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Socio-Economic and environmental indicators: do they go hand in hand or back to back? A zoom into SDG 7

Carla Rodrigues Teotónio*, **Maria Rita Martins and Micaela Alegria Antunes**

Univ Coimbra, CeBER, Faculty of Economics, Av Dias da Silva 165, 3004-512 Coimbra, Portugal

ABSTRACT

The EU is succeeding in the achievement of climate and energy targets, but affordability of energy services, cannot be overlooked.

Interlinkages between SDG 7's social, economic, and environmental dimensions are assessed to understand whether they go hand in hand or back to back. Using Eurostat data for 27 countries on the share of households unable to keep homes warm, energy dependency, and the share of renewables, we compute correlations and plot scatter and Venn diagrams, to expose national relative performances in the three indicators. Results show a diversity of synergistic or trade-off paths, making clear that the solutions to improve the progress in SDG 7 cannot be the same for all Member States and that even the most urgent measures in a domain should not compromise progresses in others.

The micro affordability ratios computed and the share of households with affordability problems expose a greater extension of issues than those revealed by the EU affordability indicator, confirming the relevance of looking at the problem from different lenses. Moreover, households with elders and living in more isolated areas are especially prevalent among those with affordability problems. This should be accommodated in policy measures to support those most in need.

Keywords

SDG 7;
Affordability;
Reliability;
Sustainability;
Interlinkages;

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1. Introduction

The United Nations' 2030 Agenda and its 17 Sustainable Development Goals (SDG) [1] set the scene to achieve a better and more sustainable future for all. The fulfilment of SDGs and corresponding targets for the 2030 horizon is monitored by a comprehensive list of indicators which aim to provide an accurate portrait of targets' accomplishment at national scales; presently, the indicators total 231 [2]. Such multitude of indicators allows for an assessment of national pathways towards sustainability, even though compliance with some targets might be achieved at the expense of a poorer performance towards others. This opens room for research on the interlinkages between the different dimensions covered by each SDG so that more informed policies can be designed.

United Nations (UN) SDGs frame many national public policies and international pledges and, thus, the fulfilment of SDGs is at the origin of a vast research. One strand in literature refers to the establishment of countries' rankings (e.g., [3–6]), with the European Union (EU) and other Organisation for Economic Co-operation and Development (OECD) countries taking the lead of the SDGs achievement [7]. According to Hametner and Kostetckaia [7], within the EU, Scandinavian countries tend to record the highest levels of fulfilment, whereas the lowest refer to Southern and Eastern countries, but Tóthová and Heglasová [4] show that each country results and rankings' position greatly depend on the method and indicators used in the analysis.

Another strand in literature that has gained major importance is the investigation of the interlinkages

*Corresponding author – e-mail: carla.teotonio@fe.uc.pt

between goals and targets, with several studies focusing on the analysis of synergies (that is, progressing in one dimension can contribute to progress in others) and trade-offs (i.e., progressing in one dimension may hamper progress in others), emerging in the pathway towards the 17 SDGs and corresponding targets (e.g., [8–15]).

Our research falls within the latter strand, but focusing specifically on the SDG 7 – 'Ensure access to affordable, reliable, sustainable and modern energy', as few studies have empirically investigated the interlinkages within this particular SDG - Ribak et al. and Firoiu et al. [16,17] are an exception. Both studies investigate how the EU 27 countries progressed towards SDG 7 carrying out cluster analysis and using the Eurostat set of indicators for SGG 7 accomplishment. Ribak et al. [16] analysed the period between 2000 and 2019 and found out that differences in the direction of changes and in the pace of progresses have been intensifying between countries, with the most recent EU Member States still facing significant challenges. Firoiu et al. [17] restricted their analysis to the period after the adoption of the Paris Agreement and therefore compared countries' performances in 2015 to those in 2019, in terms of SDG7 indicators. The authors found out that the cluster of best performing countries has grown over time, but also that some other countries barely progressed or even worsened their performance over this period.

Our study adds to the literature in that we use alternative ways to group countries according to their performances in SDG 7 indicators, thereby obtaining a more comprehensive understanding of EU27 diverse realities. First, a correlation analysis for 2005-2020 informs us about the synergies, trade-offs or absence of interlinkages between the different dimensions of SDG 7 - notably the affordability of energy services and the reliability and sustainability of the energy system. These performances somehow explain the actual relative position of each Member State in these indicators. Then, a pairwise analysis for the countries' current performance in those dimensions allows us to understand that an apparently similar positioning may translate very distinct combination of situations. Finally, comparison of countries' performance with the EU27 average is combined for all domains, thereby gathering countries according to their overall position towards the fulfilment of SDG 7. As we proceed from one empirical step to another, we are not thus tied to a single form of grouping countries.

Awareness of the synergies and trade-offs within SDG 7 is crucial not only to ensure that sectoral policies are aligned in a way that pursuing certain objectives do not compromise attaining the others, but also to ensure a broader positive impact of policies towards the fulfilment of other SDGs. Indeed, several articles emphasize the influence of SDG 7 over the progress in other SDGs (e.g., [9,18–22]).

The pathway towards SDG 7 targets is monitored via the abovementioned UN SDGs indicator list, from which the EU established its own SDGs indicator set to better reflect European characteristics [23]. Hence, within the EU, the monitoring of SDG 7 relies on advancements regarding energy consumption, energy supply and widespread access to affordable energy [2], with the EU SDG 7 indicators' list encompassing the following: i) primary energy consumption; ii) final energy consumption, iii) energy productivity, iv) the share of renewables in final energy consumption, v) energy import dependency, vi) greenhouse gas emissions and vii) the unability to keep the home adequately warm [24].

In the EU, the SDG 7 backs the Community policies for climate and energy, under which there have been established, for successive time spans, ambitious targets that make the EU the global leader towards sustainability. In particular, the EU is presently committed to achieve, by 2030, at least a 55% reduction in greenhouse gas emissions (from 1990 levels) [25,26]; the target for energy efficiency is proposed to follow an increase from 32.5% to 36% for final, and to 39% for primary energy consumption [27]; and the target for the share of renewable energy in the overall energy mix is proposed to increase from 40% to 45% [28]. The EU targets for 2030 build on the Europe 2020 Strategy [29–31], which established the so-called '20-20-20' targets for climate change mitigation, renewable energy deployment and energy efficiency gains. According to the European Environment Agency [32], these were achieved, and, therefore, countries are broadly succeeding in promoting sustainability, especially in its environmental and economic dimensions, even if in part owed to the significant decrease in energy consumption resulting from the restrictions imposed by the COVID-19 pandemics.

Despite the overall satisfactory performance, socio-economic aspects of sustainable development, such as the affordability of energy services, cannot be left behind. It is consensual that energy affordability is key to ensure universal access to energy and to avoid energy poverty. However, affordability is not always given the same priority in the national and EU political agendas as the other dimensions. Even in energy systems modelling, socio-economic aspects are often disregarded, possibly due to the difficulties in their correspondence with quantitative metrics [33]. Current disruptions in energy markets, caused by the economic recovery in the post pandemic and the war in Ukraine, have further underlined the importance of ensuring affordability of energy services and diversification of energy supply to safeguard energy security, and triggered the implementation of REPowerEU Plan [28], whose motto is "affordable, secure and sustainable energy for Europe".

That is, in the EU climate and energy policy framework, alongside with climate concerns, affordability of energy services constitutes, more than ever before, a topic of utmost importance. Besides, in what concerns affordability, accurate and wide diagnoses are needed. These are the starting point to design adequate policies to ensure universal access and to tackle energy poverty, notably through the improvement of energy efficiency in the residential sector. What happens, though, is that analyses based in a single indicator of affordability with aggregated data may inhibit to see the entire picture of the problem and, thereby, are strongly discouraged [34]. Das et al. [35], for example, quantify the prevalence of energy poverty in Canada through the computation of households' energy burden, but recognize the need of considering complementary approaches to measure energy poverty. Bryan and Kelley [36] (in an assessment of households' inability to meet basic energy needs adequately in the Southeast, USA) recommend using an array of metrics to analyse affordability so as to effectively inform policymakers.

Actually, despite affordability ratios are one of the most used measures of affordability of essential services [37], their outcomes may induce a misinterpretation of affordability problems when used alone. In fact, affordability ratios may be low not only due to the inexistence of affordability problems, but also because households refrain consumption due to budget constraints without the minimum level of comfort being assured. Underconsumption thus configures a "hidden" affordability problem that is not detectable by this metric per se. Conversely, high affordability ratios may be associated with high expenditures due to low efficiency of buildings and domestic appliances or they may be simply because households can afford to spend more, without affordability issues arising from that situation [38,39]. An integrated approach to affordability is thus desirable to fully capture the different extensions of this problematic.

