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MASTER'S DEGREE IN INDUSTRIAL ENGINEERING

Impacts on energy vulnerability caused by the 2022 energy crisis in the framework of a just transition in Spain

Author: Laura Blas Álvarez

Supervisor: Roberto Barrella

Co-Supervisor: Miguel Ángel Ríos Ocampo

Madrid

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DEGREE'S THESIS

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Madrid

IMPACTS ON ENERGY VULNERABILITY CAUSED BY THE 2022 ENERGY CRISIS IN THE FRAMEWORK OF A JUST TRANSITION IN SPAIN

Author: Blas Álvarez, Laura
Supervisor: Barrella, Roberto
Co-Supervisor: Ríos Ocampo, Miguel Ángel
Collaborating Entity: ICAI School of Engineering, Comillas Pontifical University & Chair of Energy and Poverty

ABSTRACT

The increase in energy prices caused by the complications of the war in 2022 has aggravated the already difficult situation of vulnerability for certain households. This project aims to shed visibility to the concept of energy poverty by proposing a new methodology based on a valuable indicator of energy vulnerability for the Spanish households. This indicator measures energy vulnerability from 0 to 5, being 5 the level assigned to those municipalities in a more vulnerable situation and, therefore, with higher risk of suffering energy poverty.

The results for the Spanish case study show that over 84% of the municipalities show a vulnerability index of 3 or higher and, 30% of this municipalities (25% of the total municipalities) are located in the regions of Andalusia, Extremadura and Castille – La Mancha.

This project highlights the differences in terms of energy vulnerability between the north and the south of the Spanish mainland and its geographical breakdown at the municipality level can be used to compare this indicator to past studies and help policy decision makers.

Keywords: energy poverty, energy vulnerability, sustainability, Just Transition.

1. Introduction

The Russian invasion of Ukraine caused a deep energy crisis that affected the whole world, especially impacting Europe, and its most vulnerable regions.

The increase in energy prices has worsened people's quality of life, especially in disadvantaged households, with lower incomes, that live in buildings that are not very energy efficient located in areas where the climate forces high heating consumption, [1].

To outline a strategy against the use of energy as a weapon by Russia, the EU has created a series of plans or regulations, in some cases emergency ones, such as a contingency plan to withstand the winter of 2022 in the event of a gas supply cut, [2]; a plan to reduce gas consumption, [3], and certain mid and long-term measures to promote investment and development in renewable energies and end dependence on Russian gas.

2. Project definition

This project aims to examine the consumption reduction policies proposed by the EU, as well as to analyze the main variables on which energy poverty depends in order to create an indicator of vulnerability that can be used to assess whether a household is prone to suffer from energy poverty or not.

3. Methodology

In order to comply with the project description, for the statistical part of the thesis, a vulnerability index has been created, and it has been tested in several scenarios: a "global" vulnerability index, with the average electricity price of 2022, and then several seasonal scenarios, such as the highest electricity price (August 2022), the lowest electricity price (November 2022), the summer season of 2022 and the winter season of 2022.

According to [4], [5], [6] and [7], the main drivers in energy poverty are net income, buildings with low Energy Performance Certificates, electricity prices and the climate zone, since the cooling and heating expenditure affects greatly in this matter.

The net income was obtained from the INE, [8], and the personal net income of the year 2020 was used for this project. The Energy Performance Certificates were obtained from the Open Data Catalog of each Autonomous Community, which upload the most recent version of the data. Electricity prices were obtained monthly for the year 2022 from the CNMC, [9]; and lastly, climate zones were obtained according to the data from each Autonomous Community.

The values of these variables were then translated into numerical values and a weight was assigned to each of them, depending on the scenario. For the seasonal scenarios, only the appropriate climate zone was used, and each variable contributed 25%. For the "global" vulnerability index, the difference in cooling and heating expenditure was taken into account, according to [1]; and different weights were assigned to the summer and the winter climate zones.

4. Results

The results of this study were presented in color maps, disaggregated by municipalities.

The “global” vulnerability index, called Multi – Factor Energy Vulnerability Index (or MFEVI from now on), is shown in *Figure* 1:

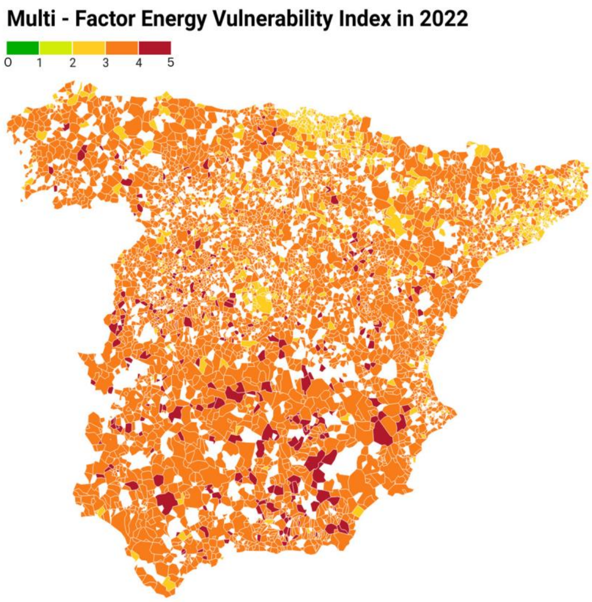

Figure 1: Map of the MFEVI in 2022. Source: own elaboration

For the seasonal scenarios, the only variable that changes is the electricity price, depending on the scenario.

Figure 2 shows the scenario for the prices in August 2022, which had the highest prices that year.

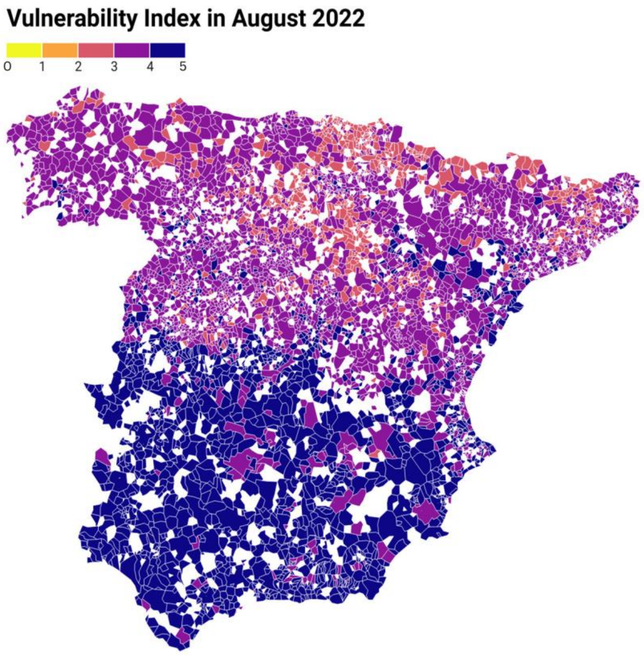

Figure 2: Map of the Vulnerability Index with electricity prices from August 2022. Source: own elaboration

5. Conclusions

The seasonal scenarios show that, in all cases, the municipalities belonging to Andalusia, Extremadura, Castille – La Mancha and Murcia, were the most prone to suffer from energy poverty. This is mainly caused by low net income, since the average energy certification for buildings is E. Although these Autonomous Communities enjoy warmer winters and, therefore their heating expenditure is lower, the lower levels of income overshadow this reduction of costs.

For the “global” indicator the difference between north and south is less evident. Mainly because, for those municipalities with higher net income (located mostly in the north of the Spanish mainland), also have a high heating expenditure because they are located in regions with colder winter zones.

When compared to the same scenario with electricity prices from 2021, there is a clear difference between both. Mainly because of the increase in energy prices, certain municipalities that had lower vulnerability index in 2021, have now higher vulnerability indexes the 2022 scenario.

6. References

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IMPACTO EN LA VULNERABILIDAD ENERGÉTICA CAUSADA POR LA CRISIS ENERGÉTICA DEL 2022 EN EL CONTEXTO DE UNA TRANSIÓN JUSTA EN ESPAÑA

Autora: Blas Álvarez, Laura
Director: Barrella, Roberto
Co-Director: Ríos Ocampo, Miguel Ángel
Entidad Colaboradora: Escuela de Ingeniería ICAI, Universidad Pontificia Comillas & Cátedra de Pobreza Energética

RESUMEN

El aumento de los precios de la energía provocado por las complicaciones de la guerra de 2022 ha agravado la ya difícil situación de vulnerabilidad de algunos hogares.

Este proyecto pretende dar visibilidad al concepto de pobreza energética proponiendo una nueva metodología basada en un valioso indicador de vulnerabilidad energética para los hogares españoles. Este indicador mide la vulnerabilidad energética de 0 a 5, siendo 5 el nivel asignado a aquellos municipios en situación de mayor vulnerabilidad y, por tanto, con mayor riesgo de sufrir pobreza energética.

Los resultados para el caso de estudio español muestran que más del 84% de los municipios presentan un índice de vulnerabilidad de 3 o superior y, el 30% de estos municipios (25% del total de municipios) se encuentran en las regiones de Andalucía, Extremadura y Castilla - La Mancha.

Este proyecto pone de manifiesto las diferencias en términos de vulnerabilidad energética entre el norte y el sur peninsular y su desglose geográfico a nivel de municipio puede servir para comparar este indicador con estudios anteriores y ayudar a los responsables políticos.

Palabras clave: pobreza energética, vulnerabilidad energética, sostenibilidad, Transición Justa.

1. Introducción

La invasión rusa de Ucrania provocó una profunda crisis energética que afectó a todo el mundo, impactando especialmente en Europa, y a sus regiones más vulnerables.

El aumento de los precios de la energía ha empeorado la calidad de vida de la población, especialmente en los hogares desfavorecidos, con menores ingresos, que viven en edificios poco eficientes energéticamente, situados en zonas donde el clima obliga a un elevado consumo de calefacción, [1].

Para trazar una estrategia contra el uso de la energía como arma por parte de Rusia, la UE ha creado una serie de planes o normativas, en algunos casos de emergencia, como un plan de contingencia para soportar el invierno de 2022 en caso de corte del suministro de gas, [2]; un plan para reducir el consumo de gas, [3], y ciertas medidas a medio y largo plazo para promover la inversión y el desarrollo de las energías renovables y acabar con la dependencia del gas ruso.

2. Definición del proyecto

Este proyecto pretende examinar las políticas de reducción del consumo propuestas por la UE, así como analizar las principales variables de las que depende la pobreza energética con el fin de crear un indicador de vulnerabilidad que pueda utilizarse para evaluar si un hogar es propenso a sufrir pobreza energética o no.

3. Metodología

Para cumplir con la descripción del proyecto, para la parte estadística de la tesis, se ha creado un índice de vulnerabilidad, y se ha probado en varios escenarios: un índice de vulnerabilidad "global", con el precio medio de la electricidad de 2022, y luego varios escenarios estacionales, como el precio más alto de la electricidad (agosto de 2022), el precio más bajo de la electricidad (noviembre de 2022), la temporada de verano de 2022 y la temporada de invierno de 2022.

De acuerdo con [4], [5], [6] y [7], los principales impulsores de la pobreza energética son los ingresos netos, los edificios con Certificados de Eficiencia Energética bajos, los precios de la electricidad y la zona climática, ya que el gasto en refrigeración y calefacción afecta en gran medida en este asunto.

La renta neta se obtuvo del INE, [8], y para este proyecto se utilizó la renta neta personal del año 2020. Los Certificados de Eficiencia Energética se obtuvieron del Catálogo de Datos Abiertos de cada Comunidad Autónoma, donde se carga la versión más reciente de los datos. Los precios de la electricidad se obtuvieron mensualmente para el año 2022 de la CNMC, [9]; y por último, las zonas climáticas se obtuvieron según los datos de cada Comunidad Autónoma.

Posteriormente, los valores de estas variables se tradujeron a valores numéricos y se asignó un peso a cada una de ellas, en función del escenario. Para los escenarios estacionales, sólo se utilizó la zona climática correspondiente, y cada variable aportó un 25%. Para el índice de vulnerabilidad "global" se tuvo en cuenta la diferencia de gasto en refrigeración y calefacción, según [1]; y se asignaron pesos diferentes a las zonas climáticas de verano y de invierno.

4. Resultados

Los resultados de este estudio se presentaron en mapas de colores, desglosados por municipios.

El índice de vulnerabilidad "global", denominado *Multi - Factor Energy Vulnerability Index* (o MFEVI a partir de ahora), se muestra en la Figure 1:

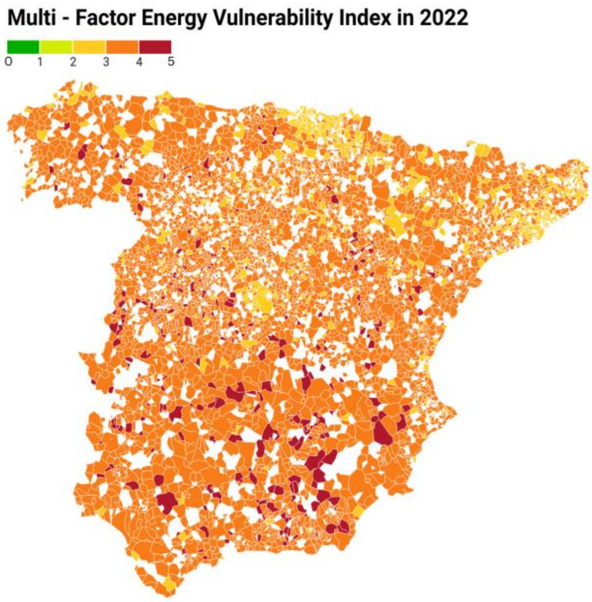

Figure 1: Mapa del MFEVI en 2022. Fuente: elaboración propia

En los escenarios estacionales, la única variable que cambia es el precio de la electricidad, dependiendo del escenario.

Figure 2 muestra el escenario de los precios en agosto de 2022, que tuvo los precios más altos ese año.

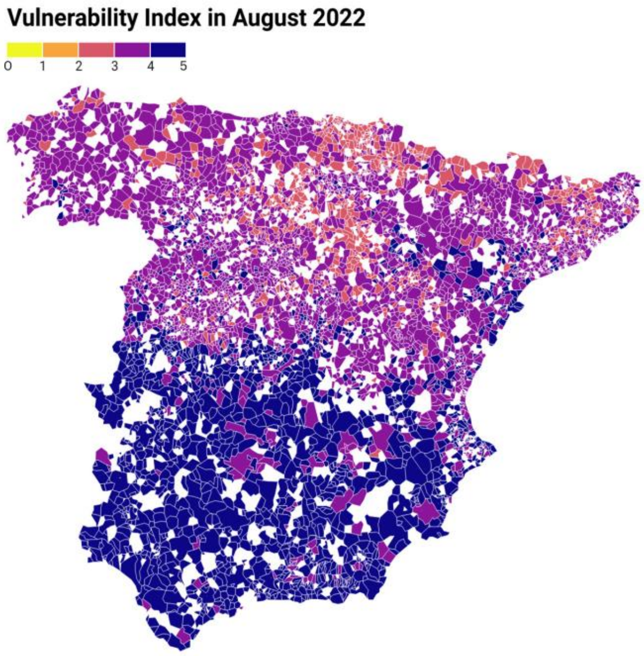

Figure 2: Mapa del Índice de Vulnerabilidad con los precios de la electricidad de Agosto, 2022. Fuente: elaboración propia

5. Conclusiones

Los escenarios estacionales muestran que, en todos los casos, los municipios pertenecientes a Andalucía, Extremadura, Castilla - La Mancha y Murcia, fueron los más propensos a sufrir pobreza energética. Esto se debe principalmente a los bajos ingresos netos, ya que la certificación energética media de los edificios es E. Aunque estas Comunidades Autónomas disfrutan de inviernos más cálidos y, por tanto, su gasto en calefacción es menor, los menores niveles de ingresos eclipsan esta reducción de costes.

