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The Role of Household Income in Identifying Energy Poverty

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***Abstract* – Energy poverty and the identification of households at risk of it have become increasingly important topics for research and national policy implementation. This issue has gained significance due to rising energy resource costs, geopolitical events, income inequality, and rapidly occurring climate change. It affects indicators that characterize households' quality of life, such as health status, life expectancy, and education level, while also significantly impacting climate change and efforts to reduce greenhouse gas emissions. Reducing the proportion of households at risk of energy poverty is particularly relevant in countries with extreme temperatures, where ensuring a suitable indoor climate is crucial, such as in Latvia. To develop a data-driven concept for identifying energy poverty that is suitable for Latvia and could be applied by other European Union member states in the long term, this paper analyses information from the integrated energy and climate plans of EU member states regarding their current approaches and indicators for identifying energy poverty. Using a decomposition method, the most frequently used indicators are the share of household energy expenditure in total household income (%), and the household's critical income level (EUR). Based on the information mentioned above, the paper analyses the concept of affordable housing, concluding what share of household expenditure in household income should be considered affordable, while also identifying mandatory housing-related expenditures. As the result of study, a data-driven method and formula for calculating the critical income level of a household (EUR/month per household member) is developed.**

***Keywords* – Affordable housing; data-based approach; energy poverty; EU approach; housing costs; household expenses; household income.**

1. INTRODUCTION

Energy poverty and the identification of households at risk are becoming increasingly important subjects of research and national policy implementation. This issue has gained significance due to rising energy resource costs, geopolitical events, income inequality among households, and climate change. Reducing the proportion of households at risk of energy poverty is especially crucial in countries with extreme temperatures, where maintaining an adequate indoor climate is necessary. This is particularly relevant in Latvia, where the concept of energy poverty and its identification have not been sufficiently developed.

Latvia has adopted the European Union-level definition of energy poverty, which is included in the Energy Law. At the same time, the Energy Law states that households at risk of energy poverty are those that have been granted the status of low-income or poor

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households [1]. However, this target group is very narrow and does not fully include all households that may be at risk of energy poverty. It should also be noted that Latvia currently lacks a mechanism to identify such households, and consequently, there are no measures in place aimed at reducing their proportion. The inclusion of a formal definition in national legislation does not, in itself, facilitate the identification of the target group or the reduction of its share. Regarding mentioned the development of a mechanism for identifying households at risk of energy poverty in Latvia is significant. This would serve as a basis for creating policies aimed at reducing the proportion of such households.

The definition of energy poverty as a concept has been relevant since the 1980s, when the British government decided to define energy poverty and identify the target group to reduce the proportion of households vulnerable to this risk. However, it should be noted that the concept initially developed by the British government, along with the approach to identifying energy poverty, was more tailored to the specific needs of national policy [2]. The concept of energy poverty, which is relevant to European Union member states, is currently being developed by international organizations and institutions such as the Organization for Economic Co-operation and Development (OECD), the United Nations (UN), the International Atomic Energy Agency (IAEA), the International Energy Agency (IEA), and the European Commission.

An analysis of European Union-level legislation reveals that energy poverty was first mentioned in the 2009 Electricity Internal Market Directive, which required member states to develop mechanisms to protect vulnerable groups in society and reduce energy poverty [3]. A similar approach was also included in the 2009-approved Natural Gas Internal Market Directive [4]. However, the definition of energy poverty and the specific criteria for its identification are not included in either of the directives. On the other hand, when analysing current European Union-level legislation, it can be concluded that the definition of energy poverty is included in the Directive on Energy Efficiency. It defines energy poverty as "household's lack of access to essential energy services, where such services provide basic levels and decent standards of living and health, including adequate heating, hot water, cooling, lighting, and energy to power appliances, in the relevant national context, existing national social policy and other relevant national policies, caused by a combination of factors, including at least non-affordability, insufficient disposable income, high energy expenditure and poor energy efficiency of homes" [5].

Access to quality, warm housing that meets minimum sanitary standards, as well as access to energy resources, is essential for fulfilling basic human needs. This is closely linked to maintaining stable health, hygiene, access to education, and even everyday activities such as food storage and preparing balanced meals. Ensuring this access depends on both the technical condition of the housing and the income of individuals. Additionally, it should be noted that the relevance of these issues varies depending on the climatic zone in which the housing is located, as well as the average outdoor air temperature. The concept of energy poverty encompasses all these aspects.

According to data from the Eurostat database, the main aggregator of statistics for all European Union (EU) member states, 17.9 % of people lived in inadequately heated homes during the winter in 2023. Of these, 31.2 % were individuals at risk of poverty and social exclusion, while 14.4 % were individuals not at risk [6]. Data collected by the OECD at the country level indicates that the average proportion of households in Europe unable to keep their homes sufficiently warm is 16.3 % [7], UN data shows that most European countries provide all residents with access to electricity and clean energy for food preparation. However, limited access has been identified for some residents in Serbia, Bosnia and Herzegovina, Montenegro, and North Macedonia [8]. Data collected by the IEA also indicates

that 100 % of the European population has access to electricity and clean energy for food preparation [9], [10]. On the other hand, data collected by the IAEA, covering only a portion of European countries, shows that clean energy is available to most of the population in these countries [11]. These differences can be explained by the varying methodologies used to collect and calculate statistical data, as well as the inclusion of different countries in the dataset. Therefore, it is important to also analyse the individual approaches of countries in identifying energy poverty, which will be discussed further in the study.