In this context, the aim of this paper is two-fold. The first is to perform a joint analysis, within the EU, of the advancements on affordable, reliable and sustainable energy strands of SDG 7, to contribute to a more in-depth understanding of the interlinkages between the targets set, and to gain insight on whether underlying policies may be mutually reinforcing or jeopardizing.

The second aim is to deepen the knowledge on the affordability strand to derive policy recommendations to promote energy affordability. More specifically, we intend to conduct a comparative analysis between the indicator assigned within the EU to monitor affordability progress (the share of households unable to keep their homes adequately warm) and the share of households with problematic affordability ratios for EU countries, that we compute from micro data. Also, by exploring the richness of microdata and within this second objective of the paper, we aim to compare the burden of energy expenditures of the poorest fringe of the population with that of the total population, and to understand whether there are expressive differences between households with affordability problems and the total population, regarding households' sociodemographic profiles and the population-density of the living areas.

Our research thus fits into the strand of literature that analyzes the pathways to progress towards a sustainable energy future. Sustainable energy is critical to improve the quality, accessibility and reliability of services, which corresponds to the main concerns within the SDG 7. Multi-faceted approaches are needed to address how policies should orient energy systems to adapt, by accommodating demand side needs with constraints from supply side solutions and by avoiding that the improvements in one dimension endanger the performance in others.

To perform our analysis, and concerning the first objective, we take advantage of selected EU SDG 7 indicators referring to the affordable, reliable and sustainable energy strands, notably the share of people not able to keep their homes adequately warm, the energy import dependency and the share of renewables in final energy consumption, respectively, obtained via the EU Statistics on Income and Living Conditions (EU-SILC) and the Eurostat database.

To address energy reliability and sustainability, we selected, among the seven indicators established in the EU SDG set for SDG 7, two that we consider reasonable proxies for each. As to energy reliability, it is proxied by energy import dependency in the sense that dependence on imports of energy carriers exposes national economies to world market prices and to the risk of supply shortages (like the one the EU is facing nowadays due to the war in Ukraine) – therefore, the national energy system is all the more reliable as the lower its energy dependency from the exterior, what encompasses increasing domestic production (notably from renewables), curbing energy demand and improving energy efficiency [2].

Concerning sustainability, we use the share of renewable energy in final consumption due to its direct link to climate change mitigation and consequent contribution to the environmental protection embodied in sustainable development.

To measure affordability of energy services, we use the share of people not able to keep their homes adequately warm, which is set within the EU SDGs indicator list based on the idea that the lack of access to affordable energy derives from low levels of income combined with high expenditure on energy services and energy inefficient buildings [40], and is an ever-present indicator to monitor and investigate energy poverty in the EU (see e.g., [41–43]).

Empirical evidence shows, however, that the information on energy affordability provided by this indicator is not unequivocal. For example, Deller et al. [44] concluded, for the UK, that energy affordability problems captured by expenditure-based metrics are much more expressive than households' self-assessed inability to afford adequate warmth, whilst Agbim et al. [45], for Texas, concluded the opposite. Additionally, two major drawbacks are pointed out to the share of people not able to keep their homes adequately warm as a metric of energy affordability: on the one hand, it disregards subjective factors that condition energy needs, and, therefore, energy expenditure, such as age, health status or climatological culture; on the other hand, it only considers heating needs, despite cooling needs are increasingly becoming an urgent matter due to rising temperatures and the frequency of extreme climate events [46].

Hence, beyond being disregarded by energy policies – in the EU context, affordability is mostly addressed by social policies, it is also not certain that the measure used to assess affordability provides the most consistent picture of reality by itself, as well as of the dimension of this problematic all over the EU. A more accurate analysis of energy affordability may benefit from the complementarity with other metrics that take into account information disregarded by this indicator. One of the metrics that can provide an effective contribution to the assessment of energy affordability problems in the EU are affordability ratios, commonly used in the literature (e.g. [47–51]) and also by international institutions such as the UN, OECD and the World Bank, as well as by economic regulatory agencies.

Affordability ratios provide the weight of energy expenditure on households' resources and are, then, compared with thresholds that can be either absolute, i.e., a fixed percentage, or relative, i.e., considering the median or average weight of energy expenditure on income. Among the absolute thresholds, the most common practice is to consider that households whose affordability ratio surpasses 10% face energy affordability problems. This threshold, defined in the 1990s for the British context [52], is widely spread in literature, but, since then, other [lower] limits have been proposed: 6-7% [53,54], 5-10% [48], or 4% [55], for example.

The use of microdata is crucial in affordability analyses to overcome limitations arising from the use of aggregate data on energy expenditure and households' resources. Nonetheless, such microdata is not readily available, as it may stem from expenditure surveys that are carried out with long time intervals, such as the national households' budget surveys over Europe, or from surveys specifically designed for the purpose of a particular research. Despite some shortcomings (see e.g., [46,56]), their easiness of operation, objectivity and effectiveness in passing a message make affordability ratios one of the most used tools to assess energy affordability in developed countries [57].

Summing up, the inability to keep homes adequately warm and the share of households with problematic ratios capture different facets of households lives to measure the same problem of affordability of energy services. Whereas the former relies on a subjective indicator collected from self-reported perceived conditions about thermal comfort of dwellings, the latter relies on households' resources and energy expenditures. Given their distinct nature, the combination of the two has the potential to reveal diverse features and deepen the knowledge of the affordability problem in the EU so that policy implications can be derived.

Focusing on the EU, the contribution of this paper to the literature is twofold. First, to go further in the research about the interlinkages arising from the progress towards SDG 7 to understand whether each country pathway towards the ambitions of affordable, reliable and sustainable energy for all are converging or, conversely, following divergent pathways. This is important for calling the attention for the fact that certain policies, intended to contribute to progress in one area may have undesirable repercussions in others. For instance, in a country where it is critical to reduce energy dependency and large fringes of the population face affordability problems, it is necessary to ensure that solutions to solve or mitigate the first do not result in worsening the second.

The second contribution is to deepen the research on the affordability dimension, by computing a complementary indicator - the share of households with problematic affordability ratios - to be used along with the EU proxy (the share of households unable to keep their homes adequately warm). Besides, using microdata enables us to highlight how severe affordability problems are for the poorer and to figure out which families are particular hit by affordability problems, relying on households' composition and location. This exercise can, therefore, effectively contribute to the design of more informed EU and national policies.

The remainder of the paper is organized as follows: Section 2 describes the methods and data used in this research; Section 3 presents the results; Section 4 concludes.

2. Methods and data

To carry out the analysis about the interlinkages between the different dimensions covered by SDG 7, in the first part of the paper, we focus in three selected indicators of the EU SDGs set to understand if the ambitions of Affordability, Reliability and Sustainability of the energy system are going hand in hand or back to back, i.e., whether there exist synergies or trade-offs between the performance of countries in each of those dimensions.

Accordingly, access to affordable energy is addressed by the proxy used by the EU to monitor the affordability of energy services, that is, the share of households that self-reported to be unable to keep their homes adequatly warm (hereafter, the %UKW indicator). Reliability is addressed by energy import dependency defined as the ratio of net imports to gross available energy (hereafter,%ED). Gross available energy is the overall supply of energy for all activities on the territory of the country and thus also includes energy transformation, losses and use of fossil fuel products for non-energy purposes. Finally, sustainability is addressed by the share of renewable energy in gross final energy consumption, which includes the energy used by end-consumers and grid losses, as well as self-consumption of power plants (hereafter, %RES).

Our analysis includes the current 27 EU countries (AT-Austria; BE-Belgium; BG-Bulgaria; CY-Cyprus; CZ-Czechia; DE-Germany; DK-Denmark; EE-Estonia; EL-Greece; FI-Finland; FR-France; HR-Croatia; HU-Hungary; IE-Ireland; IT-Italy; LT-Lithuania; LU-Luxembourg; LV-Latvia; MT-Malta; NL-Netherlands; PL-Poland; PT-Portugal; RO-Romania; SE-Sweden; SI-Slovenia; SK-Slovakia; SP-Spain).

We firstly describe national performances in these indicators for the period 2005-2020, provided by Eurostat [24]. Whenever relevant, we add information on the EU27 average, also provided by Eurostat [24].

