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HOW LOCKDOWN MEASURES IMPACT ELECTRICITY CONSUMPTION
EVIDENCE FROM PORTUGAL AND SPAIN

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RESUMO

A pandemia espoletada pelo Coronavírus denominado SARS-CoV-2, que originou a doença COVID-19, levou a que as rotinas e hábitos da população global sofressem alterações profundas. Com o objetivo de abrandar a propagação do vírus, os governos foram forçados a adotar medidas de mitigação do vírus, através de regras de isolamento e distanciamento social, que levou ao fecho parcial dos mais diversos setores económicos de países por todo o mundo. Além dos efeitos económicos, também os sistemas elétricos e energéticos sofreram as consequências. Esta dissertação debruça-se sobre este tema, e estuda o impacto da pandemia na procura e consumo de eletricidade em Portugal e Espanha durante os anos de 2020 e 2021. Faz uso de um modelo econométrico de consumo de eletricidade, cruzando-o com dados reais, observados, desse consumo nos dois países e com a base de dados Oxford COVID-19 Government Response Tracker (OxCGRT) e o seu índice Stringency Index (SI), que quantifica a severidade das medidas de mitigação. O objetivo é estudar e compreender as mudanças na procura e no consumo de eletricidade nos dois países, como é que estas se relacionam com o grau de severidade das medidas adotadas e quais as medidas que mais afetam o consumo de eletricidade. Para Portugal é também realizado um estudo que compreende os diferentes estados de alerta adotados pelo governo português, analisando a sua linha temporal e a sua influência no consumo. Os resultados obtidos estão parcialmente alinhados com os trabalhos previamente consultados e existentes na literatura. Em Portugal, as medidas de mitigação tiveram um efeito negativo e significante no consumo de eletricidade em 2020 e 2021, e em Espanha apenas em 2020. A medida que teve mais impacto na redução do consumo de eletricidade, para ambos os países, foi o fecho das escolas.

Keywords: Consumo de Eletricidade; Gestão de Recursos; Economia e Mercados de Energia; Modelação Ambiental.

ABSTRACT

The global outbreak of COVID-19 led to unprecedented transformations in socioeconomic habits and personal relationships. Around the world, governments-imposed restrictions that affect the lifestyle of citizens and industries to mitigate the virus spreading. In many countries, shelter-at-home orders and a partial shutdown of non-essential economic activities directly affected the electricity systems. This work studies the pandemic's impact on electricity consumption in Portugal and Spain in 2020 and 2021. It makes use of an electricity consumption econometric model to cross information between actual observed electricity demand data and several variables, including data provided by the Oxford COVID-19 Government Response Tracker (OxCGRT) Stringency's Index (SI) regarding the stringency of the mitigation measures. The goal is to understand the shifts in demand, their association with the stringency of the measures, and how this stringency differently affected the electricity demand. For Portugal, a deep analysis of the timeline of government announcements is further conducted to comprehend better how the different alert levels issued by the Portuguese government had different impacts. The results are partially aligned with those found in the existing literature, providing information that the restriction measures and lockdowns had a negative effect on Portuguese electricity consumption in 2020 and 2021, but regarding Spain, only in 2020. Schools closing was the individual measure that represented the most considerable reduction in both countries.

Keywords: Electricity Demand; Utilities Management; Energy Economics and Markets; Environmental Modelling.

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LIST OF ABBREVIATIONS

CDD	Cooling Degree Days
ENA	Energy Networks Australia
ES	Spain
GDP	Gross Domestic Product
GHG	Green House Gas
HDD	Heating Degree Days
HDL	Hours of Daylight
IEA	International Energy Agency
IP	Industrial Production
OxCGRT	Oxford COVID-19 Government Response Tracker
PT	Portugal
REE	Red Eléctrica España
REN	Redes Energéticas Nacionais
SI	Stringency Index
SME	Small and Medium Enterprises
UAE	United Arab Emirates
UK	United Kingdom
USA	United States of America

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CHAPTER I

1. Introduction

The ongoing globalisation trend has allowed countries and populations to be more connected daily, and travelling is now easier than ever. Globalisation positively affects economic growth and employment; nevertheless, it also presents a negative aspect, as displayed by many confirmed COVID-19 cases and deaths worldwide (Farzanegan et al., 2021). World Health Organization (WHO) declared COVID-19 a pandemic on 11 March 2020, and on December 2021, there were more than 273 million confirmed cases and more than 5.3 million deaths (WHO, 2022). Governments made efforts to contain the spread of the virus, and restriction measures were imposed, sometimes leading to partial or total lockdowns, in a global fight against an uncommon health challenge. Due to isolation and fear, psychological effects, such as stress, anxiety, and depression, emerged in the general population (Serafini et al., 2020). The unfortunate consequences of the pandemic were not only to public health but also suspended activity in several key sectors of the economy. Through social distancing, financial markets, offices, businesses, and events were shut down, and the uncertainty led to a drop in consumption and spending (Ozili & Arun, 2020). This impact extended to all sectors, including the healthcare and pharmaceutical industry, agriculture, food distribution and the energy sector (Nicola et al., 2020). However, the economic effects of COVID-19 are heterogeneous across regions, countries, and sectors (Sforza & Steininger, 2020).

The motivation for this study is to provide not only further but also new insights on how the pandemic affected electricity demand, studying the relation between several factors, such as restriction measures and alert levels, and the actual and observed electricity consumption in Portugal and Spain. This event created a unique research environment and conditions of study that can be exploited across the scientific fields. What can we learn from this pandemic for the future? Understanding this is important not only for future pandemics but for emergencies that may require short, or even long-term scenarios of electricity or energy consumption load reduction.

Following this perspective, we propose to answer the following research questions:

(i) How did the COVID-19 containment measures impact electricity consumption?

(ii) Did the restrictions have a more significant impact in 2020 than in 2021?
(iii) Which measures impacted electricity consumption?
(iv) Which alert levels impacted the electricity demand?

This adds to the literature as it is one of the first studies to provide empirical information on Portugal, and one of the first to analyse the impact on electricity consumption for two years, instead of the short-run first lockdown and post-lockdown periods usually found. Hence the importance of the first research question.

As for the second one, highlighting that our data comprises two years and several pandemic waves, it is crucial to understand, together with the context of each country, if the restrictions had less impact in the second year of the pandemic, which could imply that the population got used to life under containment measures and this reduced the effect on electricity consumption. This is particularly relevant for future emergencies that may require long-term solutions.

The third question arises from the same perspective of acquiring fundamental knowledge for better decision-making in the future, always bearing in mind that this study looks at a pandemic situation that triggered an urgent need for social distancing to prevent the spread of a virus. To accomplish this goal, several policies and measures were adopted by governments, but future situations may only require a minor solution. Therefore, taking advantage of the measures specifically related with the pandemic situation, we assessed how they affected the electricity demand.

The fourth and last proposed research question focused on the government decisions, in our case study, the Portuguese government, on activating the different alert levels. It became essential to gather information at this level because, from a legal point of view, several measures can only be imposed under an alert state established by the civil protection laws. Knowing the consequences of electricity consumption for each alert state is fundamental for public decision-makers in possible future emergencies.

This work is organised into five chapters. The theme is reviewed in Chapter 1, and the various research questions are proposed. Chapter 2 summarises the current literature and recent research on energy and electricity systems. In Chapter 3, Methodology, the choice of the methodological framework and how data collection was carried out are explained. In Chapter 4, Results and Discussion, the results are presented and related to the literature, then cross-analysed to draw conclusions and find possible explanations. Chapter 5 concludes by overviewing the achievements of this study, comments on limitations and suggests possible future research.

CHAPTER II

2. Analysis of previous studies

This chapter surveys the relevant literature on the topic and summarises the most recent findings. It is an important methodological step as it allows us to frame our research, placing it alongside current articles, aiming to complement them and provide new evidence. We start by looking at the more comprehensive picture and reviewing the impact of the pandemic on general consumption and spending. After linking how electricity consumption can be used as a quick measure of economic growth, we transition to the consequences of lockdowns on general energy demand and electricity consumption. We then look further into these and split them into environmental consequences, changes in residential and industrial demand, and how the lockdown strictness affects electricity consumption, exploring the impact of different measures and policies.

In each sub-section, data is segregated by geographical region (Asia; Australia; Africa; North America; South America; the United Kingdom; Europe). A table with the summarised content of each country can be found for each sub-section.

2.1 Impact of COVID-19 on consumption and spending

COVID-19 had a profound impact at both micro and macroeconomic levels, affecting countries all around the world. This effect is unlike any previous shocks because the pandemic is not a short-term event affecting a specific geographical area, and initial changes made in the beginning, such as working from home, persist. Table 1 gathers the information regarding the first months of the pandemic, where a decline in employment levels was observed. Consumption and spending patterns were altered, with an initial positive shock on groceries due to panic buying, but with the population buying less of the other products.

Table 1 Impact of COVID-19 on consumption and spending.

Country	**Main findings**	**Reference**
India	Less frequent consumption: local grocery shops preferred to large retails;	Patil et al., 2021

Country	Main findings	Reference
Tanzania	Negative impact on tourism and GDP;	Henseler et al., 2022
USA	Income loss; spending drop;	Coibion et al., 2020; Baker et al., 2020
	Increased unemployment rate;	Beland et al., 2020; Chetty et al., 2020
	Consumption reallocated from non-essential to essential stores	Goolsbee & Syverson, 2021
UK	Spending declined with lockdown, recovered after	Chronopoulos et al., 2020
Spain	Spending declined; Consumption pattern changed	Carvalho et al., 2020
Portugal	Big impact on tourism;	Santos & Moreira, 2021
	Purchase of essential goods increased, spending on leisure activities decreased	Carvalho et al., 2020

In the stock market, stock returns quickly decreased as cases increased (Ashraf, 2020). Studies suggested that when governments issued stricter lockdowns, stock returns decreased, and its volatility rose temporarily (Alexakis et al., 2021; Zhuo & Kumamoto, 2020).

In India, in a survey of 730 households, consumption of essential goods became less frequent but in a larger quantity due to the uncertainty of the future, and small neighbourhood grocery stores were given preference because of their proximity (Patil et al., 2021).

In Tanzania, the economic impact could be measured by the negative impact on the tourism sector, which represents a significant share of its Gross Domestic Product, and was highly affected by the travelling restrictions and borders closure, and links with several other sectors such as transport and retail, which impact household income (Henseler et al., 2022).

In the United States, a study showed that more than 50% of the participants reported income and wealth losses, and one of the most significant drops in consumption was in travelling

(Coibion et al., 2020). Beland et al. (2020) found that the pandemic increased the unemployment rate while decreasing the number of labour hours, mainly in states that implemented lockdowns. In these states, consumer spending in the first weeks dropped twice as much, with the individuals radically altering how they spend (Baker et al., 2020). Chetty et al. (2020) find that consumer spending and employment declined and that low-income households are the most impacted. Consumption was reallocated from non-essential to essential stores (Goolsbee & Syverson, 2021).

In Great Britain, spending declined during the first six months of 2020 as the government announced the lockdown, and this thread continued through the lockdown. However, as restrictions eased, it recovered to pre-lockdown levels (Chronopoulos et al., 2020).

In Spain, through the first lockdown, the closure of big retail establishments had a significant impact on expenditures, and the composition of consumption also changed (Carvalho et al., 2021).

The Portuguese tourism sector, one of the most important in the country's economy, was deeply affected in 2020 due to the prohibition of foreign and, sometimes, regional mobility, drastically reducing both international and domestic tourism (Santos & Moreira, 2021). Purchases of essential goods such as groceries had a mild increase with the initial stockpiling, contrasting with many sectors which saw their activities closed by government order, such as the leisure industry and restaurants, which also depend a lot on tourism (Carvalho et al., 2020).

From the stock market to the local grocery stores, consumption and spending patterns suffered alterations, mostly with essential goods being given more importance as the pandemic unpredictability reduced spending on leisure activities.

Although the previously referred authors implied that lockdown had a profound impact on the economy, Famiglietti and Leibovici (2022) suggested that lockdowns are practical tools to contain the spread of the virus and that in the short-term, the economic contraction they carry with may have only transitory articles. Some studies stated that their effectiveness and consequences possibly also derive from the population taking voluntary measures, such as Caselli et al. (2022), that studied a large sample of economic activities of different countries to show that the economic crisis during the first seven months of the pandemic was only partly due to government-issued lockdowns, but also because of voluntarily measures as social distancing. They concluded that lockdowns could incur high costs, although they are an effective tool to control the infection rate, especially if introduced early in the pandemic stage.

Maloney & Taskin (2020) used Google mobility data to conclude that the decrease in mobility was voluntary, ' that lockdowns' effectiveness was dependent on voluntary actions, and that the economic impact of the pandemic in the US started before the imposition of lockdown rules.

By analysing movie theatre demand in Sweden, a country in which government did not enforce any lockdown, Maloney and Taskin (2020) suggested that mobility decreased as much as in countries which had imposed non-pharmaceutical interventions.

Government imposing containment measures had profound outcomes on the economy, but some authors believe it is partly due to the voluntary nature of people's actions, an aspect important to highlight.

