi's ESI performance in 2019 and 2020: (**A**) change in total monthly electricity consumption; (**B**) change in total monthly electricity imports; (**C**) profile of electricity transmission losses; (**D**) total monthly amount of electricity generated.

Tariff Movement

Given the low demand for electricity and relatively high plant availability, the expectation was that the price of electricity would drop. In Malawi and Uganda, base tariffs for utilities are set at the beginning of every calendar year [5,17]. These are regularly adjusted to reflect movement in foreign exchange rates, consumer price index, and oil prices. The disruptions in global supply chains, additional operating expenses resulting from implementing NPIs, increased technical and commercial losses, rising inflation, and a reduction in energy demand were reported to have caused an increase in weighted average tariff by 6.2% in Uganda [17]. However, the average declared end-user tariff in 2020 was 1.1% lower than 2019′s in Uganda and was unchanged in Malawi, possibly in response to political directives meant to stimulate economic recovery [17,34].

In the UK, the regulator sets a default tariff cap which limits the price that the utilities can levy on customers. This cap is adjusted every six months to reflect the cost of delivering electricity to the consumers. In 2020, the Regulator proposed an adjustment to the cap by an additional GBP 21 per customer to accommodate the uncertainty due to the pandemic especially towards the debt repayment component which had not been accounted for within the existing mechanism [32]. Nevertheless, the domestic electrical energy prices dropped by 10% compared to 2019 [29], mainly driven by a dramatic reduction in demand, with the first lockdown causing a 16% reduction and the second by 6.3% [12] (Figure 3B).

Revenue Collections and Operational Costs

Although distribution utilities in Uganda had made remarkable inroads of digitalizing the electricity payment system and connecting 97% of their domestic customers to prepaid meters, those customers accounted for only 30% of the revenue [43]. In April 2020, one month after the first lockdown, the electricity energy revenue went down by 19% [35]. In comparison with annual revenues of 2019, the largest distribution utility company in Uganda, Umeme Limited, registered a reduction of 7%, breaking its 6-year growth trend [43]. The transmission utility registered a decrease of 16% of energy sales revenue for the quarter following the first lockdown and an increase of 2% in the cost of sales [27]. Similarly for Malawi, there was a 1% decrease in electricity revenues [42]. Part of the reduced profitability arose from increased operational costs related to enforcing COVID-19 NPIs. The costs included purchase of personal protective equipment, disinfectants, computers, and internet connection to support remote working, teleconferencing facilities, vehicles and associated consumables to adhere to reduced office occupancy mandates [5,17]. In addition, a high proportion of post-paid meters and increase in defaulting on bill payments significantly contributed to reduced revenues in Malawi [5]. Moreover, it was observed that the electronic payment system for electricity in Malawi was highly unreliable and ironically inefficient due to frequent power outages [5].

In all three countries, reduction in consumption by industrial users was the primary cause of reduced revenues [4,5,35]. In the UK, to provide quality and reliable power, the transmission system operator (TSO) incurred a 42.4% increase in balancing costs, and ultimately, the operating costs from the main energy suppliers increased by 2.3% [44]. The balancing costs were driven by increased demand uncertainty and a high penetration of renewable energy sources into the generation mix. Moreover, electricity energy revenues for the UK in 2020 reduced by 12% [45].

Energy Losses, Reliability and Security

The restrictions inhibited utilities from importing the necessary components, deploying staff and procuring contractors to carry out surveillance and maintenance, and as such, this was cited for the increased technical and commercial power losses during lockdowns [17]. Power losses in Uganda (Figure 4C) and Malawi (Figure 5C) were driven, in part, by increased illegal connections, whereas increased frequency and duration of system faults were due to deferral of several maintenance activities [36,46]. Compared to the month prior to lockdown, in Uganda, the overall power system losses increased by 31% in one month, and by the third month, they were still 9% higher [47]. In respect to 2019, the transmission and distribution losses increased by 0.2% and 1.6%, respectively [27,41]. This was the first time in 10 years that the trajectory of annual wheeling losses was reversed, and consequently, the increase in losses during the first lockdown was valued at USD 6 Million [17]. In Malawi, the transmission outage hours increased by 7% and transmission losses rose by 0.2%, but the unserved energy and outage costs reduced by 6% and 9%, respectively [36]. These observations for Malawi underscore the fact that while utilities reduced their routine system maintenance activities, they were on high alert for responding to emergencies.