Reducing the proportion of households at risk of energy poverty is crucial, as it affects several important sectors. For example, it places a burden on the social sector and the budgets of municipalities and countries, increases the strain on the healthcare system by requiring care for individuals suffering from chronic diseases due to inadequate housing conditions, and lowers average education levels. This is because members of households without stable access to energy resources, including electricity, especially during the dark hours of the day, tend to have poorer educational outcomes.

Additionally, energy poverty has been found to have both direct and indirect impacts on greenhouse gas emissions. Analysing the direct impact, it can be concluded that energy poverty results from factors such as the technical condition of housing in households at risk (e.g., energy-inefficient homes with high heat energy losses), the ability of households to effectively reduce energy consumption, and the use of individual devices to control heat energy and electricity consumption, or the availability of aggregation services. On the other hand, analysing the indirect impact, it can be concluded that households at risk of energy poverty often purchase lower-cost goods and products, the production processes of which are not sustainable and contribute to climate change.

The issue of identifying energy poverty and households at risk of it has been widely analysed in academic field, including through the analysis of various countries' case studies. There is no consensus on what constitutes a household affected by energy poverty or how to identify it. Some sources distinguish between cost-based and income-based approaches. For example, direct and objective measurement (temperature approach), where the level of energy services achieved in the home is compared to a set standard, or expenditure approach, where income, housing costs, or energy costs are measured [12]. It is also possible to identify physical approaches to energy infrastructure access, where the indicators for identifying energy poverty are linked to the household's average energy consumption, or approaches which evaluate the energy supply services received by households. From the perspective of the physical access to energy infrastructure approach, energy poverty is a pressing issue in Southern regions, for example, in low-income countries in Africa and South Asia [13], but in more developed countries of the Southern region, cost-based approaches are more relevant, where energy poverty is associated with access to affordable energy and the ability to afford energy for heating and cooling, paying attention to energy vulnerability [14]. At the same time, energy poverty has been analysed from the perspective of homeowners and renters, and from the perspective of the level of household income [15].

There are several approaches identified to evaluate energy poverty at the EU level. There are approaches based on the legal framework, which generally indicate that energy poverty has received more focused attention since its definition and the assignment of responsibilities to EU member states were established in EU legislation. However, energy poverty indicators are often analysed within a limited scope, based on European Commission recommendations and perspectives, focusing on issues such as the ability to keep a housing warm; inadequate living conditions; poverty; and social exclusion [16]. A multidimensional approach has also been used to identify energy poverty in EU member states, which includes a composite index of energy poverty covering indicators such as: inability to keep the home warm, arrears on

utility bills, the total population considering their dwelling too dark, pollution, grime or other environmental problems, housing cost overburden, and the harmonized index of consumer prices [17].

As an additional approach to identifying energy poverty in European countries, a seasonal approach can be distinguished. For example, in Southern Europe, the so-called summer energy poverty has been identified, particularly evident in Mediterranean countries experiencing heatwaves. Within the approach the specific heat maps has been developed in Spain and Italy [18]–[20]. In relation to the countries of Northern Europe, the concept of winter energy poverty does not appear in academic discourse. However, available studies in Finland and Sweden indicate that in Nordic countries energy poverty is more often analysed through the vulnerable energy users and their ability to cover expenses on energy [21], [22].

When examining the information available in academic field on energy poverty and its identification, as well as the approaches used by various countries and international organizations to identify energy poverty and households at risk of it, it becomes evident that these approaches differ significantly. Definitions of energy poverty and the indicators used to identify households at risk of it vary even among European Union (EU) member states, despite the existence of a common legal framework across the EU. Given the impact of energy poverty on other sectors – including indicators of human well-being – it is increasingly important for EU member states to actively engage in identifying energy poverty and to reduce the share of households at risk of it.

The main research problem identified is the current lack of consensus on how to identify such households complicates not only efforts by EU member states to exchange practical approaches and share best practices for reducing the prevalence of energy poverty but also hinders the development of practical mechanisms and tools for reducing energy poverty as such. This can result in a situation where the concept of identifying energy poverty has been formally introduced, but is not applied in practice, and no mechanisms have been developed to reduce the share of households at risk of it.

Considering the mentioned, the development of a new, unified approach to identify households at risk of energy poverty in Latvia is significant, and reducing their share is not possible without effective identification tools.

Therefore, this study introduces a scientifically novel, data-driven methodology for identifying households at risk of energy poverty by developing a formula for calculating the critical income threshold based on actual household housing expenditure data. Unlike many existing approaches that rely on subjective survey data or generalized poverty thresholds, this paper integrates the concept of affordable housing – as defined by international organizations such as the OECD, UN, and World Bank – with Latvia-specific consumption statistics and inflation-adjusted expenditure categories.

2. METHODOLOGY

This study uses comparative qualitative analysis to examine the approaches employed by various global organizations, institutions, and EU Member States in defining and identifying energy poverty. A detailed analysis of the information included in National Energy and Climate Plans (NECPs) was conducted to select indicators and data used for identifying energy poverty. It was concluded that the data sources used by EU Member States to identify energy poverty and determine indicator values often vary significantly. Specifically, some Member States rely on general statistical data compiled by international organizations, while others use data from national household surveys or registers regarding individuals' status. As

a result, there is no consensus on how to identify energy poverty. Therefore, the methodology section provides an overview of the different approaches to defining and identifying energy poverty, as well as an assessment of their relevance.

Energy poverty, both in academic research and among international organizations, is generally defined as a household's or individual's inability to access energy and basic energy services such as heating, cooling, electricity, and energy for food preparation. Additionally, it is recognized that energy poverty is linked to low energy efficiency in housing and poor technical conditions (e.g., leaking roofs, broken windows, doors, floors, mold, etc.), as well as the household's inability to pay bills for energy resources supplied by service providers.