Para el indicador "global" la diferencia entre norte y sur es menos evidente. Principalmente porque, para aquellos municipios con mayor renta neta (situados mayoritariamente en el norte peninsular), también tienen un gasto en calefacción elevado por estar situados en regiones con zonas invernales más frías.

Si se compara con el mismo escenario con los precios de la electricidad a partir de 2021, se observa una clara diferencia entre ambos. Debido principalmente al aumento de los precios de la energía, algunos municipios que tenían un índice de vulnerabilidad más bajo en 2021, tienen ahora índices de vulnerabilidad más altos en el escenario de 2022.

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1. INTRODUCTION

The world is constantly experiencing changes due to the dynamic and fast-paced environment surrounding it. These changes may be affecting certain individuals differently from one another.

The Russia's invasion in Ukraine, along with the pre-existing COVID-19 crisis, has aggravated the already challenging situation of finding affordable energy for certain households. These events are specially worrying for the least developed countries and in certain areas with less resources. The constant increase of gas prices has caused an important impact in energy prices and patterns of demand. It is this very situation that presents a challenge for a just energy transition. One of its main principles is to solve the issues related to energy poverty by providing clean, reliable, accessible, and affordable energy.

Other pillar projects to be developed in this matter must provide certain benefits to the territories in which they are installed, especially in terms of supply, generation and employment, in order to achieve a redistribution of wealth [1]. According to a study conducted by the Eurostat, [2], energy import prices increased in a 115% between December 2020 and December 2021. Although these prices are rather volatile, there has not been a change higher than 30% in the past, as it is clearly shown in Figure 3.

The rapid increase in energy prices and the Russian war with Ukraine along with the existing impact due to COVID-19 have worsened this already challenging situation.

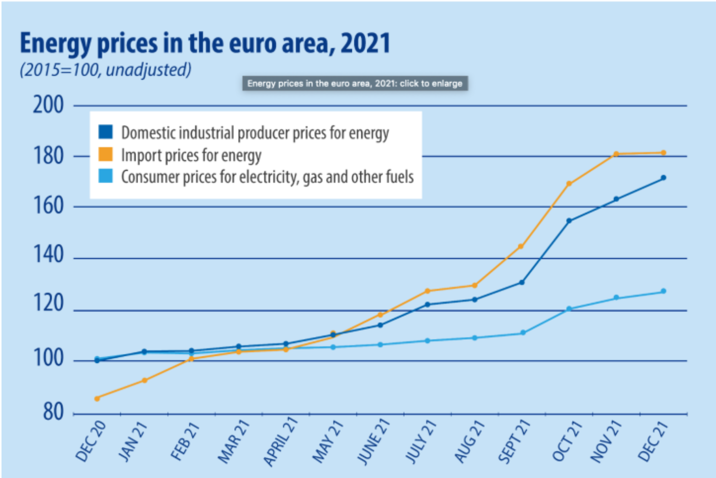

Figure 3: Increase in energy prices in the Euro area from December 2020 to December 2021. Source: Eurostat, [2]

The need for a just energy transition stems from the importance of providing clean, safe, and reliable energy to those households with fewer resources in order to establish a redistribution of wealth and provide access to just, sustainable, and healthy living conditions.

The energy crisis of 2022 in Spain highlighted several pressing issues that have made crucial defining three main concepts: "Energy Poverty", "sustainability" and "Just Transition".

Two approaches can be taken when defining the concept "Energy Poverty" (EP). The first is the European approach, therefore, according to the Energy Efficiency Directive (recast), [3], EP is a situation in which households are unable to meet their basic energy supply needs, due to unaffordability. Additionally, these households also lack access to essential and reliable energy services, affecting several aspects of people's lives, such as their healthcare, productivity, education and, quality of life. Some of the activities that are included in the basic levels of comfort and health and that households under the line of energy poverty cannot partially or fully access to are heating, hot water, cooling, lighting, and energy power appliances.

The second approach that is worth highlighting in this thesis is the National Strategy against Energy Poverty, defined by the Spanish Ministry for the Ecological Transition and the Demographic Challenge. According to [4], Energy poverty happens when a household finds itself in a situation in which its basic energy supply needs cannot be met, as a result of an insufficient level of income and which, if applicable, may be aggravated by having an energy inefficient home.

Although a universal understanding of this concept does not exist, Energy Poverty can be impacted by high energy prices, low incomes, energy inefficient buildings and each household energy necessities, [5]. Energy Poverty is a growing problem affecting millions of households, especially in Eastern, Central and Southern Europe.

According to [6], the concept of sustainability implies meeting the needs of the present generation without compromising the ability of future generations to meet their own needs. It involves a balance between economic, social, and environmental factors, ensuing that development and growth do not deplete natural resources, increase inequality, or cause irreparable harm to ecosystems. Since resources are finite, they should be used wisely and in a conservative form, avoiding the consequences caused by damaging use, and should be viewed from a long – term point of view and support economic health, and human and ecological development.

When defining what sustainability is, it is important to highlight the difference between "renewable energy" and "sustainable energy". While the two terms are often used interchangeably, a few areas overlap between them. Renewable energy comes from sources that naturally renew themselves, such as biomass, solar, wind and hydropower. On the other hand, sustainable energy comes from sources that fulfill energy demand without jeopardizing future generations, and minimizing their environmental impact, [7]. Sustainable energy is efficiently acquired, and it is regulated so there are no disparities or public interest in their infrastructures.

The last concept is "Just Transition", which consists of a framework that emphasizes a fair and equitable shift from fossil-fuel-based economies to more sustainable and low-carbon alternatives. It recognizes the need to address the social and economic consequences of transitioning to a more sustainable energy system. This includes ensuring the well-being of workers and communities that might be affected by changes in industries and energy sources, supporting them with job retraining, financial assistance, and social protection measures during the transition period.

The concept of "Just Transition" was created around the 1980s, when the US trade unions used it in a movement that protected workers from the new pollution regulations, [8]. It has gained popularity in recent days because of its relationship with global climate goals that unite workers from all types of social groups, in order to achieve these common objectives and improve the future of the next generation.

Lastly, as Spain explores cleaner energy alternatives, defining the concept of "Just Transition" becomes critical to protect the interests of workers and communities reliant on fossil fuel industries. Proper planning and support for those affected can mitigate potential economic and social disruptions, fostering a smooth and inclusive energy transition.

The energy crisis has exacerbated energy poverty in Spain, with rising energy prices making already vulnerable communities in a more pressing situation. Additionally, this energy crisis has highlighted even more the importance of transitioning to sustainable energy sources to reduce reliance on fossil fuels and minimize the impact of future crisis due to cuts or energy weaponization. By defining these three concepts, this project can be contextualized, and the policies explained become an essential part in order to understand the vulnerability index and the conclusions of this thesis.

1.1. MOTIVATION OF THE PROJECT

The relevance of this project comes from the importance of analyzing the relationship that European policies may have on energy demand, as well as the impact that such measures may have on the most disadvantaged households and their living conditions.

The main motivation is to analyze and address the conditions under which certain individuals live in Spain regarding to energy poverty and provide improvements that can be made in order to establish healthy, secure, and sustainable living conditions.

1.2. OBJECTIVES

In this section, it is important to differentiate two sets of objectives: general objectives and specific objectives.

The specific objectives of this project are stated below:

1. To define the current context in which the measures of two European Plans (Save Gas for a Safe Winter and REPowerEU) take place as well as a definition of the main concepts required to contextualize the project: Just Transition, sustainability, and Energy Poverty.
2. To establish the impact that the energy crisis and the consequent increase in households' energy prices has had on Energy Poverty in Spain. This will constitute the statistical part of the project. To achieve this objective, a vulnerability index will be defined according to the impact of the four main variables that interfere with energy vulnerability: net income, electricity prices, energy efficiency certificates of buildings and climate zones. These variables will constitute the Multi Factor Energy Vulnerability Index (MFEVI) that will be used to assess the Spanish situation in terms of Energy Poverty and sustainability. Additionally, several scenarios will be created to analyze the MFEVI's performance over different periods of the year 2022.

The general objective of this thesis is the following:

1. To analyze energy vulnerability in Spanish households during 2022 with the maximum level of geographic disaggregation. This objective will be fulfilled when the specific objectives 1 and 2 are fulfilled.

1.3. METHODOLOGY AND RESOURCES

For this project, the first objective is to compile all the information on the European packages, as well as to put into context the current situation with the war between Russia and Ukraine and the level of dependence on Russian gas exports to the rest of Europe. Then, it will be specified the situation for Spain in the context of energy poverty and a vulnerability measure will be defined to analyze Energy Poverty due to the increase of electricity prices caused by the energy crisis.

The main objective of this project is to establish how the energy crisis has affected the poorest neighborhoods in Spain and how has their energy poverty situation been impacted. In order to understand this subject in depth, the main four variables that interfere with Energy Poverty will be analyzed.

According to [3], [9] and [10], the main drivers in energy vulnerability are as follows: net income, electricity prices (for this thesis, the prices from 2022 will be analyzed), energy efficiency certificates of buildings and climate zone. By analyzing them, relevant scenarios will be defined in order to establish the impact of Energy Poverty across the country and a Multi – Factor Energy Vulnerability Index (MFEVI) will be used to assess the situation. The weight of each of the variables defined in MFEVI will be explained in Chapter 3.

It is important to highlight in this section that there will be no Profitability Analysis in this project. Although an economic approach would be appropriate to further delve into this matter, this approach could be done in several forms, and it would constitute a different project that could be interesting to develop in the future.

Nevertheless, if a Profitability Analysis of this project were to be carried out, the total cost of the development of this thesis would be calculated. For this purpose, the calculation would be divided into the following sections: labor, technology used, and licenses required.

- Labor: the calculation should take into account the hourly cost of an engineer with a master's degree, the hourly cost of a chief engineer for supervision and the number of working hours of each of them.
- Technology: costs would be calculated for the equipment used for the development of this project, in this case an HP laptop and an iPad Pro 12.9.
- Licenses: in this case, the cost of the Office 365 license.

To accomplish the objectives of this project, the following tools was used:

- Microsoft Excel: this program will be used for any numeric calculations regarding to the demand data as well as perform certain methods to better understand and analyze such data. It will also be used to create graphics and tables to present data and display useful graphs required for this project.
- Datawrapper: this program is a web-based data visualization tool that enables users to create interactive and visually appealing charts, graphs, and maps without requiring coding skills. It will be used to present the data obtained from the analysis of the variables that impact energy vulnerability in an engaging manner, creating a color map to display the data.

2. STATE OF THE ART

2.1. *THE RUSSIAN INVASION OF UKRAINE*

The Russian war against Ukraine began in 2014 with the annexation of Crimea by Russia, which was followed by a conflict in the eastern regions of Ukraine, where pro-Russian separatists have been fighting against Ukrainian government forces. The conflict has been ongoing for several years, with intermittent periods of relative calm and periods of violent outbreaks.

2.1.1. TIMELINE OF THE 2022 INVASION

In February 2022, the situation escalated significantly when Russia launched a full-scale invasion of Ukraine, which marked a significant turning point in the conflict. The invasion was preceded by the deployment of Russian forces on the border with Ukraine and a propaganda campaign to justify the invasion. On February 24th, Putin affirmed that this invasion, which he called "special military operation" was aimed at "denazification" of the country, [11].

The following months, Russia claimed control of several regions in the south of Ukraine specially attacking those cities with important resources such as nuclear power plants, which is the case of the plant located in Zaporizhzhia. This event is a key point for the energy supply in Europe, since losing control of this nuclear plant would mean losing the energy supply that covered a large part of the continent's demand.

The Russian invasion was internationally condemned, and several sanctions were imposed. In April 2022, Russia ceased its attempts to take Kiev and since the summer of 2022, the conflict has been confined to the south and eastern part of Ukraine, [12], with the Donbas region also being attacked by Russian forces.

The conflict remains open and has resulted in a refugee crisis as well as tens of thousands of deaths.

2.1.2. THE CONSEQUENCES OF THE INVASION

The Russian invasion resulted in a large-scale military conflict, with fighting occurring across much of Ukraine. The conflict has resulted in significant loss of life and displacement of civilians, with reports of human rights abuses by both sides.

The international community has condemned Russia's actions and imposed economic sanctions on Russia in response. The war has also had a significant impact on Ukraine's economy, with damage to infrastructure and disruption of trade.

The conflict has deep historical roots, as Ukraine was once part of the Soviet Union, and many Ukrainians speak Russian as their first language. The conflict has also been fed by geopolitical tensions between Russia and western nations, as well as Russia's desire to maintain influence over Ukraine.

Despite efforts to negotiate a peaceful resolution to the conflict, the situation remains tense, and fighting continues in some areas. The conflict has become one of the most significant ongoing conflicts in Europe, with far-reaching consequences for both countries and their surroundings.

The invasion of Ukraine has brought serious consequences for Europe, causing a profound economic impact, and aggravating pre-existing tensions in international commodity markets.

One of the most affected markets has been the energy market, since Russia was one of the largest gas exporters in Europe.

Historically, Russia has been the main supplier of natural gas to the EU, accounting for around 40% of imports. In 2021, prior to the invasion, Russia planned a strategy that consisted in using its title as main supplier as a form of blackmail on Europe, thus securing enough demand and high prices for its exports. These events have been reflected in the total or partial disruptions to 14 European states. The high dependence from Russian gas is worsened by the EU's low LNG import capacity: only 30% of the Member States have access to the LNG global market through regasification terminals. Spain accounts for 34% of all EU's regasification capacity [13].

2.2. *THE IMPACT ON EUROPE'S ECONOMY AND THE EU'S REACTION*

The Russian war is clearly visible in many countries of the European Union. This military aggression has provoked a lack of resources and is having a direct impact in availability and affordability especially for the food and energy markets.

