A multi-criteria classification approach for assessing energy poverty in the European Union

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Abstract

Energy poverty is a prevalent problem in the European Union that affects people's health and affects sustainable development. In the literature, a small number of studies that attempted to measure the extent of fuel poverty in the EU was found, and none of the methods from the ELECTRE family, Multi-Criteria Decision Analysis methods, had been applied in the context of measuring energy poverty. The purpose of this study was to classify energy poverty in European Union member states in the year of 2020 through a multi-criteria classification approach, by using the ELECTRE-Tri-nC method. The SRF method was also used to complement the ELECTRE-Tri-nC to assign weights to the chosen criteria. We built a model that integrated 9 criteria to classify 24 European Union member states according to their energy poverty level. The results of the carried out study showed that, generally, Eastern and Southern Europe have a high energy poverty level, the Scandinavian countries studied in this work, and Central Europe, have a low energy poverty level, and western Europe and the Baltic countries have a moderate energy poverty level.

Key words: Energy poverty, fuel poverty, European Union, Multi-criteria Decision Analysis/Ainding, ELECTRE-Tri-nC.

1 Introduction

Energy poverty is a challenge that people face all over the world and the European Union is no exception. In the European Commission (2021) State of the Energy Union report, it is stated that 31 million people in the EU were affected by energy poverty in 2019. Furthermore, since Russia's invasion of Ukraine in February of 2022 and the consequent ongoing war between these two countries, the number of energy poor is expected to have increased due to the rise in energy prices (Kryk & Guzowska, 2023).

Households rely on energy, in its various forms, to guarantee adequate living conditions. As such, fuel poverty (or energy poverty) has several consequences, direct and indirect, on one's health and well being (Energy Poverty Advisory Hub, 2022; Recalde et al., 2019).

Not only does the energy poverty problem pose as a great threat to people's health, but it also affects sustainable development, as it limits the ability of citizens to benefit from and actively take part in the energy transition (Kryk & Guzowska, 2023).

The term "energy poverty" first appeared in the European Union legislation in 2009. Consequently, several EU measures to eradicate fuel poverty are already ongoing, including EU directives and other initiatives, such as the Energy Poverty Advisory Hub (EPAH), and several EU funded projects tackling the issue. Nevertheless, an accurate energy poverty assessment is needed to help guide policy development, implementation, and follow up in the European Union.

Since only eleven studies were found that assess energy poverty in the European Union, we build on the existing literature by assessing energy poverty in the European Union in the year of 2020. In this work, we contribute to the existing literature by applying a multi-criteria classification approach that has not been used in this context, the ELECTRE-Tri-nC, to classify EU member states according to their energy poverty in an attempt to answer the following research questions:

(1) How can we assess the energy poverty of EU member states in a structured framework?

(2) Can energy poverty patterns be discerned across the EU based on the varying levels of energy poverty among

member states?

This summary of the developed work is structured as follows: Section 2 presents the conclusions taken on the dissertation's overview of main European Union directives and initiatives that, among other things, contributed, or contribute, to energy poverty mitigation. Section 3 provides a summary of the Literature Review of the dissertation, by touching on the existent methods, the different energy poverty definitions adopted, the data sources found in the literature, and the existent studies that measure energy poverty in the EU. Section 4 describes the research gap found. Section 5 presents a summary of the Methodology used, such as the ELECTRE Tri-nC and the SRF methods. Section 6 delineates the data sources used. Section 7 presents the results and compares them with the results found in the literature. Finally, section 8, includes the main conclusions, limitations, and possible future research.

2 EU policies and other initiatives

While the topic of energy poverty emerged largely in the scientific community in 1991 (Boardman, 1991). Energy poverty emerged in the policy agenda sporadically at first and more frequently during recent years. As such, the fuel poverty issue has been growing its importance in the EU in recent years, as the European Commission has been taking heed of energy poverty policies, and, consequently, several measures to alleviate energy poverty are already ongoing, and this phenomenon is expected to be strengthened in the future.

Moreover, the existent EU policies and initiatives boosted the existence of available data at the EU level, facilitating evaluations of fuel poverty. Moreover, a list of indicators at this level exists: the Commission's recommendation (European Commission, 2020) includes a list of indicators produced by Eurostat (Statistical office of the European Union) and EPOV (Energy Poverty Observatory). Nevertheless, there is still space for additional indicators beyond those recommended by the Commission.