In the UK, the electricity conversion losses reduced by 1% [29], possibly because of increased penetration of renewable generation which inadvertently reduced the high conversion losses from fossil fuel plants. In addition, there was an increase in outages in the major power producers, particularly the nuclear power stations, leading to a reduction of load factor by 0.7% [29]. System stability was affected by the increased renewable penetration into the system, which necessitated the TSO to employ several balancing mechanisms to keep the system within acceptable operational parameters [44]. The Optional Downward Flexibility Management (ODFM) and Dynamic Containment were introduced to manage reduced and uncertain demand as well as to fast-track frequency response services [1,44]. Accordingly, relatively new ancillary technologies, such as synchronous condensers and battery storage, were procured to manage system frequency instead of services ordinarily offered by traditional fossil fuel plants [44].

Compliance Monitoring and Organizational Effectiveness

In Uganda, nine power generators filed for Force Majeure [17]. This declaration is warranted within the license provisions in which a utility is relieved from fulfilling certain obligations during an event with adverse effects and beyond the control of any party under the agreement [48]. Lockdown restrictions deterred developers and utilities from acquiring the necessary human resource and equipment, inevitably causing them to fail to meet their contractual obligations. Similarly, targets for generator utilities spelt out in power purchase agreements (PPA) and grid Codes were unattainable due to interrupted maintenance schedules and reduced demand. Utilities, developers, and regulators had to downsize their active staff leading to a decline in the levels of service delivery. This resulted in reduced numbers of customer connections, increased vandalism, reduced system surveillance, and increased commercial losses [46]. The regulator suspended all physical compliance inspections, and as such, they did not verify utilities' investments or investigate non-compliance issues, and subsequently, remedial actions were delayed [17]. This was akin to Malawi where several developers could not meet contractual obligations [34]. Moreover, projects reliant on expatriates were severely affected given a ban on international travel [34]. Local consultants were hired to perform tasks which were already contracted to expatriates, leading to considerable time and budget overruns [5].

3.2.2. Investment Impacts

In Uganda, it had been projected that the installed capacity would grow by 707 MW in 2020 [41] but rather, only 16.5 MW (the 10 MW Tororo Photovoltaic Power Plant and the 6.5 MW Timex Bukinda hydropower plant) was commissioned [41]. Likewise, the regulator had approved USD 83 million to enable growth in electricity access, improvement of quality of supply, reduction of energy losses, digitization, and completion of the roll out of prepaid metering [47]. By end of 2020, only 25% of the funds had been spent [35], and the total number of customers supplied by the distribution utilities grew by only 3% compared to 14% in the previous year [41]. The utilities that were heavily reliant on foreign experts and imports incurred time and budget overruns whilst projects such as construction of power lines had minimal interruptions given the country's capacity to manufacture the necessary materials, existing sufficient inventory, and skilled human resource. For example, in 2020, the transmission utility in Uganda commissioned three large substations in Mbale, Mukono and Iganga industrial parks [41]. In addition, about 2700 km of power lines were constructed [41].

In Malawi, the import of energy equipment was completely halted, causing both a delay in commissioning ongoing energy infrastructure projects, maintenance of existing infrastructure and a widespread deficiency in supply of domestic energy devices such as solar-home kits [5]. The start of the 300 kW and the 300 MW hydropower plants at Usingini and Mpatamanga, respectively, and the 120 MW grid-connected solar projects at Golomoti, Nanjoka and Nkhotakota were all delayed [5]. This delay will likely affect the attainment of targets of diversifying the generation capacity to 23% of solar by 2025 and increase in grid access to 30% by 2030 [5].

In the UK, investments in the energy sector were generally down by 23% compared to 2019, but for ESI, it went up by 10% with a total of GBP 10 billion invested in 2020 [29]. The investments followed the overarching plan of transitioning the power sector to the net-zero agenda through rapid growth in renewable generation, electrifying and decarbonatization of heat and transport, and provision of highly effective and low-cost system balancing mechanisms. To this effect, 3.2 million smart meters were installed, the interconnector capacity was increased to 6 GW, GBP 3 billion was availed for green energy projects, and GBP 700 million was designated for research and development [49]. The increase in funding was one of the exceptions given that in several countries, COVID-19 had a negative impact on liquidity and consequently on investments [50].

3.2.3. Policy Impacts

The government's lockdowns implemented under the Public Health Rules [51], constituted "change in law" in Uganda [48]. Several conditions for "change in law" are included in PPAs to protect utilities and developers against government interventions that could lead to repulsion, modification, re-enactment, or interpretation of any standing laws or enacting of new laws that impinge on their core objectives. To adhere to the directives, utilities and developers' operational costs increased, revenues reduced, and ongoing projects incurred time overruns. The resultant costs between April and June 2020 were estimated to be USD 4.3 million [17]. Furthermore, the funding under the electricity connection policy (ECP) was halted, resulting in only 24% of the planned connections made [41]. The free connection waiver under ECP was ultimately revoked, and new costs for different categories of connections were announced by the government [52]. The government also issued revised guidelines for an energy rebate program in which eligible consumers who could extend the distribution line to their premises qualify for compensation through monthly offset of energy bills [53].