Prior to the outbreak of the war, commodity markets had already gone through a series of events that made them vulnerable. The implications of climate change and the COVID pandemic challenged the supply systems creating a critical situation. This instability has been worsened by the effects of the Russian conflict, since Ukraine was considered "the breadbasket of Europe", its invasion triggered a global food crisis and an increase in energy prices and basic commodities. Sanctions and trade restrictions imposed by the current state of affairs between the two nations have disrupted supply chains and created uncertainty for traders and investors, resulting in price volatility and market instability. Consequently, the commodity markets have been suffering changes in supply and an increase in prices for basic products such as grain and poultry. The Russian weaponization of food shortage has prompted several nations to implement measures and adopt restrictions to prevent a continued increase of prices and ensure supply affordability.

Since Russia was a major supplier of energy resources such as gas and oil to many European countries, the disruption of this supplies has led to concerns about energy security and the vulnerability of Europe's energy infrastructure.

As shown in *Figure* 4, the price increase has been remarkable since the outbreak of the war. Some fossil fuels such as coal have risen by almost 70%, followed by wheat and numerous minerals used daily in industry, aggravating the critical raw material situation, and provoking a global food crisis.

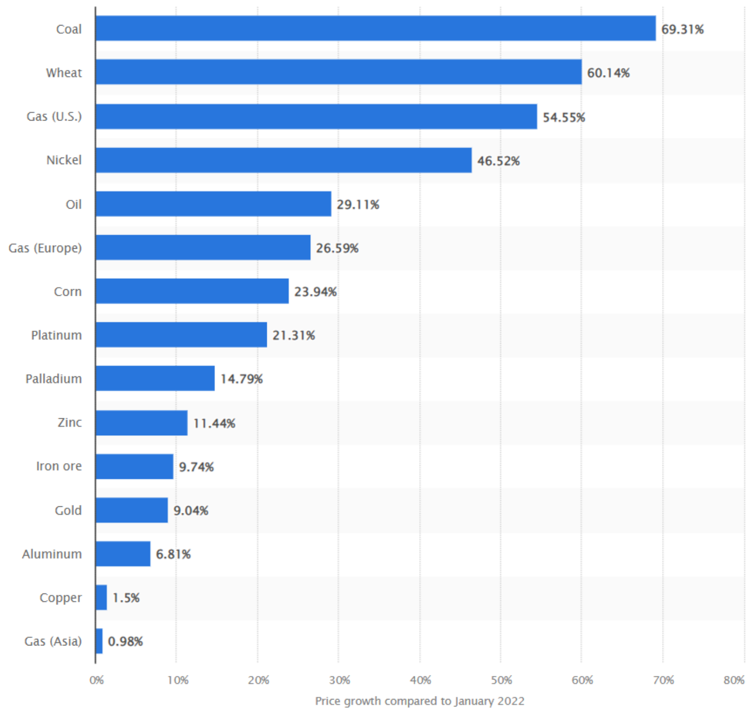

Figure 4: Change in average price of selected commodities from February 24 to June 1, 2022, compared to January 2022. Source: Statista, [14]

Addressing energy poverty requires a multi-faceted approach that involves improving energy efficiency, increasing access to renewable energy sources, enhancing energy infrastructure, and promoting social and economic empowerment.

2.2.1. REPOWEREU

Russian supplier Gazprom is the largest gas producer in the country. It produced 431 billion cubic meters (BCM) of gas in 2020, which makes it the most dominant company in the Russian natural gas industry [15].

Due to the steady rise in prices since the war began, Gazprom has threatened to break some of the long-term contracts it had with certain European Union countries. The constant price extortion and threats from the Russian supplier have forced the EU to take measures to cease dependence on the country's exports. Such measures begin by creating a legislative proposal called "REPowerEU". Said proposal outlines a plan to achieve energy independence from Russian fossil fuels by 2027. Its main objective is to avoid this dependence being weaponized against the EU that has already started with the increase in gas prices and the disconnection of Poland and Bulgaria from Russian gas deliveries.

2.2.1.1. RepowerEU Measures

"REPowerEU" is founded on a series of short, mid, and long – term measures to achieve its main goal. One of its first short - term measures for the situation in May 2022 was demand reduction, which was then concretized in the "Save Gas for a Safe Winter" ("SGSW" from now on) proposal. Between February 27th, 2022, and March 27th, 2022, the EU Member States paid around 1 billion of € per day for Russian fossil energy deliveries. The impact of a lower demand will be directly reflected in lower payments and, ultimately, lower emissions [16].

Its short to mid– term measures include diversifying delivery options and proofing existing infrastructure. As mentioned before, obtaining the lowest gas price possible, is key in order to maintain electricity costs down because of the price formation system, which remunerates all generation at the price set by the last power plant needed to meet demand. This is usually a gas – based thermal plant. In addition to this, gas infrastructure is known to be the most flexible to use for other non – fossil fuels, such as hydrogen and ammonia. Achieving terminals that could receive both gas and renewable molecules would allow for a double utility to potential energy partners [16].

The main mid to long – term objective is to accelerate the clean transition to renewable sources within the EU's borders. This would reflect the compromise of the European Commission to integrate the three fundamental aspects to achieve a just energy transition: sustainability, security, and competitiveness.

REPowerEU and the initiative Save Gas for a Safe Winter are two distinct initiatives aimed at addressing different aspects of energy use and conservation. While both initiatives have a common goal of promoting sustainable energy practices, there are some key differences between them.

2.2.2. SGSW PLAN

In this context, the European Union is responding with a legislative proposal consisting of two coordinated action packages: "REPowerEU" and "Save Gas for a Safe Winter".

"Save Gas for a Safe Winter" is a proposal which main objective is to protect the EU against a disconnection from Russian gas. In order to do so, a 15% demand reduction between August 1, 2022, and March 31, 2023, is proposed. Initially, this measure involves all Member States and is voluntary. However, it will become mandatory in the event of an 'EU Alert'. This new approach aimed at encouraging households and businesses to reduce their energy consumption during the coldest months, seeks to address the issue of energy insecurity by reducing demand for natural gas, which is the primary source of heating for many households in the winter.

This is a relevant proposal because, while previous initiatives where mainly focused on diversifying supply and storage; SGSW focuses explicitly on reducing consumption. This approach is critical in the event of a total disconnection from Russian gas and will become the only way to avoid relevant consequences of energy shortages [17].

Figure 5 shows the storage level of the pre-war scenario (during the years 2019 - 2021) and after the 15% reduction in demand proposed by the EU strategy.

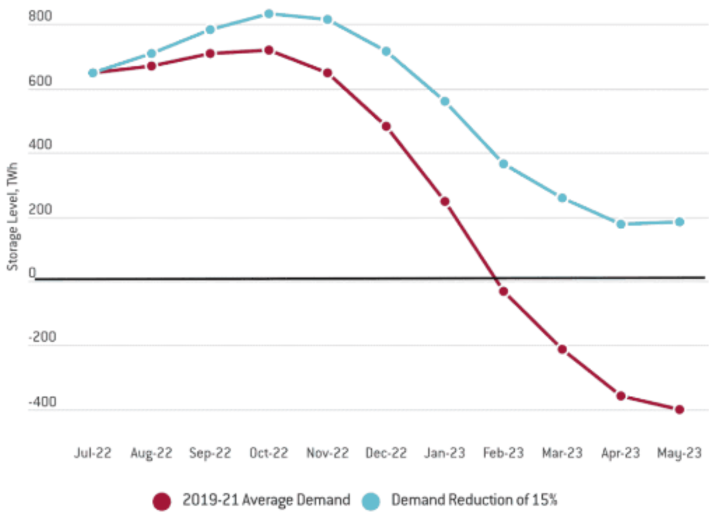

Figure 5: EU Storage/Demand scenarios without Russian gas imports. Source: Florence School of Regulation, Brussels, 2022, [17]

The proposal includes several measures to promote energy conservation, such as tax incentives for energy – efficient upgrades to homes and businesses, public education campaigns on energy conservation, and subsidies for low – income households to improve energy efficiency.

2.2.2.1. SGSW Measures

In this section, two scenarios must be taken into consideration: the pre – EU alert and the EU alert.

In the pre – EU alert, all Member States will make their best efforts in reducing their gas demand by 15%, although considering total or partial derogations. Member States will implement alternatives to natural gas, especially aiming to promote more sustainable options like renewable energy, limit heating and cooling temperatures un public buildings, voluntary auctions to reduce consumption and implement fuel switching measures, [17].

An EU alert implies that there is an identified substantial risk or severe gas shortage, and therefore a significant threat to the gas supply in the Union, and at least five Member States have issued national – level alerts. In this case, more severe measures will be implemented.

Some of these measures include reinforce monitoring and the exchange of information, implement a crisis management group if necessary, and a mandatory reduction of 15% of demand, although considering the total or partial derogations mentioned below.

2.2.2.2. SGSW Derogations

Article 5 of the definitive version allows for derogations from the obligation for Member States to reduce gas demand.

- Island nations such as Ireland, Cyprus, and Malta are exempt from the obligation since they are not physically connected to the European gas grid.
- Partial derogations or adaptations of the objectibeve are also possible in cases where infrastructure does not permit solidarity between Member States, such as the Iberian Peninsula, France, or Croatia. In such cases, Member States must demonstrate that they are maximizing their ability to provide solidarity with the available infrastructure.
- Total derogations may be granted if gas saving measures risk disrupting electricity supply, such as in Estonia, Latvia, and Lithuania. Partial/temporary derogations are possible for Member States whose electricity supplies heavily rely on gas-fired generation and are at risk of disruption.
- Further partial derogations may also be granted subject to individual assessment by the Commission, for instance, if Member States have exceeded their gas storage filling targets, are heavily dependent on gas for critical industries, or have seen an increase in gas consumption of 8% or more in the past year compared to the previous five-year average, such as in Bulgaria, Greece, Poland, and Slovakia.

2.2.3. EUROPEAN GAS REDUCTION PLAN

The European Gas Reduction Plan is a strategy developed by the European Commission to reduce the demand for natural gas in the European Union. This strategy aims to assist Member States in achieving the required reduction in demand. This plan outlines coordinated measures, principles, and criteria for demand reduction. The plan emphasizes the substitution of gas with other fuels and overall energy savings in all sectors. Its objective is to ensure a stable supply of gas to households, hospitals, and essential industries, which are critical to the provision of essential products and services to the economy, as well as EU supply chains and competitiveness. The Plan offers guidelines for Member States to consider while developing curtailment plans. The ultimate goal of the European Gas Reduction Plan is to create a more sustainable and resilient energy system in the EU.

The Demand Reduction Plan can assist Member States in determining and prioritizing their "non-protected" consumer groups, [18], taking into account the following criteria and overall economic considerations:

- Societal criticality, including sectors such as health, food, safety, security, refineries, defense, and the provision of environmental services.
- Cross-border supply chains, encompassing sectors or industries that provide essential goods and services for the smooth operation of EU supply chains.
- Potential damage to installations to avoid production delays, regulatory hurdles, and costs.
- The possibility of reducing gas consumption and substituting products/components, including the capacity of industries to switch to imported products/components and the extent to which product/component demand can be met through imports.

REPowerEU is a comprehensive and long-term plan to transition the European Union towards a sustainable energy future. The initiative focuses on increasing the share of renewable energy sources, improving energy efficiency, and reducing greenhouse gas emissions while decreasing EU's dependence on Russian fossil fuels. The aim is to address the climate crisis and to create new job opportunities and boost economic growth in the process.

On the other hand, Save Gas for a Safe Winter is a short-term campaign aimed at encouraging households and businesses to reduce their energy consumption during the winter months of between 2022 and 2023. The initiative promotes energy-efficient practices such as turning down the thermostat, sealing drafts, and using energy-efficient appliances. The aim is to reduce energy costs, conserve natural resources, and promote energy independence.

While these initiatives may seem different, they actually complement each other. By promoting energy-efficient practices, the SGSW initiative can help to reduce energy consumption in the short term, which will help to achieve the long-term goals of REPowerEU. By reducing energy consumption, there will be less need for fossil fuel-based energy sources, which will help to reduce greenhouse gas emissions and promote the use of renewable energy sources. In addition, the REPowerEU initiative can help to support the development of new technologies and infrastructure that will make it easier for households and businesses to adopt energy-efficient practices. For example, by increasing investment in energy storage, it will be easier to store and use renewable energy sources such as solar and wind power, which can help reduce energy costs and promote energy independence.

In conclusion, while REPowerEU and the Save Gas for a Safe Winter initiative may seem different, they are both important parts of a broader strategy to promote sustainable energy practices and combat climate change. By working together, these initiatives can help to achieve the EU's long-term goals of becoming climate-neutral by 2050, [13], while also promoting energy efficiency, economic growth, and energy security in the short term.

2.3. THE IMPACT ON SPAIN'S IMPOVERISHED NEIGHBORHOODS

As it has been clearly established before, the weaponization of Russian fossil fuels is a geopolitical issue that has significant impacts on global energy markets and political relations. However, not only nations and governments are affected by this practice. This weaponization can have a devastating impact on impoverished neighborhoods, particularly those already struggling with energy poverty. These communities rely heavily on fossil fuels for heating and other daily activities, and fluctuations in prices and supply can make it difficult for them to access the resources they need to survive. This can result in increased energy costs, rationing of resources, and even blackouts, further exacerbating the already dire living conditions in these neighborhoods. In addition to this, it can also limit the ability of these communities to invest in renewable energy sources, which could provide a more sustainable and affordable solution to their energy needs. In this context, it is essential to understand the broader implications of the weaponization of fossil fuels and its impact on those most vulnerable in society.

The energy crisis caused by the Russian – Ukrainian War, was perceived more intensely during the 2022. The increase in energy prices due to the lack of electricity available has caused that the consumers now are obligated to pay higher electricity and gas bills. Consequently, there has potentially been a decrease in energy consumption that has aggravated the already serious situation in 2021, [19].

Additionally, due to the scarcity of electricity from renewable energy, governments have opted to switch back to more polluting energy sources, such as coal or oil, leading to an increase in greenhouse gas emissions. This constitutes a problem globally because those emissions contribute to the depletion of the ozone layer.

Furthermore, the increase in energy prices has led to a decrease in the purchasing power of citizens, since, with inflation and the increase in the electricity bill, they have less money available for other expenses. This has led to a decrease in the quality of life of Spanish citizens, who have been forced to reduce their electricity consumption, [20].

According to [21], the electricity prices during summer 2022 were 7.5 times higher on average that those at the start of 2021. It has been estimated that the rise in energy prices has increased household living costs by approximately 7%. Particularly in Spain, this cost has increased more than 5% due to energy costs in 2022 between direct and indirect causes[1].

[1] Direct causes include the direct increase in energy prices, while indirect causes refer to the increase in energy prices due to the increase in prices of other non-energy goods.

The industrial sector constitutes an essential part of the Spanish economy. According to [22], the manufacturing sector has a weight of 13% of GDP. If energy sector is included, it would reach 15%. It also accounts for 12% of employment and 85% of exports (which are mainly intermediate goods) and is responsible for 50% of total business investment in R&D&I.

