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Development of Energy Poverty and its Solutions from the Perspective of Renewables Use

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Abstract: The problem of energy poverty, when energy becomes unaffordable for some population group, is not only a problem for developing countries, but this phenomenon is appearing more and more often in European countries as well. In Europe, it is estimated that 50 to 125 million people are at risk of energy poverty. We hear more and more about energy poverty in connection with the current energy crisis and rising energy prices, but also as a result of insufficient use of renewable energy sources. Due to rising energy prices, we are increasingly hearing about deepening energy poverty in Slovakia as well. The aim of the contribution is to examine the development of energy poverty in Slovakia compared to other EU countries. The situation is studied from the view of the number of days of heating and cooling, the percentage of the population that cannot maintain adequate heat at home, the percentage of the population that has a lack of heat and the percentage of residents without enough heat. During the research, we used distribution analysis, trend analysis, analysis of variance and one-way analysis. The main results show that HDD index recorded decrease, CDD index recorded increase, and Energy poverty is most obvious in low-income group of inhabitants, having shortage of heat, when RES use contribute to mitigation of energy poverty. Solving the unfavorable situation with energy poverty is possible by increasing the share of Renewable energy sources in the gross final energy consumption for heating and cooling, primarily in residential buildings. The results provide information for policy makers in area of economic, social and environmental decision-making.

Keywords: energy consumption; cooling and heating degree-days; renewable energy sources; quality of life; risk of energy poverty

1. Introduction

In the early 1990s, energy poverty was broadly defined as households whose energy bills exceeded 10% of their net income. This definition was used by Mold and Baker (2017) to assess the situation in Scotland [1]. According to the indicator of high-energy costs and low income, Belaid (2018) found that 12% of households in France were in energy poverty [2]. The context of energy poverty was once limited to the United Kingdom, where it struggled for years to gain political recognition, but slowly began to enter the EU agenda [3]. Anderson et al. (2012) investigated how low-income households in Great Britain cope with limited financial resources in the winter months [4]. Specifically, it found that 63% of low-income households reduced their energy use in the winter and 47% experienced colder homes. Improving the thermal performance of homes has reduced but not eliminated the risk of a cold, as any heating costs could be a burden on the lowest-income households. Bouzarovski et al. (2022) also examined the relationships between ethnicity and energy end-use inequity in the UK, focusing on the drivers and experiences of fuel poverty and energy vulnerability among ethnic minorities [5]. Their research shows that black African communities, in particular, are more vulnerable. And so there is a need to consider differentiated, cross-sectoral, and combined energy vulnerability among ethnic minorities in the UK. Baker et al. (2018) show similar results [6]. In the following period, Bouzarovski et al. (2023) compared the energy poverty alleviation policies of former post-communist countries outside the EU, finding that most states in the region did little to address some fundamental challenges related to improving housing quality, energy efficiency, and gender inequality [7]. However, energy poverty is present in the politics of all countries.

According to Acheampong et al. (2021), there is a dearth of research on the impact of energy access on human development, especially in energy-poor countries [8]. The results present the effect of access to electricity, and clean energy on various aspects of human development. Access to energy is key to human development, but it does not benefit all components of human development equally. The impact of human development on energy poverty could be manifested, among others, through improved social mobility and employment, where an increase in human development generally improves energy poverty [9]. Rodriguez-Alvarez et al. (2021) created an energy poverty analysis model with an estimated boundary of the minimum level of energy poverty that a country can achieve given its income level, energy prices, energy intensity, and other specific characteristics of the country [10]. The results suggest that financial assistance targeted at vulnerable groups, reductions in energy consumption and improvements in energy efficiency were beneficial against energy poverty. These factors may partly explain why, despite the negative impact of the financial crisis on incomes, we have seen a steady and general reduction in energy poverty over the period in almost all analyzed countries. Li et al. (2021) show that even a modest increase in household income has a significant impact on reducing energy poverty [11]. If GDP per capita increases by USD 1000, the energy efficiency of GDP improves by USD 1 per kg of oil equivalent. The increased well-being of the population is, therefore, a factor in reducing energy poverty and improving energy efficiency.

It is clear from the mentioned studies that there is a need to examine energy poverty from a regional point of view. Pan and Dong, (2022) examines the subject area from a regional perspective, illustrating that regional energy vulnerability is minimized under Chinese provincial conditions under an energy consumption quota allocation model that considers both equity and efficiency [12]. This contribution provides a reference for other countries to address energy poverty. Xia et al (2022) in rural areas of China investigated the spatial -temporary interaction of energy poverty and economic indicators over a fifteen-year period, pointing to the fluctuating trend of energy poverty in rural areas of China, dynamic local spatial dependence and the process of unstable spatial development [13]. In the long-term, the disposable income of rural residents had the greatest impact on rural energy poverty. From a country comparison perspective, Wu et al. (2019) found that in terms of household consumption, energy consumption in China is half that of the US [14]. To ensure sustainable energy use, developed countries are advised to strengthen their comparative advantages. There are considerable studies on the conditions related to the use of energy services with respect to payment terms, especially in developed countries [15] (Emre et al., 2023). The amount of research published so far confirms that the situation is conditioned by high energy prices, low household incomes, inefficient buildings and appliances, and specific household needs. These researches are confirmed mainly in Eastern, Central and Southern Europe [16] (Bouzarovski, 2014).

According to Biernat-Jark et al. (2021), energy poverty is a problem that affects all member states of the European Union to varying degrees [17]. The authors follow the development of the situation in Poland, where about 9% of the population is at risk of energy poverty and evaluate government measures aimed at reducing energy poverty through investments based on renewable energy sources and pointing to a visible decrease in the level of energy poverty due to investments in renewable energy sources. Han et al. (2023) examines the relationship between energy poverty and economic growth in selected Eastern European countries, emphasizing the importance of addressing energy poverty in order to promote economic growth and improve access to clean energy, which can increase economic growth and the well-being of citizens [18]. Therefore, efforts to reduce energy poverty should be a priority to support economic development and quality of life. Sokolowski et al. (2020) create a multidimensional index that combines energy factors, namely: low income and high costs; insufficient warm home; housing defects; problems with paying energy bills [19]. For example, in Poland in 2017, 10% of households suffered from energy poverty, mainly households living in buildings built before 1946, households living in the countryside and households dependent on old-age and disability pensions.