2.2 General energy and electricity demand variations

In this subsection, we go through different pandemic stages, analysing energy and electricity consumption oscillations. From around the globe, different studies and reports suggest that, in most cases, energy and electricity demand first suffered a negative impact. However, after the first lockdown, levels started to recover. Moreover, high-intensity electricity consumption data is available at a fast rate, much faster than most economic indicators, such as GDP. Therefore, this data provides valuable information to measure the economic impact of the pandemic, as most industries and businesses need electricity for their activities, resumed in Table 2.

Global electricity demand fell by 1% in 2020 and, as expected, recovered in 2021 as economies recovered from the pandemic (IEA, 2021). Generally, countries with bigger initial impacts took longer to recover (Buechler et al., 2022).

Table 2 General energy and electricity demand variations.

Country	**Main findings**	**Reference**
China	Demand was on average 29% lower	Q. Wang et al., 2021

Country	Main findings	Reference
	Consumption had recovered by April 2020	IEA, 2021; Jiang et al., 2021
	Demand of industries that are human capital intensive decreased more	X. Wang et al., 2021
	Huhan province suffered a decrease of 27,8%	Ai et al., 2022
India	Heterogeneous impact across regions	Aruga et al., 2020
	Demand decreased 15,9% from March to June 2020	Shekhar et al., 2021
	Demand recovered to its normal levels in August 2020	Jiang et al., 2021; IEA, 2021
Japan	Softer impact as lockdown was not as strict	Zhong et al., 2020; Jiang et al., 2021
Australia	Electricity demand dropped 7,15% in March 2020	Madurai Elavasaran et al., 2020
	Larger businesses suffered a smaller impact	ENA, 2020
USA	Energy demand dropped in the short-term	Gillingham et al., 2020
	In the first five months, consumption dropped between 3% and 12% in Florida	López Prol & O, 2020
	Demand dropped 13,7% in New York City in April 2020	Madurai Elavasaran et al., 2020
	In the state of New York demand dropped from March to May 2020, and then started to recover	Ruan et al., 2021
	The initial impact and recovery period varies from state to state	Buechler et al., 2022

Country	Main findings	Reference
Canada	In Ontario, total daily demand suffered reductions in April 2020	Abu-Rayash & Dincer, 2020
Mexico	Demand was 1,9% lower in 2020 than in 2019	González-Lopez & Ortiz-Guerrero, 2022
Brazil	There was a heterogeneous reduction across the country	Carvalho et al., 2021; Delgado et al., 2021
UK	Not so strong and immediate initial impact	Lopéz Prol & O, 2020
	First lockdown had a bigger impact than the second	Mehlig et al., 2021
Sweden	Without lockdown, consumption in 2020 was similar to previous years	Halbrugge et al, 2021; Buechler et al., 2022
Turkey	Consumption reduced on restricted days	Ozbay & Dalcali, 2021
	In four industrial zones, electricity and natural gas decreased in April and May 2020	Cihan, 2022
Poland	In the first months, demand was 6,9% lower in 2020 than in the 2019	Czosnyka et al., 2020
Italy	March and April 2020 had reductions of 20%	Fezzi & Fanghella, 2020; Madurai Elavarasan et al., 2020
	After lockdown, consumption started to recover	Zhong et al., 2020
Spain	Consumption reduced from February to April 2020	Santiago et al., 2020
Portugal	Demand reduced to below average levels	Bento et al., 2021

In the study by Wang et al. (2021), comparing pandemic-free scenarios based on China's electricity consumption between 2015 and 2019 with actual energy consumption in 2020, results suggested that the actual consumption was on average 29% lower, which is bigger than the year-to-year comparison. This reduction was positively correlated with the number of new cases from January to March 2020, when the Covid-19 outbreak in China By April 2020, due to the reopening of industrial and business activities, electricity demand recovered from the initial impact of the pandemic, with its levels being in line with pre-pandemic trends, and from August these values were even higher than the Wang et al. (2021) values registered in 2019 (IEA, 2021; Jiang et al., 2021). A study analysed the fluctuations of electricity consumption that several industries from Eastern China suffered in 2019 and 2020, with results suggesting that industries that require more human mobility were the most affected due to the mobility-restrained nature of the virus spreading prevention measures, although after these measures were eased, the electricity demand was back to pre-pandemic levels. In the Huhan province, electricity consumption suffered a decrease of 27,8%, in the earlier stages of the pandemic, with the most affected industries being secondary, as manufacturing, and tertiary, as transportation, with reductions in electricity consumption of around 30%, which started to recover one month after the lockdown (Ai et al., 2022).

Aruga et al. (2020) analysed how the pandemic evolution, through the number of new cases, impacted energy consumption in each of the five Indian regions and how the recovery was heterogeneous in each region with different average income levels. The outcomes suggested that the easing of restrictions positively influenced energy consumption and that regions with higher income levels recovered faster, implying that poorer areas suffered more from the economic damage. Furthermore, from March to June 2020, demand decreased by 15.9% compared to 2019 (Shekhar et al., 2021). Nonetheless, consumption retrieved to its normal levels, at the cost of the pandemic worsening (Jiang et al., 2021), reaching 2019 values in August and even exceeding them by 10% in October (IEA, 2021).

In Japan, as the directives issued by the government were softer, the impact did not follow the same trend as in other countries with stricter lockdowns. With lower change rates than the ones observed in countries that adopted more severe measures, as the pandemic progressed, electricity consumption recovered to its normal levels (Zhong et al., 2020; Jiang et al., 2021).

When comparing data from 2020 to previous years, electricity demand dropped 7.15% in March in Australia (Madurai Elavarasan et al., 2020). Small and Medium Enterprises were the most affected, and larger businesses suffered a minor impact. (ENA, 2020).

In the USA, energy demand dropped in the short term, with jet fuel, gasoline and electricity consumption decreasing 50%, 30% and 10%, respectively (Gillingham et al., 2020). In a study that forecasts pandemic free values and compares them with the actual observed data of several states of the USA, results suggest that in the first five months, when restrictions were applied, cumulative electricity demand declined between 3% and 12%, except for the state of Florida (López Prol & O, 2020). Compared to previous years, electricity demand dropped 13.7% in New York City in April 2020 (Madurai Elavarasan et al., 2020). In the state of New York, demand started to drop from March 2020 to May 2020, and when containment measures were gradually falling, its levels started to recover to average pre-pandemic values (Ruan et al., 2021). The states and regions of California, North and South Carolina, Midwest and Tennessee suffered a severe initial impact, with reductions of as much as 11%. In contrast, the states and regions of Florida, New England, Texas, Central, Mid-Atlantic, Northwest and Southeast had a mild initial impact, with smaller reductions reaching 5%. Of these, except for North and South Carolina and Tennessee, which had a slow recovery, all the states showed short recovery periods (Buechler et al., 2022). In Mexico, electricity demand in 2020 was 1,9% lower than in 2019 (González-López & Ortiz-Guerrero, 2022) and had a slow recovery after a severe initial impact on electricity consumption (Buechler et al., 2022). In Ontario, Canada, total daily and specific on-peak hour demand suffered reductions, comparing April 2020 to April 2019 (Abu-Rayash & Dincer, 2020).

Comparing the periods before and after the mobility restrictions across several geographical regions of Brazil, the results showed a heterogeneous reduction in consumption in the different areas (Carvalho et al., 2021) and (Delgado et al., 2021).

In the UK, the initial impact was not so strong and immediate (López Prol & O, 2020). However, the first lockdown had a more significant impact than the second, with the stay-at-home orders shifting weekday consumption patterns to mimic weekend demand (Mehlig et al., 2021).

In Sweden, which did not impose any significant restrictions or closures, the consumption levels were similar to the years before (Halbrügge et al., 2021; Buechler et al., 2022). In Turkey, it was observed that electricity consumption had a significant reduction on restricted days (Özbay & Dalcali, 2021). In four industrial zones in Turkey, as lockdowns were imposed in April and May 2020, electricity demand and natural gas decreased significantly, meaning that the economy suffered a significant impact (Cihan, 2022). In Poland, in the early months of Covid-19, electricity demand was 6.9% lower than in 2019 and 8.1% lower than in 2018, which resulted from the economic slowdown caused by the pandemic. (Czosnyka et al., 2020). Comparing the daily electricity consumption from 2017 to 2020, consumption in countries with containment measures, such as France and Germany, was lower during the pandemic. (Halbrügge et al., 2021). The three weeks of severe lockdowns with partial and total shutdowns in Italy, in March and April 2020, created significant reductions in electricity consumption by 20%. (Fezzi & Fanghella, 2020; Madurai Elavarasan et al., 2020). After the containment measures were eased, consumption started to recover to previous levels. (Zhong et al., 2020). Santiago et al. (2021) studied the lockdown effects on the electricity demand in Spain, its daily consumption patterns, and the generation mix. A reduction was observed by comparing the actual demand from February to April 2020 to the same period from 2015 to 2019. This came after the Spanish government issued several restricting measures. From March 14, when the industrial and a large part of the service sector went on a partial shutdown, to March 29, the reduction of the total electricity consumption was 8,84%. On March 30, the Spanish government forced the still ongoing companies to shut for nine days, and this period represents a reduction of 15,71% that reached over 25% on the days around Easter. From April 13, some sectors resumed work, and the electricity demand started to recover, but the values were still around 13% lower than the ones for the same period of previous years. The consumption pattern changed as well. The electricity demand decreased to below-average levels in Portugal, with variations of around 12% (Bento et al., 2021).

The effect of electricity consumption on economic growth was negative during the Covid-19 pandemic because of the government's measures (Güler et al., 2022). As the first European countries softened the lockdown strictness in April, consumption started to recover. However, August was still below 2019 levels. In October, some European nations reached the values of the previous year. Still, with the strengthening of the measures in November, consumption decreased again, only to recover to above 2019 values at the end of the year. (IEA, 2021).

A conclusion that most of the articles here presented was that there was a significant electricity reduction during lockdowns. However, its values recovered to the pre-pandemic level after the softening of restrictions.

2.3 Reduced demand consequences on the environment

One of the many outcomes of economic activity and electricity consumption is the emission of polluting gases into the atmosphere. As observed in Table 3, with lockdowns stopping non-essential industries and heavily reducing human mobility, was observed that emissions were reduced, even if this was just temporally. In some countries, modifications in the energy generation mix were also observed, with Renewable Energy Sources assuming a more significant share during the lockdown.

Table 3 Reduced demand consequences on the environment.

Country	Main findings	Reference
China	Economic shutdown led to a reduction in emissions	Q. Wang & Su, 2020
	Renewables kept a high share in the generation mix	IEA, 2021
Israel	Solar power generation broke its record	Carmon et al., 2020
USA	Renewable generation outpaced coal in lockdown	IEA, 2021
UK	Both lockdowns reduced emissions	Mehlig et al., 2021
France	CO_2 emissions had a decrease of 6,6% in March 2020	Malliet et al., 2020
Ukraine	Wind and solar power generation doubled in March 2020, compared to March 2019	Morva et al., 2020
Italy	Generation from renewables increased from 23% to 40% in lockdown	Ghiani et al., 2020
Spain	Lower electricity demand reduced CO_2 emissions	Santiago et al., 2021
Portugal	GHG emissions in Lisbon decreased in lockdown but increased in May 2020	Samani et al., 2021

A short-term reduction in energy consumption was observed in China, with the decline of economic activities, which led to a reduction in emissions. However, the authors suggested that the trend was unlikely to continue in the long run (Q. Wang & Su, 2020). As the lockdown measures were progressively released, coal-fired power generation levels recovered after the considerable reduction under confinement, and renewables kept their high share in the generation mix (IEA, 2021). In Israel, solar power generation broke its record, reaching 29% of the total generation on April 5, 2020 (Carmon et al., 2020).

In the USA, as the first measures of confinement were announced and electricity demand decreased, generation from renewable sources outpaced the contribution of coal-fired power plants. However, in July and August 2020, as demand was growing, coal peaked. (IEA, 2021).

In the UK, emissions were reduced in both lockdowns (Mehlig et al., 2021).

Haxhimusa & Liebensteiner (2021) study, through the development of a two-step econometric model, the impact of Covid-19 infections on electricity demand and how it translates into emissions reductions in 16 European countries from January 2020 to March 2020, finding that CO2 emissions were reduced, on average, by 34% per hour. In France, CO2 emissions had decreased by around 6,6%(Malliet et al., 2020). In Ukraine, wind and solar power generation doubled in March 2020 compared to March 2019 (Morva et al., 2020). In the northern region of Italy, which is heavily industrialized, as the factories stopped their production, energy consumption was heavily impacted. Consequently, electricity production from Renewable Energy Sources (RES) reached values higher than 40%, increasing from the usual average of 23% (Ghiani et al., 2020). In Spain, electricity reduction resulted in a reduction in CO2 emissions and a higher share of renewable energy in the generation mix. At the same time, production from non-renewable sources declined in the confinement period (Santiago et al., 2021). In the first four months of 2020, Green House Gas (GHG) emissions in Lisbon, Portugal, were lower than in the same period of 2019 but slightly increased in May 2020 due to the relaxation of lockdown measures (Samani et al., 2021).