Next, we use the nonparametric Spearman's rank correlation, supported by the literature (e.g, [9,58]) to measure the sign and strength of the association between each pair of indicators for each country, for the greatest time span available, generally, 2005-2020 (the exception is the %UKW indicator for Romania (2007-2020), Croatia (2010-2020) and Italy (2005-2019)). The formula for Spearman's rank correlation (ρ) is given in Eq.(1):

$$\rho = \frac{s_{x,y}}{s_x s_y} = \frac{\frac{1}{n}\sum_{i=1}^{n}\left(R(x_i)-\overline{R(x)}\right)\left(R(y_i)-\overline{R(y)}\right)}{\sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}\left(R(x_i)-\overline{R(x)}\right)^2\right)\left(\frac{1}{n}\sum_{i=1}^{n}\left(R(y_i)-\overline{R(y)}\right)^2\right)}} \quad (1)$$

For variables x and y, the Spearman's rank correlation is calculated as Pearson's correlation computed on the ranks (R) and average ranks ($\bar{R}$), where n is the number of observations.

Following Pradhan et al. [9], a correlation coefficient greater than 0.6 in absolute value is assumed to reveal an association between the two indicators, that may be a synergy, if both indicators record a favorable trajectory, or a trade-off, if one indicator records a favorable trajectory and the other does not. By turn, a correlation coefficient lower than 0.6 in absolute value indicates the interlinkage is weak. The statistical significance of the correlation is evaluated at the 10% significance level.

Then, focusing on 2020, the most recent year for which there is joint available information on the three indicators, we represent scatter plots for a pairwise analysis of each country's position in the different dimensions (Reliability-Sustainability, Affordability-Sustainability and Affordability-Reliability).

Finally, for 2020, we combine the three dimensions in a Venn diagram which gathers the countries whose performance is, at least, as good as the EU27 average in each domain, to envision which countries perform better in one, two, or the three dimensions.

In the second part, we use microdata from the 2015/16 wave of the European Household Budget Survey (EHBS), which was released in mid-2021 and thus corresponds to the most recent data available (access was granted under the Eurostat research project RPP 60/2020-HBS), with 272,022 observations. Austria was not included in the analysis due to unavailable data and, so, in this second part, we rest on 26 EU countries. Sample weights provided in the dataset were used.

We compute the Energy Affordability Ratio for each household i, in each country j, EARij, as indicated in Eq. (2):

$$EAR_{i,j} = \frac{Exp\_energy_{i,j}}{Exp\_total_{i,j}} * 100 \tag{2}$$

Where $Exp\_energy_{i,j}$ is the expenditure on energy (including electricity, piped gas, liquefied gas in cylinder, liquid fuels, coal, other solid fuels and thermal energy) of household *i* in country *j* and $Exp\_total_{i,j}$ corresponds to the total consumption expenditure of household *i*, in country *j*, a proxy for households' resources. One of the advantages of using total expenditure instead of income is that it is less susceptible to conjunctural changes, especially at times of economic crisis [59]. Furthermore, total expenditure can derive from different sources of households' resources as well as from the financing of current consumption through savings or credit [60].

From the information on households' EAR, and bearing in mind the 10% threshold generally used in the literature and reports from international organizations as the threshold beyond which families are considered to have affordability problems, we also compute, for each country, the share of families with affordability problems (%Afford_problems).

Following the computation of average national affordability ratios, from microdata, we represented a boxplot for every country, together with the corresponding EU26 average, to summarize some of the main descriptive statistics (average, 25th, 50th and 75th percentiles), regarding the EAR. Finally, we combine the information on the share of families unable to keep their homes adequately warm (% UKW) and the share of families with affordability problems (%Afford_problems) in a scatterplot, using the latest common data available (2015), for a contemporaneous comparison of national performances. In fact, the most recent data for the EHBS refer to 2015 and, therefore, for the sake of accuracy and because our ultimate goal is to understand to what extent these two metrics provide identical portraits of energy affordability, we contrast the outcomes provided by both indicators for the same year.

To densify our analysis on microdata, we replicate the analysis of the EAR for poorer households, proxied by families in the first expenditure quintile. Moreover, we look deeper into those families facing affordability problems (EAR>10%), to give some insights about the following sociodemographic features: presence of children (*child*) or elder (*old*) in the household, family size (*fam_size*), and the population density level of the residence area, ranging from densely populated areas (*dens*) – with at least 500 inhabitants/km^2, to sparsely populated (*spars*) - less than 100 inhabitants/km^2. Cyprus, Croatia, Hungary and Lithuania were dropped from the analysis at this phase, for problems with reported data on the type of household. This means that we end up with 256,489 observations (and 65,516 for families with affordability problems), for the (now) EU22.

3. Results

In Section 3.1 we analyse the interlinkages between socio-economic and environmental indicators used to monitor SDG 7 in the EU. Section 3.2 is devoted to the affordability of energy services.

3.1. Measuring interlinkages between energy indicators

The EU trajectory in the dimensions of energy affordability, reliability and sustainability over the period 2005-2020 is quite diverse. Whereas in the domains of affordability and reliability there is no uniform trend, with some countries better off and some worse off, in one or both, at the end of the period, in the domain of sustainability there is a consistent positive trend all over the EU, with all countries strenghtening the role of renewables.

Concerning the affordability of energy services, as measured by %UKW indicator, the EU recorded a continuous declining trend (from 11.2% in 2012 to 6.9% in 2019; [24]), although in 2020 this share raised to 8.2%, probably due to the COVID-19 pandemics that deteriorated the living conditions of numerous households all over Europe, mainly the most vulnerable, and very likely to be worsened due to the war in Ukraine.

The trajectory of the EU27 as a whole hides very different national performances. The situation is of particular concern in Bulgaria, Lithuania, Cyprus, Portugal and Greece, whose shares are more than twofold the EU27 average (ranging from 16.7% in Greece to 27.5% in Bulgaria). The most significant progresses occurred in Eastern countries whose %UKW indicator was very high some years ago, notably in Poland, Latvia, Czechia and Hungary (Table 1). As to the reliability of energy supply, the EU27 energy import dependency was kept almost constant between 2005 and 2020, reaching 57.5% in 2020. Among the EU27, Malta, Cyprus, Luxembourg and Greece record the highest dependency rates (all above 80%).

During 2005-2020, 18 out of the 27 countries reduced their reliance on imports (Table 1); the greatest improvements were achieved by Estonia, Latvia, Portugal and Finland, whose energy import dependency reduced by more than 20% (ranging between -23% in Finland and -61% in Estonia). Finally, achieving a sustainable energy system requires that the role of renewables is increasingly strengthened. Among the EU27, the %RES rounded 24% in 2020, resulting from a 94% increase between 2005 and 2020 (4.5%/year; Table 1). The EU27 average derives from very heterogeneous performances at the country level: while in some Member States the %RES had not attained 15% yet in 2020 (Malta, Luxembourg, Belgium, Hungary and the Netherlands), in others it already attained or surpassed 30%, the EU target for 2020 (see [29]), ranging from 30% in Estonia to 60% in Sweden.

Afterwards, we computed the nonparametric Spearman's rank correlation for each country to measure the sign and strength of the association between each pair of indicators, for the period between 2005 and 2020. Table 2 summarizes the breakdown of the different interlinkages for each pair of indicators, per country. Focusing on the interlinkages between national energy indicators, the pair 'Reliability (ED) – Sustainability (%RES)' exhibits the largest number of synergistic interlinkages (for 13 countries). For the pairs 'Affordability (%UKW) – Sustainability (%RES)' and 'Affordability (%UKW) – Reliability (ED)', we could not find a statistically significant association between the indicators for a substantial number of countries (14 and 15 out of 27, respectively).

Within the EU27, only three countries – Bulgaria, Latvia and Portugal – record a synergistic relationship between the three dimensions. These countries evolved favorably over the period 2005-2020 in the three indicators, lowering their energy dependency from the exterior, increasing the penetration of renewables in their energy consumption and diminishing the share of households with perceived affordability problems. However, there is still a way to go in Bulgaria and Portugal, especially to ensure affordable energy services for all, as shown in Figures 1 to 3.

Latvia, in particular, has traced a favorable and consistent pathway over this period in the three dimensions, with noteworthy progresses in the affordability dimension, as its performance was the sixth poorest in the EU27 in 2005 (around 30% of households revealed affordability problems), as well as in energy dependency, which was aligned with the EU average but is nowadays well below, and in the role of renewables, where the country performs better than the EU since ever.