The Commission's recommendation (European Commission, 2020) on energy poverty and the proposal to recast the Energy Efficiency Directive (European Union, 2012) represent notable progress towards establishing an official definition of fuel poverty in the EU. However, as of now, such a definition does not exist, leaving it to the member states to formulate their own definitions.

The European Union has made legislative efforts to acknowledge the energy poverty problem and provide a framework for monitorization and mitigation of the phenomenon at the member state level. Despite these efforts, there has not been a EU-wide agreed measurement, and a detailed understanding of the problem as a whole across the EU. Several authors argue that, despite the increasing significance of the energy poverty issue in the EU agenda, the policy recommendations are vague, impractical, and inadequate (Bouzarovski, 2018). The literature highlights that the primary obstacle to addressing this problem effectively is the reluctance to adopt a unified and commonly agreed definition (Bouzarovski, 2018).

3 Literature Review

In order to identify the research gap, the literature review of the dissertation provided (1) an overview of the existent methods, both uni-dimensional and multidimensional, that assess energy poverty; (2) the different energy poverty definitions adopted by the authors throughout the years; (3) the data sources used in the literature; and (4) the existent studies that measure energy poverty in the EU. The main points of these topics, elaborated upon in the literature review of the dissertation, will be presented in the following paragraphs.

Regarding the **overview of the existent methods**, uni-dimensional indicators assess energy poverty of the unit of analysis (individual or household) by a presented thresholds or energy poverty line (Alkire et al., 2015); whereas multidimensional methods are more complex, as they make use of both quantitative and qualitative dimensions and criteria. The phenomenon of fuel poverty was assessed, at first, using uni-dimensional indicators. Nevertheless, a consensus among most authors now exists, acknowledging that energy poverty is a multidimensional issue. Uni-dimensional indicators fall short of fully capturing its comprehensive scope and impact. Hence, it should be measured at the appropriate scale. This is, there should be more than one energy-related variable or dimension considered when evaluating energy poverty.

The first official definition of energy poverty (Boardman, 1991), that states that "a household is said to be fuel poor if it needs to spend more than 10% of its income on fuel to

maintain an adequate level of warmth" is one of the unidimensional indicators analysed in the literature review of this dissertation. The Low Income High Costs (LIHC) indicator, proposed by Hills (2012), that focuses on individuals in households "living on a lower income in a home that cannot be kept warm at a reasonable cost." (as described by Warm Homes and Energy Conservation Act 2000 (WHECA) in the UK), is also presented. The study of Tirado-Herrero and Ürge-Vorsatz (2012), that apply 3 different expenditure based thresholds to assess energy poverty in Hungary, was also introduced. Lastly, the studies of Barnes et al. (2011), who use energy consumption and income to define an indicator to determine energy poverty in rural Bangladesh in their work, and Jiang et al. (2020), who extended the Barnes et al. (2011) method to assess energy vulnerability in rural Qinghai, China, were discussed.

Several multidimensional energy poverty approaches were found in the literature, the most common ones are the counting approach (Aristondo & Onaindia, 2018; Betto et al., 2020; Sokołowski et al., 2020) and the composite index approach (Arsenopoulos et al., 2020; Bouzarovski & Petrova, 2015; Che et al., 2021; Llera-Sastresa et al., 2017; März, 2018; Maxim et al., 2017).

The methods used to evaluate energy poverty heavily depend on the **energy poverty definitions** adopted. As such, we found that several definitions of the concept have been used in the literature.

In the dissertation, we adapted the definition stated by the Commission (European Commission, 2020), by clarifying it. We defined fuel poverty as a situation in which households are unable to afford essential energy services, this is, energy services that reflect a decent standard of living and health.

As for the **data sources** used to measure the energy vulnerability problem, national surveys data (Barnes et al., 2011; Betto et al., 2020; Jiang et al., 2020; Sadath & Acharya, 2017; Sokołowski et al., 2020), census data (März, 2018; Simões et al., 2016) and national statistical entities (Betto et al., 2020; Papada & Kaliampakos, 2018; Simões et al., 2016; Sokołowski et al., 2020; Tirado-Herrero & Ürge-Vorsatz, 2012) are used to obtain data at a local or national level. Eurostat data (Arsenopoulos et al., 2020; Bárcena-Martín et al., 2020; Kryk & Guzowska, 2023; Papada & Kaliampakos, 2018; Tirado-Herrero & Ürge-Vorsatz, 2012) are employed to gather information at both the European and national levels. At a global level, data from the World energy balances, The Energy balances of OECD and Non-OECD countries and the data from the World Bank are used (Che et al., 2021). In this work, we utilized the Eurostat data source (Eurostat, 2011).