2.4 Residential up vs commercial down

By force of shelter-at-home orders or voluntary behaviour only, in the first period of the pandemic, people took social distancing measures and spent much more time at home. At the same time, in many countries, heavy lockdowns shut all non-essential industries, businesses, schools and workplaces. Table 4 shows that as a result, day-to-day life and social habits changed for a while, and residential electricity consumption increased. This was met with a decrease in the industrial and commercial sectors.

Table 4 Residential up vs commercial down .

Country	**Main findings**	**Reference**
China	Decline in public transportation use; Energy related to household cooking and entertainment higher in lockdown	Cheshmehzangi, 2020
	Lockdown reduces electricity consumption in public building	Su et al. 2020
Dubai	Electricity increases in residential and governmental sectors and decreases in industrial and commercial	Al-Awadhi et al., 2020
UAE	Residential demand increases	Shanableh et al., 2022
Australia	Residential demand increases, pattern of consumption changed	ENA, 2020
Nigeria	Increase in residential consumption and reduction of commercial and industrial demand	Edomah & Ndulue, 2020
USA	Consumption in weekdays higher than pre-pandemic, in New York City	Li et al., 2021
	In the state of New York the shelter-at-home orders increase domestic utilities expenditure	Chen et al., 2020
	In Austin, Texas, domestic demand was 32% higher after lockdown	Krarti & Aldubyan, 2021
	In Arizona and Illionois residential demand increased by 4-5%, and commercial demand declined by 5-8%	Lou et al., 2021
Canada	Household daily consumption increased in Ottawa	Abdeen et al., 2021
	With strict lockdown measures, consumption increased as much as 46% in a social housing building	Rouleau & Gosselin, 2021
Brazil	Residential consumption increased against a reduction in the commercial, industrial and transportation-related sectors	Carvalho et al., 2021; Delgado et al., 2021
Chile	Higher income communes had a bigger domestic demand increase under lockdown rules	Sánchez-López et al., 2022

Country	Main findings	Reference
UK	Residential demand increased by 17% in the lockdown	Krarti & Aldubyan, 2021
Scotland	Public buildings in the Perth and Kinross regions have bigger electricity demand reductions when the lockdown stringency intensifies; Schools showed the biggest reduction	Huang & Gou, 2022
Spain and Portugal	The consumption loss of commercial and industrial sectors is greater than the increase in residential electricity demand	Bento et al., 2021
Ukraine and Hungary	Reduction on the industrial and commercial sectors was met by an increase at the residential demand	Morva & Diahovchenko, 2020

Cheshmehzangi (2020) studied 352 households in China to see how energy consumption changed as people received stay-at-home orders during the pandemic's early stage, lockdown, and post-lockdown periods. There was a significant decline in public transportation use, with a shift to private vehicles. Energy consumption related to household cooking and entertainment was higher in the lockdown. The increase in heating, cooling, and lighting was 60% and 40%, respectively. Su et al. (2022) quantified the impact on a commercial building in Dalian, China, comparing the data from the lockdowns with the same periods from the previous year. The results reflect the impact of the lockdowns, with stricter measures representing more considerable reductions in electricity consumption, because of the social distance constraints. Al-Awadhi et al. (2022) assess three time periods in the pandemic - pre-lockdown, lockdown, and post-lockdown - to compare to the pre-pandemic years of 2017-2019 for the city of Doha, Dubai. Results show that, during the lockdown, electricity has increased in the residential and governmental sectors, but the declines in the industrial and commercial sectors outweigh the increase in domestic demand. In the post-lockdown time, electricity consumption started to recover. In Sharjah, the United Arab Emirates, data shows that electricity consumption in the residential sector increased (Shanableh et al., 2022).

Smart meter data from the State of Victoria, in Australia, show that the residential demand increased considerably. As a result, the consumption patterns were also altered, with more energy used throughout the day instead of the usual morning peak. In June, with the softening of restrictions, residential and industrial demand started to recover. Still, with the re-introduction of stricter measures for July and August, the impacts were once again felt, but not as much as the first time (ENA, 2020).

In Lagos, Nigeria, results from a study that analysed different scenarios with different levels of lockdown show that stay-at-home orders and the non-essential shutdown of industrial and commercial activities translated into an increase in the residential shutdown and a decrease in the commercial and industrial sectors (Edomah & Ndulue, 2020).

Li et al. (2021) studied the residential demand by analysing 390 apartments in New York City. On weekdays, consumption was predicted to be 15% to 24% higher in 2020 than pre-pandemic levels in 2019 due to residents working and studying from home. In a survey made in the state of New York, results suggested that the stay-at-home requirements led to higher expenses in utilities (Chen et al., 2020). In Austin, Texas, as most residents started to work and learn from home, domestic electricity demand was almost 32% higher than in the weeks after and before the lockdown (Krarti & Aldubyan, 2021). Lou et al. (2021) found that residential electricity consumption increased by 4-5% in Arizona and Illinois, primarily for low-income and ethnic minority groups, and commercial electricity consumption declined by 5-8%.

Abdeen et al. (2021) used electricity consumption data from 500 households in Ottawa, Canada, to study the impact of the residential demand. Compared with data from 2019, daily household consumption increased. In Quebec, a study that analysed a social housing building found that in the first month of the pandemic, when lockdown measures were stricter, not only did the total residential energy consumption increase, with electricity consumption increasing as much as 46% but also that energy consumption occurred throughout the day instead of being concentrated towards the end of the day, as in the pre-pandemic period (Rouleau & Gosselin, 2021).

In Brazil, residential electricity consumption increased against a decline in industrial and transportation-related sectors (Carvalho et al., 2021; Delgado et al., 2021).

Data from 230 thousand smart meters in Santiago, Chile, show that strict lockdown measures brought commercial and industrial demand down, and the residential sector had a steep increase, but at a different rate for the different social-economic classes, as higher income communes showed higher demand increases (Sánchez-López et al., 2022).

In the UK, data from 2000 custom smart meters showed that residential demand increased by 17% during the lockdown, most of which occurred during daytime hours. According to a survey-based analysis in Ireland, domestic electricity consumption was 11% to 20% higher during the lockdown (Krarti & Aldubyan, 2021). Huang & Gou (2022) studied the effects of COVID-19 restrictions on the electricity consumption of public buildings in Scotland's Perth and Kinross regions. The data of 35 public buildings over 2020 and 2021 showed that restrictions significantly impacted the first year, and schools presented the most considerable reduction.

In the European countries, due to the partial shutdown of the non-essential economy and stay and work-from-home orders, the residential load increased as much as 40% (Zhong et al., 2020). Bento et al. (2021) discussed the timeline of pandemic-related events in the Iberian electricity market. Even though the residential sector represented a growth in the electricity demand, as stay-at-home orders were issued, the loss from the industrial and commercial sectors was more significant. Data from around 7000 energy meters in Warsaw, Poland, show that the domestic energy consumption increased, as people spent practically the whole day inside (Bielecki et al., 2021). Comparing the values of the electricity demand in Ukraine and Hungary in 2020 and 2019, Morva & Diahovchenko (2020) suggested that lockdowns and their consequences on economic and social activities led to a reduction in the industrial and commercial sectors, met by an increase in the residential level, however, the total electricity demand was reduced, but started to recover with the lifting of several restrictions.

2.5 Linking containment measures with energy consumption

As it can be seen in Table 5, several articles analysed the relation between lockdown stringency or individual measures, such as school closure and restrictive mobility measures, and the fluctuation of electricity and energy demand values. Lockdown stringency can be measured in the literature in different ways, either by the Oxford Stringency Index, introduced by Hale et al. (2021), which is an index created to quantify the measure's strictness or by analysing the different levels of government alert levels.

Mobility and government restrictions were associated with variations in electricity demand. This suggests that measures affecting individual behaviour can be a tool to impact consumption. Countries with higher scores on the Oxford Stringency Index are linked to reduced electricity consumption (Buechler et al., 2022).

Table 5 Relation between containment measures and energy consumption.

Country	Main findings	Reference
USA	Mobility restrictive measures in the retail sector are the main factor impacting electricity consumption in New York City and Philadelphia	Ruan et al., 2020
	Schools closing and limiting commercial activities increase domestic demand by 4-5% and decrease commercial demand by 5-8%.	Lou et al., 2021
New Zealand	The strictest Alert Level had the biggest and most significant impact on the electricity consumption	Wen et al., 2022
Scotland	Higher lockdown stringency leads to bigger reductions in public buildings electricity consumption.	Huang & Gou, 2022
European countries	In countries with stricter measures, electricity consumption reduction was bigger	Bahmanyar et al., 2020
	The measures that most impact electricity consumption are workplace and schools closing, restrictions on internal movements and stay-at-home orders	Werth et al., 2020
Turkey	Higher stringency led to higher reductions	Yukseltan et al., 2022

Ruan et al. (2020) took a cross-domain approach to analyse the short-run impact of Covid-19 on the US electricity sector. The data observed include public health, mobility data, electricity market, weather, mobile device location and satellite imaging data. In New York City and Philadelphia, in March 2020, there was a strong relation between new infection cases and new restriction orders with a reduction in electricity consumption. In June 2020, a slight recovery in consumption came with a partial economic opening. The findings suggested that mobility restrictive measures in the retail sector are the main factor influencing electricity consumption and that the number of new covid cases may not have had such a strong direct influence. However, it had an indirect path through social distancing and commercial activity. Lou et al. (2021) studied the impact of school closure and limiting commercial activities on electricity consumption behaviour in low-income and ethnic minorities in Arizona and Illinois, USA. Findings advocated that, due to these two measures, residential electricity consumption increased by 4-5%, but commercial electricity consumption declined by 5-8%.

Wen et al., 2022 analysed the timeline of the several Alert Levels issued by the New Zealand government and how these impacted the energy demand from February 2020 to February 2021, using an augmented auto-regressive-moving-average model. The results showed that the strictest Alert Level, 4, had the biggest and most significant effect on electricity consumption, at about 12%. However, as Alert Levels softened, their impact on consumption reduced. Nevertheless, the results were insignificant, suggesting that commercial activity owners and the population slowly learned how to live under the restricted containment measures.

Huang & Gou (2022) used the Oxford Coronavirus Government Response Tracker (OxCGRT) to measure the stringency of restrictions and their impacts on public buildings in Scotland. When the restriction intensity increased, the electricity consumption in public buildings decreased, concluding that the consumption reduction differed across the different stages of the pandemic.

Bahmanyar et al. (2020) compared the impact of the stringency of containment measures on the electricity demand of several European countries, using data from electricity consumption related to the week after restrictions were announced and a reference week from 2019. For all the countries that imposed lockdown policies, the demand was reduced after the pandemic was declared, with stricter measures meaning bigger load reductions. Werth et al. (2021) investigated the impact of governmental restrictions on the electrical load of 16 European countries, using the index of the OxCGRT as a stringency quantification, comparing the restriction periods of 2020 with the same periods of previous years. The results showed that workplace and school closing, restrictions on internal movements and stay-at-home orders impacted the electricity demand, causing its reduction. Yukseltan et al. (2022) analysed how the restrictions and their timing impacted total and daily demand in Turkey. In the early period of the pandemic, aggregate demand decreased from March to June 2020, and this reduction was more considerable as stricter measures were imposed.

Using the Oxford Stringency Index (SI), the authors concluded that lockdown strictness was as high in Turkey as in other countries and that higher stringency led to higher reductions.

CHAPTER III

3. Methods

In this Chapter, several methodological frameworks considered for our study are described and discussed, indicating and justifying the one chosen. Then, the specific variables are presented as well as the data was collected.

3.1 Methodological framework selection process

Do et al. (2016) studied the modelling of electricity consumption, designing a daily electricity forecasting model that uses industrial production, temperature, hours of daylight, and dummies for days of the week and months of the year as an explanatory variable.

A different approach was followed by Aruga et al. (2020), that used an autoregressive distributed lag (ARDL) model to test the impact of the pandemic, through the number of accumulative confirmed COVID-19 cases, in several regions of India.

Additionally, Santiago et al. (2021) analysed how the restriction measures modified the electricity consumption in Spain, using expected and actual demand from February 24th to April 30th, 2020, comparing its values with the average total daily actual demand for 2015 to 2019.

Wang et al. (2021) compared a pandemic-free scenario with China's electricity consumption. For the simulation approach, the study combined the autoregressive integrated moving average (ARIMA) model and back propagation neural network (BP), basing the pandemic-free scenario on China's electricity consumption values from 2015 to 2019.

To recall what was mentioned in the first chapter, our goal is to study the impact that the several lockdown levels and the strictness of containment policies had on the actual and observed electricity demand in both Portugal and Spain. Therefore, we dismiss the comparative methodologies in Santiago et al. (2021) and Wang et al. (2021). Furthermore, even though the severity of the pandemic is directly related to the confirmed COVID-19 cases, we did not find that this quantifies the strictness of the restriction measures. Hence the dismission of Aruga et al. (2020). We thus chose the approach by Do et al. (2016), as the model uses both environmental and economic factors, is expandable to add variables, and can provide conclusions on the impact of several factors on the actual observed electricity demand.

This model uses the following variables:

The dependent variable, f_{daily}, is the actual and observed electricity demand.