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Unlike most European countries, energy poverty in Australia is associated with difficulties in maintaining adequate heat during winter and ensuring sufficient cooling during summer. Energy poverty in Australia is also associated with health problems [20]. Energy poverty as can be seen from the previous study is necessary to monitor due to the health of the population. From this point of view, Kose (2019) found that energy poverty is negatively associated with the level of health of individuals [21]. Doganalp et al. (2021) examines the relationship between copper and growth, energy consumption, employment, education and inflation in the BRICS countries [22]. The results of the analysis show that income growth has a positive effect on employment and that there is no problem of energy poverty in the BRICS countries. Nevertheless, due to the air pollution caused by the consumption of fossil fuels, it is also crucial in these countries that they use renewable energy sources. Alem and Demeke (2020) contribute to the literature on energy poverty in developing countries, suggesting that increases in energy prices lead households to energy poverty, when households in developing countries respond to significant energy price increases by consuming more charcoal, which has serious environmental, climate and health consequences [23].

The basis for the emergence of energy poverty is the lack of political and institutional recognition. Simcock et al. (2021) found that people suffering from energy poverty are somewhat marginalized [24]. Therefore, a progressive country policy is needed to solve energy inequalities. There are efforts to address energy poverty at the level of the EU and its member states, with the EU supporting regulatory measures in the form of the EU Clean Energy Package, as well as the establishment of an EU energy poverty monitoring center [25]. These political efforts were largely influenced by the recent COVID-19 pandemic, which also demonstrated negative effects on the health of citizens due to the increase in energy poverty [26]. The negative effects of the pandemic on the level of energy poverty will decrease very slowly, at the earliest in 2025, with significant differences between countries, further widening the gap between countries with low and high-energy poverty. The study of energy poverty takes on importance during the COVID-19 pandemic when a significant part of the population was confined to their homes and had to face higher energy costs, which affected their health and safety [27].

One of the options for solving energy poverty is to increase the share of use of renewable energy sources. McGee and Greiner (2019) examined how national income inequality affects how renewable energy sources are used, finding that renewable energy displaces more fossil fuel energy sources as income inequality increases, and vice versa – as inequality decreases, fewer existing fossil energy sources are displaced [28]. It is therefore necessary for states to adopt policies that ensure the efficient displacement of fossil fuels and reduce income inequality. Energy poverty also affects the state of drawing subsidies for the use of renewable energy sources [29].

For example, in Slovakia, a draft definition of energy poverty was presented in September 2023. The proposal was submitted to the government for negotiation by the Office for the Regulation of Network Industries. Until now, the proposal is awaiting approval by the government. According to the proposal that the government received from the ÚRSO, a household will be considered at risk of energy poverty in cases where at least one of the following three criteria applies (we present the original wording from the ÚRSO proposal):

1. A household is at risk of energy poverty if, after paying the costs for the basic level of energy and water consumption, which ensures a decent standard for the life and health of household members, it has less than 1.5 times the subsistence minimum and at the same time its total net annual equivalent disposable income for the previous year, calculated per number of household members, is less than the national median.

2. A household is at risk of energy poverty if its annual energy costs for the previous calendar year are below half of the national median and at the same time its total net annual equivalent disposable income for the previous calendar year is below 60% of the national median.

3. A household without physical access to the supply of electricity for reasons that are exhaustively determined (www.urso.gov.sk).

In accord with mentioned, when there is lack of studies in Slovakia as post-communist country, the goal of the paper is to evaluate energy poverty development in Slovakia compared to other EU

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countries from the view of the heating and cooling days and the percentage of the population that cannot maintain adequate heat at home.

2. Materials and Methods

The goal of the paper is to analyze the energy sector in EU countries, based on publicly available data, with a focus on energy requirements and the standard of living of the population. During the research we resulted from free available data published annually within the Eurostat portal. The indicators were analyzed in the following structure:

- Heating degree days index (HDD) (1979 – 2022)
- Cooling degree days index (CDD) (1979 – 2022)
- Energy poverty (2003 – 2021)
- RES rate on gross total energy consumption (2004 – 2021).

when daily degrees (Daily degree (Dº) is a unit that expresses the intensity of the need for heat for heating depending on the climatic conditions (changes in the outside temperature) (norm STN 73 0540-4).

The dataset contains monthly data published by the Joint Research Centre's AGRI4CAST resource portal. Please note that Eurostat is not the author of the monthly data, but only republishes it. Annual data are calculated as the sum of monthly Eurostat data. These indicators were collected for the years (1979 - 2022) within the EU countries. A total of 140,015 data were collected. As part of the analysis, the development trend of each indicator was assessed and a comparison of countries within the EU was carried out using variability analysis, distribution analysis, cartographers and dot charts.

As part of the contribution, we analyzed the energy demands of the population through indicators defining the need for heat and cold in buildings (HDD, CDD).

The Heating Degree Index (HDD) is a weather-based technical index designed to describe the energy requirements of buildings for heating. It is based on the severity of the cold in a specific period of time, taking into account the outside temperature and the average room temperature (in other words, the need for heating). The HDD calculation is based on the base temperature, defined as the lowest daily average air temperature that does not lead to interior heating. The value of the basic temperature basically depends on several factors connected with the building and the surrounding environment. Using a general climatological approach, the base temperature in the HDD calculation is set to a constant value of 15°C.

When $T_m \leq 15$ °C then [HDD = $\sum_i$ (18 °C - T^i_m)] Otherwise [HDD = 0] , *where* T^i_m *- average air temperature in the day i.* (1)

For example, if the average daily air temperature is 12°C, the HDD index value for that day is 6 (18°C-12°C). If the average daily air temperature is 16°C, the HDD index is 0 for that day.

The cooling degree-days (CDD) index is a weather-based technical index designed to describe the need for cooling (air conditioning) requirements of buildings. The index is based on the intensity of heat in a specific time period, taking into account the outside temperature and the average temperature in the room (in other words, the need for cooling). The CDD calculation is based on the base temperature, which is defined as the highest daily average air temperature that does not lead to interior cooling. The value of the basic temperature basically depends on several factors connected with the building and the surrounding environment. Using a general climatological approach, the base temperature in the CDD calculation is set to a constant value of 24°C.

When $T_m \geq 24$°C then [CDD = $\sum_i T^i_m$ - 21°C)] Otherwise [CDD = 0], where T^i_m *- medium air temperature in the day i.*(2)

For example, if the average daily air temperature is 26°C, the value of the CDD index for this day is 5 (26°C-21°C). If the average daily air temperature is 22°C, the CDD index for that day is 0.