It was observed in Malawi that existing policies and regulations were inadequate to respond to the complex challenges presented by the pandemic [5,34]. A fall in demand and an increase in expenses necessitated the utilities to recover the costs through the tariff, but the government issued a moratorium on the tariff revision scheme. This was contrary to observed increments in two of the main factors that influence tariff rates: fuel prices (130%) and exchange rate (3.41%) [54]. It was expected that the deferred tariff increment would be applied retrospectively in the following year. In addition, similar to Uganda, the staff for utilities, developers, and agencies within the ESI were deemed "essential" by the Public Health Act [55], and as such, they were mandated to continue working throughout the pandemic.

The UK government generally used the pandemic period to organize and reorientate the ESI towards what was reckoned a holistic net-zero agenda and to position itself as a global leader in clean technologies. In 2020, the government unveiled a ten-point plan meant to set and consolidate the UK green economic recovery [28]. The plan, among other goals, envisages in 10 years a quadrupling of the off-shore wind capacity to 40 GW and production of 5 GW of low-carbon hydrogen [28].

3.2.4. Comparison of Impacts

Table 1 summarizes the changes in selected indicators of the ESI's performance for 2020 compared to 2019. The cells are color-coded to demonstrate the preference of the observed change to each country. In this case, "green" represents a desirable and "orange" an undesirable outcome in relation to each country's development ambitions. In addition, changes are presented with a sign to indicate if they are an increment (+) or a decrement (−). To account for any other casual agents of observed changes within the ESI, the study undertook a basic assessment of the recorded rainfall, wind and temperature as simplified proxies for flood, windstorm and drought events. These events are known to be the main causes of power system disruptions in the three countries [56–58].

Compared to long-term averages, in 2020, the UK experienced disparately high mean daily temperatures (+0.8 °C) and rainfall (+113%), and it had three major named storms, Ciara, Dennis and Jorge [59]. Comparably, 2019 was the 12th warmest year since 1884, the rainfall was 112% higher than the long-term averages (1961–1990), and it had six named storms [60]. It is notable that 2020 was a slightly windier year than 2019 (by 0.4 m/s) [29] but whatever increment of generation from wind power plants in 2020 was only significant to the extent that the NPIs ensured that demand was generally down to accommodate a relatively high share of wind penetration. In essence, there were no significant discernible differences between the weather patterns within the two years that would weigh heavily on the observed performance indicators of the system. A similar conclusion can be reached at when meteorological data [61] are assessed for Malawi and Uganda. There are no known economic, environmental or geological factors that would make 2019 significantly dissimilar from 2020. The underlying premise in this study is that the observed changes were mainly shaped by the impacts of the pandemic and whatever contribution originating from other influences were insignificant in comparison.

In Table 1, the energy demand for Malawi and Uganda increased, whereas for the UK, it decreased. In all cases, the outcomes were deemed desirable. The ESI development goals in both Malawi and Uganda are aimed at increasing electricity consumption given its direct correlation with socio-economic development, whereas in the UK, energy efficiency campaigns have over the years been advocated and implemented to drive demand down. The UK's 2012 energy efficiency strategy set a goal of decreasing per capita demand by at least 31% by 2050 relative to 2017 [62], whereas in Uganda and Malawi, the increase in per capita consumption is prioritized within their respective national development plans [63,64]. A similar explanation holds for the increase in domestic consumption, peak demand and, to some extent to, commercial and industrial consumption. In the UK, although demand was preferred to decrease, the extent to which commercial and industrial consumption fell in 2020 (by 10.4%) was considered excessive to the country's sustenance of economic growth [29].

In line with ESI strategies, all countries had desirable outcomes regarding domestic tariff changes, customer connection, and installation of prepaid or smart meters [29,41,45]. Even though the tariff rates in Malawi and Uganda were artificially suppressed, it served the purpose of aiding economic recovery and easing the financial burden to the customers during the pandemic. Despite of the increase in consumption and an increase in the share of revenues collected in respect to energy sales, Uganda's biggest distribution utility registered a decrease in revenues of 7% [27]. In addition, unlike Malawi which remained unchanged in renewable and fossil fuel capacity and generation, the UK and Uganda had desirable outcomes.