Heating Degree Days (HDD) and Cold Degree Days (CDD) – Temperature captures seasonality and has a strong relationship with electricity demand. This method has been used in (Hor et al., 2005; Mirasgedis et al., 2006; Pardo et al., 2002; Valor et al., 2001).

Instead of retrieving data from several cities, we only use the daily average temperature for Lisbon, Portugal, Madrid, Spain, and Stockholm, Sweden. This model divides the temperature in Heating Degree Days (HDD) and Cold Degree Days (CDD), with the following equations (1) and (2), where T is the average observed temperature in the day and T_{ref} is the reference temperature 18ºC, which is common in the literature (Valor et al., 2001; Pardo et al., 2002).

$$CDD = \max(T - T_{ref}, 0) \quad (1)$$

$$HDD = \max\,(T_{ref} - T, 0) \quad (2)$$

Industrial Production (IP) – to include economic trend we use Industrial Production, as it affects electricity consumption. We use values from OECD's Index of Industrial Production, which covers production in mining, manufacturing, and public utilities, and excludes construction. This Index is used as a short-term economic indicator, and is compiled monthly, so for each day, we calculate a 90-day moving average.

Using dummy variables for the days of the week (W), with Wednesday being day 1, and for the months of the year (M), with January being month 1, is an additional possibility to capture seasonality.

Hours of daylight (HDL) – used in (Molnár, 2015) to capture seasonality in the load component, rather than just using the monthly dummies. To calculate *HDL*, we use equations (3) and (4) (Kamstra et al., 2003), starting by calculating the sun's inclination angle λ_t:

$$\lambda_t = 0.4102 \sin(\frac{2\pi}{365}(l_t - 80.25)) \quad (3)$$

Where $l_t \in [1,365]$ and 1 represents January 1st, etc.

$$HDL_t = 7.722 arccos\ (-\tan\ (\frac{2\pi\delta}{360}\tan(\lambda_t)) \quad (4)$$

Where δ is the latitude. As hours of daylight for each day are approximately the same for each of the referred countries. we defined latitudes as 39 for Portugal, 40 for Spain and 59 for Sweden.

Major holidays (H) and Minor holidays (*MinorH)-* using Holidays is necessary because of the drop in the demand during these days (Fezzi, 2007). For this study we only account Major Holidays (H), which are public holidays. The traditional way to incorporate the holiday effect is to use binary dummy variables (Pardo et al., 2022). The use of the lagged dummy is also central, because of the effect it has on adjacent days (Engle et al., 1992).

The methodological novelty consists on the addition of the lockdown stringency level, using the Oxford Covid-19 Government Response Tracker (*OxCGRT*), which offers information about government responses to the pandemic over time, in a form of combined data and indices regarding measures. To quantify and compare the policy measures, Hale et al. (2021) introduced a continuously updated dataset, which contains, among others, government policies related to closure and containment. Between several indices, the Stringency Index is a useful tool that can measure lockdown policies stringency. Several authors included this dataset in their studies, as follows.

Werth et al. (2021) used the indices to study which measures had a greater and more significant impact on the electricity consumption. The results suggested school closing (C1), workplace closing (C2), stay at home requirements (C6), and restrictions on internal movements (C7). Yukseltan et al. (2022) used the Stringency Index to compare its levels for Turkey and other countries, and to conclude that higher stringency led to higher electricity demand reductions. Buechler et al. (2022) suggested that countries with higher scores on the Stringency Index are linked to reduced electricity consumption from January to October 2020. Huang & Gou (2022) used the Stringency Index to analyze the restriction intensities and their impact on public buildings in Scotland at different periods of the pandemic, concluding that when it increases, the average electricity use of the public buildings decrease.

The Stringency Index (*SI*) therefore reflects how strict are those measures and how they affect people's behaviour, combining eight indicators of containment and closure policies (C) and one of health measures (H), described in Table 6.

Table 6 Stringency Index components

ID	**Name**	**Value info**
C1	School closing	No measures Recommended closing, or open with alterations Require closing (only some levels, eg just high schools) Closing all levels
C2	Workplace closing	No measures Recommended closing, or work from home Require closing, or work from home, for some sectors Require closing, or work from home, except essential workplaces
C3	Cancel public events	No measures Recommended cancelling Require cancelling
C4	Restrictions on gatherings	No restrictions Restrictions on very large gatherings (above 1000 people) Restrictions between 101-1000 people Restrictions between 11-100 people Restrictions of 10 people or less
C5	Close public transport	No measures Recommended closing, or reduce Require closing, or prohibiting most citizens from using
C6	Stay at home requirements	No measures Recommended not leaving house Recommended not leaving house, with exceptions (exercise, grocery shopping or essential trips) Require not leaving house, with minimal exceptions (only once per week, or one person at a time)
C7	Restriction on internal movements	No measures Recommended not to travel between regions/cities Internal movement restrictions in place
C8	International travel controls	No measures Screening Quarantine arrivals from high-risk regions Ban on arrival for some regions

ID	Name	Value info
		Ban on all regions or total border closure
H1	Public information campaigns	No Covid-19 public information campaign Public officials urging caution about Covid-19 Coordinated public information campaign

The Stringency Index is then calculated using the equation (5):

$$I = \frac{1}{9}\sum_{j=1}^{9} I_j \tag{5}$$

State Issued Alert Levels are variables added to the framework by (Do et al., 2016). These binary dummy variables, used only for Portugal, add information about the periods of alert levels issued by the Portuguese Government, so that this study can get deeper knowledge about the consequences on electricity consumption in Portugal. From the strictest to the less strict: Emergency; Calamity; Contingency; Alert.

Time is the time trend variable.

Model 1 (equation 6) is the base model for daily electricity demand as in (Do et al, 2016).

$$f_{daily}(t) = \alpha_1 + \alpha_2 HDD_t + \alpha_3 CDD_t + \alpha_4 IP_{t-1} + \sum_{\substack{i=1 \\ i\neq 3}}^{7} \alpha_5 W_{i,t} + \alpha_6 H_t + \alpha_7 H_{t-1} + \sum_{j=2}^{12} \alpha_8 M_{j,t} + \alpha_9 HDL_t + \alpha_{10} time_t + \epsilon_t \tag{6}$$

Model 2 (equation 7) is the correction of first order autocorrelation by enabling robust standard errors and including the lagged dependent variable ${f_{daily}}_{t-1}$.

$$f_{daily}(t) = \alpha_1 + \alpha_2 HDD_t + \alpha_3 CDD_t + \alpha_4 IP_{t-1} + \sum_{\substack{i=1 \\ i\neq 3}}^{7} \alpha_5 W_{i,t} + \alpha_6 H_t + \alpha_7 H_{t-1} + \sum_{j=2}^{12} \alpha_8 M_{j,t} + \alpha_9 HDL_t + \alpha_{10} time_t + \alpha_{11} f_{daily_{t-1}} + \epsilon_t \tag{7}$$

Model 3 (equation 8) adds the Stringency Index variable. This variation has the purpose of answering our first research question, whether containment measures impact electricity consumption.

$$f_{daily}(t) = \alpha_1 + \alpha_2 HDD_t + \alpha_3 CDD_t + \alpha_4 IP_{t-1} + \sum_{\substack{i=1 \\ i\neq 3}}^{7} \alpha_5 W_{i,t} + \alpha_6 H_t + \alpha_7 H_{t-1} + \sum_{j=2}^{12} \alpha_8 M_{j,t} + \alpha_9 HDL_t + \alpha_{10} time_t + \alpha_{11} f_{daily_{t-1}} + \alpha_{12} SI_t + \epsilon_t \tag{8}$$

Models 4 and 5 address the second research question, which has the goal of studying if the restrictions had a bigger impact in 2020 than in 2021.

Model 4 (equation 9) studies the impact of the Stringency Index for each year. Values for Stringency Index from 2015 to 2019 are 0, as there were no active measures in place during these years, therefore, they are omitted.

$$f_{daily}(t) = \alpha_1 + \alpha_2 HDD_t + \alpha_3 CDD_t + \alpha_4 IP_{t-1} + \sum_{\substack{i=1 \\ i\neq 3}}^{7} \alpha_5 W_{i,t} + \alpha_6 H_t + \alpha_7 H_{t-1} + \sum_{j=2}^{12} \alpha_8 M_{j,t} + \alpha_9 HDL_t + \alpha_{10} time_t + \alpha_{11} f_{daily_{t-1}} + \alpha_{12} 2020SI_t + \alpha_{13} 2021SI_t + \epsilon_t \tag{9}$$

In Model 5 (equation 10), and to further study the effect of lockdown on electricity consumption and to access in which months the lockdown had more severe impact, several variables are created which are the product of SI and the monthly dummies, resulting in:

$$f_{daily}(t) = \alpha_1 + \alpha_2 HDD_t + \alpha_3 CDD_t + \alpha_4 IP_{t-1} + \sum_{\substack{i=1 \\ i \neq 3}}^{7} \alpha_5 W_{i,t} + \alpha_6 H_t + \alpha_7 H_{t-1} + \sum_{j=2}^{12} \alpha_8 M_{j,t} + \alpha_9 HDL_t + \alpha_{10} time_t + \alpha_{11} f_{daily_{t-1}} + \alpha_{12} 2020SIJan_t + \alpha_{13} 2020SIFeb_t + \cdots + \alpha_{34} 2021SINov_t + \alpha_{35} 2021SIDec_t + \epsilon_t \quad (10)$$

In Model 6 (equation 11), there is a different approach, splitting the Stringency Index (SI) in its components, addressing the third research question, about what measures have impacted the electricity demand:

$$f_{daily}(t) = \alpha_1 + \alpha_2 HDD_t + \alpha_3 CDD_t + \alpha_4 IP_{t-1} + \sum_{\substack{i=1 \\ i \neq 3}}^{7} \alpha_5 W_{i,t} + \alpha_6 H_t + \alpha_7 H_{t-1} + \sum_{j=2}^{12} \alpha_8 M_{j,t} + \alpha_9 HDL_t + \alpha_{10} time_t + \alpha_{11} f_{daily_{t-1}} + \alpha_{12} C1_t + \alpha_{13} C2_t + \alpha_{14} C3_t + \alpha_{15} C4_t + \alpha_{16} C5_t + \alpha_{17} C6_t + \alpha_{18} C7_t + \alpha_{19} C8_t + \alpha_{20} H1_t + \epsilon_t \quad (11)$$

Models 7 and 8 were built for Portuguese data only, and study how the different lockdown levels affect the electricity consumption. These two and last models were built to answer the fourth research question: “Which alert states impacted the most?”

In Model 7 (12) we simply add information about the different alert levels from the Portuguese government (Alert; Contingency; Calamity; Emergency).

$$f_{daily}(t) = \alpha_1 + \alpha_2 HDD_t + \alpha_3 CDD_t + \alpha_4 IP_{t-1} + \sum_{\substack{i=1 \\ i \neq 3}}^{7} \alpha_5 W_{i,t} + \alpha_6 H_t + \alpha_7 H_{t-1} + \sum_{j=2}^{12} \alpha_8 M_{j,t} + \alpha_9 HDL_t + \alpha_{10} time_t + \alpha_{11} f_{daily_{t-1}} + \alpha_{12} Alert_t + \alpha_{13} Contigency_t + \alpha_{14} Calamity_t + \alpha_{15} Emergency_t + \epsilon_t \quad (12)$$

In Model 8 (equation 13) we combine information on the different alert levels from the Portuguese government (Alert; Contingency; Calamity; Emergency) and the Stringency Index. This complements the information that the previous model, 7, will provide, as it is important to quantify the strictness of each alert state.

$$f_{daily}(t) = \alpha_1 + \alpha_2 HDD_t + \alpha_3 CDD_t + \alpha_4 IP_{t-1} + \sum_{\substack{i=1 \\ i \neq 3}}^{7} \alpha_5 W_{i,t} + \alpha_6 H_t + \alpha_7 H_{t-1} + \sum_{j=2}^{12} \alpha_8 M_{j,t} + \alpha_9 HDL_t + \alpha_{10} time_t + \alpha_{11} f_{daily_{t-1}} + \alpha_{12} SIAlert_t + \alpha_{13} SIContigency_t + \alpha_{14} SICalamity_t + \alpha_{15} SIEmergency_t + \epsilon_t \quad (13)$$

The endogenous variables must be either integrated of order zero or one to use the model. To test this, we initially performed stationarity tests on energy consumption. Then, we performed the augmented Dickey-Fuller (ADF) and Philips-Perron (PP) unit root tests for this purpose.

3.2. Data collection

All data collected is publicly available ranging from January 1st, 2015, to December 31st, 2021.

The Portuguese daily electric load data ($f_{daily}(t)$), which include production from thermal energy and network feed-in from renewable energy, is from *Redes Energéticas Nacionais* (REN, 2022), and is represented in Figure 1.