The study identifies key indicators used to identify energy poverty, as included in NECPs (by all EU Member States) and international organizations, and provides an overview of how definitions and policy implementation vary among them. This methodological approach allows us to evaluate how the concept of energy poverty is operationalized across different governance levels and contributes to understanding the complexity and context-specific nature of the issue.

To further support the development of a data-driven method for identifying households at risk of energy poverty, a decomposition method is applied. This method enables the classification of indicators included in the NECPs of EU Member States into three main indicator groups. The study also identifies the most frequently used and most data supported indicators by analysing both the practices of international organizations and approaches recognized in academic research.

The reviewed and categorized indicators serve as a basis for developing a national methodology to identify energy poverty in Latvia, with potential for implementation by other EU Member States.

2.1. Methodological Approach of International Organizations

The OECD has adapted its approach to defining energy poverty to align with the framework outlined in European Union legislation, leading to the development of the concept of affordable housing and its identification in OECD member states [23]. On the other hand, in 2010, the UN defined indicators for identifying energy poverty, including a household's inability to access electricity and its dependence on traditional biomass for cooking [24].

In the IEA's view, energy poverty is the lack of access to electricity and clean energy for cooking [25], like the UN definition. However, the IEA closely links energy poverty to a household's access to energy, which is defined as access to reliable, clean, and affordable energy for cooking, electricity available in sufficient quantities to meet basic energy needs, as well as an increasing amount of available electricity at the regional level [26]. The IAEA also views the concept of energy poverty through the lens of accessible energy, stating that it is crucial to ensure households have access to reliable, affordable, clean energy, including electricity. This is essential for achieving sustainability goals, reducing poverty, developing the manufacturing sector, raising living standards, improving health outcomes, maintaining a clean environment, and supporting a sustainable economy [27].

2.2. Methodological Approach of EU Member States

Since 2009, EU member states have been required to develop measures to reduce energy poverty and the proportion of vulnerable social groups at risk. Several EU members states have developed national-level energy poverty identification indicators and models. However, despite the inclusion of certain common factors in EU-level legislation for identifying

households at risk of energy poverty – factors that could be used to create national-level models – the approaches of EU member states still vary.

In Latvia, which has formally adopted the provisions of EU legislation regarding the identification of energy poverty, there is no detailed or current mechanism for identifying households at risk of energy poverty that reflects the current situation. In the long term, it is essential to focus on developing a method that can accurately identify households at risk, while creating a system that could also be used by other EU member states, especially those where the concept of energy poverty has not been fully developed or has only been introduced formally. Additionally, when developing such a method, attention should be given to the data sources used, ensuring that data collected by other countries is also applicable for other purposes, such as reporting statistical indicators to international organizations.

2.3. Data Sources Used for Defining Energy Poverty

The study also analyses the information on data sources used for identifying energy poverty, as included in the National Energy and Climate Plans (NECP) [28] of EU member states or other sources indicated by the member states. It should be noted that not all member states have provided information about the data sources used, though nineteen member states have done so. Therefore, it is possible to gain an overview and general understanding of the data sources used to determine indicator values and whether the respective data sources contain objective or subjective information.

Overall, the data sources used by EU member states can be categorized into three groups: international-level statistical data (e.g., EUROSTAT, OECD), household surveys and other subjective data, and specific, objective calculations and data (e.g., building energy certification data, energy price data, data on individuals receiving state support). Analysing the data sources used to calculate the values of the most frequently used indicators for identifying energy poverty, it can be concluded that, for the indicator 'household energy expenditure as a percentage of household income, seven member states rely on international-level statistical data, mostly from EUROSTAT, which includes EU statistics on personal income and living conditions obtained through surveys. Eight member states use household survey data to determine this indicator, while two member states use specific data, such as national-level data on citizens' tax payments, from which average income calculations are made. Two member states have not included information in their NECPs regarding the data sources used to determine this indicator value. It should be noted that several member states use multiple data sources to determine indicator values; for example, Austria and Ireland use both EUROSTAT data and specific, objective calculations. Meanwhile, Bulgaria and Portugal use both EUROSTAT and household survey data, which are subjective, but also provide information on whether the data collected by EUROSTAT correlates with data obtained from national-level household surveys.

The study conducts a qualitative analysis by comparing and analysing the definitions of energy poverty and the indicators used across EU member states. The decomposition method (Fig. 1) is used, where 14 indicators are grouped into three categories: specific household status, indicators based on household income and expenditure, and indicators related to the technical condition of housing, and an analysis is performed to identify the most frequently used ones for identifying households at risk of energy poverty in all EU member states. A detailed analysis is then carried out on the most applied and data-supported indicators (the share of energy expenditure from income (%), and critical household income level (EUR/ per household member), drawing on information from academic research and the approaches of various international organizations.