The installed capacity and supply from wind increased by a corresponding 2.5% and 18% in the UK [29], whereas in Uganda, 1.3% of renewables were added onto the grid [41]. However, the UK suffered a significant decrease in its capacity margin due to closure of coal-fired plants [29], thereby highlighting the precariousness between pursuing net-zero goals vis-à-vis maintaining decent capacity redundancies to respond to contingencies. In Uganda and the UK, several power plants were commissioned, and the transmission system was strengthened, and extended. The UK had a rather fortunate electricity trade scenario in which electricity energy imports decreased, whereas the exports increased [29]. It was also reported in Uganda that deemed energy fees, which are fees that the government incurs due its failure to transmit energy being produced by the generators, were paid to various utilities [17].

3.3. Resilience Capacities Evaluation

Five popularly cited capacities were selected to assess the resilience of each country's ESI against COVID-19 as seen in Table 2. The capacity to *prevent*, and by implication to *anticipate*, the effects of the pandemic on the system was evaluated by the existence of strategies or plans directly tailored to electricity industry contingencies against extreme events as proposed by [18,21]. The UK maintains several policies, plans and strategies intended to prepare, withstand, respond, and recover the ESI from emergencies caused by extreme events even though they are not explicit about pandemics. The National Emergency Plan: Downstream Gas and Electricity [67], the Energy Act 2013 [68] and the Climate Change Act 2008 [69] contain a description of the level emergencies, how responses are activated, the necessary action plan, and assessment and monitoring of responses. Although Uganda's 2010 National Policy for Disaster Preparedness and Management [70] foresees the impacts of pandemics, it restricts them to epidemiological impacts and not CIS. In contrast, the 2015 National Disaster Risk Management Policy [71] by Malawi makes no reference to either pandemics or energy systems. In this study, although the existence of a regulatory or strategic framework was taken as a proxy for preparedness on the national scale, it should not be misconstrued to reflect a lack of such strategies for individual utilities.

Table 1. Changes in Key ESI Performance Indicators.

Indicators	Change in the Indicators		
	Malawi	**Uganda**	**UK**
I. Operations			
1. Energy demand	+2.8%	+0.5%	−4.6%
2. Domestic consumption	+8	+4.7%	+3.9%
3. Commercial and Industrial consumption	+1%	−1.8%	−10.4%
4. Demand peak	−7.9%	+2.3%	−3.2%
5. Domestic tariff	0%	−1.1%	−10%
6. Electricity revenues	−0.7%	−7%	−12%
7. Load factor	+0.3%	0%	−0.7%
8. Customer connections	+2.9%	+3%	+0.8%
9. Energy losses	+0.2%	+1.4%	−1%
10. Transmission system faults	−25.4	+2.0%	+21.7%
11. Customer satisfaction	-	+1.5%	+1%
12. Generation capacity	0%	+1.3%	−2.7%
13. Renewable generation capacity	0%	+1.3%	+2.1%
14. Fossil fuel generation capacity	0%	−44.3%	−3%
15. Generation from renewable sources	0%	+1.2%	+13%
16. Energy imports	−26.1%	+4.7%	−27%
17. Energy exports	−4%	−26%	+32%
18. Electricity capacity margin	0%	+0.3%	−11%
19. Operational costs	-	+18%	+2.3%
20. Microgeneration	0%	+17.7%	+1.9%
II. Investments			
1. Commissioned grid power plants	0	2	3
2. Start of construction of power plants	2	0	-
3. Length of transmission lines	-	+7.0%	+2.6%
4. Prepaid or smart meters installed	+5.1%	+3%	+5%
III. Policies			
1. "Change in law" invoked?	No	Yes	No
2. Revision of electricity policies	No	No	Yes
3. Payment of deemed energy or bailout	No	Yes	Yes

Key: -, Data unavailable: [orange], Undesirable, [light green], Desirable. Data source [4,5,27,28,30,34,41,45,65,66].

The *absorption* capacity was evaluated by how low the system's demand fell by comparing the maximum monthly demand peak prior to effecting NPIs with the lowest recorded monthly peak afterwards. In this case, Malawi had the lowest decrease in its demand. Conversely, both Uganda and the UK lost nearly a quarter of their demand during lockdowns [29,35]. The *adaptation* (coping) capacity was regarded to be the time the system took to recover from the lowest monthly slump in demand to the time the monthly peak demand equalled or surpassed pre-NPIs' peak demand. In this case, it took the UK two and four times longer to recover its demand compared to Uganda and Malawi, respectively.

Table 2. Change in selected resilience capacities indicators.

S/N	Capacity	Indicator	Change in the Indicators		
			Malawi	**Uganda**	**UK**
1.	Prevention	Existing response framework	No	No	Yes
2.	Absorption	How low demands fell (%)	5.5	24	28
3.	Adaptation	How long the system took to recover (months)	2	4	8
4.	Recovery	Rate of recovery (% of lost demand/month)	50	25	12.5
5.	Transformation	Changes in renewable generation capacity (%)	0	1.3	2.1

Data source [4,27,41,67,72].