However, when comparing Spain with other countries, the Spanish industrial sector plays a relatively minor role in the overall productive system. While countries like Germany or Sweden have a substantial share of 22% and 19% respectively, the contribution of industry in Spain remains below the European average at 18%. This is a burden when it comes to making the sector more competitive at the European level. Another noteworthy aspect is the size of companies operating in this sector, predominantly consisting of small or medium-sized enterprises, with only 0.1% being classified as large companies.

The majority of the industrial enterprises are subject to the volatility in prices because they buy their energy at *the pool*, and, additionally, according to [22], energy costs constitute between 60% and 70% of total costs. This situation has caused to many enterprises to consider whether it is more profitable to cost the plant than continue working. For the small consumer, the closing of energy factories would translate into a reduction of the energy supply, which would further increase the price of electricity, aggravating the aforementioned consequences: lower energy consumption, less economic availability for other essential expenses, and an increase in the level of energy poverty at the national level.

3. METHODOLOGY

In recent years, energy poverty has emerged as a critical social and environmental issue, both globally and within the context of Spain.

Defined as the inability to afford adequate energy services for basic household needs, energy poverty disproportionately affects vulnerable populations, exacerbating social inequalities and hindering sustainable development efforts. As Spain strives to achieve its energy transition goals and reduce greenhouse gas emissions, it becomes imperative to understand the multifaceted factors contributing to energy poverty. This chapter aims to delve into the importance of income, the different climate zones, energy prices, and energy efficiency certificates of buildings, in shaping the energy poverty landscape in Spain.

By comprehensively examining the significance of these factors, this thesis aims to contribute to the existing body of knowledge on energy poverty in Spain.

This chapter will analyze the four main variables that contribute to energy poverty. Subsequently, several scenarios will be formulated to be taken into consideration when presenting conclusions. These scenarios will analyze the impact of each of the variables on energy poverty, especially the climate zone and the variation in electricity prices over the year 2022.

Finally, a vulnerability index will be developed. To properly explain energy poverty, this index will consider each and every one of these variables with their corresponding weights as a theoretical indicator of energy poverty in the Spanish municipalities in 2022. Additionally, this global index will be aggregated by Autonomous Communities in order to compare it to previous studies.

It is important to mention that the scenarios and the MFEVI will be analyzed only for the Spanish mainland, in which neither the Canary Islands, the Balearic Islands, Ceuta nor Melilla will be considered.

The findings from this research can inform policy decisions and facilitate the development of targeted interventions that address the specific challenges faced by energy-vulnerable populations. Ultimately, by addressing energy poverty, Spain can advance its energy transition goals, promote social equity, and foster a sustainable and inclusive society.

3.1. VULNERABILITY VARIABLES

In this section, the main drivers of energy vulnerability will be defined and analyzed in order to assign weights to elaborate a vulnerability index.

To better understand the purpose of this thesis, it is important to highlight the difference between "energy vulnerability" and "energy poverty".

As it has been stated before, energy poverty is a situation in which a household cannot afford to meet its basic energy needs, such as lighting, heating and cooling, and hot water. These needs are critical to a healthy development of the individuals, their social interactions, and their quality of life.

On the other hand, energy vulnerability can be defined as the predisposition to fall into a situation of energy poverty. It is therefore a valuable indicator to determine whether a household is close to the energy poverty threshold or not.

These two concepts will be mentioned frequently throughout this project, and it is important that the difference is clear for future reference.

3.1.1. NET INCOME

Income, as a primary determinant of household well-being, plays a pivotal role in energy poverty. According to [23] and [24], low-income households often face a disproportionate energy burden relative to their income, forcing difficult trade-offs between meeting basic energy needs and other essential expenses. Consequently, exploring the relationship between income levels and energy poverty can provide valuable insights into the socioeconomic dynamics driving energy vulnerability.

This analysis has used the last record of personal income in Spain collected by the INE institute, which dates to 2020. Although 2020 was a year influenced by the COVID – 19 and certain variations could be expected in net income, the geographical distribution of this variable between the year 2019 and 2020 has been thoroughly examined and, since there were no major differences, all the indexes in this thesis are calculated with data from 2020, since it was the most recent data of net income disaggregated by municipality.

To calculate index value for net income, the distribution has been divided in five parts, each of them corresponding to a percentile bracket. Therefore, index value 1 has been assigned to the highest net income and index 5 to the lowest net income, as shown in Table 1:

Percentile	Net Income range (k€/year)	Index Value
0.2	[0; 10.17]	5
0.4	(10.17; 11.59]	4
0.6	(11.59; 12.79]	3
0.8	(12.79; 14.17]	2
1	(14.17; 31.67]	1

Table 1: Index value assignation for net income. Source: own elaboration, INE, [25]

Figure 6 shows the distribution of net income by municipality from 2020:

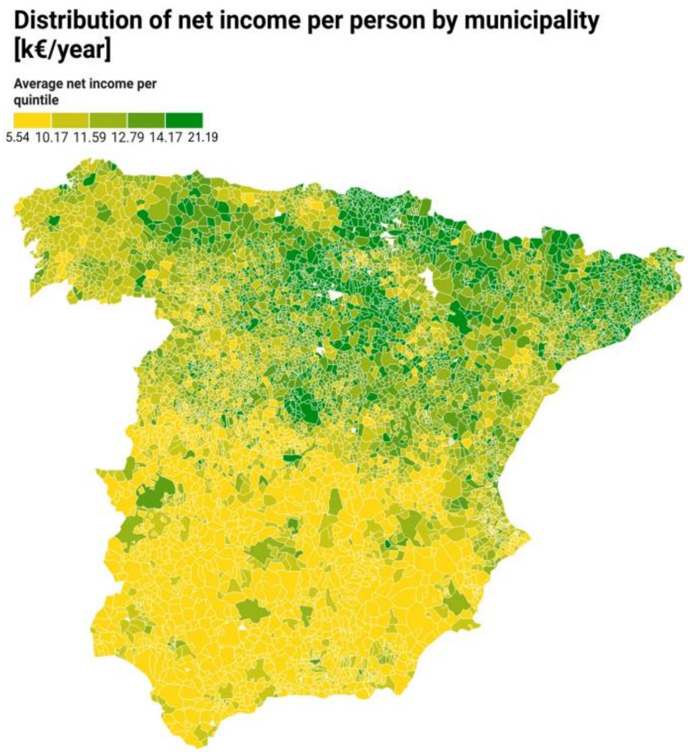

Figure 6: Distribution of net income per person in k€/year. Source: INE, [25]

In Figure 6, it is clearly visible how the south of Spain has lower income, as it is mostly below 10,000 € per year. This will be an important issue when analyzing the vulnerability index as it will be discussed later in this thesis.

3.1.2. ELECTRICITY PRICES

Energy prices, both electricity and fuel costs, are critical in determining the affordability of energy services for households, [26]. Fluctuating energy prices can significantly impact energy poverty levels, particularly for low-income households who are more susceptible to the rising costs. Analyzing the relationship between energy prices and energy poverty provides valuable insights into the affordability challenges faced by vulnerable households and assists policymakers in developing measures to mitigate their effects.

The rise in energy prices during 2022 caused mainly by the Russian-Ukrainian war has been a particularly important factor affecting a multitude of households in Europe. This increase is most relevant when analyzing months with higher energy consumption, such as the hottest or the coldest seasons of the year. This topic will be discussed further in this thesis.

Before the start of the war and after the change in tariffs (1/6/2021), the average price of electricity[2] for the second half of 2021 was around 0.19 €/kWh, [27].

Table 2 shows the average prices of electricity per month of 2022:

Month 2022	Electricity Price (€/kWh)	Index Value
January	0.26	5
February	0.26	5
March	0.36	5
April	0.24	5
May	0.23	5
June	0.26	5
July	0.30	5
August	0.36	5
September	0.28	5
October	0.21	5
November	0.17	5
December	0.18	5

Table 2: Average electricity prices and index value per month of 2022. Source: own creation and CNMC, [27]

To calculate index value for electricity prices in 2022, the price distribution has been divided in five parts, each of them corresponding to a percentile bracket. Therefore, index value 1

[2] The regulated market tariff has been taken as a reference, since this is the one used by vulnerable consumers who benefit from social tariffs.

has been assigned to the lowest price bracket and index 5 to the highest price bracket, as shown in Table 3:

Percentile	Price range (€/kWh)	Index Value
0.2	[0; 0.21086]	1
0.4	(0.21086; 0.247227]	2
0.6	(0.247227; 0.261411]	3
0.8	(0.261411; 0.296876]	4
1	(0.296876; 0.363364]	5

Table 3: Index value assignation for electricity prices. Source: own elaboration, CNMC [27]

The average price of electricity throughout the year 2022 was 0.26 €/kWh, which implies an increase of almost 37% of the prices with respect to the second half of 2021 (the average electricity price for this period of 2021 was 0.19€/kWh, as mentioned above), period in which energy prices had already experienced an important increase, [28]. This rise may have forced many Spanish families to reduce their consumption, as happened in 2021, [19], especially during the coldest months of 2022.

Higher energy prices disproportionately affect low-income households, pushing them further into energy poverty, [29].

For economically disadvantaged individuals and families, the increased cost of energy can consume a significant portion of their income, leaving them unable to adequately heat, cool, or power their homes. This exacerbates social inequalities and can lead to adverse health and well-being outcomes. In addition to this, some households may resort to switching to cheaper, but more carbon-intensive energy sources as a response to soaring energy prices, [30] as it is already happening in several regions of Europe, [31]. This behavior may result in an increase in greenhouse gas emissions that undermine the proposed sustainability goals.

3.1.3. ENERGY PERFORMANCE CERTIFICATES

The Energy Performance Certificate (EPC from now on) is an official document drafted by a technician that includes objective information on the energy characteristics of a property. In this sense, said certificate qualifies a property by calculating the annual energy consumption necessary to meet the energy demand of certain building under normal occupancy and operating conditions which include the production of hot water, heating, lighting, cooling, and ventilation.

The energy certification process concludes with the issuance of an energy efficiency certificate and the assignment of an energy efficiency label. The energy rating scale consists of letters and ranges from A (most energy efficient building) to G (least energy efficient building), [32].

EPCs of buildings offer means to evaluate the energy efficiency and sustainability of residential structures. Energy-efficient buildings can substantially reduce energy consumption and costs for occupants. Examining the role of EPCs in relation to energy poverty enables a comprehensive understanding of how building standards and regulations influence energy affordability and access.

Figure 7 shows the distribution of EPCs across the Spanish mainland:

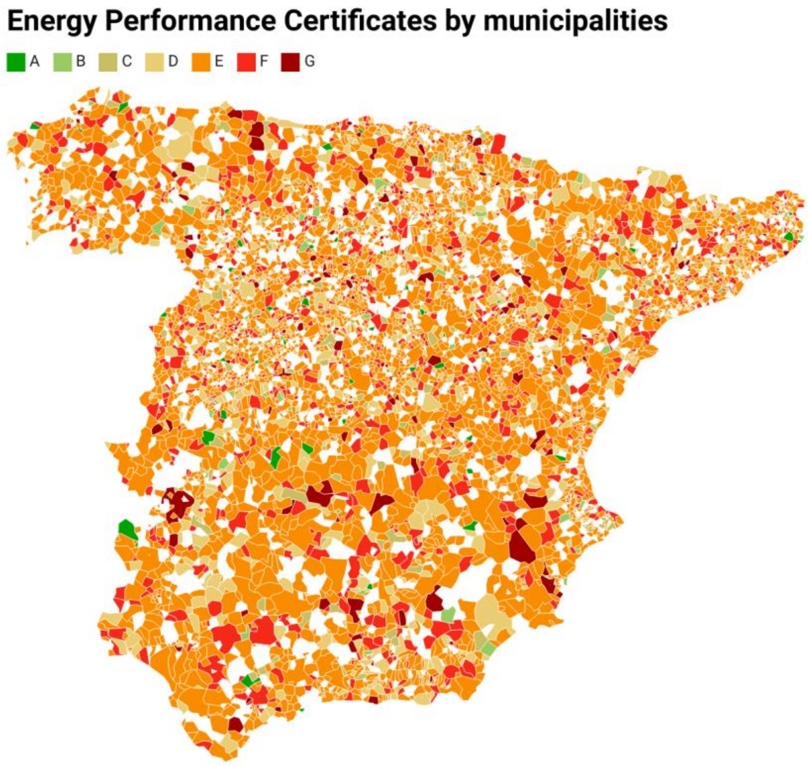

Figure 7: Energy Performance Certificates per municipality. Source: catalog of Open Data of each Autonomous Community

Although in Spain it is mandatory to obtain this certificate for rented dwellings and buildings to be sold, it is important to keep in mind that the process of obtaining it can be slow and that it will take several years to have data for all buildings. Therefore, in Figure 7, certain municipalities are shown in blank because there was no data available.

In order to incorporate these certificates in the calculation of the vulnerability index, an index value has been assigned to each level depending on the number of occurrences of each level. Since EPCs range from A (most efficient) to G (least efficient), Table 4 shows the assignation made:

EPC	Index value
A	1
B	1
C	2
D	3
E	4
F	5
G	5

Table 4: Assigned index values to different EPC levels. Source: own elaboration

This allocation has been made according to the frequency of each of the denominations. The letters A and B, F and G have repeated numbers, 1 and 5 respectively. This is because A and B energy ratings are repeated less often in the population and represent energy efficient buildings or dwellings while F and G represent energy inefficient buildings or dwellings; while the letters C, D and E are central ratings and E is the most common one in Spain (54% of existing buildings[4], [33]), thus, the three of them obtain their own unique energy vulnerability number.

3.1.4. CLIMATE ZONES

Climate zones refer to geographical areas characterized by distinct climatic conditions, including temperature, humidity, precipitation, and wind patterns. These zones are determined by factors such as latitude, altitude, proximity to bodies of water, and prevailing weather systems. In the context of energy poverty, climate zones play a significant role in influencing energy consumption patterns and, consequently, the prevalence of energy poverty, [10].

Firstly, climate zones determine the extent of heating and cooling requirements in residential buildings. In colder climates, households rely more on heating systems to maintain comfortable indoor temperatures, leading to higher energy consumption during winter months. On the other hand, in hotter climates, cooling needs, such as air conditioning,

[4] The buildings constructed before the application of the CTE (2007) are classified as "existing buildings" in the official rating report of Spain.

become essential for comfort. These energy demands are directly influenced by climate zones, and the associated costs can contribute to a higher level of energy poverty.

Secondly, climate zones contribute to seasonal variations in energy consumption. Regions with distinct seasons experience fluctuations in energy demand throughout the year. In colder climate zones, energy consumption tends to peak during winter, whereas hotter climate zones witness higher energy demand during summer. These seasonal fluctuations can lead to increased energy bills, posing financial challenges for households already grappling with energy poverty. It is also important to highlight that season duration is also affected by climate zones, for example, in colder regions, the winter conditions may last for several months, thus increasing the heating demand. Conversely, in hotter climates, a longer summer season also increases the cost of energy by rising the cooling demand.