Such synergies are likely the result of national policies in these domains and of concrete measures to tackle the problems, that, evidently, are not an exclusive of these three countries. The fact is that in these cases, the outcomes of such policies resulted in a combined positive evolution of all the indicators used to measure such dimensions (as confirmed by the annual average growth rates between 2005 and 2020 shown in Table 1). Other countries recorded similar favorable average growth rates in the three indicators, but either the association between the variables is weak (between -0.6 and 0.6), what occurs for Slovakia, between the Reliability and Sustainability dimensions, or there is no statistically significant association between the variables (this occurs, e.g., for Finland, Hungary and Ireland between Reliability and Affordability, and between Affordability and Sustainability).

Our results are, thus, aligned with Szép et al. [61], who concluded that Bulgaria, Latvia and Portugal are among those EU27 countries that progressed favorably in economic, social and environmental energy sustainability between 2007 and 2019, whereas Germany, Lithuania, the Netherlands, Slovenia and Slovakia are among the laggards in sustainable energy transition.

Table 1: National and EU trends on Affordability, Reliability and Sustainability dimensions of SDG 7

Country	Affordability		Reliability		Sustainability	
	%UKW		%ED		%RES	
	2020	AAG 2005-2020	2020	AAG 2005-2020	2020	AAG 2005-2020
AT	1.5%	–4.9%	58.4%	–1.4%	36.5%	2.7%
BE	4.1%	–7.9%	78.1%	–0.2%	13.0%	12.2%
BG	27.5%	–6.0%	37.9%	–1.5%	23.3%	6.4%
CY	20.9%	–3.1%	93.1%	–0.5%	16.9%	11.9%
CZ	2.2%	–9.2%	38.9%	2.3%	17.3%	6.1%
DE	7.0%	2.8%	63.7%	0.3%	19.3%	6.8%
DK	3.0%	–7.0%	44.4%	199.1%	31.7%	4.7%
EE	2.7%	0.3%	11.0%	–6.0%	30.1%	3.7%
EL	16.7%	0.4%	81.8%	1.2%	21.7%	7.6%
FI	1.8%	–2.4%	42.0%	–1.7%	43.8%	2.8%
FR	6.5%	1.4%	44.5%	–1.0%	19.1%	4.9%
HR	5.7%	–2.5%*	53.6%	0.1%	31.0%	1.8%
HU	4.2%	–9.1%	56.6%	–0.6%	13.9%	4.7%
IE	3.3%	–1.3%	71.3%	–1.5%	16.2%	12.3%
IT	11.1%	0.1%**	73.5%	–0.8%	20.4%	6.8%
LT	23.1%	–2.7%	74.9%	2.0%	26.8%	3.2%
LU	3.6%	9.7%	92.5%	–0.3%	11.7%	15.2%
LV	6.0%	–10.1%	45.5%	–2.2%	42.1%	1.8%
MT	7.2%	–3.7%	97.6%	–0.2%	10.7%	34.7%
NL	2.4%	–1.7%	67.9%	4.0%	14.0%	12.2%
PL	3.2%	–14.5%	42.6%	6.0%	16.1%	5.8%
PT	17.5%	–5.4%	65.3%	–2.0%	34.0%	3.8%
RO	10.0%	–7.7%***	28.2%	0.2%	24.5%	2.2%
SE	2.7%	4.5%	33.9%	–0.8%	60.1%	2.8%
SI	2.8%	0.5%	45.8%	–0.7%	25.0%	1.6%
SK	5.7%	–5.6%	56.2%	–1.1%	17.3%	6.9%
SP	10.9%	1.0%	67.9%	–1.2%	21.2%	6.3%
EU27	7.5%	–2.7%*	57.5%	0.00%	22.0%	5.3%

Note: AAG–average annual growth; *between 2010 and 2020; ** between 2005 and 2019; *** between 2007 and 2020

AT-Austria; BE-Belgium; BG-Bulgaria; CY-Cyprus; CZ-Czechia; DE-Germany; DK-Denmark; EE-Estonia; EL-Greece; FI-Finland; FR-France; HR-Croatia; HU-Hungary; IE-Ireland; IT-Italy; LT-Lithuania; LU-Luxembourg; LV-Latvia; MT-Malta; NL-Netherlands; PL-Poland; PT-Portugal; RO-Romania; SE-Sweden; SI-Slovenia; SK-Slovakia; SP-Spain.

Tables 1 and 2 portray the countries' evolution in the three domains over the period 2005-2020, Figures 1 to 3 provide a pairwise picture of the 27 Member States' current performance in the three dimensions of SDG 7 – Affordability, Reliability and Sustainability. The dashed lines splitting the quadrants indicate the averages for the EU27.

Figure 1 compares national performance regarding Reliability (%ED) and Sustainability (%RES). The desirable position lays in the bottom-right quadrant (at green), which implies higher shares of renewables and lower energy dependency rates. Northern and Baltic countries, along with Croatia, Romania, Bulgaria and Slovenia, record the best performances, whereas a considerable number of Central and Southern countries still have some way to go in this respect as they locate in the top-left undesirable quadrant (at red). Focusing in these latter, current performance is the culmination of distinct pathways recorded from 2005 to 2020.

Table 2: Interlinkages between SDG 7 dimensions, per country, 2005-2020

	Type of interlinkage			
Indicators	Synergy*	Trade-off*	Weak*	No statistical significance
Reliability (%ED) – Sustainability (%RES)	BG, CY, EE, FI, FR, HU, IE, IT, LU, LV, PT, SE, SP	CZ, DE, DK, PL	AT, NL, SI, SK	BE, EL, HR, LT, MT, RO
Affordability (%UKW)-Sustainability (%RES)	AT, BE, BG, CY, CZ, LV, PL, PT, RO	LU	DE, EL, IT	DK, EE, FI, FR, HR, HU, IE, LT, MT, NL, SI, SE, SK, SP
Affordability (%UKW) – Reliability (%ED)	BG, LV, PT	CZ, IT, LU, PL	CY, DE, HR, SP	AT, BE, DK, EE, EL, FI, FR, HU, IE, LT, MT, NL, RO, SE, SI, SK

* Spearman's correlation coefficient statistically significant at 10% level

AT-Austria; BE-Belgium; BG-Bulgaria; CY-Cyprus; CZ-Czechia; DE-Germany; DK-Denmark; EE-Estonia; EL-Greece; FI-Finland; FR-France; HR-Croatia; HU-Hungary; IE-Ireland; IT-Italy; LT-Lithuania; LU-Luxembourg; LV-Latvia; MT-Malta; NL-Netherlands; PL-Poland; PT-Portugal; RO-Romania; SE-Sweden; SI-Slovenia; SK-Slovakia; SP-Spain.

In fact, despite still presenting a poor performance in these two indicators, Cyprus, Ireland, Italy, Luxembourg and Spain recorded a synergistic interlinkage between these two dimensions in the last 15 years, meaning that both indicators have been evolving favourably (what is corroborated by Table 1). Conversely, in Germany the current poor performance is backed by a trade-off, due to the unfavorable evolution of energy dependency. In the Netherlands, the association between the two variables is too weak to infer any interlinkage and in Belgium, Greece and Malta no association was found (see Table 2).

However, not only the location in the red quadrant may be of concern; the origin of energy imports, as well as the strong reliance on a sole provider constitute additional challenges and may put stronger strains on countries than energy dependency itself, as the current situation in the EU has shown. For instance, Lithuania records an energy dependency rate lower than several other EU27 countries, but its dependency on Russia imports reaches 96% [62], what may trigger a quicker response to improve the reliability dimension of SDG 7.

Also, three countries in the bottom-left quadrant record among the lowest energy dependency rates, but their energy mixes are clearly dominated by fossil fuels (Poland; 80%), nuclear energy (France; 75%) or both (Czechia; 46% fossils and 32% nuclear energy; see [62]). Hungary, Slovakia and Austria are quite aligned with the EU average as regards energy dependency but not on the Sustainability dimension, with nuclear energy and fossil fuels clearly dominating in the former two countries.

Figure 2 portrays the Affordability and Sustainability dimensions, scattering the share of population unable to keep their homes adequately warm (%UKW) against the share of renewables in final energy consumption (%RES). Once more, some Northern and Baltic countries, along with Croatia and Slovenia, in the bottom-right quadrant, record the best performances, whilst those performing badly in both dimensions are Southern countries. Again, the present situation in these dimensions derives from distinct pathways since 2005. Whereas in Cyprus both indicators recorded a favorable synergistic interlinkage over the period, in Greece and Italy, the relationship between them was weak and in Spain it was not statistically significant (see Table 2).