Using the *absorption* and *adaptation* metrics, the recovery capacity was determined as a rate of demand restoration. The UK, at 12.5% demand/month, had a slower recovery than Uganda (25%) and Malawi (50%). The *transformation* capacity was determined by changes in renewable generation capacity. Uganda and Malawi's generation mix is somewhat similar in that it is dominated by hydropower generation constituting 80% [41] and 68% [73], respectively. There were no commissioned plants in Malawi in 2020, and only two small renewable resource power plants with a combined capacity of 16.5 MW were commissioned in Uganda [41]. In the UK, the biggest increase in renewable resource capacity was from offshore wind, which was up by 5% compared to 2019 [29]. For the first time, renewable resources in the UK generated more electricity than fossil fuel plants. As such, the total renewable generation share increased by 6.2% and capacity by 2.1% [4].

3.4. Evaluation of Consequences of NPIs

The assessment of system resilience by reduced output or by the duration it takes in a degenerated state, as explained in Section 3.3 above, fails to account for its interconnectedness to other systems and its impact on broad socio-economic factors. In this study, resilience was ultimately evaluated in terms of consequences by quantifying how selected SDG7 indicators were impacted in 2020 in contrast to 2019. Therefore, Table 3 shows changes in selected indicators that have a significant bearing on socio-economic outturns of any given country. Again, similar to the previous Sections 3.2 and 3.3, the observed changes are premised on the effects of the pandemic's NPIs given that no other event was recorded in each of the contrasted years to have had a substantial effect on the ESIs performance. The authors were not able to identify any cause in market forces or nature that could explain the changes within the development indicators other than the disruptions resulting from NPIs.

It can be observed from Table 3 that there was a 3.1% decrease in the proportion of the households with access to electricity in Uganda. This could be, in part, due to the suspension of the government's subsidized electrification scheme and the fact that population growth outpaced electrification rate [41]. In contrast, grid electricity access in Malawi grew by 2.2%, although it is only 13% of the households, and the per capita consumption of 109 kWh is five times lower than the sub-Saharan average [72]. No significant changes within the UK's access to electricity were observed given that it is deemed to have attained universality. As an indicator of how much installed capacity was available per individual, it was observed that in all three countries, *capacity* decreased by 2% in both Uganda and the UK [29,41] and by 2.8% in Malawi [42]. The reasons are somewhat different in all three instances. In Uganda, the increase in generation (1.3%) was smaller than the increase in population (3%) [74], whereas in Malawi, no generation capacity was installed in 2020 to match with the increase in population. As for the UK, the 2020 reduction in installed capacity was due to the closure of coal power stations at Fiddler's Ferry and Aberthaw B as well as Dungeness B nuclear power plant. However, both Uganda and the UK had an increase in the share of (modern) renewables by 1.3% [41] and 2.1% [4], respectively.

Availability, as measured by transmission system outage hours, was observed to decrease by 88% in Uganda, meaning that transmission system's components outages nearly doubled within 2020 but given the meshed topology of the system, the resultant system reliability decreased slightly by 1.7% [27,41]. Similar observations were made in Malawi in which system availability decreased by 7.4% but hardly affected reliability, which instead rose by 6.3% [36,42]. In the UK, the transmission system availability decreased by 0.2% with no significant effect on its reliability. These observations demonstrate the complexity of assessing resilience and the necessity of its evaluation as a factor of consequences of the disruption considering that not every system fault necessarily leads to loss of system service. As per *quality*, it was observed that the UK did not have a single event with frequency or voltage excursion outside the range permitted by the grid code [75], whereas for Malawi and Uganda, the authors were unable to obtain the relevant data from the respective grid operators.

Table 3. Percentage change in selected development targets.

S/N	Indicator	Malawi	Uganda	UK
1.	Access to Electricity	+2.2	−3.1	0.0
2.	Capacity	−2.8	−2.0	−2.0
3.	Availability	−7.4	−87.6	−0.2
4.	Reliability	+6.3	−1.7	0.0
5.	Quality	_	_	+100
6.	Affordability	0.0	+0.4	+0.1
7.	Formality	+5.2	+11.9	+46.0
8.	Health and safety	0.0	+61.1	0.0
9.	Modern renewables	0.0	+1.3	+2.1
10.	Energy intensity	−5.5	−3.2	+5.3

Data source [4,29,36,41,42,72,74–77]: Key: "−" represents a decrease in the indicator, "+" represents an improvement, and "_" represents "no data".