Lastly, climate zones can be associated with extreme weather events, such as heatwaves, storms, or cold snaps. These events have a significant impact on people and energy infrastructure, potentially leading to power outages or disruptions in energy supply. In the EU, the most warning extremely hot days are forecasted for central and southern Europe (Hoegh-Guldberg et al., 2018, [34], Castaño-Rosa et al., 2021, [35]), being Spain one of the particularly affected countries. Vulnerable households already experiencing energy poverty may face additional challenges in coping with these extreme events, further exacerbating their energy vulnerability.

In Spain, each climate zone is determined according to the locality where the building is located and its altitude above sea level. There are 6 climatic zones for winter and 4 climatic zones for summer. Although theoretically there are 24 possible combinations, the different Spanish regions are defined by only 13 of them. The first five winter zones are designated from A to E and the sixth zone is designated with the Greek letter α, which is used exclusively for the Canary Islands. The summer zones are designated with the numbers 1, 2, 3 and 4.

For the winter zones, letter E is the most severe, with cold winters and usual snow. Letter A implies warm winters, with practically no rainfall or snow and no strong winds. Letter α is reserved for the climatic situation of some areas of the Canary Island, which have a subtropical climate, which is characterized by high humidity and high temperatures throughout the winter, with an average of 21ºC, according to [36], thus no heating demand.

The summer climate zones go from 1 to 4, being 1 the number assigned to the zones with a mild summer, with abundant rainfall and high humidity, and 4 assigned to zones with hot and dry summers, with high temperatures and practically no rainfall.

Spain's diverse climate zones influence energy consumption patterns and subsequently impact energy poverty rates. Different regions within Spain experience varying weather conditions, including temperature extremes and varying heating and cooling demands. Understanding how climate zones influence energy usage and the resulting implications for energy poverty is crucial for tailoring effective policy interventions and targeted support mechanisms.

In order to properly contextualize the impact of the different climate zones in energy poverty, it is important to highlight that the energy expenditure varies greatly from season to season. According to [10], there is a big difference between the required annual expenditure in heating and cooling.

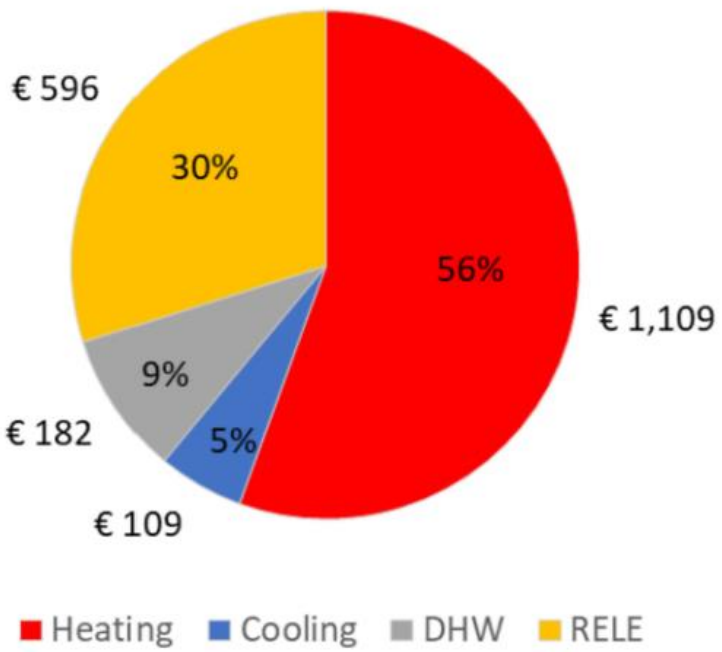

Figure 8: Average required expenditure [€/year] and costs' share [%] for each energy use in 2019. Source: [10]

According to Figure 8, if only heating and cooling costs were taken into account and isolated from DHW [5]and RELE[6], the required expenditure in heating would account for 92% of the total required expenditure, while the required cooling expenditure would be equal to only 8% of the total required expenditure. This fact can be explained because only 35.5% of Spanish households have air conditioning units, [10].

Due to this difference, households located in colder regions would likely suffer more from energy poverty than those located in regions with warmer and less extreme winters. To properly evaluate each case, different weights will be applied to summer and winter climate zones. Each of these weights will be explained in Chapter 4.

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[5] Domestic Hot Water
[6] Required ELectricity Expenditure

3.1.4.1. Winter climate zones

Figure 9 shows the different climate zones for the coldest months by municipality:

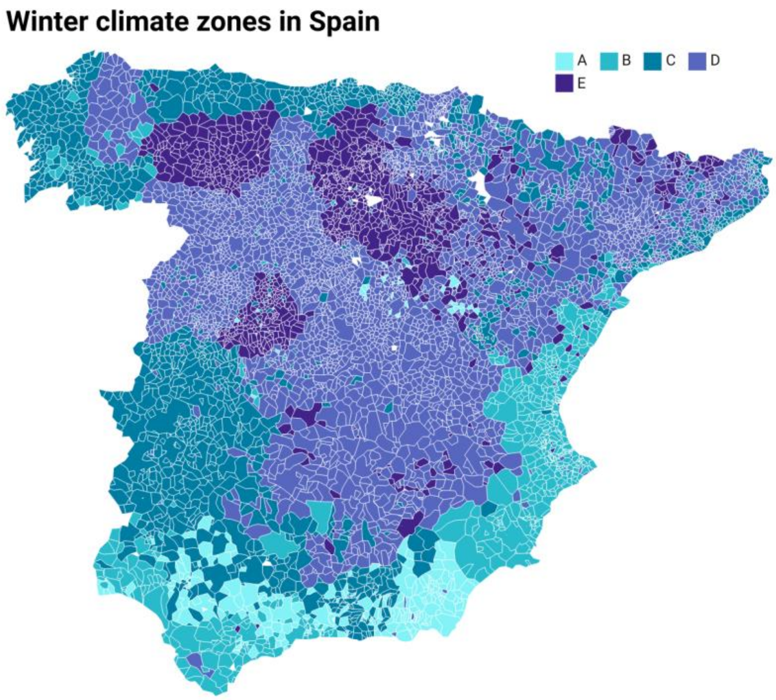

Figure 9: *Distribution of winter climate zones by municipality, Source: Barrella et all. (2022), Energy Research and Social Science, [10]*

As it is shown in the figure above, warmer winters are expected in the southernmost regions of the peninsula and in general in the coastal areas, while the most extreme conditions are shown in dark blue and usually located in the inland and sometimes north side of the country (like in the Pyrenees areas of Catalonia). Most of these cold municipalities are located in the Autonomous Community of Castilla y León, especially in León, Ávila, Soria and Burgos, but also in the northernmost part of the Catalonian region and in Aragón.

3.1.4.2. Summer climate zones

It is important to highlight that, according to Figure 8, the annual cost of heating constitutes almost 92% of the total required cost on HVAC, whereas the cost of cooling, which mainly comprises the cost of air conditioning, accounts for only 8%. Therefore, this variable will have less weight when exploring the scenarios in the following chapter.

Figure 10 shows the different climate zones for the hottest months by municipality:

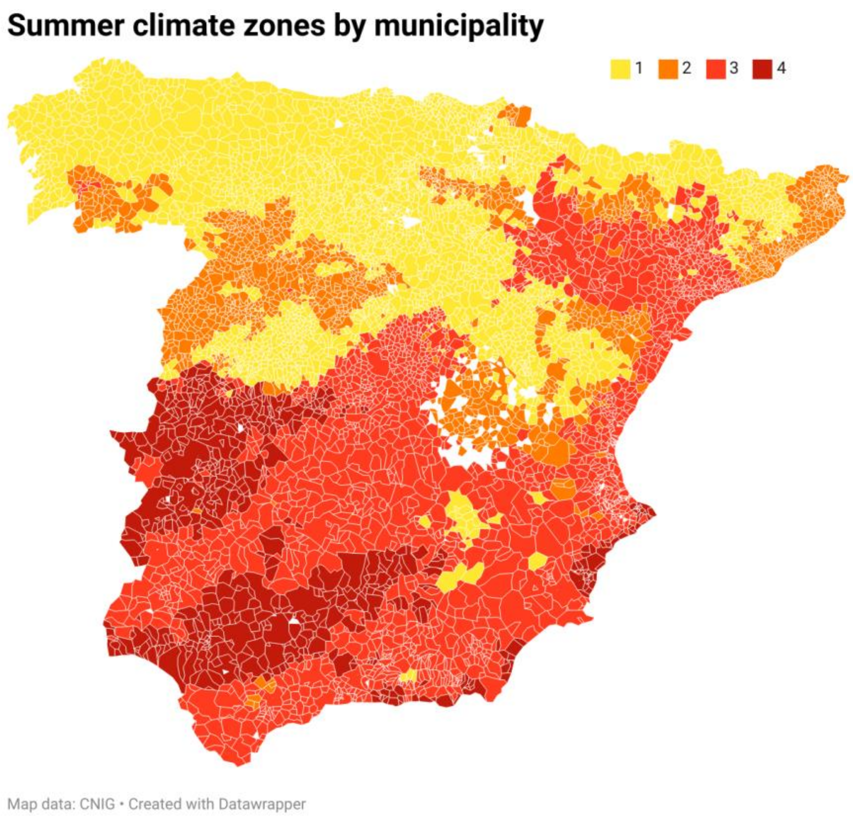

Figure 10: Distribution of summer climate zones by municipality. Source: Barrella et all. (2022), Energy Research and Social Science, [10]

According to Figure 10, the most extreme temperatures during the summer are expected in the North of Extremadura and the provinces of Huelva, Sevilla, Córdoba and Jaén, located in the south of Spain. These locations experience long and heated summers with temperatures of over 35ºC, whereas in the northernmost part of the country, colder temperatures are expected, with occasional rain and a shorter summer season.

3.2. MULTI – FACTOR ENERGY VULNERABILITY INDEX (MFEVI)

This section will explain the calculation and the factors that comprise the Multi – Factor Energy Vulnerability Index (from now on MFEVI) for subsequent analysis and conclusions, therefore a global scenario will be established to contextualize the MFEVI, which consists of a measure of energy poverty during the year 2022 explained by municipalities according to net income, Energy Performance Certificates, climate zone and average electricity price during that year.

The variables' indexes used to calculate each of these scenarios follow the same rules explained in section 0. Therefore, Net Income Index go from 1 to 5, according Table 1.

For the calculations in the analyzed case study, the average electricity price of 2022 has been calculated and the index assigned to this calculation has been used to define the MFEVI.

For the winter climate zones, values go from 1 to 5 in the same manner described before, while summer climate zones go from 1 to 4 following their nomenclature.

Lasty, Energy Performance Certificates (EPC) have an index assigned according to Table 4.

The weight for each of the variables' indexes is described in the formula below:

$$MFEVI_i = 0.25 \cdot NII_i + 0.25 \cdot EPI + 0,25 \cdot EPCI_i + 0.23 \cdot WCZI_i + 0.02 \cdot SCZI_i \quad (1)$$

Where:

- NII_i: Net Income Index of each municipality, i.
- EPI: average Electricity Price Index in 2022[7].
- $EPCI_i$: Energy Performance Certificate Index of each municipality, i.
- $WCZI_i$: Winter Climate Zone Index of each municipality, i.
- $SCZI_i$: Summer Climate Zone Index of each municipality, i.

The first three variables (Net Income, Energy Performance Certificate and Electricity Price) weight 25% each. In order to introduce both winter and summer climate zones, 23%

[7] The average electricity price for 2022 in the Spanish mainland was 0.259€/kWh, and the index assigned to this figure is 3.

of the weight is for the winter zone index and 2% is for the summer zone index, according to their share of the average required energy expenditure (Figure 8).

In addition to this, an aggregated map of the MFEVI for each Autonomous Community was calculated. This map uses the population of each locality of the Autonomous Community as a weight for the average MFEVI obtained, following the equation below:

$$MFEVIag_i = \frac{\sum MFEVI_j \cdot p_j}{p_i} \quad (2)$$

Where:

- $MFEVIag_i$: MFEVI aggregated for each Autonomous Community, i.
- $MFEVI_j$: MFEVI of municipality j.
- p_j: population of municipality j.
- p_i: population of Autonomous Community i.

The population figures used for this calculation are shown in Table 5: Population of each Autonomous Community with available MFEVI data. Source: own elaboration, INE, [39] .

The results obtained will be presented in Chapter 4 in color maps and compared to those from 2021. This comparison will allow to analyze the impact that energy price had on energy poverty.

The index values that will be shown in each map range from 0 to 5, with 0 being the lowest level of energy poverty and 5 being the highest level.

The electricity prices to calculate the 2021 scenarios are shown in Table 6.

As shown in Table 6, electricity prices slightly increased in July and August of 2021 and started their unusual rise in September 2021. This rise was mainly caused by tensions between international electricity markets due to the increase in the cost of natural gas exports, prior to the upcoming war, [37]. It is also important to highlight the fact that the upcoming winter months and the consequent increase in energy expenditure might have helped to exacerbate the rise in electricity prices.

The index value in Table 6 has been calculated according to the methodology used in section 3.1.2, specifically following energy price brackets in **Error! Reference source not found.**.

Additionally, for the MFEVI, results will show a map weighted by number of habitants in each Autonomous Community to compare it with other indicators proposed in past studies.

3.3. SEASONAL SCENARIOS

This section will analyze certain seasonal scenarios (from now on SS) based on the variables explained above. Four scenarios will be presented whose variations are mainly focused on the winter and summer seasons, since climate zones have an important impact on energy poverty. In addition, in these scenarios, the prices assigned to each of the months of 2022 will also vary depending on the season of the year according to Table 2.

The variables' indexes used to calculate each of these scenarios follow the same rules explained in section 0.

Therefore, Net Income Index and Electricity Prices Index go from 1 to 5, according Table 1.

For the winter climate zones, values go from 1 to 5 in the same manner described before, while summer climate zones go from 1 to 4 following their nomenclature.

Lasty, Energy Performance Certificates (EPC) have an index assigned according to Table 4.

3.3.1. SS1. HIGHEST ELECTRICITY PRICE IN 2022 (AUGUST)

The month with the highest electricity price was August with an average price of over 0.36 €/kWh. Since this month belongs to the summer season, only the summer climate zone has been used to calculate the vulnerability index in this section.

The weight of each variables' indexes is shown in the equation below:

$$SS1_i = 0.25 \cdot NII_i + 0.25 \cdot EPI_8 + 0.25 \cdot EPCI_i + 0.25 \cdot SCZ_i \tag{3}$$

Where:

- EPI_8: average Electricity Price Index in August 2022[8].

Each of the variables that conform this index weights 25%, since, for this particular scenario (and all Seasonal Scenarios), all variables have the same importance.

The price of electricity explains 25% of the variation in the vulnerability index, therefore, since in this scenario, the highest price is being used, the index is expected to be high overall.