HDD and CDD are derived from meteorological observations of air temperature, interpolated to regular 25 km grids for Europe. The calculated grid HDD and CDD are aggregated and subsequently presented at the NUTS-2 level, for the years 2017 and 2018 also at the NUTS-3 level. These calculations are performed on a daily basis, added up to calendar months and then to calendar years.

Trend of the indicators development can have influence to the climax and weather in the given region. Mathematical expression is following equation:

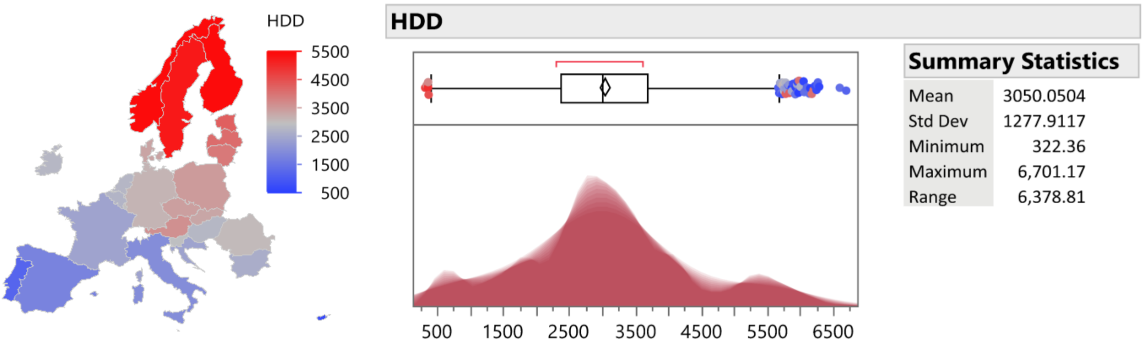
$$f(x)=1{,}65x \quad (3)$$

where (x) – number of years

(f(x)) – number of cooling days.

3. Results

The analysis showed that the number of daily heating degrees in the EU is on average at the level of 3,050.05 with a range of 6,378.81 degrees (Figure 1). There is a significant difference between the countries, which significantly affects the style of life in the given countries. The highest values are shown by the northern countries of the European Union such as Norway, Sweden, Estonia, Lithuania, Latvia with values higher than 5,000 degree-days, the lowest values are achieved by Cyprus, Malta, and Portugal with values up to 1,000 degree-days.



a) left – countries comparison *b) right – distribution analysis*

Figure 1. Heating degree-days index in EU.

The development of the indicator over time showed the decrease in the number of daily heating degrees per year by 13 units (Figure 2). This is indirect evidence of climate warming, as the number of days when it is necessary to heat is decreasing.

If the number of heating days decreases over time, this has several consequences, such as the regulation of heating by a law that determines what the usual heating period is in a given country, for example in Slovakia, the usual heating period is from September 1 to May 31. This means that heating companies cannot arbitrarily start and charge for heating before September 1 or after May 31 of the following year. The average outside temperature can also be a key factor. If the temperature drops below a given number of degrees for two days in a row (for example, in Slovakia below 13 °C) without a forecast of significant warming, heating is started. This can be interrupted after a while in case of warming. The development of the indicator can also be affected by individual differences, because there can be great variability in the beginning of the heating season in individual regions of the country.

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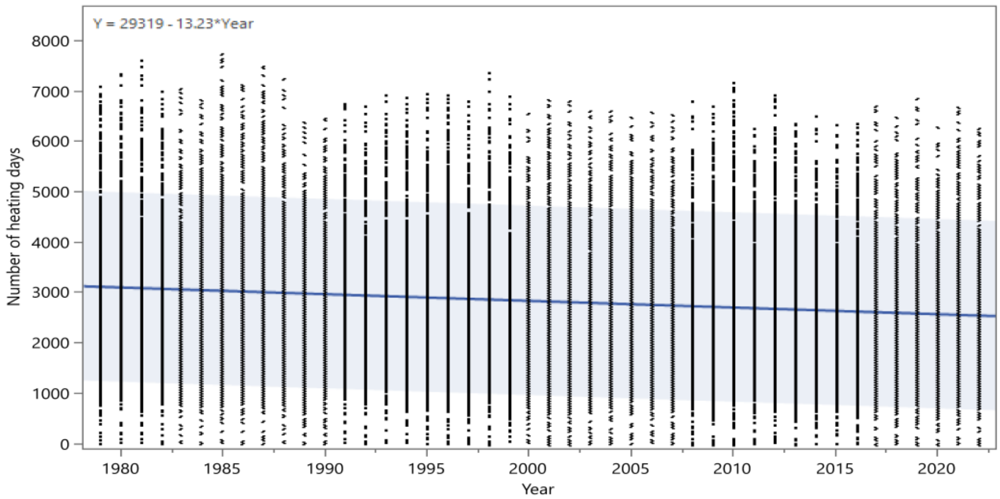

Figure 2. Number of heating degree-days in EU in 1979 – 2022.

The development of the indicator number of cooling days over time points to an increase in cooling days by 1.65 days per year (see Figure 3). The linear increase can have various consequences, such as changes in crop production, energy needs or the environment. It is important to monitor such trends and take measures to adapt to a changing climate. If the number of cooling days increases, it may be related to meteorological phenomena. For example, radiative cooling occurs at night, when the air temperature at lower altitudes drops significantly. Advection cooling is caused by the flow of cold air in the middle layers of the troposphere. These phenomena can affect the weather and temperature in a given region.