Numerous papers highlight the shortage of available data, which frequently constrains the choice of criteria and indicators utilized to construct the model (Papada & Kaliampakos, 2018; Zhao et al., 2021).

There was a limited amount of research on the measurement of **energy poverty in the EU** as we only found eleven studies on the topic: Healy and Clinch (2002) Bouzarovski (2013); Thomson and Snell (2013); Bollino and Botti (2017) Maxim et al. (2017); Bouzarovski and Tirado-Herrero (2017); Recalde et al. (2019); Arsenopoulos et al. (2020), and Bárcena-Martín et al. (2020); Che et al. (2021); and Kryk and Guzowska (2023).

4 Research Gap

A noteworthy research gap was found in the literature review: none of the methods from the ELECTRE family, despite being widely used in Multi-Criteria Decision Analysis (MCDA), have been applied in the context of measuring energy poverty. To address this gap, the dissertation implements the ELECTRE-Tri-nC method to assess fuel poverty.

Moreover, we found only eleven studies attempting to measure the extent of energy poverty in the European Union. As a result, our study complements the existing literature on the measurement of fuel poverty in the EU, given the limited number of published studies on this matter.

As discussed in section 2, the lack of a universally adopted EU-wide fuel poverty definition stands as the primary reason for the vagueness, impracticality, and inadequacy of EU policy recommendations, as observed by some authors (Bouzarovski, 2018). To bridge this gap, this study adopts a definition of energy poverty that allows us to establish a common EU-wide framework for the assessment of energy poverty.

5 Methodology

5.1 ELECTRE Tri-nC

To classify 24 EU member-states in regards to energy poverty, the ELECTRE Tri-nC method, introduced by Almeida-Dias et al. (2012), was used. The ELECTRE Tri-nC is part of the ELECTRE (ELimination Et Choix Traduisant la Realité - ELimina- tion and Choice Expressing the Reality) family of Multicriteria Decision Analysis/Aiding (MCDA) and it helps solve sorting problems.

The MCDA-ULaval programme ("Multicriteria Decision Aiding software MCDA-ULaval", n.d.) was used to implement the ELECTRE-Tri-nC method.

By taking into account the performance of a set of alternatives, denoted by $A = \{a_1, a_2, ..., a_i, ...,\}$, which are evaluated by a set of n criteria, denoted $F = \{g_1, g_2, ..., g_j, ..., g_n\}$, with $n \geq 3$, the goal of ELECTRE-Tri-nC is to allocate the set of alternatives to the set of completely ordered categories (from worst to best), denoted by $C = \{C_1, C_2, ..., C_h, ..., C_q\}$.

In this framework, each category is defined by a set of reference characteristic alternatives, denoted by $B = \{B_1, B_2, ..., B_h, ..., B_q\}$. $B_h = \{b_h^r, r = 1, ..., m_h\}$ denotes a subset of reference alternatives that characterize category C_h, such that $m_h \geq 1$ and $h = 1, ..., q$.

It is crucial to draw attention to the arbitrariness that affects how the criteria are defined as well as the inherent imperfect knowledge associated with the data from computing the performances $g_j(a)$ for every a in A. For that reason, discriminating thresholds p_j and q_j model this arbitrariness and imperfect knowledge and must be defined when applying the method.

Moreover, in this framework, a preference parameter denoted by λ, the credibility level, has to be established.

5.2 Set of Alternatives and Set of Categories

The set of alternatives for this work consists of the following: a_1 Austria; a_2 Belgium; a_3 Bulgaria; a_4 Croatia; a_5 Czechia; a_6 Denmark; a_7 Estonia; a_8 France; a_9 Germany; a_{10} Greece; a_{11} Hungary; a_{12} Ireland; a_{13} Italy; a_{14} Latvia; a_{15} Lithuania; a_{16} Luxembourg; a_{17} Netherlands; a_{18} Poland; a_{19} Portugal; a_{20} Romania; a_{21} Slovakia; a_{22} Slovenia; a_{23} Spain; a_{24} Sweden. These alternatives were assigned to one of the categories outlined in table 5.1.