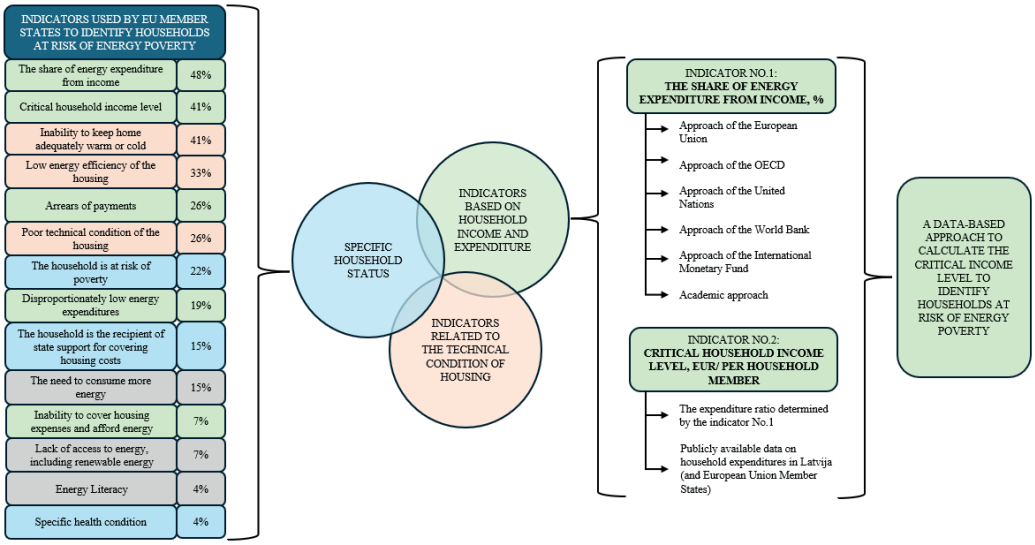

Fig. 1. Decomposition method for introducing a data-based approach to calculate the critical income level for identifying households at risk of energy poverty.

Additionally, the study includes a quantitative analysis of indicators related to household income and expenditures, an examination of publicly available data, and the development of calculation formulas for determining household income and, subsequently, identifying households at risk of energy poverty.

As part of the research process, a new formula for the energy poverty threshold was constructed. This formula integrates official statistical data on housing expenditures, inflation dynamics, and average income levels. It is not derived from existing models but developed specifically to reflect Latvia's economic and consumption context based on EU level experience.

3. RESULTS

3.1. Defining Energy Poverty in the NECPs

To gain a comprehensive understanding of how EU member states define and identify energy poverty and the social groups at risk, an analysis has been conducted of the updated National Energy and Climate Plans (NECPs), or their drafts in the case of individual countries, submitted by the member states by December 31, 2024 [28]. The analysis of the NECPs was chosen because they are based on unified approach, which means the content of the relevant documents is similar. Energy poverty is one of the areas that must be analysed within the NECP framework, including specifying both the methods for identifying energy poverty and the potential measures to reduce its prevalence. Additionally, the European Commission has provided specific recommendations to each member state for improving the content of the NECPs, including the information on energy poverty. It should also be noted that not all NECPs contain detailed information on identifying energy poverty; however, in such cases, the member states have included relevant information in other specific legislation

or action plans that address energy poverty identification, and the national policies implemented to reduce its prevalence. Countries that have included information on the definition of energy poverty and indicators in other documents include Bulgaria, where the NECP indicates that this information is included in the Energy Act [29], Estonia (the information is included in the Energy Sector Organization Act) [30], Greece (the information is included in the National Action Plan to Combat Energy Poverty [31], Latvia (the provisions are included in the Energy Law) [1], Poland (the provisions are included in the Energy Law) [32], Portugal (the information is included in the National Long-term Energy Poverty Mitigation Strategy 2023–2050) [33], Slovakia (the provisions are included in the Act on Roads) [34], Spain (the information is included in the National Strategy against Energy Poverty 2019–2024) [35].

Analysing the information provided by EU member states on energy poverty, it can be concluded that, despite EU-level legislation mandating the definition of energy poverty and the development of methods for its identification and reduction, only 14 out of 27 member states (Austria, Bulgaria, Cyprus, Estonia, France, Greece, Ireland, Latvia, Lithuania, the Netherlands, Poland, Portugal, Slovenia, Spain) have clearly defined energy poverty. Eight member states (Belgium, Czech Republic, Finland, Germany, Hungary, Luxembourg, Romania, Slovakia) have either indicated how energy poverty is indirectly addressed at the national level or are actively working on developing a definition, with their NECPs including information on a potential definition that could be approved in the coming years. Meanwhile, five member states (Croatia, Denmark, Italy, Malta, Sweden) have not developed a definition of energy poverty and have not included information on the progress of its development in their NECPs. It is important to note that Denmark [36] and Sweden [37] both explain that their long-standing social policies are comprehensive and aimed at reducing the proportion of households at risk of general poverty. These policies also include a wide range of social and housing assistance services. Additionally, both countries have specific policies and programs focused on promoting building energy efficiency and improving housing. Given this, both countries have indicated that energy poverty is not a primary social issue, and its prevalence is minimal. It should also be noted that Estonia, in its NECP, mentions that, given the low statistical indicators of energy poverty, the country does not consider energy poverty a primary issue, and a significant portion of the problem is already addressed by existing social policies [38].

Specifically analysing the content of the definitions of energy poverty provided by the member states, it can be concluded that, for the most part, the definitions are quite similar. Most definitions link energy poverty to household income (in 12 definitions), difficulties in accessing basic energy services, meeting basic energy needs, and covering energy costs (in 14 definitions). It is also stated that individuals at risk of energy poverty are those granted a specific status, such as protected user status in the electricity and gas sectors, low-income or poor status, or individuals with specific health conditions, such as disability or a severe chronic illness (in eight definitions).

Additionally, the definitions provided by the member states include elements such as: energy costs exceeding the average household energy expenditure in the country or region (in one definition), the proportion of energy costs relative to income (in four definitions), high energy prices (in two definitions), low energy efficiency of the home or poor technical condition of the building (in six definitions), and the inability to keep the home adequately warm (in two definitions). Less frequently, energy poverty definitions include elements such as the proportion of household energy expenditure relative to income, energy costs exceeding the national average, high energy prices, low energy efficiency, poor building conditions, or the inability to maintain sufficient warmth in the home. These elements are more likely to be

included as indicators, as many countries use them to identify households at risk of energy poverty. It should also be noted that the inability to keep the home sufficiently warm may be closely related to the difficulties mentioned in the definitions regarding access to basic energy services and meeting basic energy needs.