3.3.2. SS2. Lowest electricity price in 2022 (November)

November was the month with the lowest electricity price of 2022. The average price throughout this month was around 0.17 €/kWh. Since this month belongs to the winter season, only the winter climate zone has been used to calculate the vulnerability index in this section

The weight of each variables' indexes is shown in the equation below:

$$SS2_i = 0.25 \cdot NII_i + 0.25 \cdot EPI_{11} + 0.25 \cdot EPCI_i + 0.25 \cdot WCZ_i \tag{4}$$

Where:

- EPI_{11}: average Electricity Price Index in November 2022[9].

In this context, the scenario mentioned in this section will be the counterpart of the scenario in section 3.3.1.

[8]For the EPI used in this scenario, since the average price of August was around 0.36 €/kWh, the index assigned was 5.
[9]For the EPI used in this scenario, since the average price of November was around 0.17 €/kWh, the index assigned was 1.

3.3.3. SS3. ELECTRICITY PRICE DURING THE SUMMER OF 2022

According to the CTE, [38], the summer season goes from June to September.

In this scenario, the average electricity price for the months mentioned above was over 0.30 €/kWh, [27].

The weight of each variables' indexes is shown in the equation below:

$$SS3_i = 0.25 \cdot NII_i + 0.25 \cdot \frac{\sum_{j=6}^{j=9} EPI_j}{4} + 0.25 \cdot EPCI_i + 0.25 \cdot SCZ_i \quad (5)$$

Where:

- EPI_j: average Electricity Price Index for month j[10].

The average electricity price for summer 2022 is responsible of 25% of the variation in the vulnerability index of this scenario, and the winter climate zone has been applied to this calculation. The rest of the variables (net income, climate zone and energy performance certificate) weight 25% each as well, which means that each variable contributes equally to the calculation of the vulnerability index.

3.3.4. SS4. ELECTRICITY PRICE DURING THE WINTER OF 2022

According to the CTE, [38], the winter season goes from January to May, and from October to December, both months included in each case.

The weight of each variables' indexes is shown in the equation below:

[10] For the EPI used in this scenario, since the average price of June, July, August and September was around 0.30 €/kWh, the index assigned was 5.

$$SS4_i = 0.25 \cdot NII_i + 0.25 \cdot \frac{\sum_{j=1}^{j=5} EPI_j + \sum_{j=10}^{j=12} EPI_j}{8} + 0.25 \cdot EPCI_i + 0.25 \cdot WCZ_i \quad (6)$$

Where:

- EPI_j: average Electricity Price Index for month j[11].

In this scenario, the average electricity price was around 0.24 €/kWh, [22]. As in the previous scenario, each variable has a weight of 25% in the calculation of the vulnerability index.

[11]For the EPI used in this scenario, since the average price of the winter period was around 0.24 €/kWh, the index assigned was 2.

4. RESULTS

In this section, the results obtained from applying the aforementioned methodology will be shown. To better visualize them, results have been displayed in color maps disaggregated by municipality and colored according to the level of vulnerability of each municipality.

4.1. MFEVI

According to the variables defined earlier in this project, and the weights established in section 1, the "global" vulnerability index (MFEVI) is shown in Figure 11:

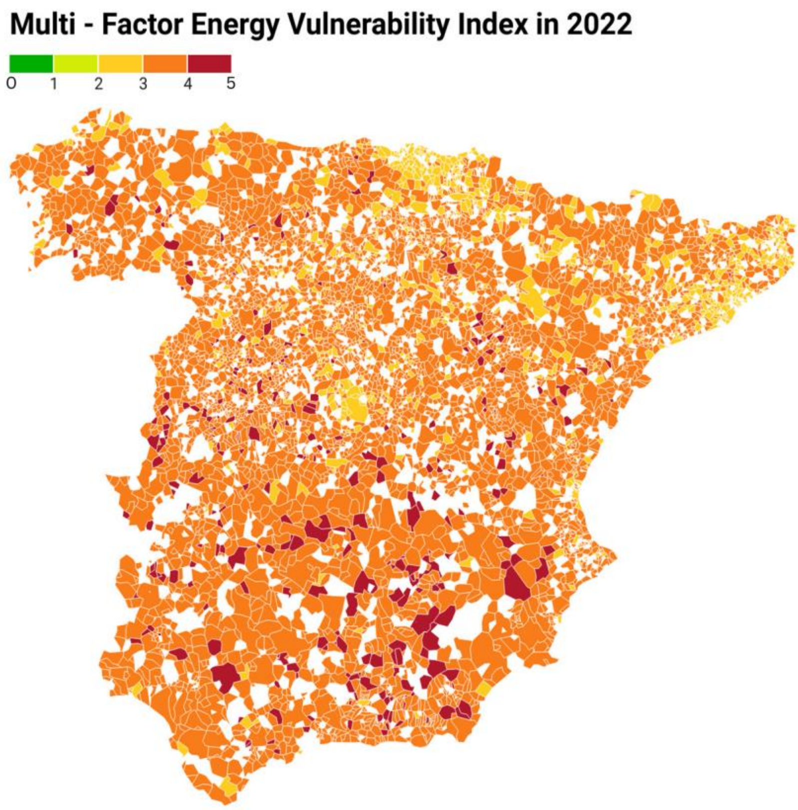

Figure 11: Map of the MFEVI for 2022. *Source: own elaboration*

As shown in Figure 11, since electricity prices were high throughout 2022, the average MFEVI is 3.3 points. It can be observed that most of the more vulnerable municipalities can be found in the southernmost part of Spain. As it has been stated before, this can be due to lower net income in this part of the country. The municipalities between MFEVI 4 and 5 are typically small towns or cities, with population smaller than 10,000 inhabitants. Nevertheless, it is important to highlight four municipalities with more than 20,000 inhabitants. These cities are: Montilla in Córdoba, Carmona in Sevilla, Villena in Alicante, and Jumilla in Murcia. These cities have an MFEVI of 4 and average personal net income between 9,000 €/year and 10,000 €/year, clearly below the national average (around 12,000 €/year)

Figure 12 compares the MFEVI in 2021 against the 2022 scenario.

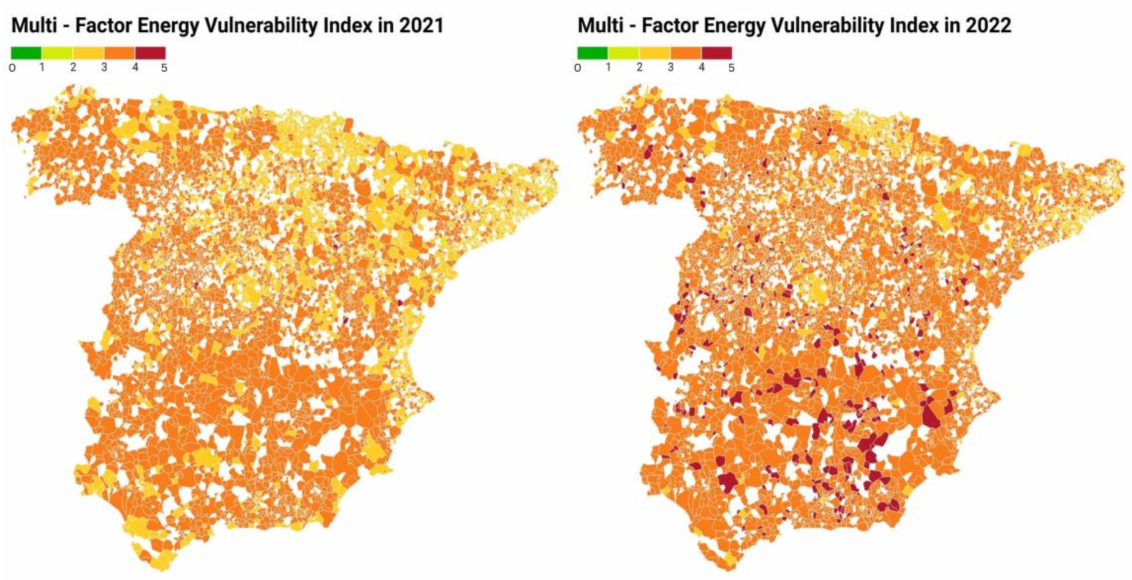

Figure 12: Comparison of MFEVI of 2021 and 2022. Source: own creation

As it can be seen in Figure 12, the most repeated color is orange for both scenarios, which means vulnerability index between 3 and 4. For the 2021 scenario, the average MFEVI is 3.1 points, while for the 2022 scenario, this index increases to 3.4. This difference is very interesting, because despite the worsening of the energy crisis in 2022, the vulnerability index does not show a very sharp rise. This is due to electricity price containment measures in the regulated market, especially the Iberian Exception. Nevertheless, this difference is caused by the increase in energy prices since the remaining variables have not changed.

In those municipalities in red, with a vulnerability index between 4 and 5, the impact of electricity price has been greater due to lower net income, warmer winter climate zones (all municipalities over MFEVI 4 are in winter zones C, D or E), hotter summer climate zones (more than 55% of the municipalities with MFEVI over 4 are located in summer zones 3 or 4), or EPCs for those municipalities are less efficient (all municipalities with MFEVI over 4 have EPCs E, F or G).

In order to compare this index with past studies, Figure 13 shows the MFEVI aggregated by population of each Autonomous Community. This map has been created by calculating the average MFEVI per Autonomous Community and using the population of each of them as weight. The intervals in the legend assign one color or another depending on the quintile in which the aggregate MFEVI of each Autonomous Community is found. This change in the legend compared to the previous maps is due so that Figure 13 can be compared with the MIS index in Figure 14, and the HEP indicator in Figure 15.

Because the differences between Autonomous Communities are so small, leaving the legend as in previous maps would only allow for two different colors that would not be helpful when comparing Figure 13 to past studies.

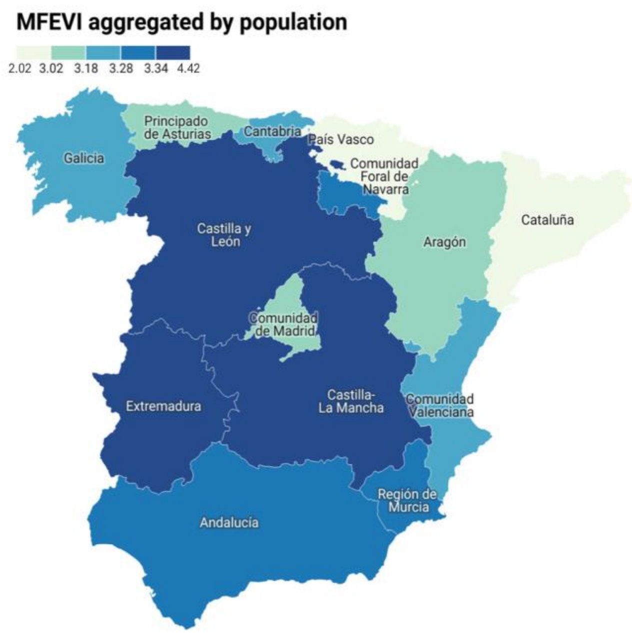

Figure 13: MFEVI map aggregated by population of each Autonomous Community. Source: INE, [39] and own elaboration

In Figure 13 it can be observed that the differences between Autonomous Communities are not as significant as in previous maps, since in Figure 13, the difference between one coloration or another is due to decimals in the aggregated MFEVI, while for other maps, this difference was more significant.

This can help highlight the importance of this project in terms of accuracy in determining energy poverty in the Spanish mainland, thanks to energy vulnerability mapping at the municipality level.

While the northernmost part of the country presents lower MFEVI, Extremadura, Castille – La Mancha and Castille and León show higher degrees of energy poverty. In the case of Extremadura and Castille – La Mancha, lower levels of net income and heating and cooling demands above the national average are the main reasons for their color, while for Castille and León, that enjoys higher net income, its level of energy vulnerability can be explained due to its coldest and severe winter zone.

According to Figure 6, since the required expenditure on heating is much greater than the one on cooling, severe winters have a higher impact in this Autonomous Community. In the case of Andalusia, it could have been expected a higher level of energy vulnerability, since it has overall low net income and high temperatures during the summer season, but the impact that a warmer winter has, allows this Autonomous Community to lower its aggregated MFEVI.

Lastly, in the case of Madrid, its medium-low aggregated MFEVI is explained mostly by the higher levels of net income.

The aggregated MFEVI is useful to compare energy poverty levels with past studies. According to [19], the MIS indicator's results allow for a very similar map to Figure 14.

Figure 14: MIS indicator for Spain in 2021. Source: [19]

Although the data used for this current project uses electricity prices from 2022 and the MIS indicator is obtained for 2021, the energy vulnerability explained by the MFEVI has not changed greatly from one year to another, thus the comparison can be considered valid.

Lastly, Figure 15 shows the extreme Hidden Energy Poverty (HEP) indicator presented in [19].

Figure 15: HEP indicator by region for Spain in 2021. Source: [19]

The comparison between Figure 13 and Figure 15 is especially relevant because the HEP indicator takes into consideration the climate of the Spanish regions. The differences between the HEP map are more visible because of this reason. Since the HEP takes into consideration the climate (as it has been done in this project with the climate zones), the difference resides in the weight given to this variable. As it can be observed in Figure 15, the more the required energy expenditure, the higher the HEP indicator. Since the main differences are for Castille and León, Castille – La Mancha, Extremadura, and Andalusia, this can be caused by the different weights given to the summer and winter climate zones.

4.2. SS1. HIGHEST ELECTRICITY PRICE IN 2022 (AUGUST)

This scenario computed the Vulnerability Index with the highest price of 2022, which was 0.36 €/kWh in the month of August. According to the weights explained in section 3.3.1, the Vulnerability Index for this scenario is shown in Figure 16:

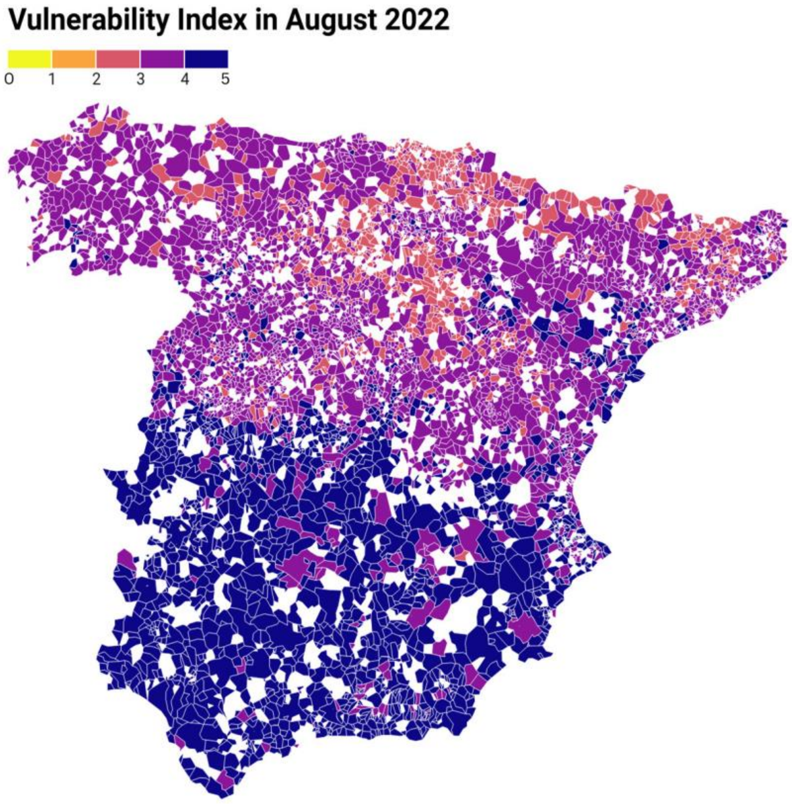

Figure 16: Map of vulnerability index in SS1 (August 2022). Source: own elaboration

Since the southernmost part of the country shows lower net income and more critical summer climate zones, it can be inferred that this areas were more affected. Nevertheless, the price impacts greatly in the whole peninsula, because, on average, vulnerability index for this scenario was 3.9, which is painted in dark purple, as it can be observed in Figure 16.