Table 5.1: Set of categories

C_1	Very high energy poverty level
C_2	High energy poverty level
C_3	Moderate energy poverty level
C_4	Low energy poverty level

5.3 Set of Criteria

A value tree was constructed for the criteria selection, while taking into account that the criteria must be chosen based on their applicability to the fuel poverty problem and measurability (including the availability of adequate and reliable data).

The construction of the value tree involved the collaboration with four energy poverty experts.

Table 5.2: Value tree

Areas of concern	**Fundamental points of view**	**Criteria**
AC_1 Facilities/Housing	FPV_1 Household energy efficiency	g_1 Presence of leak, damp, rot
	FPV_2 Household energy services	g_2 Inability to keep home adequately warm
AC_2 Socio-economic factors	FPV_3 Vulnerable groups	g_3 Low education level g_4 Unemployment g_5 Arrears on utility bills
	FPV_4 Income	g_6 Disposable income g_7 Risk of poverty
AC_3 Cost of energy	FPV_5 Energy prices	g_8 Household electricity prices g_9 Household gas prices

5.4 SRF method and Criteria's weights

The ELECTRE-Tri-nC method allows for there to be different weights assigned to the criteria, which are established a priori to the method's implementation. The weight of a criterion in the ELECTRE method family can be thought of as its voting power. Hence, the more significant the criteria, the larger the weight allocated to that criteria (Figueira et al., 2012).

The weights' allocation was done according to Simos, Roy and Figueira (SRF) Deck of Cards approach (Figueira & Roy, 2002), which attributes weights to the criteria based on the stakeholders' perception of the importance of the criteria.

The weights were obtained by using the SRF method in the DecSpace[1] web platform, through an interactive process between the energy poverty expert and the analyst. Taking into account the opinion of the energy poverty expert, the outcome of the SRF method, this is, the weights of the criteria, were established as depicted in table 5.3.

Table 5.3: Normalized weights of the criteria

	Criteria	w_j
g_1	Presence of leak, damp, rot	19.05
g_2	Inability to keep home adequately warm	14.95
g_3	Low education level	6.81
g_4	Unemployment	6.81
g_5	Arrears on utility bills	4.76
g_6	Disposable income	19.05
g_7	Risk of poverty	14.95
g_8	Household electricity prices	6.81
g_9	Household gas prices	6.81

5.5 Thresholds; Reference alternatives, and Credibility level

The set of reference alternatives and the thresholds, were defined as depicted in tables 5.4, 5.5, respectively.

λ=0.7 was the chosen value for the credibility level.

Table 5.4: Reference alternatives

Reference alternatives	Criteria								
	g_1(%)	g_2(%)	g_3(%)	g_4(%)	g_5(%)	g_6(€/capita)	g_7(%)	g_8(€/kWh)	g_9(€/kWh)
b_1^1	30	30	45	20	30	4500	42	0.150	0.050
b_1^2	23	21	33	17	22	7500	31	0.100	0.040
b_2^1	22	20	32	16	20	9000	30	0.090	0.035
b_2^2	19	15	25	14	15	10000	25	0.080	0.031
b_3^1	15	9	22	12	10	15000	22	0.070	0.030
b_3^2	12	6.5	20	7	5	25000	18	0.060	0.025
b_4^1	10	5	10	5	4	30000	17	0.050	0.020
b_4^2	5	2	5	3	1	40000	12	0.030	0.010

Table 5.5: Thresholds of the criteria

Thresholds	Criteria								
	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9
q_j	2	2	3	2	2	250	2	0.02	0.005
p_j	4	4	5	4	4	500	4	0.03	0.01

6 Data

The data was collected from Eurostat database (European Commission, 2011), which is the statistical office of the European Union. Most of the indicators of the criteria (g_1, g_2, g_5, g_6, and g_7) were gathered from EU-SILC (European Union Statistics on Income and Living Con-

[1] http://app.decspacedev.sysresearch.org/

ditions) (Eurostat, 2011), which includes cross-sectional and longitudinal data on income, poverty, social exclusion, and living conditions in a timely and comparable manner. The rest of the indicators of the criteria (g_3, g_4, g_8, and g_9) were taken from Eurostat, however they were not taken from EU-SILC.