The definition of energy poverty is a relatively formal element of the energy poverty concept, providing a general understanding of how each EU member state interprets the concept. A more significant aspect of the concept consists of the indicators used to identify households at risk of energy poverty. Analysing the NECPs of member states, as well as the plans or strategies for reducing energy poverty or legislation that includes specific provisions for identifying energy poverty in individual countries, it can be concluded that, while five member states lack a definition of energy poverty, only Malta has not established indicators for its identification. It is important to note that some member states have set indicators based on data from EU-level databases for identifying households at risk of energy poverty, which are more formal and are not calculated within the member state itself.

3.2. Indicators Set by EU Member States

The indicators set by EU member states to identify energy poverty can be categorized into several main groups. First, there are indicators related to household income and expenditures (often influenced by high energy prices), such as the proportion of household energy expenditures relative to income. Member states have set various threshold percentages of energy expenditures to determine whether a household or individual is at risk of energy poverty. Some countries consider both the energy expenditure-to-income ratio and household status (e.g., whether the household is at risk of poverty). Another indicator is the level of household income falling below a certain threshold (e.g., the average wage in the country or the minimum income threshold), as well as household purchasing power. This group of indicators could also include disproportionately low energy expenditures, which reflect so-called hidden energy poverty and directly result from a household's total monthly income. Additionally, this group may include income-based indicators such as overdue payments or debts (including those for consumed energy resources), an inability to cover expenses, and an inability to afford energy.

Secondly, there is a group of indicators related to housing, including the inability to keep the home adequately warm (in winter) or cool (in summer), as well as the poor technical condition of the home (e.g., a damaged roof, broken windows, leaking roof, mold, or other types of fungi and microorganisms caused by poor indoor climate). This group also includes the household’s ability to improve the technical condition of their home and their energy literacy. It should be noted that the first group of indicators related to household income and expenditure is linked to the second group. A household’s ability to invest in improving the technical condition of the home and increasing energy efficiency is related to its income. Specifically, the lower the household’s income, the larger the proportion spent on meeting basic daily needs, leaving little opportunity to save for long-term investments, including those in housing.

The third group of indicators, which is related to the first group, is associated with specific household status. This includes indicators such as the proportion of households at risk of poverty, households or household members receiving state support (e.g., support for vulnerable users in the electricity and gas sectors, housing or social benefits, social assistance), as well as household members with specific health conditions (e.g., disability, severe chronic illness) that limit the individual's opportunities in the labour market.

Additionally, several indicators have been identified that do not fall into any of the groups. For example, the need for a household to consume more energy resources than the average in national level. This indicator can be influenced by the size of the household and the age of its members. For instance, Croatia's NECP explains that this indicator applies to households with many members, who consequently consume more energy resources, as well as to households with elderly members who spend a significant part of the day at home, resulting in higher energy consumption [39]. This indicator may also apply to households living in energy-inefficient homes, where more heating energy is required to maintain warmth compared to more energy-efficient homes. As such, the indicator correlates with both the first group of indicators related to household income and expenditures, and the second group related to the technical condition and energy efficiency of the dwelling.

Another indicator that cannot be included in any of the groups is access to energy, including renewable energy. This indicator is not related to household income and expenditures, but rather to the physical availability of energy infrastructure, as well as any damage to it and the time required for repairs. Bulgaria [29] and Portugal [40] has identified this indicator as relevant within its country. It should be noted that the relevant approach mainly refers to water infrastructure and renewable energy. In addition to the indicators, Bulgaria has also mentioned the overall proportion of households at risk of energy poverty. This indicator should be excluded from the set, as it does not clearly define how households at risk of energy poverty are identified [29].

Analysing the frequency of use of the aforementioned indicators in EU member states, it can be concluded that the most commonly used indicator for identifying energy poverty is the proportion of household energy expenditure relative to household income, which, in some cases, may result from high energy prices (indicator used by 13 member states – Austria, Belgium, Bulgaria, Cyprus, France, Ireland, Italy, Lithuania, Poland, Portugal, Slovenia, Spain, Sweden). Meanwhile, 11 member states (Austria, Bulgaria, Croatia, Cyprus, Denmark, Greece, Lithuania, the Netherlands, Poland, Slovenia, Sweden) have identified household income levels below a certain threshold (e.g., the average wage in the country or the minimum income threshold) and household purchasing power as indicators for identifying energy poverty, as well as the inability to keep the home adequately warm in winter or cool in summer (Austria, Belgium, Bulgaria, Czech Republic, France, Ireland, Italy, Lithuania, Poland, Portugal, Spain). Nine member states (Bulgaria, Croatia, Denmark, Ireland, Luxembourg, the Netherlands, Poland, Portugal, Sweden) have identified low energy efficiency of the housing as an indicator. These four indicators are the most frequently used for identifying energy poverty in EU member states, and they are fundamentally linked both to the energy poverty definitions approved by the member states and to the EU-level regulations on energy poverty.

3.3. Analysis of the Data Used for Determining the Indicators of the EU Member States

Regarding the data sources used to determine the value of the indicator 'household income level below a certain threshold', it can be concluded that five member states use EUROSTAT data, two member states rely on household survey data, and two member states use specific, objective data and calculations (e.g., national-level data on individual income). Meanwhile, three member states did not specify the data sources used to determine the value of this indicator in their NECPs. As for the indicator "inability to keep the home adequately warm in winter or cool in summer, eight member states use data collected by EUROSTAT, while four member states rely on national-level household survey data. None of the member states use objective data to determine the value of this indicator, which is understandable, as the individual view of warmth or cooling in a dwelling is subjective. It depends on both the

physiological characteristics of the household members and the average temperature of dwelling the household used to live in most of the year, as well as the humidity level.