To visualize the impact rising electricity prices has had in energy poverty, a comparison with prices from August 2021 has been created (Figure 17). In August of 2021, the average electricity price throughout the month was 0.13 €/kWh, which, according to the methodology used to assign indexes to electricity prices, equals to an EPI of 1, instead of the EPI of 5 that was assigned to the average price of electricity in August 2022.

For the following comparison, the remaining variables have been left the same, in order to clearly establish the impact increasing energy prices has had in this vulnerability index.

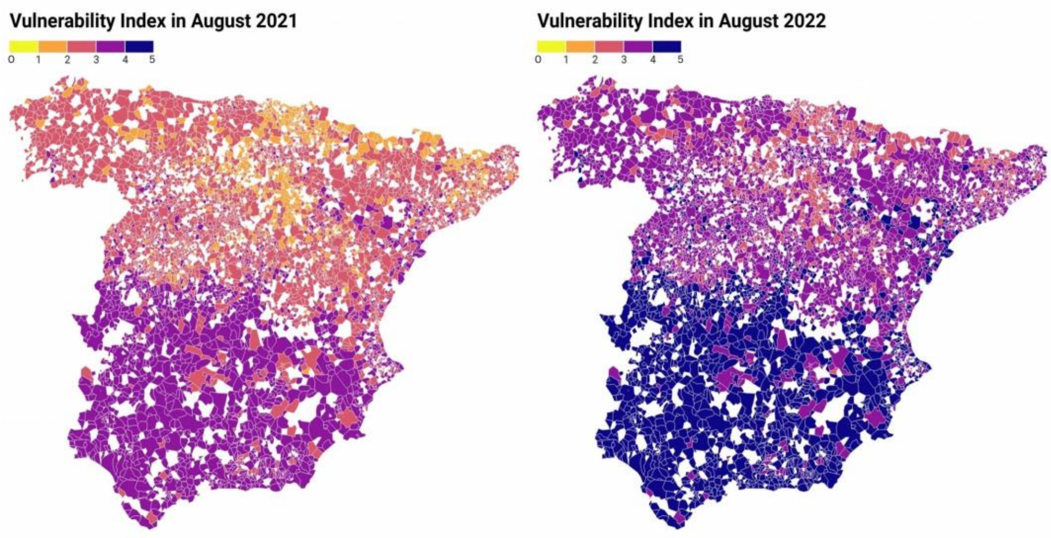

Figure 17: Comparison of vulnerability indexes in August 2021 and August 2022. Source: own creation

Figure 17 highlights the impact that rising energy prices has had in one of the hottest months of the year. Although August 2021 was not the most expensive month in terms of energy prices, with the rest of the variables remaining the same, this map shows the increase of electricity price from 0.13 €/kWh to 0.36 €/kWh, which constitutes an increase of almost 277%. Therefore, the increase in energy prices has allowed for an impoverishment of certain municipalities, aggravating the already difficult situation.

4.3. SS2. Lowest electricity price in 2022 (November)

This scenario computed the Vulnerability Index with the lowest price of 2022, which was 0.17€/kWh in the month of November, as shown in Table 2. According to the weights explained in section 3.3.2, the Vulnerability Index for this scenario is shown in Figure 18.

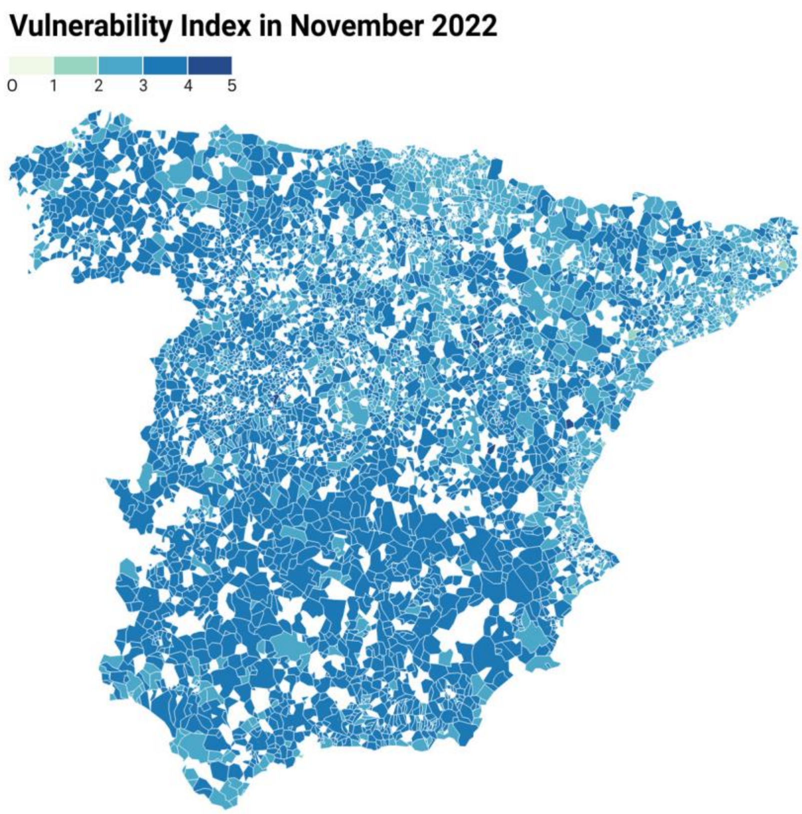

Figure 18: Map of vulnerability index in SS2 (November 2022). Source: own creation

In *Figure* 18 certain differences between the north and the south of the Spanish mainland can be observed. In the regions of Extremadura and Andalusia, a darker shade of blue is pictured, which implies a vulnerability index between 3 and 4; while for the majority of the municipalities in the Basque Country, Castille and León and Catalonia, this shade is brighter, indicating a vulnerability index between 2 and 3. This is caused mainly by higher net income in the north of the country, that overshadows the weight of the colder winter climate zones.

The importance of analyzing this scenario resides in the fact that, even when considering the lowest values possible of 1 out of 4 variables (price of electricity in this case), the level of energy vulnerability is still very high, with 2.97 points as national average.

If compared to the situation in November 2021, the maps are as in Figure 19:

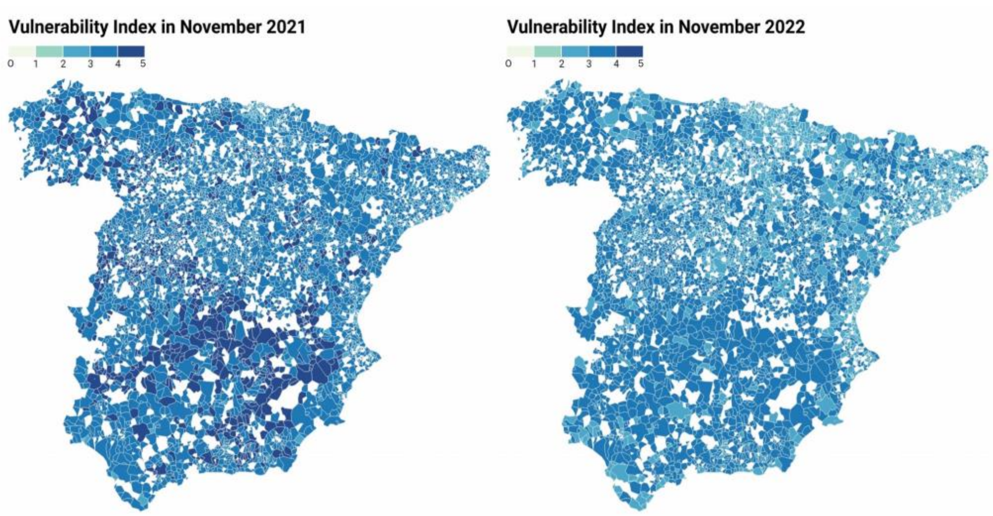

Figure 19: Comparison of vulnerability indexes in November 2021 and November 2022. Source: own creation

In this map, it can be seen how, for this particular month, prices in November 2022 where lower than in November 2021: in the latter, electricity prices where around 0.25 €/kWh while in November 2022, prices were lower, around 0.17 €/kWh. This decrease is translated into deep blue hues for 2021, which a vulnerability index average of 3.35, while in November 2022, this average goes down to 2.85 points.

4.4. SS3. ELECTRICITY PRICE DURING THE SUMMER SEASON OF 2022

As explained before, the average electricity price for the summer season of 2022 was 0.30 €/kWh.

The results obtained for this scenario are shown in Figure 20:

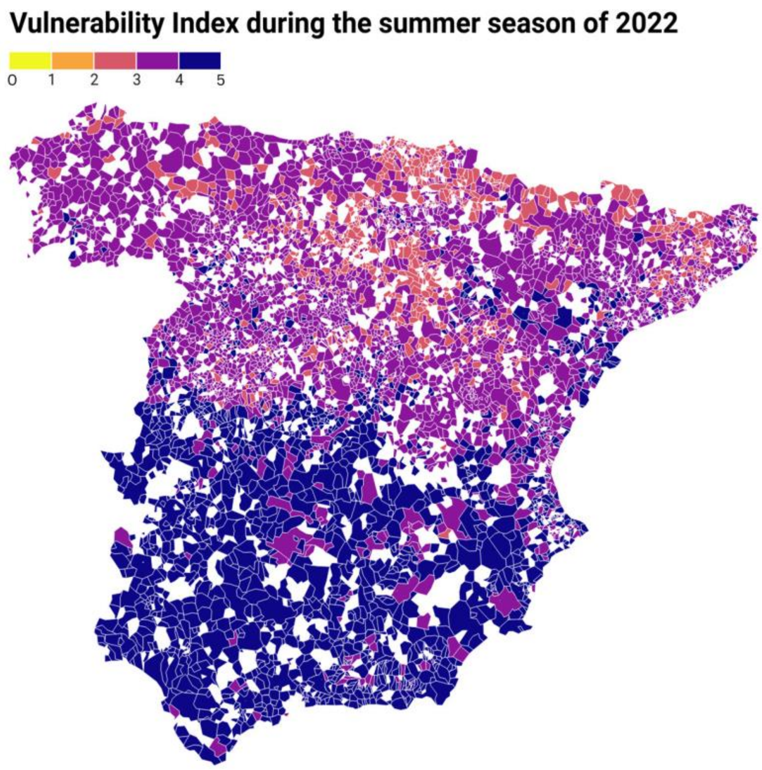

Figure 20: Map of vulnerability index in SS3 (summer season 2022). Source: own elaboration

Although the vulnerability index in this scenario is generally high (mostly over 3 points), there is a clear difference between north and south. While said difference was more appreciable in SS1 than in SS2, as the number of months increases and the vulnerability index is applied to all four months of summer (June to September), the situation between the north and the south of the country becomes more and more uneven. This may be due to the impact of income and the impact of the summer climate zone in the south. These two variables alone explain 50% of the variability in the vulnerability index, which leads to the clear difference between the north and the south of the Spanish peninsula.

The comparison between the 2021 and the 2022 scenario is shown in Figure 21.

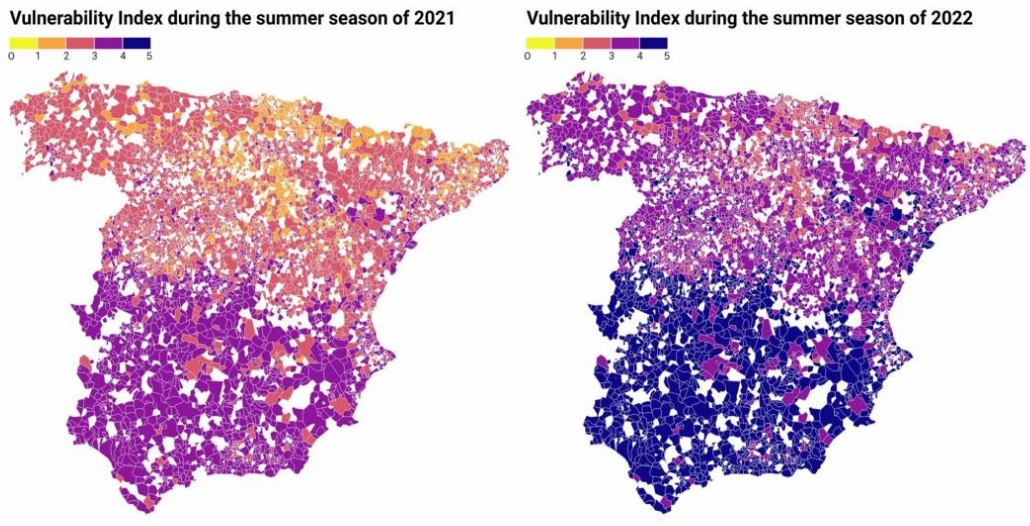

Figure 21: Comparison of vulnerability indexes for the summer season of 2021 and 2022. Source: own creation

When comparing these two scenarios back-to-back, there is a clear difference between them caused by electricity price. This variable, that accounts for 25% of the weight of the vulnerability index for both cases, impacts greatly, as it can be observed, with much darker areas for the 2022 scenario.

Using figures for both scenarios, the average vulnerability index for the summer season 2021 was around 2.4 points, while for the 2022 summer season, this number increased to 3.4 points, one whole point above the value for the counterpart scenario. This is caused by the increase in electricity prices from one year to another. As it can be seen in Table 6, the average price for the summer season in 2021 was 0.13 €/kWh, less than half of the average price for the season in 2022.

This scenario is very similar to SS1, because the average electricity price for August was 0.36€/kWh and for the summer season of 2022 w 0.30€/kWh. Even though these prices are different, due to the assignation of indexes established in Table 3, both prices have the same index assigned. Nevertheless, since the electricity price is very close to the lower limit of index 5 (if the average electricity price would be one cent lower, the index assigned would have been 4, consequently reducing energy vulnerability for this scenario), it can be stated that energy vulnerability is more severe for SS1, due to higher electricity prices.