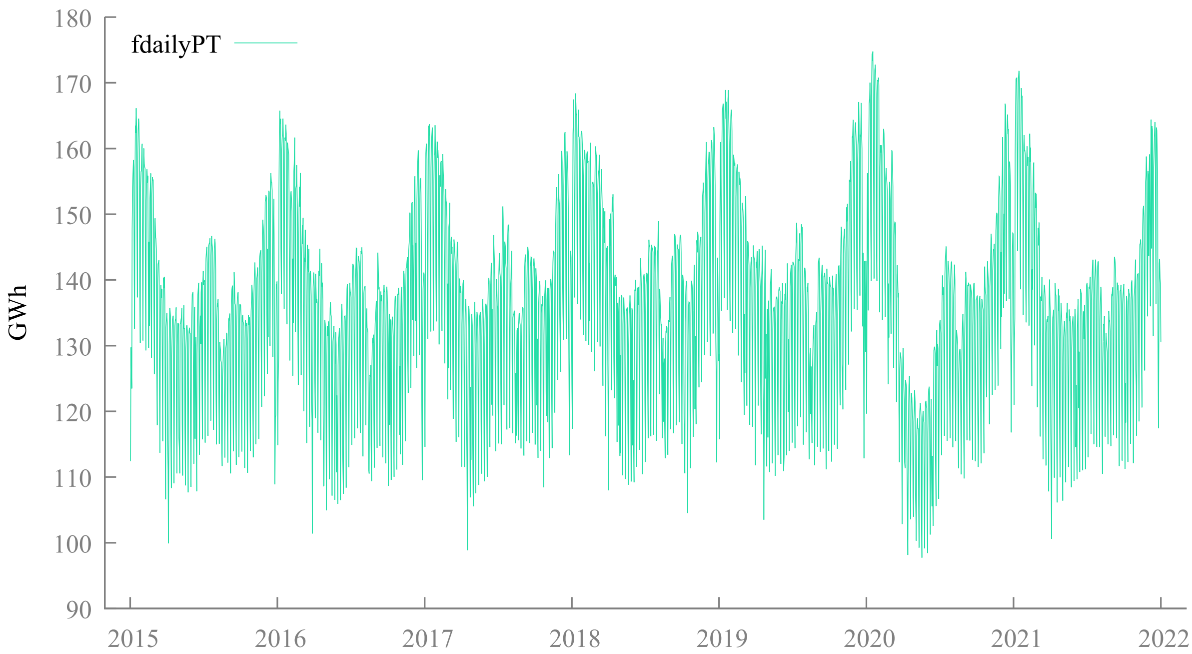

Figure 1 Portuguese daily electricity consumption 2015-2021

In 2020 electricity demand fell by 3.7% compared to 2019. This decline is the biggest one since 2011 and represents the lowest consumption in a year since 2005. It was most evident during the lockdown and then attenuated in the year's second half. Renewable energy production represented 58% of the energy generation, against 51% recorded in 2019, and this was partly because of the low consumption observed (REN, 2021). In 2021 the pandemic was still felt, but electricity demand recovered 1.7% over 2020. However still 1.7% below the values of 2019. The electricity generation went through a major change, as the last two coal-fired power stations were decommissioned, and there was a significant capacity increase in wind farms and photovoltaic installations. As a result, renewable production accounted for 59%, similarly to 58% in 2020 (REN, 2022).

In Figure 2 is shown the Spanish daily electric load data ($f_{daily}(t)$), is from *Red Eléctrica* (REE, 2022).

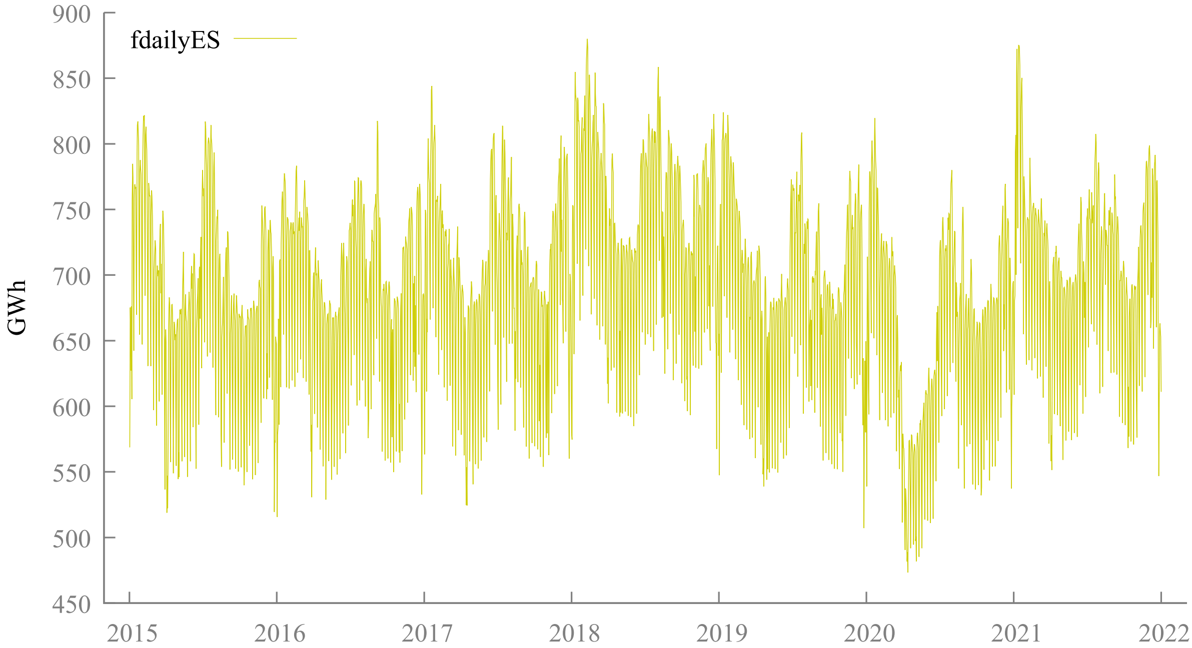

Figure 2 Spanish daily electricity consumption 2015-2021

For 2020, electricity demand was 5.5% lower than in 2019. As a result, electricity consumption fell by 8% in the first six months of 2020, reaching a negative variation of 13.3% between March 15th and June 21st. After this period, there was a reduction in the negative rate, and December observed a monthly growth. As a result, renewable energy generation reached an all-time high of 45.5%, compared with 38.9% in 2019 (REE, 2021). In 2021, electricity demand slightly recovered, 2.5% higher than in 2020. Once again, renewable energy generation reached a new record of 46.7% (REE, 2022).

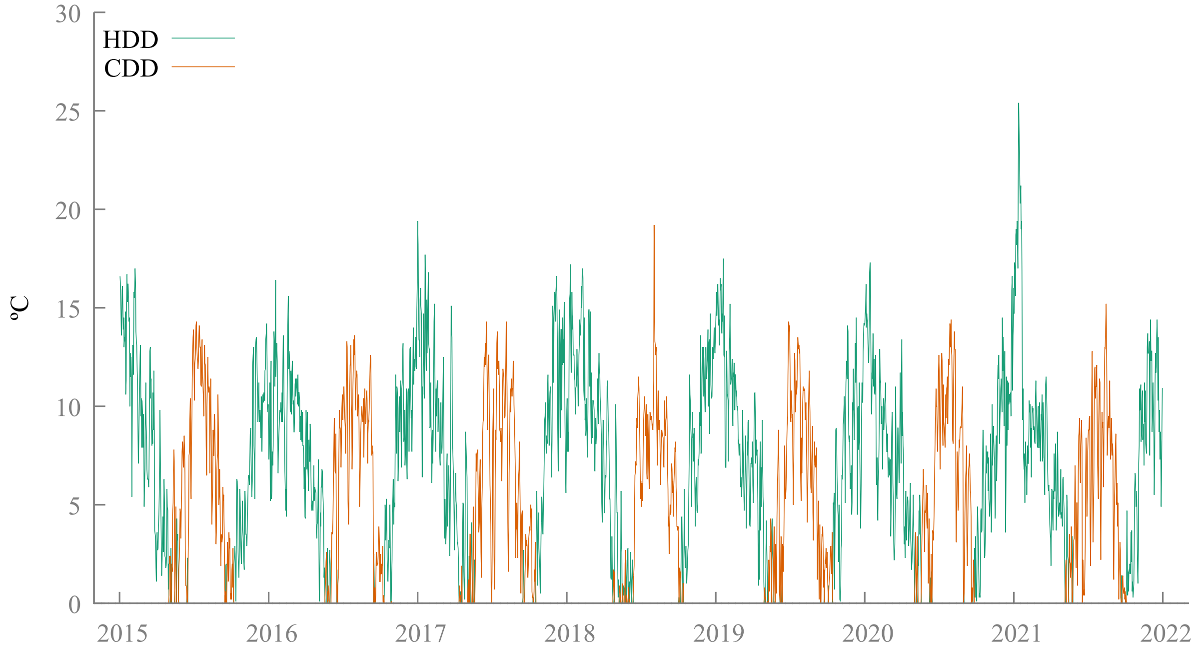

Figure 3 Heating (HDD) and Cooling (CDD) Degree Days - Portugal

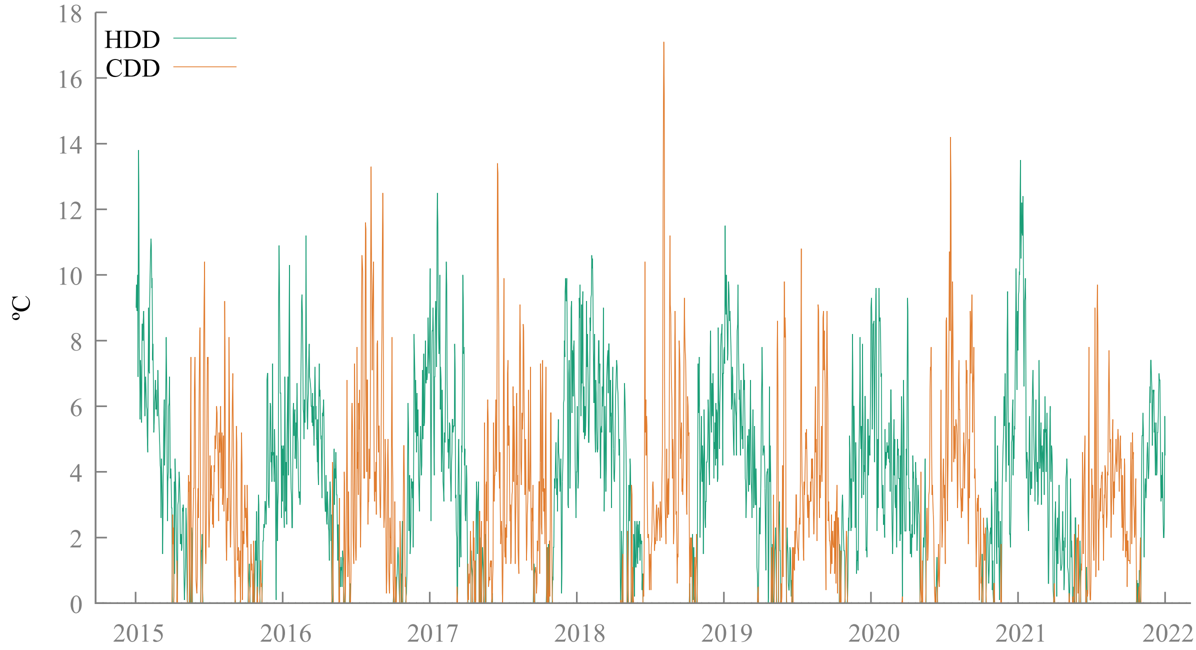

Figure 4 Heating (HDD) and Cooling (CDD) Degree Days - Spain

Heating Degree Days (HDD) and Cold Degree Days (CDD) for Portugal (Figure 3) were calculated using the daily average temperature in Lisbon (IPMA, 2022), and for Spain (Figure 4) were computed using the daily average temperature in Madrid (Wunderground, 2022).

Figure 5 shows the Industrial Production (IP), which is a 90-day moving average calculated with Index Industrial Production data retrieved from Organization for Economic Co-operation and Development (OECD, 2022).

Major holidays (H) are a binary dummy that accounts for national-wide holidays in Portugal and Spain (Calendarr, 2022).