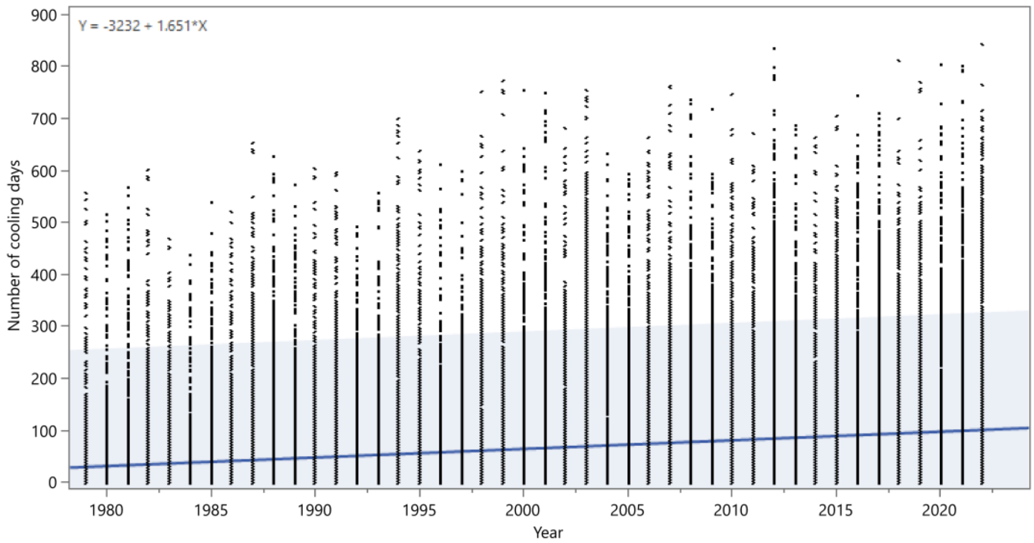

Figure 3. Number of cooling degree-days in EU in 1979 – 2022.

Based on these facts, we analyzed energy poverty, which is mainly linked to the indicator of heated days. Energy poverty was assessed through the percentage of the population that cannot maintain adequate heat at home. Figure 4 illustrates the development of the indicator in time, when Linear Fit presents percentage of inhabitants without heat = 451.31242 - 0.2174527*TIME_PERIOD.

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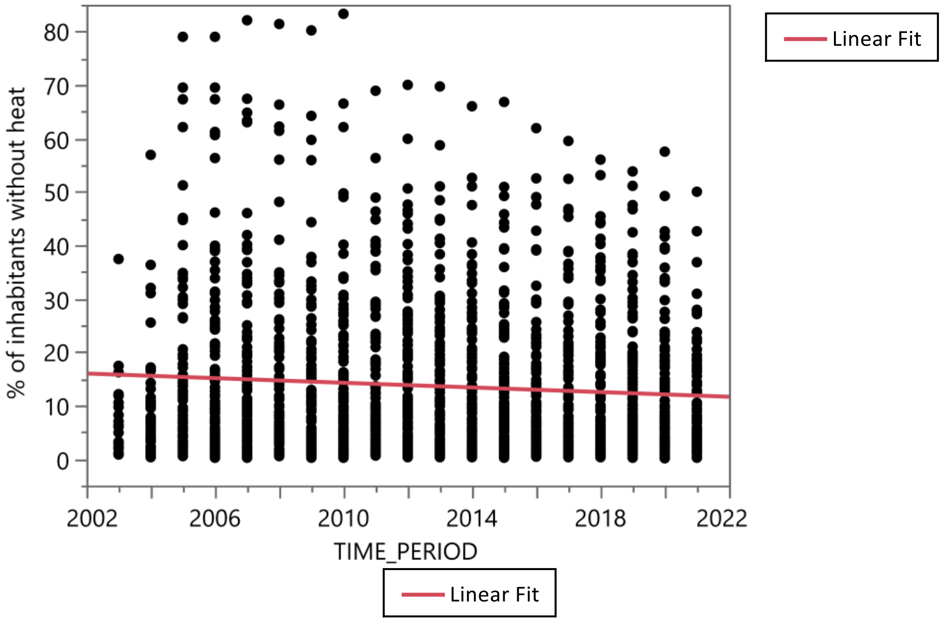
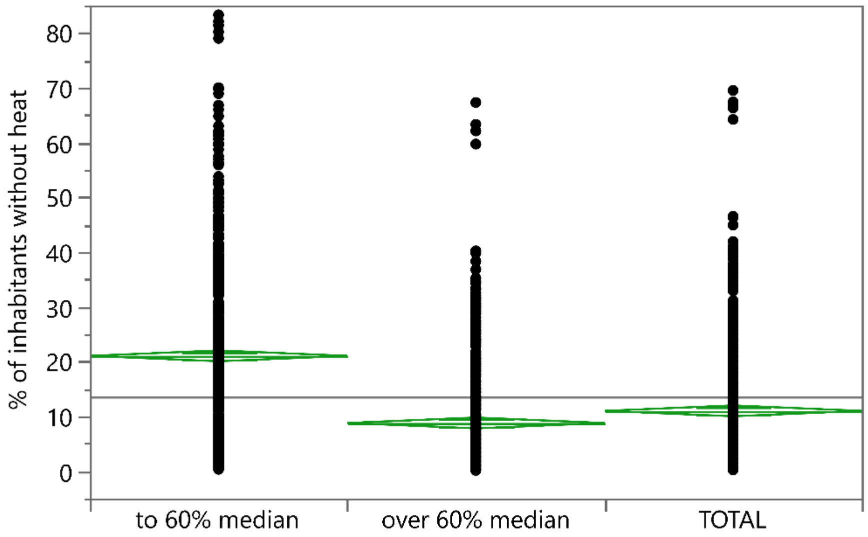


Figure 4. Trend of energy poverty development in EU in 2002-2022.

A slight decrease in the % of residents with a lack of heat was recorded. A slight decrease in energy poverty may have several reasons in the context of inhabitants without heat.

If the percentage of residents with a lack of heat decreases slightly, this can be a positive sign. This means that fewer people suffer from a lack of heat in their homes. Lack of heat can have serious consequences for people's health and well-being, especially in cold regions. The decrease in energy demand can be related to better insulation of buildings, modern heating systems or other measures to improve energy performance. This may mean that people have better conditions for keeping warm in their homes. In some cases, the decrease in energy demand can be related to social programs that help people with a lack of heat. These programs may include financial support to cover heating costs or other measures to improve living conditions. Overall, the slight decrease in energy consumption is a positive development that can have beneficial consequences for residents.

Energy poverty is evaluated also according to the inhabitants group (see Figure 5), following what is percentage rate of inhabitants with heat shortage from the category low income inhabitants, and percentage rate of inhabitants with heat shortage from the category high income inhabitants.



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
incgrp	2	54,736.67	27,368.3	168.0445	<.0001*
Error	1,920	312,698.09	162.9		
C. Total	1,922	367,434.77			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
To 60% median	641	21.0215	0.50406	20.033	22.010
Over 60% median	641	8.7605	0.50406	7.772	9.749
TOTAL	641	10.9744	0.50406	9.986	11.963

Figure 5. Groups of inhabitants without heat.

There is a difference between residents with income up to 60% and above 60% of the median income equivalent in % of residents with a lack of heat. An average of 21% of the population lacks heat (low-income category). An average of 8.7% of the population has a lack of heat (higher-income category).