4.5. SS4. ELECTRICITY PRICE DURING THE WINTER OF 2022

As stated in section 3.3.4, the winter season that has been considered for this project goes from January to May (both included) and from October to December (both months included as well). The average electricity price for this scenario in 2022 was around 0.24 €/kWh.

The results for this scenario are shown in Figure 22:

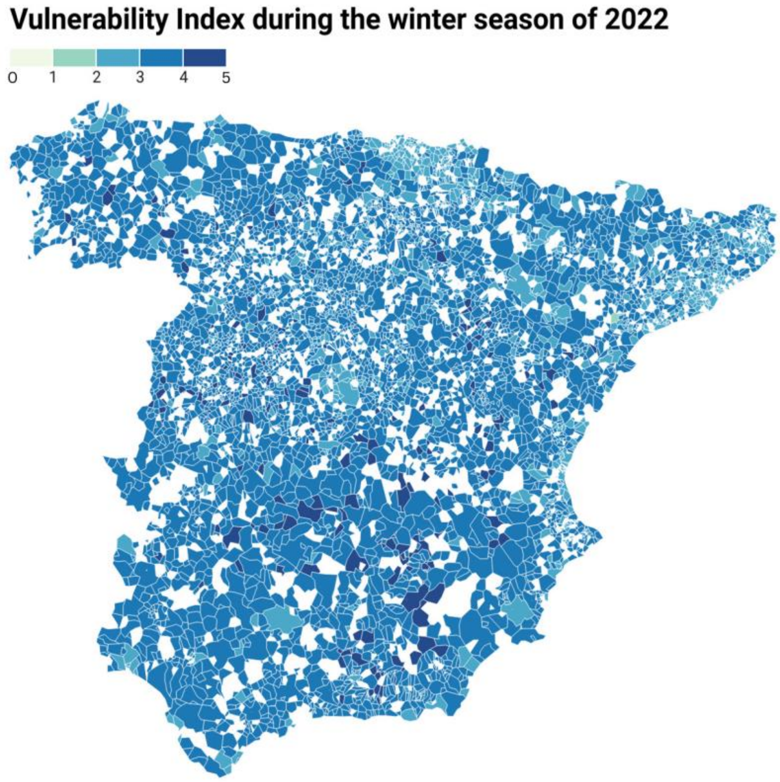

Figure 22: Map of vulnerability index in SS4 (winter season 2022). Source: own elaboration

The difference in this scenario is not as clear between the north and the south of the country as it was for the summer scenario. It could have been expected a higher vulnerability index in those municipalities where the winter climate zone causes more severe winters, such as the provinces of León, Segovia, the northeast of Castille and León and the Pyrenees, as shown in Figure 9.

This difference is not as clear mainly because of the net income difference between the north and the south of Spain. While the south has warmer winters and hotter summers - which would lead to higher vulnerability index in the summer scenario and lower vulnerability index for the winter one (due to the weight the climate zone for each scenario has) - the average net income for the Autonomous Communities of Andalusia, Extremadura and Murcia is 9.4k€/year, while for the rest of the country (without accounting for the Canary Islands nor the Balearic Islands), this number increases to 12.8k€/year, according to data from 2020, [25]. Taking this into consideration, it is clear why there is not great difference between Autonomous Communities in this scenario: for those regions with colder winter zones (aka. higher winter climate zone indexes), net income is higher, which allows for lower net income indexes, compensating the increase caused by the winter climate zones.

Figure 23 shows the comparison between the 2021 and the 2022 scenario for the winter season.

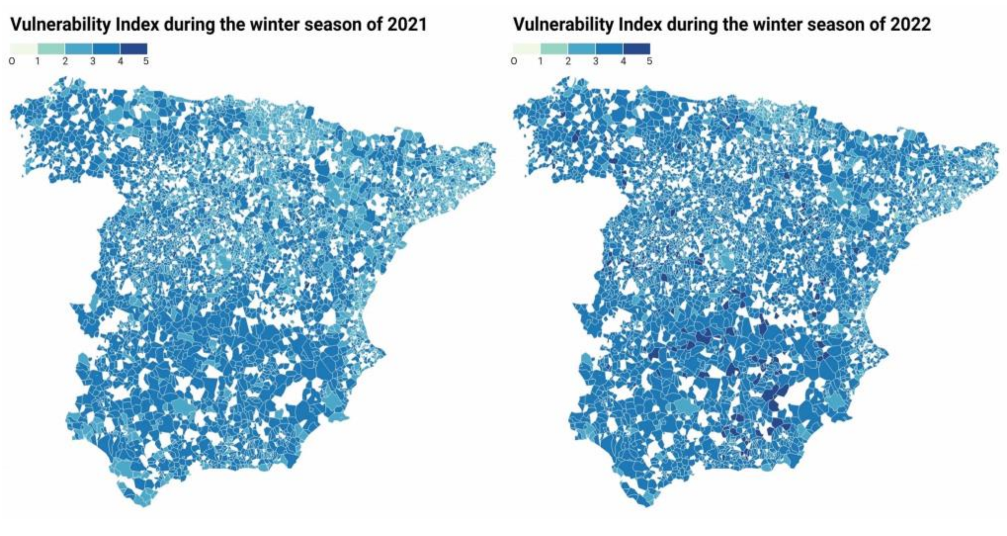

Figure 23: Comparison of vulnerability indexes with electricity prices of the winter season of 2021 and the winter season of 2022. Source: own creation

In Figure 23, it can be observed how both scenarios are very similar. This is because, according to Table 6, electricity prices start increasing in September 2021. The average electricity price for the winter 2021 scenario is 0.15€/kWh, while for the winter 2022 scenario is 0.24€/kWh. This increase of prices at the end of 2021 makes the difference between both averages smaller and, therefore, darker hues of blue can be observed for the 2022 scenario, because of the increase of prices, but since this difference is not as great as for other scenarios, the color map does not show significant changes.

5. CONCLUSIONS

This section will state the conclusions obtained from the present analysis in this project.

Spain's privileged location has allowed the country to enjoy a wide range of renewable energy sources. Although the country takes advantage of this situation and its dependency on natural gas is not as high as for other European countries, the consequences of the Russian invasion have also reached Spanish soil. The increase in energy prices and the apparent freezing in salaries has led to an increase in the number of households having difficulty paying for the energy needed for their day-to-day activities.

After analyzing the four most impactful variables in energy vulnerability, establishing weights for each of them and compounding them into a vulnerability index, it can be stated that these households are located in specific areas of the country, rather than being unevenly scattered.

In this thesis, energy poverty has been analyzed in different scenarios, that include the highest and lowest electricity price periods, and the winter and the summer seasons of 2022; as well as for the whole year of 2022.

For the municipality seasonal scenarios analysis (although certain Autonomous Communities are mentioned in this paragraph this conclusion does not include the MFEVI aggregated by Autonomous Communities), the results show in all cases that the municipalities belonging to the regions of Andalusia, Extremadura, Murcia and the southernmost part of Castille – La Mancha are the most vulnerable to energy poverty. For these specific regions, net income is lower than the national average. Although the regions of Andalusia and Murcia mostly enjoy warmer winters, which allows for a reduced heating expenditure than the national average [10], the lower levels of income overshadow this reduction in costs. The contrary can be stated for the north of the country. Municipalities in regions like Catalonia, Basque Country, Aragón, Madrid and Asturias have lower levels of energy poverty due to their higher net income. Nevertheless, this difference can be observed more clearly during the summer season because the low temperatures of the winter season increase energy expenditure and, therefore, energy vulnerability.

For the global indicator, the MFEVI, the difference is less noticeable, mainly because of the duality between energy expenditure in the winter and summer seasons, and the difference in income. Indeed, those areas with higher income tend to have higher heating costs, due to lower temperatures during the cold season; while areas with lower income (typically the south), enjoy warmer winters, with a consequent reduction in heating costs. Furthermore, when observing the map of the MFEVI in 2022, certain municipalities in the south of the Spanish mainland can be spotted in a darker shade of blue, indicating a higher level of energy vulnerability; while yellowish areas can be spotted in the north of the country (low vulnerability index), meaning that the net income differences between north and south impact energy vulnerability indicators.

When compared to scenarios with prices from 2021, it can be observed that the rising in energy costs has provoked greater levels of energy vulnerability, especially noticeable in the summer season, because prices for the summer 2021 where much lower than those of 2022.

Finally, the comparison between the MFEVI aggregated by region and the MIS and HEP indicators shown in [19], highlight everything that has been stated until this point. Both maps are very similar, showing that the level of energy vulnerability has not decreased. Furthermore, since the MIS contains data from 2021, it can be observed that certain regions have increased their energy poverty levels, such as Castille and León, Castille – La Mancha and Murcia. This fact supports the comparisons between the scenarios discussed in section 4, that show an increase of the vulnerability indexes caused by the rise in electricity prices.

In addition to this, in the comparison between the HEP map and the MFEVI aggregated by Autonomous Communities, it can be observed that the differences are not very significant, although both scenarios take into consideration the climate with different weights, proving that the MFEVI is a valuable indicator of energy vulnerability.

This project aims to contribute to shed visibility on an important issue such as energy poverty, providing a detailed and clear analysis of its main drivers and establishing indicators of energy vulnerability to help identify the causes and which regions are the most prone to suffer from energy poverty in Spain.

By comparing the indicators established in this thesis with other indexes formulated in past studies, this project presents a good performance that makes it a reliable indicator when defining regions potentially in complex situations in terms of energy poverty. Furthermore, once the reliability of these energy vulnerability indicators is proven, they could be used as a method for decision making in situations related to this topic.

6. ALIGNMENT WITH THE SUSTAINABLE DEVELOPMENT GOALS

This section analyzes the impact of this project in the context of the Sustainable Development Goals (see Figure 24) established by the United Nations. This impact will be discussed in depth by determining the SDGs with which this project is most aligned.

The Sustainable Development Goals are a series of milestones set out in 2012 by the United Nations to be reviewed in 2015 and achieved by 2030. They are a set of economic, social, political, and environmental challenges.

Figure 24: The Sustainable Development Goals. Source: United Nations, [40]

6.1. *SDG 1: END POVERTY IN ALL ITS FORMS EVERYWHERE*

The main objective of this SDG is to end every form of poverty that exists. Poverty is the condition characterized by the severe deprivation of basic human needs.

According to the UN, half of the population currently lives in poverty, which means they have less that $2 as daily income. Of those living in poverty, over 800 million people live in extreme poverty, defined as income of less than $1,25 per day. They lack access to proper food, clean drinking water, shelter, and healthcare, [41].

This is the most known form of poverty, but there are others. This project will focus on energy poverty, which is the inability of a household to achieve a socially and materially necessary level of domestic energy services, which hinders effective participation in society.

A household suffering from energy poverty cannot access essential energy services. This means that people who live in said household may be exposed to poor living conditions such as lack of thermal comfort, in addition to having less income for other goods and services. This may lead to taking undesirable decisions, such as having to decide between paying for heating or food, and/or exposing themselves to the risk of non-payment and disconnection due to lack of resources, [42].

To success in that matter, the SDG1 includes specific targets such as:

- Eradicate extreme poverty for all people everywhere by the year 2030.
- By 2030, reduce by at least in half the number of men, women and children that live in poverty in all its dimensions according to national definitions.
- Implement appropriate systems and measures on a national level to ensure social protection for all and by the year 2030 achieve substantial coverage for the poor and the vulnerable.
- By 2030, reduce the exposure and vulnerability of the poor to extreme climate – related events and other economic, social and environmental disasters.

6.2. SDG 7: AFFORDABLE AND CLEAN ENERGY

The main objective of this goal is to ensure affordable, reliable, sustainable, and modern energy for all. This goal describes the importance of access for all countries to clean and sustainable energy that facilitates technological progress and social development.

It is intended to reflect the importance of proper access to sustainable energy and the implementation of renewable sources that cover wider fields than electricity, as well as to promote energy efficiency with a close commitment to preserving the environment, reducing pollution, and establishing responsible consumption habits.

The access to clean energy is of most importance when speaking of energy poverty. It mainly affects households, and it is a complex challenge that remains to be further addressed.

6.3. SDG 11: SUSTAINABLE CITIES AND COMMUNITIES

This objective intends to make cities safer, more inclusive as well as resilient and sustainable.

The war between Russia and Ukraine along with the existing impact due to COVID-19 worsened the conditions for multiple households all over the world. This SDG plays an important role in helping improve this situation and increase the number of sustainable cities.

6.4. SDG 12: RESPONSIBLE CONSUMPTION AND PRODUCTION

The main goal of this objective is to ensure responsible and sustainable consumption and production patterns. This SDG has a triple impact: avoiding climate change, biodiversity loss and pollution. In this project, issues associated with responsible consumption and production will be addressed due to their relevance and strong relation with energy justice.

Unsustainable patterns of energy consumption are one of the main causes of energy poverty and climate change. To ensure efficient access to electricity all over the world, a collaborative compromise must be created.

Developing countries' capacity to generate energy from renewable sources has soared over the last decade. This situation becomes even more serious in case of the least developed countries ("LDCs") and landlocked developing countries. According to the UN, there is a big difference in the rates of compound annual growth of renewable energy of these countries. While developing countries achieved an annual growth rate of 9.5, these numbers drop for LDCs and landlocked countries being 5.2 and 2.4 respectively from 2015 to 2020 [43]. These events highlight the need for targeted actions to tackle this problem.

6.5. SDG 13: CLIMATE ACTION

This project is also related to the current climate change challenge. "Save Gas for a Safe Winter" consists of a set of actions to reduce gas consumption due to the current situation in Europe. This measure will clearly impact fossil fuel emissions and an analysis of the dependence of gas or fossil fuels could be implemented and related with this SDG.

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ANNEX

Table 5 was used to aggregate the MFEVI by population of each Autonomous Community. This is not the real population, but the summatory of the population in the municipalities with available MFEVI data. The real population used for this calculation was sourced from the INE's population count of 2022.

Autonomous Community	**Population**
Andalusia	6,769,806
Aragón	1,171,760
Asturias	922,060
Cantabria	371,414
Castilla y León	1,920,159
Castilla-La Mancha	1,794,584
Catalonia	6,280,295
Comunidad de Madrid	5,811,823
Comunidad Foral de Navarra	605,487
Comunidad Valenciana	4,151,276
Extremadura	641,036
Galicia	2,012,928
La Rioja	267,863
Murcia	1,390,419
Basque Country	1,861,757
Total	35,972,667

Table 5: Population of each Autonomous Community with available MFEVI data. Source: own elaboration, INE, [39]

The electricity prices and assigned index values used to calculate the 2021 scenarios are shown in Table 6.

Month 2021	Electricity Price (€/kWh)	Index Value
January	0.09	1
February	0.05	1
March	0.07	1
April	0.09	1
May	0.09	1
June	0.10	1
July	0.11	1
August	0.13	1
September	0.19	1
October	0.25	3
November	0.25	3
December	0.31	5

Table 6: Average electricity prices and index value per month of 2021. Source: own creation and CNMC, [27]