This study observed that *affordability* of electricity generally improved in Uganda and the UK, whereas it remained unchanged in Malawi. The change in the UK was mainly due to reduced electricity wholesale prices, whereas in Uganda, the different categories of end-user tariffs were reduced in response to government's directive. Regarding *Formality*, a proportion of customers connected with either prepaid or smart meters, were greatly increased across all countries, with the UK installing nearly 4 million smart meters [29]. In Uganda, installed prepaid meters increased by nearly 12% [77]. Regarding *health and safety*, there were no fatalities directly attributed to ESI components in Malawi and the UK but even though Uganda improved remarkably, it still experienced seven fatalities mainly caused by illegal connections, power thefts, accidents and vandalism [77].

In the context of electricity utilization, this study considered *energy intensity* to mean the ratio of supplied electricity to the country's gross domestic product (GDP). The indicator demonstrates the efficiency of production and utilization of electrical energy in respect to the size of the economy. The UK's energy intensity increased by 5.3%, whereas that of Malawi and Uganda reduced by 5.5% and 3.2%, respectively. For Malawi and Uganda, the decrease in energy intensity can be attributed to the growth in the GDP which was significantly higher than growth of supplied electricity. As for the UK, both GDP and electricity supply decreased, but the contraction in the GDP (9.4%) was much higher compared to electricity consumption (4.6%).

3.5. Measures to Enhance Power System Resilience to Pandemics

Unlike climatic or geophysical extreme events that cause direct and physical damages on power system components, pandemics have indirect but, perhaps similarly, devastating impacts. The impacts are highly correlated to both infection and mortality rates, the perceived risk level, security of electricity supply, and the level of dependence on foreign supply chains. This implies that the enhancement of resilience of any given power system is rather a more organizational endeavour than it is infrastructural or even operational one. To this effect, Skarvelis-Kazakos et al. [1] demonstrated this phenomenon by using a notional case study to analyse the effects of remote working and splitting of control centres on utility throughput. The ability to respond effectively before, during and in the aftermath of a pandemic has significant bearing on the availability of critical services [78]. In this case, organizational resilience implies the holistic planning and coordination of resilience enhancement measures across the major sectoral actors to maintain business continuity and key operational functionalities of the ESI system, whereas it is not in dispute that the technical solutions, such as upgrading the system's infrastructure, building robust lines, installing interconnectors, and increasing capacity reserves, are important, but against a pandemic, they offer little help except in instances of occurrence of extreme weather or geophysical events in the middle of a pandemic. Therefore, in this section, several measures are proposed that are tailored to improve ESI's resilience to pandemics with similar potency as COVID-19.

3.5.1. Prevention and Anticipation

The preventive and anticipative capacities enable organizations to prepare for and to commit resources as well as to formulate legal and contractual frameworks within which they would operate during pandemics [78]. These capacities ensure that the impacts resulting from such occurrences are greatly mitigated by reducing both the vulnerability and exposure of the ESI and by creating a proactive system in which present development actions inherently addresses future risks. In the short term, given that the primary goal during the pandemic is to protect the health and safety of utility employees, sector actors can ensure that at the earliest, their workers have access to personal protective equipment, therapeutics, and vaccines whenever they are required. In addition, utilities can make use of the available public health data to assess the risk associated to different groups of people and thereby make appropriate human resource deployment decisions. This will inevitably lead to broader working modalities that ensure personal safety but at the same time have a fully engaged workforce. It could also mean a normalization of several staff working remotely away from their usual workstations.

To ensure that such measures are woven within the business continuity plans of different organizations, it might necessitate governments to develop resilience policies with an element that focuses directly on pandemics. The resultant deliverables from policy regulations can then be made part of the routinely monitored and reported performance indicators by key ESI actors. In that case, the regulations would require the sector players to (i) demonstrate mechanisms in which their personnel's health and safety standards would be prioritized without a compromise on the system's output; (ii) demonstrate capacity for demand and supply forecasting; and (iii) improve grid-balancing mechanisms especially during highly fluctuating demand and increased penetration of intermittent renewables. Such measures can be supplemented by the government pursuing or expanding grid interconnector projects which could potentially mitigate against loss of generation in cases where generation or equipment maintenance is based on foreign supply chains. Moreover, coordinated planning across several critical infrastructure system sectors actors could potentially mitigate against conflicting actions and maladaptation.

3.5.2. Absorption

Borrowing from the conceptualization of Manyena et al. [19], the capacity to absorb is tailored at moderating impacts of the pandemics on the livelihoods of people. It seeks to primarily preserve the essential basic structure and functions of the system whilst avoiding permanent components' damage. In this regard, since the ESI's core mandate during a pandemic is to ensure an uninterrupted power supply to critical load centres, the system should be operated in a manner that such a function is prioritized. This could involve an enhanced capacity of loadshedding non-critical loads in the event of reduced generation, or on a long-term basis, an uptake of energy efficient devices can be widely encouraged to curb an abrupt rise in peak demand. Other long-term measures could be to install, increase or procure different forms of balancing capacity, diversification of the generation mix and increase in the capacity margin. These measures are meant to ensure that the grid remains operational within the normal voltage and frequency parameters whilst meeting the demand in a highly volatile environment.