Following factors could cause such development, for example measure of the poverty risk. The indicator measures the share of persons with an equivalent disposable income below 60% of the median national equivalent income. Equivalent income takes into account the size and composition of the household. Residents with lower incomes have a higher risk of poverty, which may be related to the lack of heat in their homes. The second factor is the cost of housing. Residents with lower incomes may find it more difficult to cover housing costs. For example, in the case of rental apartments, the maximum rent may be set based on the ratio of housing expenses to household income. If this ratio is high, it may mean that residents with a lower income have a harder time covering housing costs, including heating. Lower income residents may be more dependent on social programs and support. If these programs do not provide sufficient heating assistance, this may lead to a lack of heat for this group of residents. Overall, it is important to analyze the specific factors and policies that affect the difference between residents with different incomes and their living conditions, including heating.

Comparing of the geopolitical situation of the inhabitants without heat – total percentage rate of inhabitants with shortage of heat from 2005-2021 is given in Figure 6.

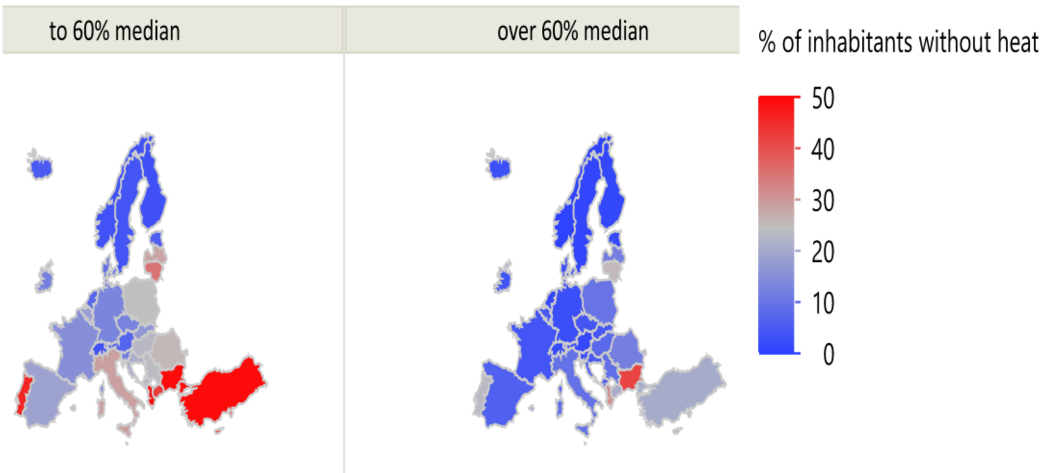


Figure 6. Percentage rate of inhabitants without heat – countries comparison in 2005-2021.

By comparing the geopolitical situation of the countries by a cartographer, it can be concluded that the highest values of energy poverty in low-income categories of the population are in the

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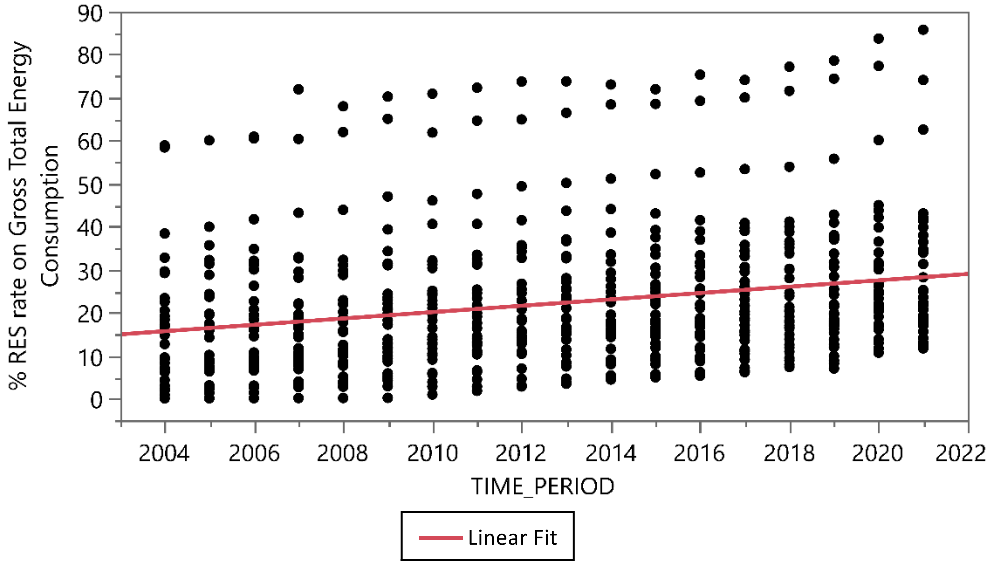
countries - Portugal, Turkey, Latvia, Albania, Macedonia, Bulgaria. Paradoxically, the coldest countries (Nordic countries) are the best. Even in the case of high-income groups of the population, energy poverty is most pronounced in Albania and Bulgaria, in the other mentioned countries there is a certain mitigation.

Currently, energy poverty needs to be examined from the point of view of the share of renewable energy sources in the gross total energy consumption, from several points of view, such as a cleaner alternative to fossil fuels, reduction of energy costs, and social measures and inclusive policy. Renewable energy source such as wind, solar, hydropower, ocean energy and geothermal energy offer cleaner alternatives to fossil fuels. Their use reduces pollution and contributes to environmental protection. For people on lower incomes, energy poverty can be a serious problem. Renewable resources can help reduce heating and electricity costs, which is important for those with limited funds. An increased share of renewable energy sources can be part of an inclusive policy that takes into account the needs of all citizens. Social programs and support can help people with lower incomes gain access to renewable energy.

The development of the share of RES in gross total energy consumption is shown in Figure 7, which shows the trend over 18 years with an annual increase of 0.74%.



Linear Fit

% RES rate on Gross Total Energy Consumption = -1464.974 + 0.7388661*TIME_PERIOD

Figure 7. RES rate on gross total energy consumption.

In the European Union, the goal of the share of renewable energy sources in gross total energy consumption is gradually increasing. In 2022, this share was 23%, and lawmakers in 2023 increased the Union's target to 42.5% by 2030, with an ultimate goal of reaching 45%1. In Slovakia, the share of renewable energy sources is also monitored, reaching 17.35% in 2020. These steps lead to a more sustainable energy system and better security for all residents.