Despite performing well in Sustainability, some of the poorest countries in terms of per capita income (Bulgaria, Portugal, Lithuania and, to a less extent, Romania) face severe affordability problems, with shares of households affected that are more than double the EU27'. Besides the high rates of poverty in these countries (ranging from 20% in Portugal to 35.8% in Romania, in 2020; see [63]), such high shares of households perceiving affordability problems may arise also from the poor efficiency of buildings that increases energy needs and, therefore, energy expenditure – and this is even more ironic for the milder climate Southern countries. In this respect, it should be noted that among the five countries with the higher prevalence of affordability problems, Portugal and Greece are the only two that are EU Members since the 1980s. It is worth mentioning that a very considerable number of Central and Eastern European countries do perform well in terms of affordability of energy services, possibly due to the relatively low energy prices as

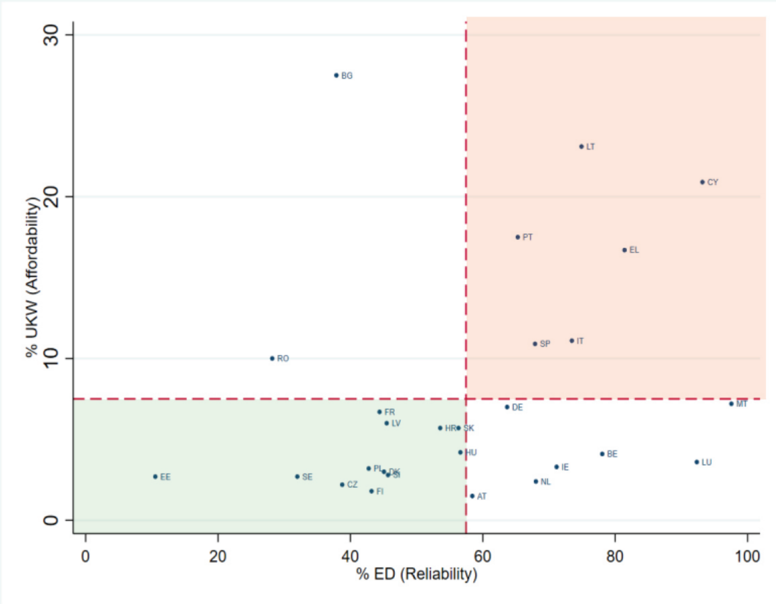

Figure 1: National positioning in the Reliability and Sustainability SDG 7 dimensions, 2020

Source: Eurostat [24]

AT-Austria; BE-Belgium; BG-Bulgaria; CY-Cyprus; CZ-Czechia; DE-Germany; DK-Denmark; EE-Estonia; EL-Greece; FI-Finland; FR-France; HR-Croatia; HU-Hungary; IE-Ireland; IT-Italy; LT-Lithuania; LU-Luxembourg; LV-Latvia; MT-Malta; NL-Netherlands; PL-Poland; PT-Portugal; RO-Romania; SE-Sweden; SI-Slovenia; SK-Slovakia; SP-Spain.

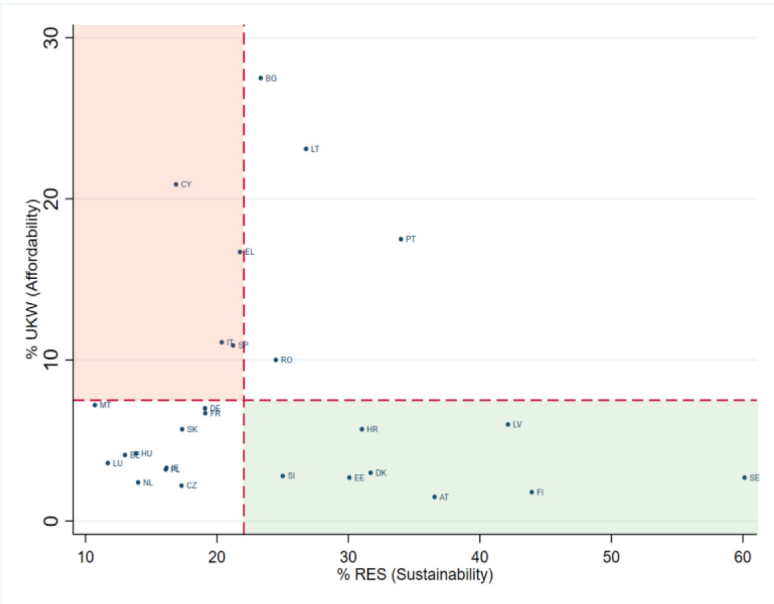

Figure 2: National positioning in the Affordability and Sustainability SDG 7 dimensions, 2020

Source: Eurostat [24]

AT-Austria; BE-Belgium; BG-Bulgaria; CY-Cyprus; CZ-Czechia; DE-Germany; DK-Denmark; EE-Estonia; EL-Greece; FI-Finland; FR-France; HR-Croatia; HU-Hungary; IE-Ireland; IT-Italy; LT-Lithuania; LU-Luxembourg; LV-Latvia; MT-Malta; NL-Netherlands; PL-Poland; PT-Portugal; RO-Romania; SE-Sweden; SI-Slovenia; SK-Slovakia; SP-Spain.

compared to other EU countries and the EU27 average (see, e.g., [64]), but not in the sustainability of the energy system (locating in the bottom-left quadrant).

Finally, Figure 3 relates the Affordability (%UKW) and Reliability (%ED) dimensions. It shows that several Eastern, Northern and Central European countries are performing well in both as well as that six countries - all Southern European, plus Lithuania have a particularly weak performance in both (in the top-right quadrant). Location in the same quadrant can translate, however, quite different realities. Focusing on the Reliability dimension, Greece has a energy dependency higher than Lithuania, but this latter depends almost exclusively on a single provider (see [65]), what may have stronger consequences over energy reliability. Regarding this group of countries, it is noteworthy that despite still having a poor performance in both indicators, Portugal has recorded a favorable trajectory in both over the period 2005-2020; conversely, Italy recorded a trade-off, with a deterioration in the affordability dimension. For Cyprus and Spain the association between them is weak and for Greece and Lithuania it is not statistically significant (see Table 2).

To obtain an overall portrait of countries' performance in these three domains simultaneously, that is, to gain insight on whether social, economic and environmental indicators have been hand in hand or back to back altogether, in each country, Figure 4 presents the set of countries whose current performance is, at least, as good as that of the EU27 average in each domain (see Table 1).

As it can be seen, seven countries record a good performance in all domains simultaneously, that is, lower shares of households without financial capacity to keep homes warm (Affordability), lower energy dependency rates (Reliability) and higher shares of renewables in final energy consumption (Sustainability). Eight countries record a good perfomance in two out of the three dimensions – Romania and Bulgaria perform better than the average in Reliability and Sustainability, whereas Poland, Czechia, Hungary, Slovakia and France perform better than the average in Reliability and Affordability, and Austria in Sustainability and Affordability.

Eight countries perform better than the average in only one dimension: Belgium, Malta, the Netherlands, Ireland, Germany and Luxembourg (Affordability); and Portugal and Lithuania (Sustainability). Regarding

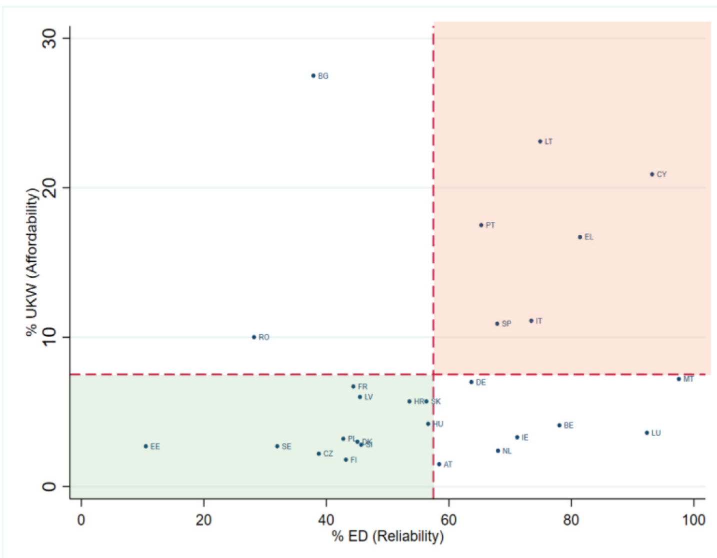

Figure 3: National positioning in the Affordability and Reliability SDG 7 dimensions, 2020

Source: Eurostat [24]

AT-Austria; BE-Belgium; BG-Bulgaria; CY-Cyprus; CZ-Czechia; DE-Germany; DK-Denmark; EE-Estonia; EL-Greece; FI-Finland; FR-France; HR-Croatia; HU-Hungary; IE-Ireland; IT-Italy; LT-Lithuania; LU-Luxembourg; LV-Latvia; MT-Malta; NL-Netherlands; PL-Poland; PT-Portugal; RO-Romania; SE-Sweden; SI-Slovenia; SK-Slovakia; SP-Spain.