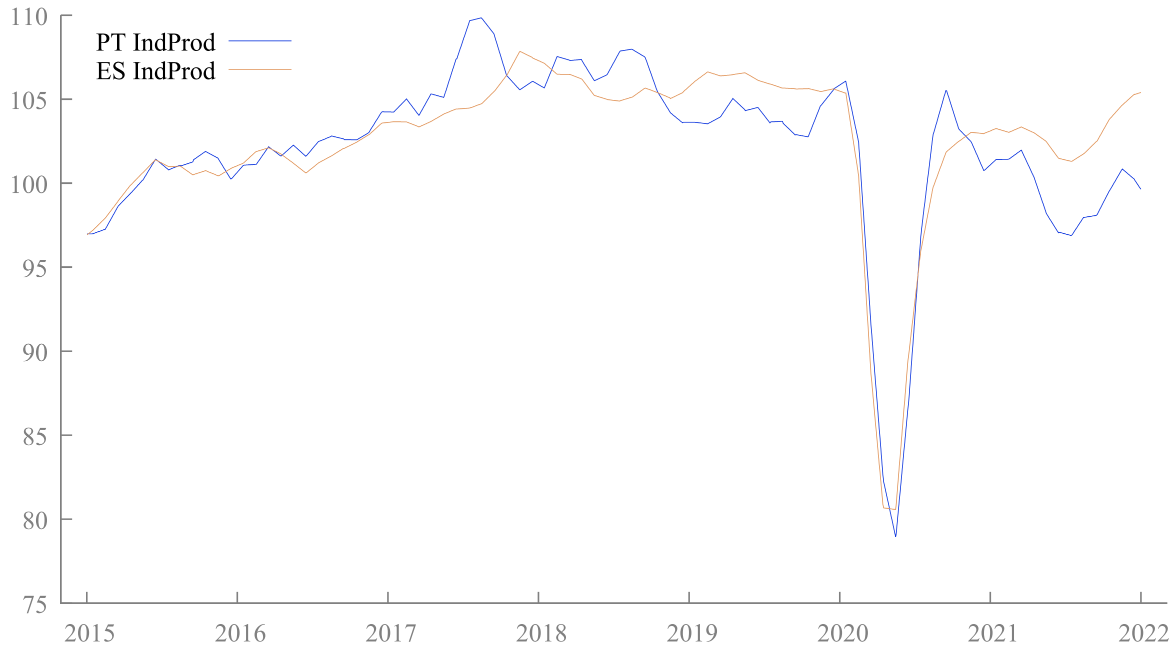

Figure 5 Industrial Production (IP) - Portugal and Spain

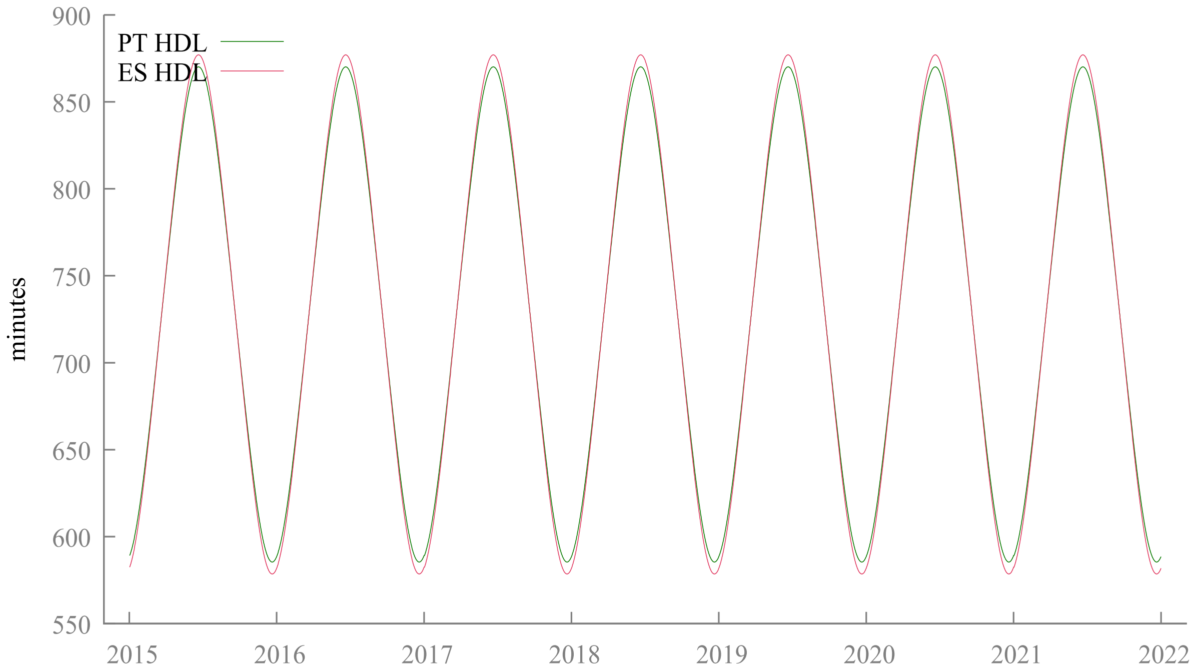

Figure 6 Hours of daylight (HDL) - Portugal and Spain

Hours of daylight (HDL) were calculated using latitudes 38.7 for Portugal and 40.4 for Spain.

Stringency Index (SI) and its components (C1; C2; C3; C4; C5; C6; C7; C8; H1), in Figure 7, were obtained from the continuously updated database of Oxford Covid Government Response Tracker (OxCGRT).

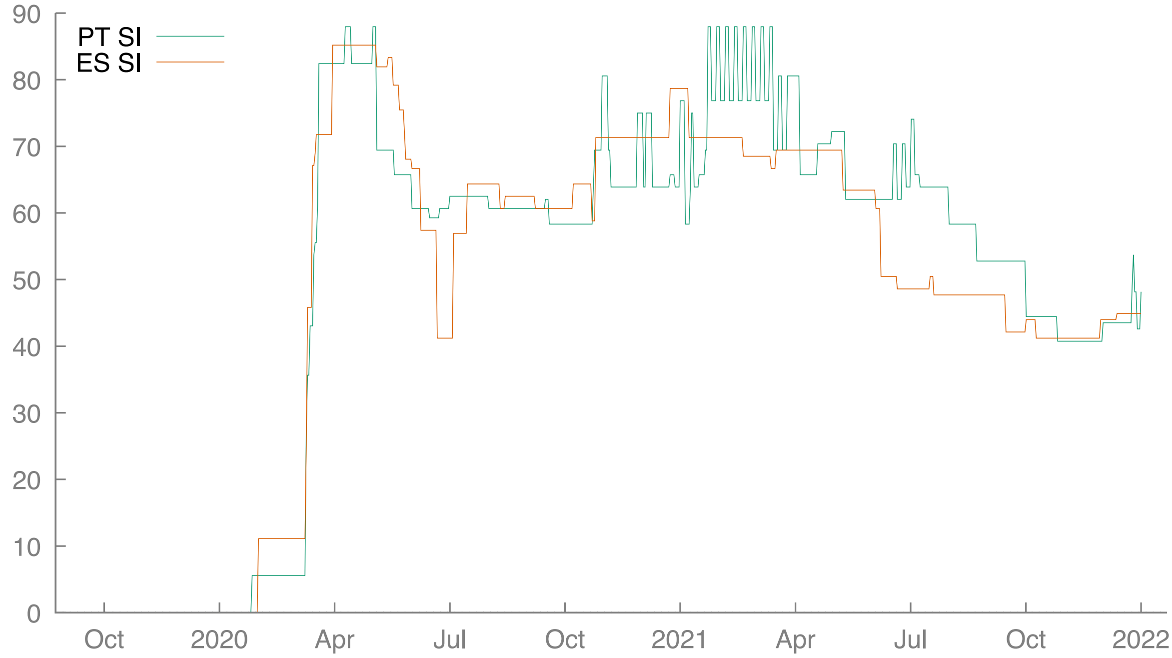

Figure 7 Stringency Index (SI) - Portugal and Spain, 2020 and 2021

As the pandemic only arrived in early 2020, the value of the SI is null until there, as there were no restrictions in place.

Alert levels (Figure 8) are official information by the Portuguese government (DRE, 2022) and transformed into a binary dummy (1 = Alert level presently in motion; 0 = Alert level presently not in motion).

Portugal confirmed its first cases on March 2nd. On March 11th, the WHO declared COVID-19 a pandemic; on March 18th, Portugal declared a state of Emergency (Bento et al., 2021). On May 3rd, the state of Calamity went into place. In late 2020, as the pandemic worsened, a new state of emergency was declared, starting on November 9th, only ending on April 30th due to multiple renewals (Table 7).

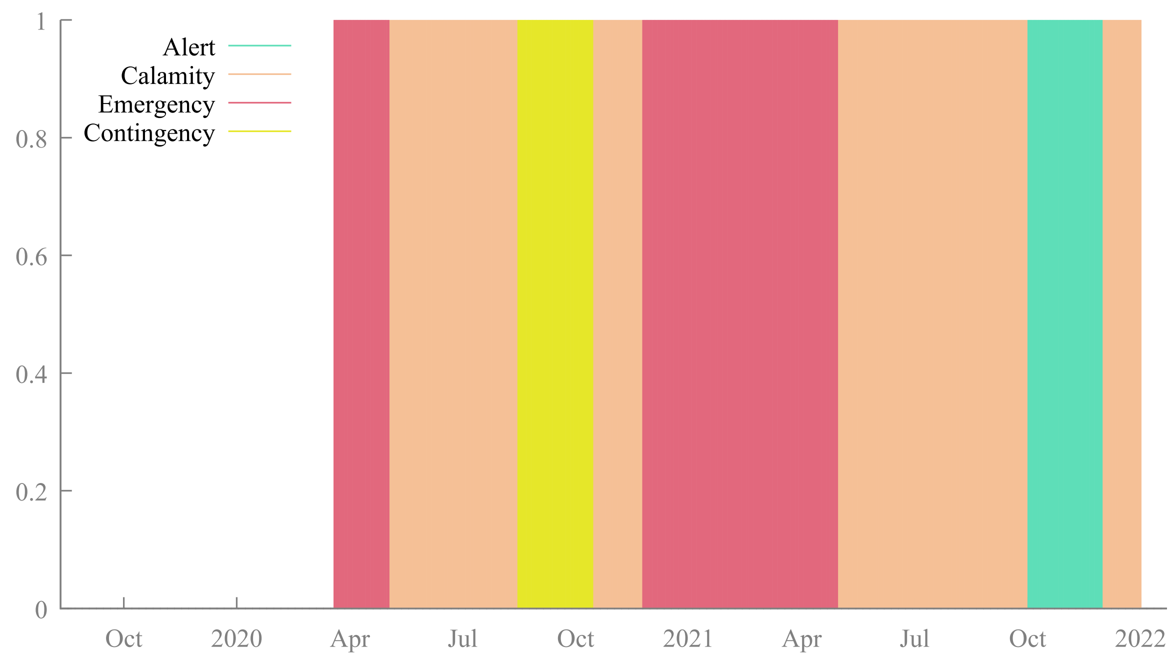

Figure 8 Alert levels issued by the Portuguese government

Crossing alert levels with the Stringency Index is essential to quantify the strictness associated with each alert level. It is important to understand that restriction measures, as does the respective stringency level, may vary during each alert level.

Table 7 Alert levels and their Stringency interval

Alert level	**Time interval**	**Stringency interval**	**Average**	**Standard deviation**
Emergency	19th March 2020 – 2nd May 2020	82.41 – 87.96	83.27	2.03
Calamity	3rd May 2020 – 31st July 2020	59.26 – 69.44	63.63	4.13
Contingency	1st August 2020 – 14th October 2020	58.33 - 60.65	59.87	1.19
Calamity	15th October 2020 – 8th November 2020	58.33 – 80.56	67.22	8.18
Emergency	9th November 2020 – 30th April 2021	63.89 – 87.96	72.55	8.51
Calamity	1st May 2021 – 30th September 2021	52.78 – 74.07	60.80	5.98
Alert	1st October 2021 – 30th November 2021	40.74 – 44.44	42.26	1.83
Calamity	1st December 2021 – 31st December 2021	45.59 – 53.70	44.39	2.44

The strictest alert level, the Emergency alert level, was imposed twice. On the first occasion, Portugal went through a strict lockdown, with the shutdown of non-essential economic activities and the average value of stringency being 83.27. On the second time, only a partial and softer lockdown and shutdown were imposed, with an average value of 72.55. However, there are more differences between those periods. Everything "closed" for a short time in the first lockdown, hence the visual straight line that we observe in March and April 2020. The second time this alert level was issued, several measures were added in each extension of the alert state, which justifies the several visual ups and downs in early 2021. One of these several measures was the government forbidding internal travelling between regions (C7) for specific periods.

Calamity alert level, the second strictest, was imposed numerous times, and most of those preceded or followed the Emergency level. Even though its average level differs each time, this disparity is never too big.

The third alert level of Contingency was only in active once in the 2020-2021 period, as the least strict level, Alert.

CHAPTER IV

4. Results and Discussion

In this sub-section we present the results from the several models. Then, we use the the results from the different models that enable us to draw several conclusions, which we subsequently cross-analyze to grasp additional explanations to the initial research questions.

Table 8 Portugal - Results from Model 1, 2, 3

	Model 1	Model 2	Model 3
Const	132,351*** (27,11)	45,175*** (11,8)	49,035*** (11,28)
$fdaily_{t-1}$		0,713*** (37,91)	0,709*** (37,83)
HDD	0,158** (2,41)	0,044 (0,897)	0,044 (0,87)
CDD	0,506*** (8,44)	0,260*** (9,186)	0,262*** (9,08)
IP_{t-1}	0,556*** (25,23)	0,158*** (9,21)	0,126*** (5,87)
H	-17,297*** (-30,97)	-13,677*** (-14,38)	-13,681*** (-14,37)
H_{t-1}	-6,838*** (-11,95)	6,001*** (7,07)	5,945*** (6,96)
HDL	-0,066*** (-9,41)	-0,027*** (-5,66)	-0,027*** (-5,76)
Time	0,0014*** (10,08)	0,0004*** (3,92)	0,0007*** (4,27)
SI			-0,013** (-2,41)
rsquare	0,8758	0,9440	0,9442
Observ.	2556	2556	2556
AR(1)	2634,51 [0,0000]	0,3765 [0,5395]	0,4794 [0,4888]
White	1132,56 [0,0000]	1095,37 [0,0000]	1131,53 [0,0000]

Notes: *t-statistics* in parentheses (* p<0.1, ** p<0.05, *** p<0.01); *p-values* in square brackets. Augmented Dickey-Fuller (ADF) test including both a constant and a trend: fdaily, HDD, CDD, IP, H and HDL are stationary with p-value < 0,05. In Model 4, linear restriction test: b[SI2020]-b[SI2021]=0 and p-value > 0,05.