Finally, regarding the determination of the value of the indicator 'low energy efficiency of the dwelling', member states primarily use objective and calculation-based data, such as building energy certificates, data on building heating or electricity consumption, and information on building renovations. Six member states have indicated that these objective data sources are used to determine the value of the indicator. Meanwhile, two member states rely on EUROSTAT data, one member state uses national-level household survey data, and two member states have not specified the data sources used in their NECPs.

Considering that the long-term goal is to develop a method for identifying energy poverty in Latvia based on objective data, and given that Latvia is an EU member state and a subject to EU-level regulatory frameworks, the author believes that, when developing this method, the following three most commonly used EU-level indicators for identifying energy poverty should be taken into account: 'the proportion of household energy expenditure relative to household income (%)', 'the household income level below a certain threshold (EUR per household member)", and 'the low energy efficiency level of the dwelling (heat consumption in MWh/m²/year)'. It should be noted that the indicator "inability to keep the home adequately warm in winter and cool in summer" is influenced by household income levels, the energy efficiency of the housing, household habits, and the physiological differences of household members. Additionally, data for this indicator is obtained through subjective household surveys, which cannot be objectively verified, as measuring a sufficiently warm dwelling at the individual level is not feasible and is influenced by several of the subjective factors. Therefore, in the author's opinion, individual obtained data for determining indicator's value may not be objective, and a detailed method for this indicator cannot be developed.

Additionally, it should be noted that the indicators related to household income and expenditure will be analysed in more detail to develop a method for determining their values. The indicator related to housing energy efficiency will also be analysed in depth as part of future work, which will involve either developing a method or utilizing existing housing maps to identify the proportion of households living in such homes.

3.4. Calculation of Indicators Related to Household Income and Expenditure

3.4.1. Indicator No. 1: Share of household energy expenditure relative to household income, %

Analysing the approach of EU member states to the indicator 'share of household energy expenditure relative to household income', it can be concluded that the critical expenditure threshold is viewed quite differently across member states. For example, Austria considers households whose energy expenditure constitutes 10–15 % of household income to be at risk of energy poverty (with the proportion of such households ranging from 3.8 % to 16.5 %, depending on the data compilation methodology used). Ireland, Italy, and Portugal set this threshold at 10 % of income. In Ireland, the proportion of such households could be as high as 29.4 %, in Italy 13.6 %, and in Portugal 11.66 %. Meanwhile, France sets the threshold at just 8 % of household income, with the proportion of affected households at 11.9 %. Belgium has not specified the exact threshold for energy expenditure, but it notes that households spending too large proportion of their income on energy are at risk of energy poverty, with the proportion of such households in the country standing at 14.9 %.

At the same time, analysing the available EUROSTAT data reveals a different trend regarding the proportion of household expenditure on energy relative to income. Specifically, in the EU, households, on average, spend 25 % of their income on energy (including water,

electricity, gas, and other fuels). Regarding the aforementioned EU member states, according to the available EUROSTAT data, the figures are as follows: Austria 25.7 %, Ireland 26.6 %, Italy 24.1 %, Portugal 19.2 %, and France 27.6 % of income, respectively. It can be concluded that the data may vary significantly depending on the data compilation methodology used. Additionally, the energy expenditure proportions indicated by individual member states may not be sufficiently objective and may not fully capture all households at risk of energy poverty [41]. Specifically, the member states mentioned primarily rely on subjective data from household surveys to determine the value of the indicator, while the EUROSTAT methodology is based on the analysis of national economic indicators, including data on energy imports, exports, consumption, residential areas, and other related metrics [42].

Considering the above, it is crucial to explore other approaches to identify household housing expenditures and determine their proportion. Analysing available literature, including the approaches developed by international organizations for identifying household housing expenditures, including energy costs, it can be said that these approaches are complex and focus more on the correlation between the amount of household housing expenditure and the household's ability to afford the respective housing. For example, the OECD states that housing is considered affordable for a household if its monthly housing expenditure does not exceed 30% of household income. Conversely, excessive housing expenditure, according to the OECD, is defined as exceeding 40 % of the household's monthly income [43]. Housing expenditure primarily refers to direct rental costs, which include rent payments for residential space. According to the OECD methodology, these are equivalent expenses that a homeowner would pay for purchasing or maintaining a home. Secondly, there are associated rental costs, such as the mandatory rent for the land under the home, payments for the use of shared spaces in the building (e.g., heating or sanitary equipment), as well as rental costs for household appliances and furniture. Thirdly, there are maintenance and repair costs necessary to keep the housing in good technical condition. The fourth category of expenditure includes utility costs, which encompass expenses for water supply, waste management, sewage collection and treatment, as well as other home-related services, such as garden maintenance, cleaning stairwells, heating and lighting of common areas, elevator maintenance, security services, snow removal, and chimney cleaning. The OECD also includes individual heating costs in the fourth expenditure group. Finally, there are energy costs – electricity, natural gas, and other energy resources, such as decentralized fuels (e.g., oil gas, diesel fuel, firewood, briquettes, pellets, etc.) [44].