Subsequently, we examined the use of RES by category - mostly for electricity generation and for heating and cooling. The results are illustrated in Figure 8.

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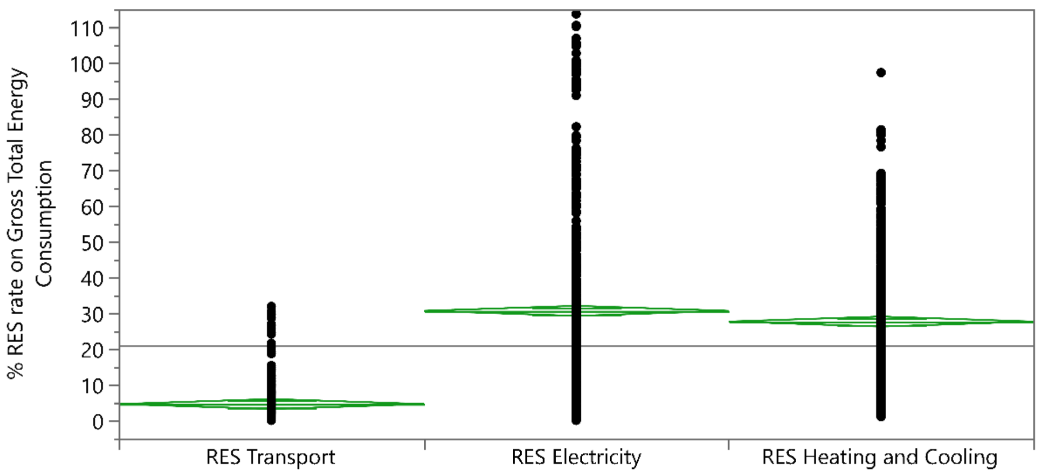

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
RES Transport	653	4.5653	0.71350	3.166	5.965
RES Electricity	653	30.6344	0.71350	29.235	32.034
RES Heating and Cooling	653	27.6310	0.71350	26.232	29.030

Figure 8. RES use according to the chosen categories.

From the oneway analysis of % RES use on gross total energy consumption in Figure 8 we see that the highest mean value is recorded for RES use in electricity at the level 30,6%, with little lower use in cooling and heating at the level 27,63%. However, there is obvious the RES use in transport is much lower – only 4,5%. Here is the space for the big improvement.

4. Discussion and Conclusions

In the frame of the research, we recorded following main results:

1. *HDD index recorded decrease, CDD index recorded increase.*

Decrease of HDD and increase of CDD is supported also by results from Andrade et al. (2021) [30]. According to Kyongmi et al. (2014), evaluation of HDD and CDD demands to use not only annual, however also monthly evaluation of electric energy consumption and mean temperature, since electricity demand to the temperature change is affected by the size of the cities [31]. The evaluation should be carried out on a regional level. Similar result is supported by Rosa et al. (2015), extending the evaluation to daily data, which are individually developed in the different cities [32]. The differences in RES uses and energy consumption is shown also by Kartal (2022), when several countries registered positive effect of energy consumption and RES use on carbon emission, whereas some countries registered negative effect [33]. In some cases, it is not enough to know only the temperature, but also impact of the temperature, for example whether there will be enough power to run cooling and heating generators [34].

Under predicted global warming, the trend of the obtained development can be expected to persist until the end of the century. Therefore, Spinoni et al. (2018) showed that despite the persisting warming, EDD would increase over northern Europe, the Baltic countries, Great Britain, Ireland, Benelux, the Alps, Spain, and Cyprus, resulting in an overall increase in EDD over Europe [35]. From the view of prediction, Petri and Caldeira (2015) predicted different development in individual part of the country [36]. Acharya and Sadath (2019) confirmed the development of the indicators is different across the states and regions [37].

2. *Energy poverty is most obvious in low-income group of inhabitants, having shortage of heat.*

Over the years, energy poverty shows a declining trend. However, Acharya and Sadath (2019) pointed the trend has an exception in less developed countries and regions [37]. In this area,

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education has a great impact on reducing energy poverty compared with income. Effects of energy poverty and renewable energy transition on development should be assessed both short-run and long-run [38]. Energy poverty (renewable energy) has an effect mainly on income, education, life expectancy, and employment. Transition to green energy partially compensates the adverse effects of energy poverty on the various development outcomes considered.

Nguyen et al. (2021) showed the role of financial development on the energy poverty, found that financial development reduce energy poverty in low- and lower-middle-income economies but have heteroscedastic different effects for various values of independent indicators in upper-middle-income economies [39]. Asad et al. (2020) examined the interaction between energy poverty, employment, education, per capita income, inflation, and economic development [40]. In relation to financing the green and low-carbon economy concept, public sector and private industries need to use modern, energy-efficient and green technologies.

3. *RES use contributing to mitigation of energy poverty registered increas*e.

Renewable energy source help to solve the problem with energy poverty. Opeyemi (2021) studied inter-fuel substitution possibility between renewable and non-renewable energy, showing substantial evidence of substitution possibilities [41]. There is a long-run relationship between renewable energy consumption and economic growth, reflecting energy poverty, when renewable energy has a positive impact on economic growth around 60% [42]. On the other hand, according to Khoshnevis and Shakouri (2017) economic growth is favorable for the development of renewable energy sector [43].

According to the WHO, indoor pollution causes an estimated 1.3 million deaths per annum in low income countries associated with the use of biomass in inadequate cook stoves [44]. To improve the situation, it would require vast investment to 2030 in subsidies to fossil fuels. As for the renewable energy solution of the energy crisis, mostly global solar energy increases quickly and now it is used worldwide to provide heating and cooling, especially due to the low initial cost and advantageous allowance that make solar heating and cooling system economically attractive [45]. Such economic attractiveness could improve sustainable development of any project [46].

Presented paper illustrates that energy poverty need to be solved together with renewable energy source strategies. However, there are still many unresolved questions about the actual implementation. The limitation of the contribution is that it does not address all aspects in an exhaustive manner, but rather presents a view of the development of the analyzed indicators of energy poverty with a focus on the use of renewable energy sources. At the same time, national policy makers are largely unaware of the existence of direct initiatives related to energy poverty at the EU level.