Table 9 Spain - Results from Models 1, 2, 3

	Model 1	Model 2	Model 3
Const	167,011*** (5,19)	76,253*** (4,05)	78,285*** (3,74)
$fdaily_{t-1}$		0,761*** (47,13)	0,761*** (47,13)
HDD	4,951*** (16,09)	1,886*** (8,35)	1,890*** (8,28)
CDD	6,904*** (19,82)	2,898*** (14,87)	2,898*** (14,87)
IP_{t-1}	4,74***	1,111***	1,090***

	Model 1	Model 2	Model 3
	(31,36)	(9,23)	(7,53)
H	-62,357*** (-16,94)	-35,639*** (-6,846)	-35,635*** (-6,84)
H_{t-1}	-26,003*** (-7,10)	22,048*** (5,17)	22,055*** (5,18)
HDL	0,028 (0,610)	-0,047** (-2,03)	-0,047** (-2,04)
Time	0,0006 (0,675)	0,0002 (0,47)	0,0004 (0,41)
SI			-0,0072 (-0,22)
rsquare	0,7777	0,9188	0,9188
Observ.	2556	2556	2556
AR(1)	3469,44 [0,0000]	0,0018 [0,9658]	0,0015 [0,9681]
White	1003,78 [0,0000]	1088,98 [0,0000]	1153,17 [0,0000]

Notes: *t-statistics* in parentheses (* p<0.1, ** p<0.05, *** p<0.01); *p-values* in square brackets. Augmented Dickey-Fuller (ADF) test including both a constant and a trend: fdaily, HDD, CDD, IP, H and HDL are stationary with p-value < 0,05. In Model 4, linear restriction test: b[SI2020]-b[SI2021]=0 and p-value < 0,05.

From Model 3, we conclude that, for Portugal (Table 8), the SI had a significant and negative impact, as expected. This means that the stricter the containment measures are, the larger the reduction in consumption. The previous conclusion is in line with the results suggested by several authors, such as Bahmanyar et al. (2020) and Yukseltan et al. (2022). For Spain (Table 9), the impact is negative. However, it is not significant and goes against the findings of Santiago et al. (2020), which suggested that the lockdown measures reduced the electricity demand from February to April 2020. Nonetheless, our study is not focused on a mere three-month period. Instead, it analyses the impact of these measures over a two-year window, concluding that the lockdown policies had no relevant effect in Spain.

Table 10 Portugal - Results from Models 4, 5

	Model 4	Model 5		*Cont.*		*Cont.*
Const	49,737*** (11,02)	60,659*** (10,43)	***SI_1.20***	0,451*** (5,55)	***SI_1.21***	-0,008 (-0,82)
$fdaily_{t-1}$	0,709*** (37,32)	0,689*** (35,28)	***SI_2.20***	-0,050 (-0,38)	***SI_2.21***	-0,016** (-2,03)
HDD	0,046 (0,91)	0,049 (0,96)	***SI_3.20***	-0,046*** (-4,01)	***SI_3.21***	-0,040*** (-5,25)
CDD	0,265*** (9,13)	0,289*** (9,44)	***SI_4.20***	-0,049*** (-4,12)	***SI_4.21***	(-0,027)*** (-2,87)
IP_{t-1}	0,121*** (5,44)	0,046 (1,32)	***SI_5.20***	-0,061*** (-3,98)	***SI_5.21***	-0,013* (-1,76)
H	-13,680*** (-14,36)	-13,751*** (-14,26)	***SI_6.20***	-0,053*** (-3,47)	***SI_6.21***	-0,024*** (-2,67)
H_{t-1}	5,94*** (6,93)	5,618*** (6,64)	***SI_7.20***	-0,036*** (-3,98)	***SI_7.21***	-0,030*** (-3,36)
HDL	-0,028***	-0,029***	***SI_8.20***	-0,017	***SI_8.21***	-0,007

	Model 4	Model 5		*Cont.*		*Cont.*
	(-5,79)	(-6,01)		(-1,29)		(-0,55)
Time	0,0007*** (4,23)	0,0009*** (4,50)	***SI_9.20***	-0,031*** (-4,83)	***SI_9.21***	-0,026** (-2,13)
SI2020	-0,017** (-2,32)		***SI_10.20***	-0,007 (-1,28)	***SI_10.21***	-0,021* (-1,73)
SI2021	-0,011** (-2,01)		***SI_11.20***	-0,007 (-0,79)	***SI_11.21***	-0,016 (-0,67)
			SI_12.20	0,003 (0,12)	***SI_12.21***	-0,006 (-0,16)
rsquare	0,9442	0,9450				
Observ.	2556	2556				
AR(1)	0,4857 [0,4859]	1,0209 [0,3123]				
White	1166,44 [0,0000]	1369,48 [0,0000]				

Notes: *t-statistics* in parentheses (* p<0.1, ** p<0.05, *** p<0.01); *p-values* in square brackets. Augmented Dickey-Fuller (ADF) test including both a constant and a trend: fdaily, HDD, CDD, IP, H and HDL are stationary with p-value < 0,05. In Model 4, linear restriction test: b[SI2020]-b[SI2021]=0 and p-value > 0,05.

Table 11 Spain - Results from Models 4, 5

	Model 4	Model 5		*Cont.*		*Cont.*
Const	110,735*** (4,63)	117,868*** (2,74)	***SI_1.20***	-0,134 (-0,56)	***SI_1.21***	0,039 (0,73)
$fdaily_{t-1}$	0,752*** (43,79)	0,747*** (43,23)	***SI_2.20***	-0,670** (-2,04)	***SI_2.21***	-0,016 (-0,32)
HDD	1,941*** (8,46)	1,931*** (8,46)	***SI_3.20***	-0,149 (-1,20)	***SI_3.21***	-0,006 (-0,13)
CDD	2,961*** (14,99)	3,014*** (14,58)	***SI_4.20***	-0,141 (-1,094)	***SI_4.21***	0,021 (0,33)
IP_{t-1}	0,848*** (5,65)	0,807** (2,29)	***SI_5.20***	-0,084 (-69)	***SI_5.21***	0,012 (0,23)
H	-35,94*** (-6,89)	-36,109*** (-6,89)	***SI_6.20***	-0,094 (-0,69)	***SI_6.21***	0,066 (0,91)
H_{t-1}	21,498*** (5,07)	21,196*** (5,03)	***SI_7.20***	-0,072 (-0,88)	***SI_7.21***	0,114 (1,42)
HDL	-0,0482** (-2,13)	-0,049** (-2,15)	***SI_8.20***	-0,079 (-1,23)	***SI_8.21***	0,042 (0,498)
Time	0,0005 (0,52)	0,0008 (0,43)	***SI_9.20***	-0,111** (-2,13)	***SI_9.21***	0,160** (2,16)
SI2020	-0,0897** (-2,21)		***SI_10.20***	-0,105* (-1,89)	***SI_10.21***	0,040 (0,44)
SI2021	0,039 (1,23)		***SI_11.20***	-0,134*** (-3,13)	***SI_11.21***	0,001 (0,01)
			SI_12.20	-0,029 (-0,27)	***SI_12.21***	0,296 (0,16)
rsquare	0,9193	0,9196				
Observ.	2556	2556				
AR(1)	0,0271 [0,8692]	0,0409 [0,8398]				
White	1163,89 [0,0000]	1344,98 [0,0000]				

Notes: *t-statistics* in parentheses (* p<0.1, ** p<0.05, *** p<0.01); *p-values* in square brackets. Augmented Dickey-Fuller (ADF) test including both a constant and a trend: fdaily, HDD, CDD, IP, H and HDL are stationary with p-value < 0,05. In Model 4, linear restriction test: b[SI2020]-b[SI2021]=0 and p-value < 0,05.

In Model 4, we split the SI by year. The results show that, for Portugal (Table 10), the containment policies had a negative and significant impact on Portuguese electricity consumption both in 2020 and 2021. Yet, for Spain (Table 11), this negative and significant impact was only in 2020. To provide accurate, more robust answer results to our second research question, we tested whether the restriction measures had a bigger, more significant impact in 2020 than in 2021. In Portugal, the effect of the lockdown measures was the same in 2021 and 2020, but in Spain, the impact was only considerable in 2020. One possible explanation for this outcome may rely on the evolution of the pandemic in both countries. Portugal presented a steep increase in new infections and deaths in late 2020 and early 2021 (Fig. 9), even bigger and more prominent than in the first months of the pandemic, which led the government to adopt new policies that eventually led to a partial lockdown starting in early 2021. In Spain, the pandemic peak by the end of 2020 was not as intense as in Portugal and might be explained by prevention and fear growth factors playing a less active role.

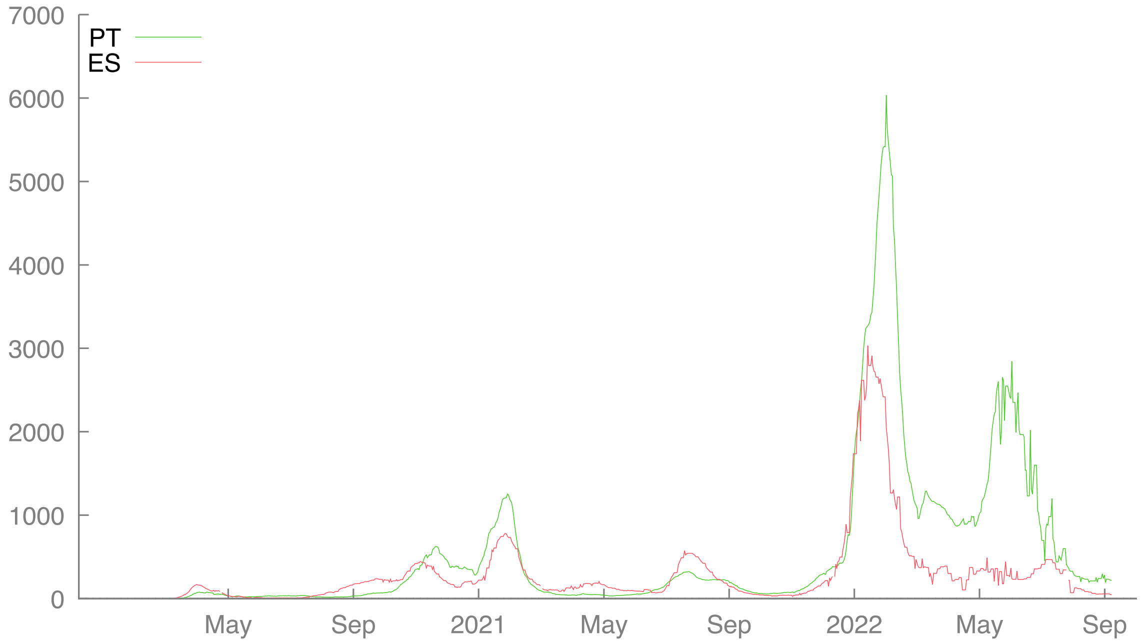

Figure 9 New cases per million – 7-day average (source: https://ourworldindata.org)

In Model 5, we split the stringency index by months, starting in 2020.

For Portugal (Table 10), January, March, April, May, June, July and September were the months that had a significant impact in 2020, and February, March, April, May, June, July, September and October were the ones in 2021. In Spain (Table 11), the results show that the measures had a significant impact in 2020: February, September, October and November; and, in 2021: September.

Peculiarly, January 2020 in Portugal and September 2021 present a different outcome to our expectations, as the results show that they positively impact electricity consumption, meaning that stricter measures represented an increase in consumption. In January 2020 (Fig. 10), the only active measure in Portugal was the health information campaign (H1). When its value is 1, public health authorities ask the population to be careful about COVID-19. A possible elucidation for the positive signal and significance is that electricity consumption increased in January 2020, a pre-pandemic period, when this measure was adopted.