It should be noted that the OECD is not the only international organization that has analysed the concept of affordable housing. The World Bank and the UN have also defined housing as affordable for a household if its housing expenses are less than 30 % of its income. Like the OECD, the World Bank and the UN include mortgage payments, rent, taxes, insurance, and service costs as part of housing expenditures [45]. At the same time, the World Bank notes that there is no consensus on how housing costs are determined, and it is important to distinguish between the costs incurred by tenants, which include rent and utility payments. However, tenants are often required to make deposit payments for the rented space, typically equivalent to one or more months' rent, which may or may not be refundable, depending on the terms of the contract. These costs can be difficult to identify, as they are not regular expenses, but they can significantly impact housing affordability for tenants. Meanwhile, the costs for homeowners include maintenance expenses (such as utilities, repairs, and homeowners association fees), property taxes, insurance, and costs associated with buying and selling the property, as well as servicing debt, without any tax relief [46].

The International Monetary Fund primarily assesses housing affordability through the lens of household income and housing prices, noting that it is determined by a household's ability

to make regular mortgage payments required to purchase housing, while also ensuring the capacity to meet other essential needs and maintain income reserves. Meanwhile, in the EU, the critical threshold for housing expenditures is considered to be 40 % of household expenses [47].

The concept of affordable housing has also been explored in academic literature. For example, Michael E. Stone, Terry Burke, and Liss Ralston argue that housing affordability must be assessed from multiple perspectives, as some households can afford any type of housing, while others can only afford subsidized or social housing. The authors further emphasize that affordable housing should be evaluated from the perspectives of tenants, homeowners, housing quality, and housing costs. In terms of housing costs, it is crucial to assess a household's ability to cover expenses such as rent or mortgage payments, interest rate, insurance, utilities, and the overall cost of maintaining the property [48]. This approach is commonly used to assess a household's ability to secure a mortgage loan and take on long-term obligations.

Meanwhile, Xiaolong Gan and his research group have proposed several sets of indicators for analysing affordable housing: economic, environmental, and social sustainability. These sets encompass a wide range of factors related to housing affordability for households. However, the indicators directly linked to household expenses include the purchase price (which determines the monthly mortgage payment), rental costs, and energy expenditures. The authors also mention such additional indicators as resilience to climate change, job availability, and sustainable land and resource use that directly impact housing affordability, though calculating them at the individual level can be challenging [49].

By analysing the above-mentioned concepts of affordable housing, along with the publicly available EUROSTAT data on the proportion of household spending on housing relative to household income, it can be concluded that household spending should not exceed 30% of income for the household to afford housing and cover all associated mandatory expenses. This suggests that a household spending more than 30 % of its income on housing is at risk of energy poverty. It is important to note that all essential household housing expenses should be considered, not just energy costs, as they constitute the overall set of expenses that a household must cover each month, with no option of leaving any of them unpaid. If a household must spend more than 30 % of its income on housing, it is often forced to reduce expenditures on essential goods (such as food and hygiene products), healthcare, education, and culture – or forgo some of these entirely – while also eliminating the possibility of making any financial savings or long-term investments.

3.4.2. Indicator No. 2: Household income level below a certain threshold (EUR per household member/in the country)

The indicator "household income level below a certain threshold (EUR/average in the country)" is closely related to the indicator "share of household energy expenditure relative to household income (%)". Specifically, by establishing that a household is at risk of energy poverty if its housing expenses exceed 30 % of its income, and calculating the amount of these expenses, it becomes possible to determine the minimum income required for a household to afford all mandatory housing-related expenses, thereby considering the housing affordable for that household.

By analysing the aforementioned information on the concept of affordable housing, the OECD, UN, and World Bank examine it in greater detail from a practical perspective, as indicated in other sources. Specifically, these organizations link affordable housing to mandatory housing expenses and regularly collect data on the proportion of households at

risk of energy poverty across various countries and regions, based on calculations derived from statistical data on these expenses. In light of this, the calculation of the indicator 'share of household energy expenditure relative to household income (%)' should follow the aforementioned approach and include expense categories such as: rental costs (including land lease for the housing), housing maintenance and repair expenses, utility costs (water supply, waste management, sewage collection and treatment, as well as other housing-related services), and energy costs – electricity, heating, natural gas, and other energy resources.

To understand what the household expenditure basket looks like in practice and how to calculate household expenses, publicly available data on household expenditures in Latvia has been analysed. The Central Statistical Bureau (CSB), conducting an irregular survey every five years, collects data on household expenses across all categories, including housing costs, which encompass the household expenses derived from the OECD's definition of affordable housing. It is important to note that, since the relevant data is collected every five years and consumer prices – including energy resource prices – are subject to change, the current inflation rate should be applied to each expenditure category when calculating household housing costs [50]. Regarding housing expenses, it should be noted that these are collected by the CSB across several data sets. By analysing the available data sets in the CSB database, it has been concluded that the CSB data set titled "Detailed Composition of Household Consumption Expenditures (ECOICOP) per Household Member per Year (euros) – Groups and Subgroups (ECOICOP), Time Period, and Territory" provides information on all the expenditure categories that could be used to calculate total household housing expenditure [51].

The main scientific result of this paper is the development of the formula for calculating the critical income threshold for energy poverty in Latvia. This formula is derived from official housing expenditure statistics and defines a practical, replicable tool for identifying at-risk households based on the concept of housing affordability. Its structure and parameters can be adjusted to reflect data availability in other countries.