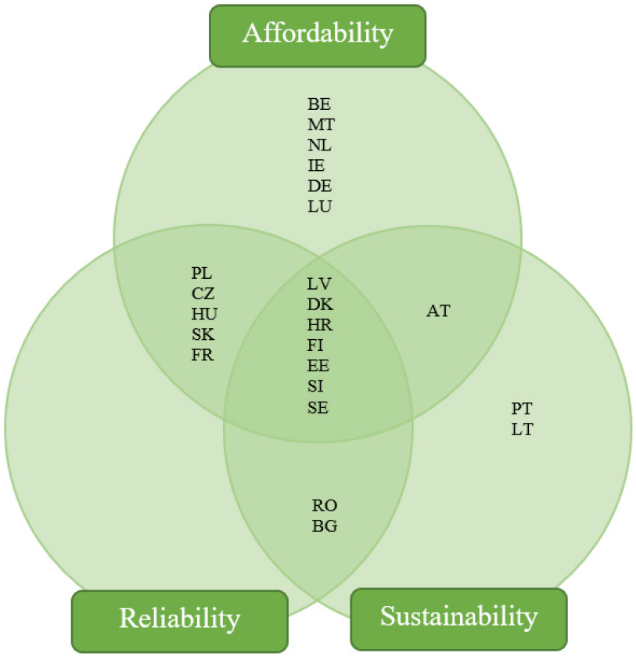

Figure 4: Above-the-average performers in Affordability, Reliability and Sustainability dimensions of SDG 7, 2020

Source: Adapted from Eurostat [24]

AT-Austria; BE-Belgium; BG-Bulgaria; CY-Cyprus; CZ-Czechia; DE-Germany; DK-Denmark; EE-Estonia; EL-Greece; FI-Finland; FR-France; HR-Croatia; HU-Hungary; IE-Ireland; IT-Italy; LT-Lithuania; LU-Luxembourg; LV-Latvia; MT-Malta; NL-Netherlands; PL-Poland; PT-Portugal; RO-Romania; SE-Sweden; SI-Slovenia; SK-Slovakia; SP-Spain.

Reliability, our results are in line with those of [61] who clustered Cyprus, Lithuania, Luxembourg and Malta as the countries with the highest average values of energy import dependence in 2019, and Bulgaria, Czechia, Denmark, Estonia, Finland, France, Romania and Sweden as those with the lowest. Four countries – Cyprus, Italy, Greece and Spain, perform poorly than the EU27 average in all the three dimensions and, therefore, they are not included in this diagram.

3.2. Densifying the analysis on the affordability of energy services

In this section we compute energy affordability ratios, from microdata, using the EHBS, thus covering 26 EU Member States (hereafter, EU26). The EU26 show a global average EAR of 6.8%, resulting from average national ratios that range from 3.6% in Malta to 13.5% in Czechia (Figure 5). Averages thus fade away energy affordability issues in several countries. Looking deeper, and according to the 10% threshold (see, e.g., [50]), eight countries go beyond this limit, thus showing affordability problems. Furthermore, for the EU26, half of the households spend more than 5.4% of their income on energy services, and 25%, more than 8.7%.

Affordability problems are particularly acute in nine Eastern and Baltic countries, with EAR ranging from 10% in Croatia to almost 14% in Czechia. In Bulgaria, Czechia, Hungary, Latvia, Estonia and Slovakia, half of the households record an EAR that surpasses 10%, and the EAR rounds or exceeds 15% for a quarter of households in these countries.

Considering that in the scope of the EU SDG 7 indicator set, energy affordability is assessed through the %UKW indicator, Figure 6 scatters the share of population unable to keep their homes adequatly warm against the share of households with problematic EAR, i.e., above 10% (%Afford_problems), in 2015.

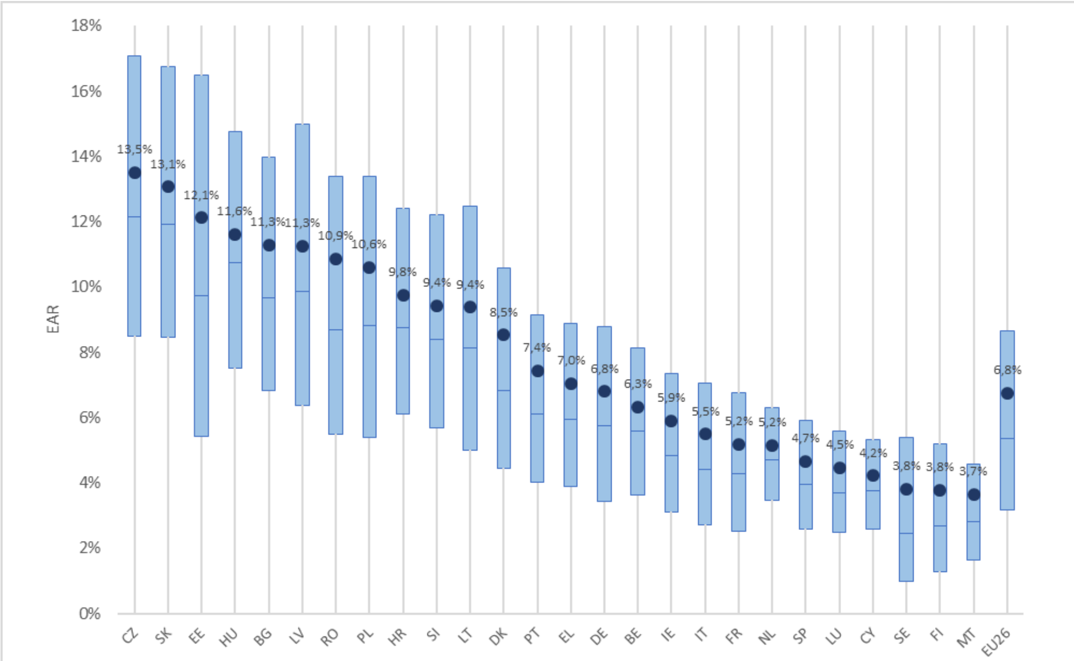

Figure 5: Box plot – National and EU Energy Affordability Ratios

BE-Belgium; BG-Bulgaria; CY-Cyprus; CZ-Czechia; DE-Germany; DK-Denmark; EE-Estonia; EL-Greece; FI-Finland; FR-France; HR-Croatia; HU-Hungary; IE-Ireland; IT-Italy; LT-Lithuania; LU-Luxembourg; LV-Latvia; MT-Malta; NL-Netherlands; PL-Poland; PT-Portugal; RO-Romania; SE-Sweden; SI-Slovenia; SK-Slovakia; SP-Spain.