It is also relevant to note that some of the indicators of the criteria, namely g_1 (Presence of leak, damp, rot), g_2 (Inability to keep home adequately warm), and g_5 (Arrears on utility bills) are self reported indicators, this is, indicators that rely on the individual's own perception, hence, these are subjective indicators. Bouzarovski and Tirado-Herrero (2017) highlight the importance of combining self-reporting indicators with indicators that are not self-reported, which we did in this work.

7 Results and Discussion

The results of the energy poverty level in the European Union taking into account 24 EU member states and their performances in 2020 according to the chosen 9 criteria, and the weights determined by the expert are presented in figures 7.1 and 7.2. The output of the model is the allocation of each country to a worst and best category, this is, an interval of categories, therefore, figure 7.1 displays the worst possible category of each EU member state within its assigned interval (pessimistic), and figure 7.2 displays best possible category of each EU member state within its assigned interval (optimistic).

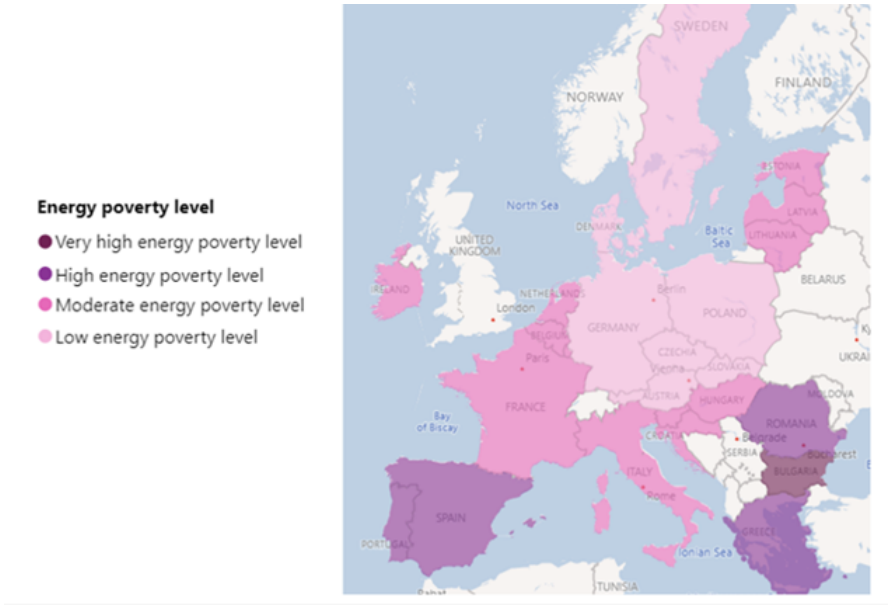

Figure 7.1: Energy poverty level in EU member states (pessimistic)

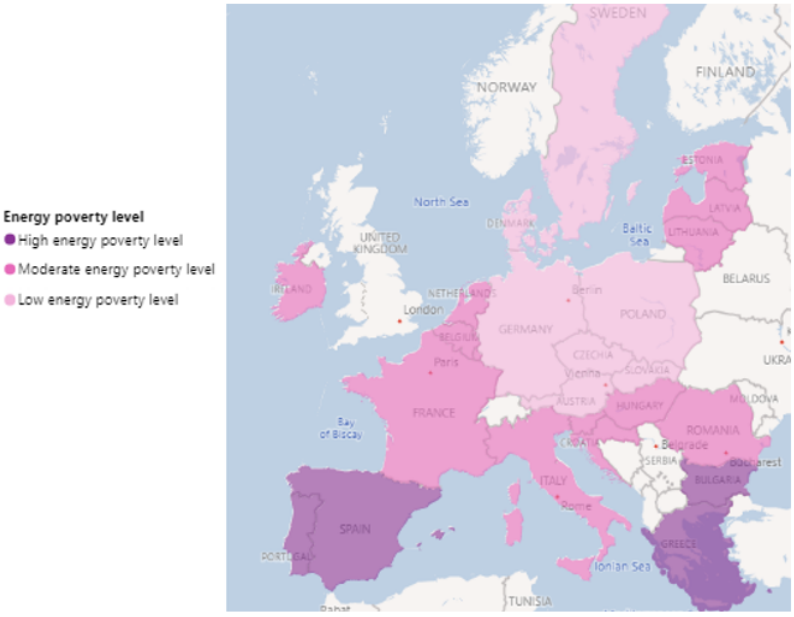

Figure 7.2: Energy poverty level in EU member states (optimistic)