Given the above, the authors propose that calculation of household housing expenditure per household member (EUR/year) should be carried out using Eq. (1) developed by the authors.

$$\begin{aligned} C = {} & R\left(R \times Ri\right) + M\left(M \times i\right) + W\left(W \times Wi\right) + D\left(D \times Di\right) + \\ & + S\left(S \times Si\right) + O\left(O \times Oi\right) + E\left(E \times Ei\right) + G\left(G \times Gi\right) + \\ & + L\left(L \times Li\right) + F\left(F \times Fi\right) + H\left(H \times Hi\right) + A\left(A \times Ai\right), \end{aligned} \tag{1}$$

where

C household housing costs per household member, EUR/per year;
R household rental costs per household member, EUR/per year;
M household maintenance and repair costs per household member, EUR/per year;
W household water supply costs per household member, EUR/per year;
D household waste collection costs per household member, EUR/per year;
S household sewage service costs per household member, EUR/per year;
O household costs for other unclassified housing-related services per household member, EUR/per year;
E household electricity costs per household member, EUR/per year;
G household gas costs per household member, EUR/per year;
L household liquid fuel costs per household member, EUR/per year;
F household costs for solid fuels per household member, EUR/per year;

H household costs for thermal energy per household member, EUR/per year;
A household costs for home equipment, household appliances, and daily home maintenance per household member, EUR/per year;
i inflation coefficient according to the type of expenditure.

Considering the previously mentioned approaches regarding the housing available to households and its overall share of household income, which does not exceed 30 %, the minimum income level required for a household to ensure access to housing can then be calculated using Eq. (2) developed by the authors.

$$I = \frac{C}{30 \times 12} \times 100, \tag{2}$$

where
I household income per household member, EUR/per month;
C household housing costs per household member, EUR/per year.

Using the two formulas that have been developed by authors as the result of the research, the CSP data set, and the inflation calculator, it has been calculated that monthly income threshold per household member for households at risk of energy poverty in Latvia has changed from 285.78 EUR in 2019 to 387.39 in 2024 (Fig. 2).

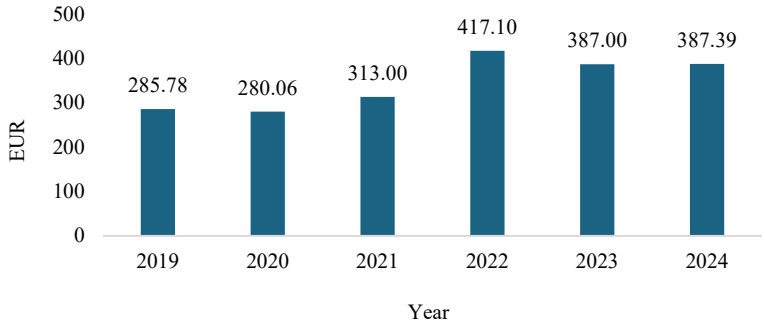

Fig. 2. Monthly income threshold per household member for households at risk of energy poverty, EUR.

The proposed formulas provide a general understanding of how housing-related expenditure and household monthly income can be assessed – specifically, whether a household can afford housing or, conversely, is at risk of energy poverty. Regarding the calculations shown in Fig. 2, it can be concluded that monthly income threshold for households at risk of energy poverty varies, and the formula proposed by authors provides the ability to monitor it regularly, which is one of the prerequisites for developing a sustainable policy aimed at reducing the proportion of such households.

It should be noted that the proposed approach does not offer a specific or detailed calculation that considers factors such as the number of household members, individual housing (especially energy) expenditures, the size of dwelling, energy efficiency, or the type and efficiency of installed heating systems. At the same time, it must be emphasized that implementing such an individualized and highly detailed approach would not be feasible without conducting a survey of all households in Latvia. Therefore, the individual, detailed approach is not suitable for determining average statistical data.

4. CONCLUSIONS

By analysing approaches to define and identify energy poverty, it can be concluded that the common factor among them is the inability of households to access energy and the services or basic needs that depend on such access.

Although many of the mentioned international organizations (EU, OECD, IEA, etc.) or institutions have overlapping member states – meaning that one country is a member of several of them – there is a noticeable lack of a unified approach to defining energy poverty and identifying households at risk of it.

Similarly, the data collected by international organizations and institutions on households at risk of energy poverty, as well as those without access to affordable housing or clean energy, vary. Countries use both data-driven and subjective indicators to identify households at risk of energy poverty.

In developing a unified approach to identifying households at risk of energy poverty, the following indicators are recognized as measurable and data-based: the share of household energy expenditure relative to household income (%), and the household income level below a certain threshold (EUR per household member/in country).

By analysing the approaches of international organizations in determining the share of household energy expenditure relative to household income, it was concluded that households experience difficulties in affording housing and covering monthly housing expenditure when it exceeds 30 % of their monthly income. Based on this, a data-driven calculation formula was developed to determine the average monthly household expenditure on housing, as well as the monthly income per household member for households at risk of energy poverty.

The proposed formulas, which constitute the main output of this research, offer a novel, evidence-based tool for identifying energy poverty. Its simplicity and reliance on publicly available data make it applicable beyond Latvia and potentially useful for harmonizing energy poverty definitions across the EU.

The proposed approach and calculation formulas for identifying households at risk of energy poverty can only be applied in practice if supported by additional tools. These tools must be capable of calculating average household income per household member in Latvia – using, for example, data held by the State Revenue Service on the incomes of all Latvian residents – and identifying households, which may consist of individuals declared or registered at the same address. The approach was developed based on publicly available data in Latvia regarding household housing expenditure. However, considering that other EU member states also compile relevant data for submission to international organizations, the approach developed in this study for identifying households at risk of energy poverty could also be adopted by other EU member states.

By applying the approach developed in this study, the proportion of households at risk of energy poverty in Latvia could be identified. Additionally, in-depth research could be conducted for the practical implementation of the proposed approach, and such factors influencing the data as shadow economy or incorrect declaration of residence must be analysed in detail. In addition, it should be assessed whether other factors should be considered when adjusting the estimated household income levels or the proportion of households identified as being at risk of energy poverty based on statistical data, and a unified correction factor for the data on share of households at risk of energy poverty could be developed.

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