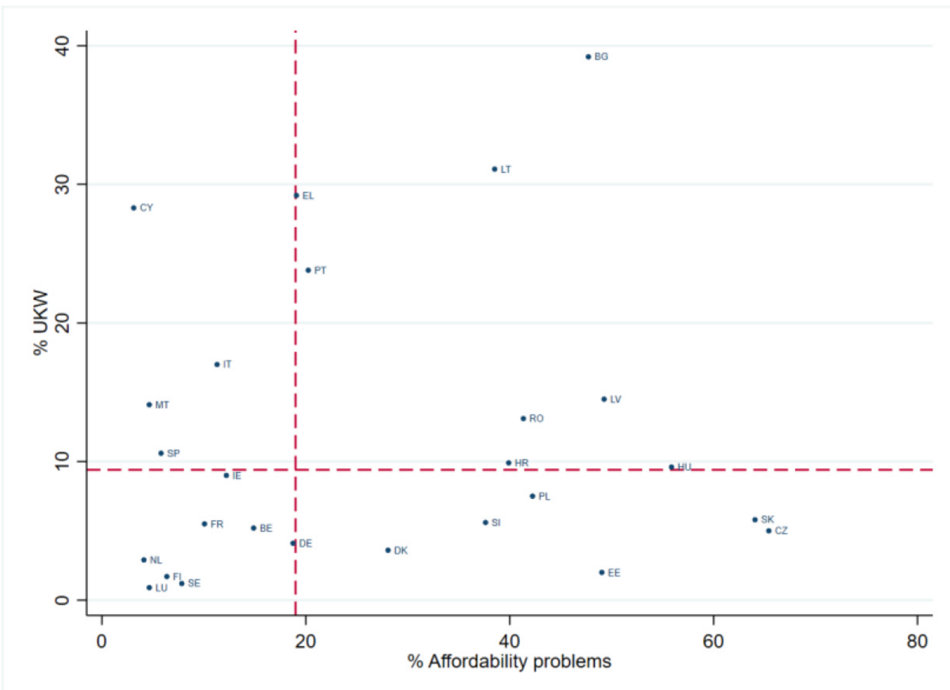

Figure 6: % Households unable to keep homes warm (%UKW) vs.% Households with problematic EAR (>10%), 2015

BE-Belgium; BG-Bulgaria; CY-Cyprus; CZ-Czechia; DE-Germany; DK-Denmark; EE-Estonia; EL-Greece; FI-Finland; FR-France; HR-Croatia; HU-Hungary; IE-Ireland; IT-Italy; LT-Lithuania; LU-Luxembourg; LV-Latvia; MT-Malta; NL-Netherlands; PL-Poland; PT-Portugal; RO-Romania; SE-Sweden; SI-Slovenia; SK-Slovakia; SP-Spain.

The share of households with affordability problems (%Afford_problems) and the EU affordability indicator (%UKW) do not provide an identical portrait of affordability. If we assess affordability through the share of households with problematic EAR, 12 countries perform well, i.e., below the average (Malta, Finland, the Netherlands, Ireland, France, Sweden, Cyprus, Spain, Italy, Germany, Belgium and Luxembourg), against 14 countries if the %UKW indicator was considered instead. Four countries that perform poorly according to the %UKW indicator – Cyprus, Italy, Malta and Spain – do perform well if % Afford_problems is considered, with Cyprus being the best-performing country in this regard (3%).

On the contrary, six countries that perform well under the %UKW indicator have a poor performance according to the alternative metric, namely: Poland, Czechia, Denmark, Slovakia, Estonia and Slovenia, with Slovakia and Czechia being the worst-performers in terms of the share of households with affordability problems (around 65%). Summing up, eight countries perform well in both indicators (Malta, Finland, the Netherlands, Ireland, France, Sweden, Germany, and Luxembourg) and eight countries (Bulgaria, Portugal, Lithuania, Latvia, Greece, Romania, Hungary and Croatia) record a poor performance in both indicators. This means that the %Afford_problems and %UKW indicators portray identical affordability scenarios in 16 of the 26 countries, whereas in the other 10 they provide contradictory outcomes.

From our point of view, the EU proxy for affordability, for being a single indicator, may be somewhat conservative for leaving outside an important part of the energy affordability problem. Recall that we computed the EAR as a proposal of an objective assessment for affordability problems to be used in complement to the EU proxy for energy affordability.

Regarding the poorest households (Table 3), the EAR rises to 8.8% in the EU26, ranging from 3.3% in Sweden to 19.3% in Estonia. That increase in EAR has different orders of magnitude, from the global to the poorer families set, ranging from only 0.6 percentage points (p.p.) in Poland to an expressive 7.2 p.p. in Estonia. More than 50% of households face an energy burden equal or higher than 10% in 13 countries, four of which (Slovakia, Czechia, Estonia and Latvia) exhibit an affordability ratio higher than 20% for a quarter of households. Compared to the global average ratio, it is noteworthy that, within the poorest households, Estonia, Latvia, Croatia, Slovenia, Denmark and Ireland moved up in the ranking of higher ratios as compared to those for total population.

Concerning the household characteristics (Cyprus, Croatia, Hungary and Lithuania were dropped from the analysis, meaning that we stay with 22 countries; see Table 3), no differences were found between the average size of the household (*fam_size*) between total and poorer families (about 2 persons, on average, by household). Similarly, results reveal that families with children (*child*) are not particularly exposed to affordability problems, as the share of households with children within the group of households with affordability problems is smaller in all countries than in the total population (24% against 31%, for the EU22). The greatest differences occur in Finland (-18p.p.) and in Malta and France (-16p.p.), and the smallest in Romania, Bulgaria and Slovakia (-5p.p.).

Completely different are results for households with older people (*old*), with the prevalence of these households rising significantly among the group of those with affordability problems. Although this occurs in all EU22 countries, 13 record differences larger than 10 p.p.. The largest occur in Finland (+35p.p.) and Malta and Sweden (+24p.p.), and the smallest in Latvia, Belgium, Poland (+7p.p.) and Romania (+5p.p.). In the EU22, the difference is 12p.p., with 32% of total households with elderly people, against 44% in those with energy affordability problems.

Finally, in what concerns the population density level, our results show that the prevalence of affordability problems is of particular concern in sparsely (*spars*) populated areas, where the share of households with affordability problems exceed that of the total population in all countries, except for Malta and Poland. The share of households with affordability problems living in densely populated areas (*dens)* is lower than that of total population in every country, with differences larger than 20p.p. in Bulgaria, Cyprus, Greece, Spain and Finland. For the EU22, the gap is -11p.p..

Summing up, the presence of elderly in the household and the sparsely populated area of residence are the examined characteristics for which the shares of households are larger for those with affordability problems. Actually, the shares of households with elderly and living in non-densely populated areas are larger among those facing affordability problems in 15 countries (Belgium, Bulgaria, Czechia, Germany, Denmark, Estonia, Greece, France, Ireland, Italy, Latvia, Portugal,

Table 3. Positioning poor households and households with affordability problems

Difference between EAR for poor and total (p.p.)		Difference between households with affordability problems and total				
		(p.p.)				(no.)
		Child	Old	Density level		Fam_size
				Dens	Spars	
BE	2.72	–10.0	6.6	–7.8	3.8	–0.42
BG	3.13	–4.9	9.8	–21.2	15.3	–0.05
CZ	5.30	–7.4	8.3	–3.9	1.4	–0.20
DE	1.74	–5.9	9.1	–7.8	3.3	–0.20
DK	3.22	–7.8	8.3	–3.5	2.7	–0.33
EE	7.18	–9.6	10.7	–6.5	6.0	–0.23
EL	2.53	–13.0	14.5	–25.5	24.8	–0.34
FI	0.32	–17.7	34.8	–27.7	28.9	–0.44
FR	2.42	–15.6	18.5	–17.9	15.2	–0.49
IE	3.32	–14.5	15.8	–13.3	11.3	–0.73
IT	2.42	–11.3	19.5	–12.6	6.2	–0.26
LU	2.08	–15.3	8.0	–10.1	12.4	–0.36
LV	5.37	–6.4	6.6	–4.8	4.2	–0.23
MT	2.33	–16.5	24.3	–1.0	0.0	–0.77
NL	1.82	–14.3	9.1	–5.2	5.2	–0.58
PL	0.58	–5.8	6.5	–0.7	–1.7	–0.15
PT	3.24	–10.6	14.8	–15.5	15.4	–0.19
RO	0.84	–4.8	4.8	–5.1	3.7	–0.16
SE	–0.53	–9.6	24.3	–19.1	21.0	–0.09
SI	3.20	–15.3	14.4	–7.0	6.6	–0.42
SK	5.30	–5.2	7.9	–6.0	5.0	–0.11
SP	1.69	–11.2	18.3	–20.9	21.6	–0.36
EU22	2.02	–7.1	11.6	–11.0	9.2	–0.16

BE-Belgium; BG-Bulgaria; CZ-Czechia; DE-Germany; DK-Denmark; EE-Estonia; EL-Greece; FI-Finland; FR-France;IE-Ireland; IT-Italy; LU-Luxembourg; LV-Latvia; MT-Malta; NL-Netherlands; PL-Poland; PT-Portugal; RO-Romania; SE-Sweden; SI-Slovenia; SK-Slovakia; SP-Spain.

Romania, Slovenia and Slovakia) and in the EU22. Our results are thus coherent with some authors (e.g. [53,66]) that report that, apart from income, there are other factors affecting the energy affordability ratios, such as households' profile, location and geography.