A limiting factor in analyzes of the impact of RES on the state of energy poverty in a given country is the lack of detailed data. For a correct analysis, it would be necessary to obtain data on specific types of RES that contribute to the provision of heat. They are primarily solar collectors, heat pumps and biomass boilers. By monitoring these parameters in relation to the support mechanisms of individual states, it would be possible to precisely define the influence of RES development in residential buildings and the state of energy poverty. According to the findings of experts in Slovakia, a more effective solution to energy poverty is to support RES installations in family and apartment buildings, rather than subsidizing direct heat costs [47, 48].

The results of the paper can be useful for the development of economically efficient policies to solve energy poverty, as well as for future analysis and forecasting prognosis in the analyzed area. By this way, the results provide information for policy makers in area of economic, social and environmental decision-making.

A direction for the future research will be develoment of the complex assessment of the impacts of household vulnerability in terms of poverty and its relationship with population health, employment and income.

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References

1. Mould, R., Baker, K.J. Documenting fuel poverty from the householders' perspective. *Energy Research & Social Science* **2017**, *31*, 21-31. SI, DOI: 10.1016/j.erss.2017.06.004.
2. Belaid, F. Exposure and risk to fuel poverty in France: Examining the extent of the fuel precariousness and its salient determinants. *Energy Policy* **2018**, *114*, 189-200. DOI: 10.1016/j.enpol.2017.12.005.
3. Bouzarovski, S., Petrova, S., Sarlamanov, R. Energy poverty policies in the EU: A critical perspective. *Energy Policy* **2012**, *49*, 76-82. DOI: 10.1016/j.enpol.2012.01.033
4. Anderson, W., White, V., Finney, A. Coping with low incomes and cold homes. *Energy Policy* **2012**, *49*, 40-52. DOI: 10.1016/j.enpol.2012.01.002.
5. Bouzarovski, S., Burbidge, M., Sarpotdar, A., Martiskainen, M. The diversity penalty: Domestic energy injustice and ethnic minorities in the United Kingdom. *Energy Research & Social Science* **2022**, *91*, Art No 102716. DOI: 10.1016/j.erss.2022.102716.
6. Baker, K.J., Mould, R., Restrick, S. Rethink fuel poverty as a complex problem. *Nature Energy* **2018**, *3*(8), 610-612. DOI: 10.1038/s41560-018-0204-2.
7. Bouzarovski, S., Brajkovic, J., Robic, S., Brown, C., Vuchkova, I. Energy poverty in the Energy Community region: Interrogating policy formulation and coverage. *European Urban and Regional Studies* **2023,** *31*(2), 096977642311622. DOI: 10.1177/09697764231162229.
8. Acheampong, A.O., Erdiaw-Kwasie, M.O., Abunvewah, M. Does energy accessibility improve human development? Evidence from energy-poor regions. *Energy Economics* **2021**, *96*(C), Art No 105165. DOI: 10.1016/j.eneco.2021.105165.
9. Opoku, E.E.O., Dogah, K.E., Kufuor, N.K., Acheampong, A.O. The importance of human development in combating energy poverty. *Journal of International Development* **2023**, *36*(2),1189-1209. DOI: 10.1002/jid.3855.
10. Rodriguez-Alvarez, A., Llorca, M., Jamasb. T. Alleviating energy poverty in Europe: Front-runners and laggards. *Energy Economics* **2021**, *103*, Art No 105575. DOI: 10.1016/j.eneco.2021.105575.
11. Li, R., Xin, Y., Sotnyk, I., Kubatko, O., Almashaqbeh, I., Fedyna, S., Prokopenko, O. Energy poverty and energy efficiency in emerging economies. *International Journal of Environment and Pollution* **2021**, *69*(1-2), 1-21. DOI: 10.1504/IJEP.2021.125188.
12. Pan, Y.L., Dong, F. Design of energy use rights trading policy from the perspective of energy vulnerability. *Energy Policy* **2022**, *160*, Art No 112668. DOI: 10.1016/j.enpol.2021.112668.
13. Xia, S.Y., Yang, Y., Qian, X.Y., Xu, X. Spatiotemporal Interaction and Socioeconomic Determinants of Rural Energy Poverty in China. *Int. J. Environ. Res.and Public Health* ***2022***, *19*(17), Art No 10851. DOI: 10.3390/ijerph191710851.
14. Wu, X.D., Guo, J.L., Ji, X., Chen, G.Q. Energy use in world economy from household-consumption-based perspective. *Energy Policy* **2019**, *127*, 287-298. DOI: 10.1016/j.enpol.2018.12.005.
15. Emre, T., Izgec, M.M., Sozen, A. Overview of the Literature on Energy Poverty. *Journal of Polytechnic* **2023**, early access December 2023. DOI: 10.2339/politeknik.588728.
16. Bouzarovski, S. Energy poverty in the European Union: landscapes of vulnerability. *Energy and Environment* **2014**, *3*(3), 276-289. DOI: 10.1002/wene.89.
17. Biernat-Jarka, A., Trebska, P., Jarka, S. The Role of Renewable Energy Sources in Alleviating Energy Poverty in Households in Poland. *Energies* **2021**, *14*(10), Art No 2957. DOI: 10.3390/en14102957.
18. Han, V., Ocal, O., Asian, A. Is energy poverty of Eastern European countries a threat or opportunity in the European Union's fight against climate change? *Environmental Science and Pollution Research* **2023**, early access October 2023. DOI: 10.1007/s11356-023-30225-0.
19. Sokolowski, J., Lewandowski, P., Kielczewska, A., Bouzarovski, S. A multidimensional index to measure energy poverty: the Polish case. Energy Sources, Part B. *Economics, Planning, and Policy* **2020**, *15*(2), 92-112. SI. DOI: 10.1080/15567249.2020.1742817.
20. Churchill, S.A., Smyth, R. Energy poverty and health: Panel data evidence from Australia. *Energy Economics* **2021**, *97*, Art No 105219. DOI: 10.1016/j.eneco.2021.105219.
21. Kose, T. Energy poverty and health: the Turkish case. Energy Sources, Part B. *Economics, Planning, and Policy* **2019**, *14*(5), 201-213. DOI: 10.1080/15567249.2019.1653406.
22. Doganalp, N., Ozsolak, B., Asian, A. The effects of energy poverty on economic growth: a panel data analysis for BRICS countries. *Environmental Science and Pollution Research* **2021**, *28*(36), 50167-50178. DOI: 10.1007/s11356-021-14185-x.