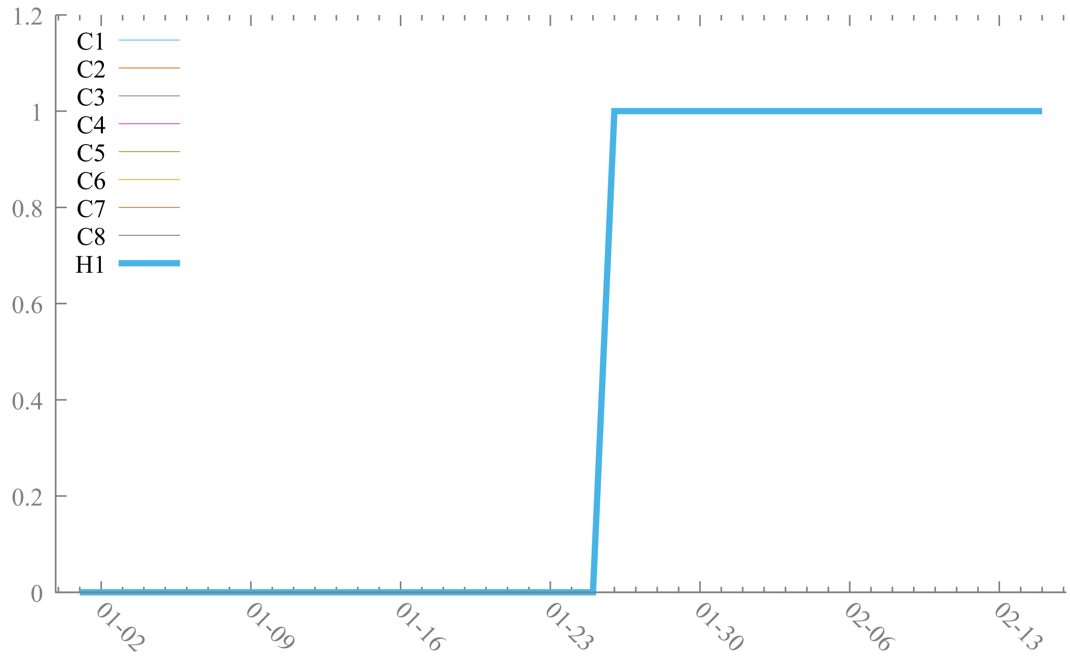

Figure 10 Measures adopted in January 2020 in Portugal

As suggested, the restrictions had no significant impact in Spain in 2021. Therefore, one possible explanation for the result of September 2021 is that as the pandemic advanced, the population got used to living under restrictions, and electricity consumption increased as economic activity recovered.

Table 12 Portugal - results from Model 6

	Model 6		***Cont.***
Const	50,747*** (4,29)	***C1 – Schools closing***	-0,504** (-2,13)
$fdaily_{t-1}$	0,697***	***C2 – Workplace closing***	-0,758

	(37,47)		(-1,53)
HDD	0,036 (0,73)	***C3 – Cancel public events***	1,231 (0,84)
CDD	0,265*** (9,13)	***C4 – Restrictions on gatherings***	-1,080*** (-2,82)
IP_{t-1}	0,128*** (5,74)	***C5 – Close public transport***	0,513 (0,73)
H	-13,696*** (-14,21)	***C6 – Stay at home requirements***	0,364 (1,31)
H_{t-1}	5,748*** (6,98)	***C7 – Restriction on internal movements***	-0,250 (-1,31)
HDL	-0,028*** (-5,74)	***C8 – International travel controls***	0,819 (0,95)
Time	0,0006*** (3,26)	***H1 – Public information campaigns***	0,180 (0,25)
rsquare	0,9447		
Observ.	2556		
AR(1)	2,1774 [0,1402]		
White	1231,13 [0,0000]		

Notes: *t-statistics* in parentheses (* p<0.1, ** p<0.05, *** p<0.01); *p-values* in square brackets. Augmented Dickey-Fuller (ADF) test including both a constant and a trend: fdaily, HDD, CDD, IP, H and HDL are stationary with p-value < 0,05. In Model 4, linear restriction test: b[SI2020]-b[SI2021]=0 and p-value > 0,05.

Table 13 Spain - Results from Model 6

	Model 6		***Cont.***
Const	104,235*** (2,99)	***C1 – Schools closing***	-5,085** (-2,34)
$fdaily_{t-1}$	0,751*** (43,44)	***C2 – Workplace closing***	-1,828 (-1,08)
HDD	1,965*** (8,32)	***C3 – Cancel public events***	3,748 (0,81)
CDD	3,001*** (14,44)	***C4 – Restrictions on gatherings***	0,078 (0,06)
IP_{t-1}	0,913*** (3,23)	***C5 – Close public transport***	-1,250 (-0,24)
H	-35,87*** (-6,90)	***C6 – Stay at home requirements***	-0,317 (-0,33)
H_{t-1}	21,569*** (5,10)	***C7 – Restriction on internal movements***	-1,866 (-1,41)
HDL	-0,049** (-2,17)	***C8 – International travel controls***	2,459 (0,99)
Time	0,0002 (0,13)	***H1 – Public information campaigns***	-0,692 (-0,33)
rsquare	0,9194		
Observ.	2556		
AR(1)	0,0394 [0,8427]		
White	1238,59 [0,0000]		

Notes: *t-statistics* in parentheses (* p<0.1, ** p<0.05, *** p<0.01); *p-values* in square brackets. Augmented Dickey-Fuller (ADF) test including both a constant and a trend: fdaily, HDD, CDD, IP, H and HDL are stationary with p-value < 0,05. In Model 4, linear restriction test: b[SI2020]-b[SI2021]=0 and p-value < 0,05.

In Model 6, we split the SI by its components. In Portugal (Table 10), the specific measures that had a significant impact on electricity demand were the schools closing (C1) and restrictions on gatherings (C4), and in Spain (Table 14), schools closing (C1).

Table 14 Portugal - Results from Models 7, 8

	Model 7		***Cont.***	***Model 8***		***Cont.***
Const	46,712*** (10,67)	***Alert***	0,022 (0,04)	48,005*** (10,99)	***SIAlert***	-0,004 (-0,38)
$fdaily_{t-1}$	0,709*** (37,29)	***Contigency***	-0,857** (-2,19)	0,707*** (37,31)	***SIContigency***	-0,016** (-2,54)
HDD	0,044 (0,86)	***Calamity***	-0,216 (-0,48)	0,044 (0,87)	***SICalamity***	-0,008 (-1,24)
CDD	0,262*** (9,21)	***Emergency***	-0,719 (-1,43)	0,263*** (9,14)	***SIEmergency***	-0,013** (-2,16)
IP_{t-1}	0,149*** (6,46)			0,138*** (6,19)		
H	-13,690*** (-14,39)			-13,685*** (-14,36)		
H_{t-1}	5,942*** (6,93)			5,920*** (6,91)		
HDL	-0,027*** (-5,72)			-0,027*** (-5,74)		
Time	0,0006*** (3,25)			0,0007*** (3,91)		
rsquare	0,9441			0,9442		
Observ.	2556			2556		
AR(1)	0,4934 [0,4825]			0,5373 [0,4636]		
White	1181,73 [0,0000]			1168,61 [0,0000]		

Notes: *t-statistics* in parentheses (* $p<0.1$, ** $p<0.05$, *** $p<0.01$); *p-values* in square brackets. Augmented Dickey-Fuller (ADF) test including both a constant and a trend: fdaily, HDD, CDD, IP, H and HDL are stationary with p-value < 0,05. In Model 4, linear restriction test: b[SI2020]-b[SI2021]=0 and p-value > 0,05.

Models 7 and 8 study the effects of the several Alert Levels issued by the Portuguese Government (Table 11). From Model 7, only Contingency, the second least stringent of the four possible, had a significant impact. However, for a better understanding of the actual stringency of each alert level, we crossed information with the Stringency Index, creating the study variables used in Model 8. From these, we conclude that the Emergency level, the strictest level, also had a significant impact.

One likely justification for the significance of the Contingency alert level is the short amount of time of application and its stringency barely decreasing concerning the second strictest level, Calamity (Fig. 11). The Contingency alert level was in action from August 1st, 2020,

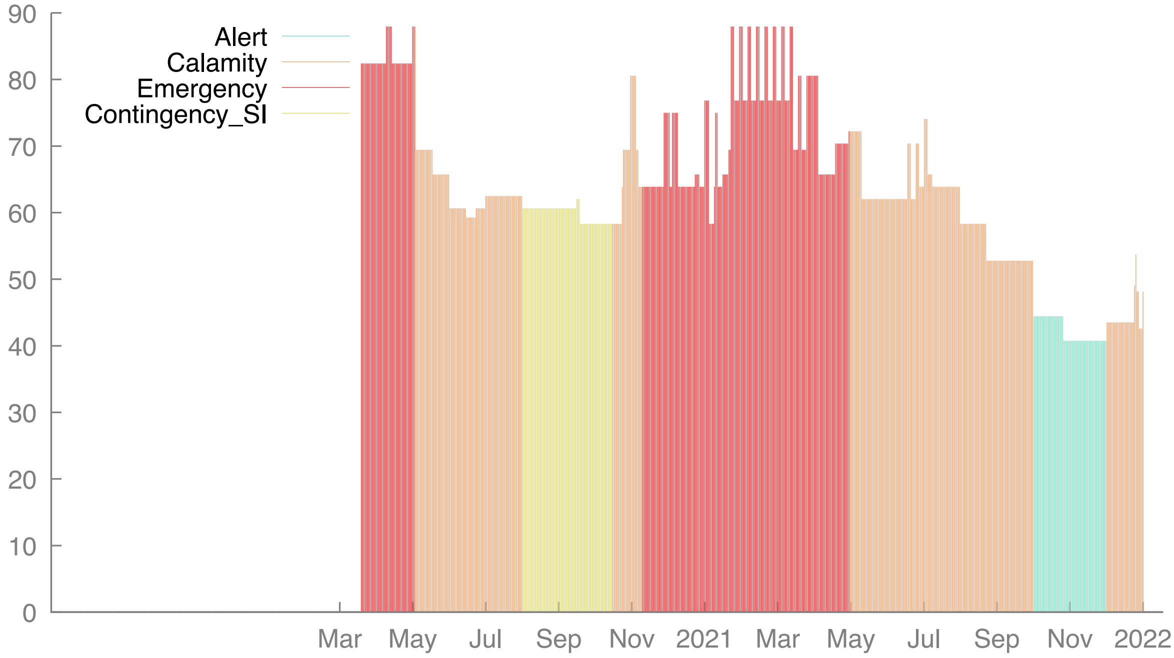

Figure 11 Alert levels with Stringency quantification

to October 14th, 2020, covering the whole of September 2020, which in the results obtained from model 5 was one of the months that had a considerable negative impact on electricity consumption. As model 6 suggests, in Portugal, the most impactful measures were the schools closing (C1) and restrictions on gatherings (C4). We analysed their behavior during this period. From August 1st to September 17th, schools closing was on level 2 of 3, and from September 18th to October 14th was on level 1 of 3. Still, we should rule out this as a justification because the academic year started between the 14th and 17th of September. Regarding restrictions on gatherings, it may be the main reason, as it was, for the whole time, in level 4 out of 4, meaning that meetings were restricted to groups of 10 people or less. Finally, in August, Portugal is typically filled with foreign tourists, but in 2020 this was not the case due to international travelling restrictions.

CHAPTER V

5. Conclusion

The recent COVID-19 pandemic had a profound and lasting effect on our daily routine and habits, affecting an extensive part of the world population. The fear brought social distancing and lockdowns, which became recently well documented in the literature by many studies. The energy and electricity systems of countries that applied shelter-at-home orders suffered load reductions. The residential demand increase was insufficient to surpass the decline in the industrial and commercial sectors. These reductions led to reduced emissions, and renewable energy sources increased their share in the energy generation mix. However, electricity consumption and emissions reduction only lasted a couple of months. In most cases, the economic drive back made possible the recuperation of the electricity demand to 2019 levels and, by the end of 2020, even surpassing them.

As earlier mentioned, this study focuses on two countries, Portugal and Spain. It uses a more extended period than most available in the literature, including two years of pandemic and measures, 2020 and 2021. Through the innovative introduction of a variable that quantifies lockdown strictness, the Stringency Index from the database of OxCGRT, in an electricity consumption forecast model, as in Do et al. (2016), we studied several factors by which the pandemic had an impact on the electricity demand of both countries: if the restriction orders had an effect, in a 2-year perspective; if the measures had a more significant impact in 2020 than in 2021; which actions impacted the electricity consumption; and which alert levels affected the electricity demand in Portugal.

The results primarily differ from Portugal to Spain. In Portugal, the restriction orders impacted the electricity demand, and the effect in 2020 was the same as in 2021. The individual measures that had an impact were schools closing and restrictions on gatherings. The alert levels that had a significant negative effect were the emergency alert level, the strictest and the one under which lockdowns are imposed, and the contingency alert level, the second least strict of four possible. In Spain, the containment measures did not significantly impact over the two years but had a significant negative effect in 2020. This could mean that the pandemic evolution was favourable to the fear factor disappearing, as no major lockdown was imposed in 2021, as happened in Portugal. The only significant measure was the schools closing, which also occurred in Portugal.

This real pandemic experience has been unique and extreme, making it possible to obtain new information that would have been impossible to gather otherwise. Therefore, these findings are important and valuable for public decision-makers in future emergencies where electricity load reduction might be required. Besides, if one or more similar measures need to be implemented, consequences on electricity load are known beforehand. As a result, key-market players can better forecast electric consumption.

Several limitations arose when attempting to replicate Models 7 and 8 to Spanish data. The country is split into several regions, each declaring its alert level, but the SI is set at a national level. Therefore, this incompatibility made it impossible to study how the alert levels impacted electricity consumption in Spain.

Suggestions for future research include replicating this methodology in any country where data is available and splitting the electricity consumption by residential, industrial, and commercial sectors.

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