3.5.3. Adaptation

The adaptive capacity is a measure of values and dynamics of an organization that are necessary to forming decisions in a quick and pertinent manner both in conventional business and in extremities, such as COVID-19 [78]. It involves aspects such as governance and decision-making structures, the obtainment, analysing, dissemination and storage of information and knowledge, and the extent of innovativeness and elasticity that the organization values. The adaptive capacity could be bolstered by effective incorporation of learned lessons from COVID-19 impacts into to mainstream industry operational manuals. It might necessitate an alteration of operational and organizational protocols to arrest further deterioration of the system functionality or stabilize the system in facilitating its recovery. For example, utilities can fast track the migration of operations on online platforms, devise means that allow relatively easy procurement of ancillary services during extreme events, and coordinate appropriate generator controls to respond to highly variable demand–supply mismatch. On the customer side, the government could provide waivers from electricity bills and taxes on bills or provide energy vouchers to a certain category of people to maintain a technically and economically acceptable base load. Such measures would prove more beneficial than for the government to pay deemed energy charges to utilities arising from reduced energy consumption. Moreover, utilities and developers could benefit from government bailout plans especially targeting loan repayments from previously verified investments. Internally within utilities, the operations and maintenance budget could be increased with an element targeted at extreme events.

3.5.4. Recovery

The recovery capacity would entail recovering the ESI services as quickly as possible to their pre-pandemic functionality. This could be achieved through bulk ordering and storage of all essential material and equipment [5], increased multiple fault ride-through and active power recovery capabilities [79], and quick detection, isolation, and response to faults [5].

3.5.5. Transformation

Elena et al. [80] regard transformation as the capacity to create a fundamentally new system when ecological, economic, or social structure make the existing system untenable. The capacity seeks to radically change the structure, institution, and relations between actors in hope of a superior level of rendered services [19]. In the short term, transformation can be driven by digitalization of core systems critical to business continuity such as billing, customer management, metering, human resource management, network control system, resource planning and management system. The transmission, distribution and supply utilities can improve network performance, outage detection and response as well as asset management by utilizing geo-spatial network information tools. In the long term, the government should ensure that the devised response and bail out packages are adherent to set development commitments. The government can tailor the bail-out packages towards utilities and developers engaged in diversification of the generation mix, installation of electronic payment machines and a distribution of prepaid or smart meters. For example, DeWit et al. [10] demonstrated the possibility of protecting public health during a pandemic whilst ensuring that fiscal stimulus support to corporations bolsters national resilience and sustainable development aspirations.

4. Conclusions

In response to COVID-19, most governments implemented stringent mitigation and suppressive strategies in 2020. Although the measures varied in severity, duration and frequency from one country to another, they nevertheless had significant impacts on the operations and development of the electricity supply industry. This study aimed to assess the resilience of ESI systems of three countries (Malawi, Uganda and the United Kingdom), and how selected SDG targets were affected by contrasting performance data for 2020 with the pre-pandemic business-as-usual case of 2019. The findings show that the UK implemented the longest total lockdown followed by Uganda. That is, all four constituent countries within the UK enforced an average of 143 days of lockdown in 2020 compared to 74 days for Uganda and none for Malawi.

There were several operational, investment, and policy impacts on the ESI. Generally, there was a shift in demand from industrial to domestic consumption, reduction in both electricity exports and imports, a fall in tariffs rates, reduction in revenue for utilities, an increase in electricity wheeling losses and operating costs, and an increase in renewable generation penetration. These findings are in line with what has previously been reported by Zhong et al. [7] and Kirli et al. [9]. The annual demand in the UK fell by 4.6%, whereas for both Uganda and Malawi, it increased by 0.5% and 2.8%, respectively. The fall in the UK's demand was mainly driven by a 10.4% decrease in industrial demand despite a 3.9% rise in domestic consumption. In addition, the level of investments in ESI projects plummeted in Malawi and Uganda while the UK invested nearly GBP 10 bn. In Uganda and the UK, there was a shift in policy implementation in which the government-subsidized customer connections were suspended by the former, whereas the latter developed a white paper stipulating the pathway to a net-zero future.