23. Alem, Y., Demeke, E. The persistence of energy poverty: A dynamic probit analysis. *Energy Economics* **2020**, *90*, Art No 104789. DOI: 10.1016/j.eneco.2020.104789.
24. Simcock, N., Frankowski, J., Bouzarovski, S. Rendered invisible: Institutional misrecognition and the reproduction of energy poverty. *GeoForum* **2021**, *124*, 1-9. DOI: 10.1016/j.geoforum.2021.05.005.
25. Bouzarovski, S., Thomson, H., Cornelis, S. Confronting Energy Poverty in Europe: A Research and Policy Agenda. *Energies* **2021**, *14*(4), Art No 858. DOI: 10.3390/en14040858.
26. Carfora, A., Scandurra, G., Thomas, A. Forecasting the COVID-19 effects on energy poverty across EU member states. *Energy Policy* **2022**, *161*, Art No 112597. DOI: 10.1016/j.enpol.2021.112597.
27. Clavijo-Núnez, S., Herrera-Limones, R., Rey-Pérez, J., Torres-Garcia, M. Energy poverty in Andalusia. An analysis through decentralised indicators. *Energy Policy* **2022**, *167*, Art No 113083. DOI: 10.1016/j.enpol.2022.113083.
28. McGee, J.A., Greiner, P.T. Renewable energy injustice: The socio-environmental implications of renewable energy consumption. *Energy Research & Social Science* **2019**, *56*, Art No 101214. DOI: 10.1016/j.erss.2019.05.024.
29. Frantál, B., Dvorák, P. Reducing energy poverty in deprived regions or supporting new developments in metropolitan suburbs? Regional differences in the use of subsidies for home energy efficiency renovations. *Energy Policy* **2022**, *171*, Art No 113250. DOI: 10.1016/j.enpol.2022.113250.
30. Andrade, C., Mourato, S., Ramos, J. Heating and Cooling Degree-Days Climate Change Projections for Portugal. *Atmosphere* **2021**, *12*(6), 715. https://doi.org/10.3390/atmos12060715
31. Kyongmi, L., Hee-Jeong, B., Chun-Ho, Ch. The Estimation of Base Temperature for Heating and Cooling Degree-Days for South Korea. *Journal of Applied Meteorology and Climatology* **2014**, 300-309. DOI: https://doi.org/10.1175/JAMC-D-13-0220.1.
32. Rosa, V. B., Scarpa, F., Tagliafico, L. A. Historical trends and current state of heating and cooling degree days in Italy. *Energy Conversion and Management* **2015**, *90*, 323-335. https://doi.org/10.1016/j.enconman.2014.11.022
33. Kartal, M. T. The role of consumption of energy, fossil sources, nuclear energy, and renewable energy on environmental degradation in top-five carbon producing countries. *Renewable Energy* **2022**, *184*, 871-880. https://doi.org/10.1016/j.renene.2021.12.022
34. Clyde, W. F. Bellow, J., Brown, Ch. 2011. Degree Days: Heating, Cooling, and Growing. ABE 381 series of the Agricultural and Biological Engineering Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Available at: Degree-Days-Heating-Cooling-and-Growing1.pdf (accessed on 15 April 2024).
35. Spinoni, J., Vogt, J. V., Barbosa, P., Dosio, A., McCormick, N., Bigano, A., Fussel, H. M. Changes of heating and cooling degree-days in Europe from 1981 to 2100. *International Journal of Climatology* **2018**, *38*(SI), e191-e208. https://doi.org/10.1002/joc.5362
36. Petri Y., Caldeira, K. Impacts of global warming on residential heating and cooling degree-days in the United States. *Scientific Reports* **2015**, *5*, Art No 12427.
37. Acharya, R. H.., Sadath, A., C. Energy poverty and economic development: Household-level evidence from India. *Energy and Buildings* **2019,** *183,* 785-791. https://doi.org/10.1016/j.enbuild.2018.11.047Get rights and content
38. Adom, K., Amuakwa-Mensah, F., Prosper, A. M., Nsabimana A. Energy poverty, development outcomes, and transition to green energy. *Renewable Energy* **2021,** *178*, 1337-1352. https://doi.org/10.1016/j.renene.2021.06.120.
39. Nguyen, C.P., Su, T.D., Bui, T.D. Financial development and energy poverty: global evidence. *Environ Sci Pollut Res* **2021**, *28*, 35188–35225. https://doi.org/10.1007/s11356-021-13038-x
40. Asad, A., Liu, Y., You J., Chandio A. A., Rasool, S.F., Lou, J. Zaman S. How does energy poverty affect economic development? A panel data analysis of South Asian countries. *Environmental Science and Pollution Research* **2020**, *27*, 31623-31635.
41. Opeyemi, M. B. Path to sustainable energy consumption: The possibility of substituting renewable energy from non-renewable energy. *Energy* 2021, *228*, 120519. https://doi.org/10.1016/j.energy.2021.120519
42. Shahbaz, M., Raghutla, Ch., Chittedi, K.R., Vo Xuan, V. The effect of renewable energy consumption on economic growth: Evidence from the renewable energy country attractive index. *Energy* **2020**, *207*, 118162. https://doi.org/10.1016/j.energy.2020.118162
43. Khoshnevis, Y., S., Shakouri, B. Renewable energy, nonrenewable energy consumption, and economic growth. *Energy Sources, Part B: Economics, Planning, and Policy* **2017**, 12(12), 1038–1045. DOI: 10.1080/15567249.2017.1316795.
44. González-Eguino, M. Energy poverty: An overview. *Renewable and Sustainable Energy Reviews* **2015**, *47*, 377-385. https://doi.org/10.1016/j.rser.2015.03.013
45. Wang, R.Z., Xu, Z.Y., Pan, Q.W., Du, S., Chen, X.M., Ma, T., Wu, X.N., Sun, X.L., Chen, J.F. Solar heating and cooling: Present and future development. *Renewable energy* **2018**, *126*, 1126-1140. https://doi.org/10.1016/j.renene.2017.06.081

 doi:10.20944/preprints202406.1192.v1

46. Teplicka, K; Khouri, S; Beer, M., Rybarova, J.: (2021) Evaluation of the Performance of Mining Processes after the Strategic Innovation for Sustainable Development. *Processes* **2021**, *9*(8), 1374. DOI: 10.3390/pr9081374.
47. Commission Staff Working Document EU guidance on energy poverty, Brussels, 20.10.2023 SWD(2023) 647 final
48. Dokupilová, D., Gerbery, D. *Deep study of energy poverty* (in Slovak). Bratislava, Prognostický ústav, Centrum spoločenských a psychologických vied, Slovenská akadémia vied, 2023.