4. Conclusions

Monitoring the accomplishment of SDG 7 is useful to understand how countries stand and the comparison of countries' performance allows to highlight the best positions on the various fronts, i.e., which countries should be viewed as benchmarks. In addition, the joint analysis of performance in several domains is relevant to signal the definition of more customized policies to guide the paths towards the achievement of priority targets, without compromising performance in areas where countries are best positioned.

Based on the fundamentals of SDG 7 - affordable, reliable and sustainable energy for all, and focusing on 27 European Union countries, we explore the type of interlinkages between socio-economic and environmental indicators used to monitor the accomplishment of SDG 7 in its three dimensions: Affordability, Reliability and Sustainability. Then, by computing Energy Affordability Ratios for EU countries as a complementary measure to the EU SDG indicator for affordability (the share of people not able to keep their homes adequately warm), and assessing whether the picture of affordability changes whether using one or another indicator, we deepen the analysis on the accomplishment of the affordability dimension of SDG 7.

With regard to the interlinkages between the national performance on Affordability, Reliability and Sustainability for the period 2005-2020, only Latvia, Portugal and Bulgaria record synergistic (pairwise) interlinkages in the three dimensions, and Cyprus records synergistic interlinkages for the pairs 'Affordability – Sustainability' and 'Sustainability'– Reliability'. On the contrary, for Poland and Czechia, trade-offs were found for 'Affordability – Reliability' and 'Reliability – Sustainability', and in Luxembourg for the pairs 'Affordability – Reliability' and 'Affordability – Sustainability'.

Also, a joint analysis of countries' current performance shows that seven countries (Croatia, Denmark, Estonia, Finland, Latvia, Slovenia and Sweden) are better than the EU27 average, in the three domains simultaneously. Latvia thus emerges as a country where the hand in hand evolution of socio-economic and environmental indicators translated by a synergistic interlinkage between the different dimensions of SDG 7 since the adhesion to the EU, has culminated in a national overall good performance by 2020.

Given the diversity of progress paths and synergistic or trade-off interlinkages between indicators found, it became clear that the solutions to improve the progress in SDG 7 cannot be the same for all Member States, as previously argued by, e.g., [51], even if EU concerted efforts and policy guidelines, like the REPowerEU plan, are desirable. For countries with the worst relative performances in indicator pairs, and where a significant trade-off has been identified between them, the policy implication is that the most urgent measures to be taken to improve countries' performance in one domain should not distract from the targets to be achieved in the other dimension. Using as an example the case of Germany, its current poor performance in Reliability and Sustainability SDG 7 dimensions, altogether with the significant trade-off between them, signals that measures designed to reduce energy dependence must not distract from the targets in the use of renewables.

Focusing on affordability, it is surprising to note that the southern European countries, with more moderate climate, perform poorly, probably due to issues of energy inefficiency of residential buildings. Therefore, solutions to improve affordability that may have a positive impact on the share of renewables at the same time should be favored. It is clear, however, that existing measures to promote affordability, such as social tariffs, do not provide enough financial means to invest in renewables or to improve the energy efficiency of their homes [67]. In the case of Central and Eastern countries, the good performance in terms of affordability seems to be linked to low energy prices, which, in turn, can be detrimental to sustainability performance.

Our results show that there are no statistically significant associations for 'Affordability – Sustainability' and 'Affordability – Reliability' for a substantial number of countries. This result is not inconceivable, considering that many circumstances underlying and explaining each indicator depend on the countries' idiosyncrasies. Indeed, the ultimate goal of this analysis is to provide researchers and policymakers with an idea of whether countries are following a consistent pathway to the achievement of SDG 7 (hand in hand) or, on the contrary, they are progressing only in some domains of a vaster common endeavor (back to back).

The correlation analysis thus indicates how each country has been evolving since 2005, and to what extent policies targeting each dimension may be hampering progresses in other(s). For example, it is expected that strengthening the role of renewables in the energy mix, and therefore, increasing their share in energy consumption may contribute to reduce countries' energy dependency on imports from the exterior; put another way, progressing in the sustainability dimension contributes to progress in the reliability dimension. Also, it is often highlighted that the energy transition (which encompasses the strengthening of renewables in the energy mix) may be more costly, in relative terms, for middle and lower income people [68], affecting particularly the affordability of energy services among these groups; that is, progressing in the reliability dimension may bring greater difficulties in the affordability dimension (even if e.g., Connolly and Mathiesen [69] conclusions point towards that the transition to a 100% renewable energy system will not raise energy costs, as long as those forecasted for 2050 remain valid).

Accordingly, our approach is necessarily affected by a wide range of factors influencing the countries performance in the indicators used, such as the economic evolution and fluctuations, the boost to economic development resulting from the adhesion to the European Union, the changes on national energy systems, or even the varying weather conditions that impact renewable power generation. Despite we are aware that our results are strongly influenced by all these factors, this approach somehow overlooks such changes by focusing in the final results rather than on the driving forces of the countries performance in each domain at all times, what may be a limitation of our study and constitute an avenue for further research.

Furthermore, it is likely that the shocks from the COVID-19 pandemics and the war in Ukraine may unevenly impact the achievement of the different targets within the SDG 7, for different EU countries. Still, we could find a significant number of interlinkages, notably synergies, for several countries, suggesting that these are in a favorable position to achieve SDG 7.

When focusing on the affordability dimension of SDG 7, our results point towards that the percentage of European households with affordability problems is not negligible. Besides, our affordability ratios findings expose a different extension of issues than those revealed by the share of households not able to keep homes warm, what confirms the relevance of looking at the problem from different lenses; the EU indicator for affordability and the energy affordability ratios seem to be rather complementary than substitutes, and thus should be used jointly. A policy implication that can be derived from this is that the development of energy affordability policies need to be complemented, as in Lima et al. [70], with the promotion of energy efficiency measures, also pointed out by Dubois and Meier [51] as the most desirable policy option. But to reach those most in need of this type of support, policies should be simplified and less demanding in terms of the investment needed, since, as stated by the European Commission [68] and Batista and Marlier [71], people more prone to face affordability issues are often at a double disadvantage: they live in more energy-inefficient houses, and they tend to have literacy and/or financial difficulties to invest in energy-saving measures and, because of that, may be excluded from the application of policies.

It also became clear that despite the EU26 affordability ratio is fairly satisfactory (6.8%) according to the threshold of 10%, affordability of energy services has not been fully attained yet, as significant asymmetries persist. The magnitude of affordability issues means that measures to tackle this problem, in force in several EU countries [72] since the 2008 financial crisis, remain justified, as well as it is their adoption where they are not yet in place. And this is particularly relevant during periods of economic and social crises, as the current one. The consequences of economic crises or of extreme events, such as a pandemic or a war, do not affect everyone in the same way. The most vulnerable fringes of the population are more exposed to loss of income and have greater difficulties to adjust to inflationary pressures. Thus, these groups, which in our study correspond to the poorest, the elderly and those living in isolated areas, are the ones who need to be assisted the first.

These characteristics provide insights on the design of adequate measures to ensure that vulnerable consumers are able to afford and to maintain the connection to energy services, for instance, by including them among the eligibility criteria to benefit from support, being it through a disconnection protection safeguard or social tariffs, for instance.

In several countries the disconnection protection safeguard to energy services was already in place in 2015, and recently, after the pandemics, other countries (e.g. from Southern Europe) also adopted this measure, at least with a temporary character to avoid the disconnection for vulnerable consumers. In some countries, this measure is restricted to winter periods and benefits only certain targeted users, such as those with medical conditions [73], but it is not common to see people ‘living in isolated areas’ included in beneficiary groups.

The worst performances according to the EU affordability indicator are found in Southern and South-eastern countries, what may derive from poor building energy efficiency as well as from the lower income level which directly affects housing standards and the ability to pay for energy services [2], not to mention that the %UKW indicator does not take into account cooling needs. Thus, other types of policies are also required to improve the [low] energy efficiency of homes, one of the main drivers, together with high energy prices and low income, of energy poverty [42]. Some of those measures, such as loans with reduced interest rates or tax reductions on investments to improve the energy efficiency of residential buildings, among others, have already been implemented in some Member States [73,74].

These policies are expected to impact affordability positively, since higher efficiency leads to energy saving, which, in turn, decreases energy expenditure, ceteris paribus, but are also relevant for sustainability, and even reliability reasons.

This study thus confirms that indicators are a useful tool to assess SDG 7 progress and to sustain informed public policies, but it is also essential to ensure that policies directed at certain areas do not compromise the achievement of other related dimensions, nor that European guidelines/strategies should dismiss the need to adjust countries' policies to their most urgent needs.

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