The study assessed resilience at a system level by quantifying five capacities: *prevention*, *absorption*, *adaptation*, *recovery*, and *transformation*. Malawi was the least prepared given that its disaster risk management policy made no reference to either pandemics or energy systems. The UK had the worst absorptivity since it nearly lost a third of its demand. It follows that the UK had the longest adaptation duration (8 months) and the slowest recovery (12.5% of lost demand per month). In contrast, Malawi had the shortest slump in its demand (2 months) and quickest recovery (50% of lost demand per month). These results attest to the fact that the resilience of the system was heavily influenced by the severity of the NPIs more than the state of the power system or the strength of the economy. This resilience analysis process has wide implications in comparing resilience of other systems in different settings against a common threat. The method prioritizes the response measures implemented by actors more than the pre-threat system status.

Outside the infrastructure systems boundaries, the study ultimately assessed resilience as a consequence of an extreme event. This was tailored to capture the socio-economic factors that affect people's welfare. To this effect, resilience was evaluated by ten selected indicators (*access to electricity, quality, capacity, availability, reliability, affordability, formality, health and safety, modern renewables, energy intensity*). It was observed that although the UK had the most severe impacts on its system operations and seemingly a mixed performance of its resilience capacities, it had the best turnout on its development commitments. *Quality, affordability, formality, modern renewables and energy intensity* for the UK all increased by 100%, 0.1%, 46%, 2.1% and 5.3%, respectively. Both its *access to electricity* (100%) and *reliability* (99.99%) were unchanged, and its *capacity* and *availability* only decreased by 2% and 0.2%, respectively. In contrast, both Malawi and Uganda experienced a slump in their valued development commitments of increasing generation capacity, energy intensity and system's availability. *Capacity* decreased by 2.8% and 2.0%, respectively, whereas the corresponding decrease in *availability* was 7.4% and 87.6%. In addition, *energy intensity* fell by 5.5% in Malawi and 3.2% in Uganda. *Access to electricity* supplied by the grid increased in Malawi by 2.2% but reduced in Uganda by 3.1%. Nevertheless, access to and consumption of electricity for both countries remain one of the lowest in the world. Consequently, this outlook emerging from the impact of the pandemic is likely to set both countries behind their goals of accelerating electricity access and diversifying their hydropower heavy-ladened generation portfolios. This method of assessing resilience at both system and macro levels provides perspective of the eminence of a particular risk such that not every degeneration in service at a system level is treated as a contingency.

Finally, the study proposed several measures to ensure that governments and utilities are in better shape to withstand and respond to the impacts of future pandemics on ESIs. Such measures need to be grounded in some form of resilience policies, strategies or plans that are binding upon all key-sector players. To mitigate against maladaptive and conflicting measures, the planning framework ought to be multi-sectoral, bringing together actors from all critical infrastructure systems. At the bare minimum, the measures must prioritize the safety of the workers and the maintenance of electricity supply to the most critical customers such as testing centres, hospitals, telecommunication, and banking infrastructure. Such goals would necessitate that the bulk of the systems used by utilities, developers and regulators to conduct their daily businesses are migrated to online platforms. Moreover, utilities ought to develop elevated capacities in demand forecasting and timely deployment of balancing measures during highly stochastic events. That said, future work on this subject should: (i) explore a wide scope of countries to eliminate probable selection bias, (ii) determine the business-as-usual case based on several years rather than the year preceding the disruption, and (iii) undertake cost–benefit analysis of proposed mitigative measures to support planning and decision-making processes.

Author Contributions: Conceptualization, F.M. and J.N.C.; methodology, F.M. and J.N.C.; software, F.M.; validation, F.M. and J.N.C.; formal analysis, F.M. and J.N.C.; investigation, F.M. and J.N.C.; resources, F.M., J.N.C. and R.B.; data curation, F.M. and J.N.C.; writing—original draft preparation, F.M. and J.N.C.; writing—review and editing, F.M., J.N.C., Z.L. and R.B.; visualization, F.M.; supervision, R.B., Z.L. and T.B.; All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Francis Mujjuni and Joyce N Chivunga acknowledge the PhD scholarship support from the Commonwealth Scholarship Commission in the UK. Joyce N Chivunga further acknowledges Schlumberger Foundation Faculty for the Future Fellowship for an additional PhD support. We wish to extend our sincere appreciation to Charles Kagona and Julia Nchilamwela of the Electricity Supply Corporation of Malawi for granting this research with useful data on Malawi.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

CIS	Critical Infrastructure Systems
COVID-19	Corona Virus Disease 2019
DRC	Democratic Republic of Congo
ESI	Electricity Supply Industry
GW/GWh	Gigawatt /Gigawatt Hour
HILP	High Impact Low Probability
kVA	Kilo Volt Ampere
LICs	Low-income Countries
MW	Megawatt
NPI	Non-pharmaceutical Interventions
PPA	Power Purchase Agreements
Ref	References
SDG	Sustainable Development Goals
UK	United Kingdom

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