In both figures 7.1 and 7.2, the countries with the highest levels of energy poverty, this is, the countries that were allocated to the very high energy poverty level and to the high energy poverty level categories, are clearly from two different regions of member states, Eastern Europe (Romania and Bulgaria for the pessimistic allocation, and Bulgaria for the optimistic allocation) and Southern Europe (Portugal, Spain, and Greece). Moreover, one can observe that the countries with the lowest energy poverty level are from Northern Europe (Sweden and Denmark) and from central Europe (Germany, Poland, Czechia, Slovakia, and Austria). Finally, the countries with moderate energy poverty are from Western Europe (France, Belgium, Netherlands, Luxembourg, and Ireland), Northern Europe, in particular the Baltic countries (Lithuania, Latvia, and Estonia), Central Europe (Croatia, Hungary, and Slovenia), one Southern European country (Italy), and one Western European country for the optimistic allocation (Romania).

Some of the results obtained overlap with the studies mentioned in section 3, while others are slightly different.

Our results show that most Southern European countries have a high energy poverty level, which coincides with the findings of other studied, however, surprisingly, according to the result of our study, Italy has a moderate energy poverty level. The results of this work in regards to the two Eastern European countries studies are in line with the results of other works. When it comes to Northern European countries, our study's outcome matches with the outcome of other findings. Central European member states were found to have low energy poverty levels and moderate energy poverty levels, which is in line with the findings of other studies. Nonetheless, our project's results of Western European countries slightly deviate with the findings of other works, since none of the Western European member states were classified in our study as having a low energy poverty level, instead, all were classified in our study as having a moderate energy poverty level.

According to the dissertation findings, Central European countries have a slightly better performance when it comes to energy poverty than Western European countries, which is not in line with the general findings of other studies. This could be because most of the work found in the literature regarding the assessment of energy poverty within the European Union dates from before 2020, the year being analysed in this work.

8 Conclusion

The objective of this work was to classify EU member states in terms of energy poverty. To do so, we defined research questions (see section 1).

In the dissertation we successfully implemented a structured framework that provided robust results for the clas-

sification of fuel poverty of 24 EU countries. Due to the multidimensional nature of the energy poverty issue, this framework consisted of taking a multi-criteria classification approach, the ELECTRE-Tri-nC method to assess energy poverty of EU member states. The SRF method was also used to complement the ELECTRE-Tri-nC method, since it was applied to determine the weights of the chosen criteria. This approach was adopted with the help of four energy poverty experts, from which we gathered information to develop the model. Moreover, the platforms MCDA-ULaval and DecSpace were used to implement the model.

After successfully implementing the previously described methodology, we were able to identify energy poverty patterns across the European Union. Generally, Eastern Europe and Southern Europe have a high energy poverty level, whereas the Scandinavian countries studied in this work, and Central Europe, have a low energy poverty level. Western Europe and the Baltic countries were found to have an overall moderate energy poverty level.

Our work has some limitations that must be mentioned. Firstly, there was a problem with data availability at a EU-wide level as there was not enough data available that fully reflected the chosen energy poverty definition or the opinion of the four energy poverty experts consulted.

Secondly, the data utilized for this study represents imperfect proxies obtained from surveys, which creates uncertainty. Thirdly, certain criteria, namely g_1 presence of leak, damp, rot, g_2 inability to keep home adequately warm, and g_5 arrears on utility bills, were based on indicators that are dependent on other people's answers and not on measurable and precise data, thus, there is some degree of subjectivity associated with these. However, the ELECTRE-Tri-nC takes into account imperfect knowledge of data and some arbitrariness associated with the construction of the criteria.

Fourthly, the findings of this analysis are highly dependent the weights of the criteria, which were defined with the help of one energy poverty expert. Despite having four experts with whom we developed the set of criteria, only one of those four, collaborated with us to define the weights. Thus, we were deprived of generating more results from our model that would allow us to compare different perspectives on the energy poverty problem.

In future research, it would be interesting to use this model to assess energy poverty's evolution in the European Union throughout the years. Specifically, it would be relevant to evaluate the impact of the current conflict between Russia and Ukraine, and the consequent energy crisis, on the EU. Furthermore, as new data on the matter will start to become available, it would be pertinent to make adjustments to the model by adding new adequate criteria to it.

In the dissertation we proposed a practical model of energy poverty assessment with easily interpreted results, in which a common EU wide fuel poverty definition is adopted in the hopes of contributing to the development of new policies.

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