The dimensions balance of the energy trilemma and the current energy crisis

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***Abstract*—The balance between the three dimensions of the energy trilemma – security, affordability, and sustainability – puts pressure on entities and decision-makers involved in managing the current energy crisis. Erroneous or ineffective management can compromise or prevent the decarbonization trajectory that has as its target "zero emissions", by moving to a carbon-neutral economy, which aims to reduce energy consumption by 50% in the next 10 years. As in the case of economic crises, these in the energy sector have a cyclical characteristic. The only mention is that the current energy crisis is different from previous ones in terms of causes and effects, with an emphasis on climate change and global warming. In this context, this paper aimed to identify the components of the energy trilemma using the "Keywords Everywhere" extension that suggests relevant keywords "Related Keywords" associated with internet queries. The energy trilemma dynamics were analyzed at the Web of Science database level for the period 2017-2023.**

Keywords—energy security, energy sustainability, access to energy, web of science.

I. INTRODUCTION

The evolution of technology implicitly generates dependence on technology, which leads to an increase in global energy consumption. Energy dependence requires the creation of new means of sustainable energy production and the infrastructure necessary to support it, on a large scale. In order to help reduce pollution and the impact of climate change, the world's population will need to benefit from clean and affordable energy in the future, by gradually reducing the use of fossil fuels and developing renewable energy sources. This can be achieved by connecting communities, actors, innovative technologies, and experts shaping a sustainable future through energy transformation. Global debates, emerging technologies, diversified strategies, and scientific research results are the pillars of this transformation. According to estimates, by the year 2025, the sustainable energy industry will benefit from investments worth more than USD 2 trillion. This paper addresses the issue of the energy trilemma in six chapters: Introduction, General considerations regarding energy security, Consumer protection to facilitate energy sources access, Energy sources sustainability, Case study, and Conclusions.

II. GENERAL CONSIDERATIONS REGARDING ENERGY SECURITY

Energy security is one of the pillars that contribute to social stability, along with food and climate security. In general, it sets out the main measures that can guarantee a good supply of natural gas and a continued diversification of the production means and sources of energy supply to protect the population against systemic risks. It also establishes the specific contractual conditions for the import of fossil fuels, uranium, biomass, and cross-border exchanges of electricity [1]. The main recommendations of the Breakthrough Institute related to energy security in the current geopolitical context are [2]:

- expansion of natural gas supply, given the estimates that their use will continue to be as important in the next 20 years;
- maintenance and development of existing nuclear power plants;
- achieving a "global nuclear renaissance", by reopening closed plants and building new plants, especially with mini modular reactors;
- acceleration of innovative processes that contribute to the reduction of carbon emissions and the implementation of related infrastructure;
- the development and implementation of new innovative financing instruments [3].

Diversifying the energy sources range, such as nuclear, wind, solar, geothermal, and hydropower, alongside alternative fuels, and energy storage, can help avoid disruptions in the energy supply and provide important geopolitical benefits. The development of LNG (Liquefied Natural Gas) filling stations, including the mobile Floating Storage and Regasification Unit (FSRU) and their intelligent relocation, can be considered a priority to ensure Europe's energy security. About 35 terawatt-hours (TWh) of clean energy are estimated to be generated from the new renewable energy projects to be launched at the European level within about a year [4]. In the opinion of the European Investment Bank, projects that promote energy efficiency or the development of local sources of renewable energy can greatly contribute to ensuring the energy security of a country, these

investments are based on a number of three pillars, which form the so-called "energy triangle": growth, security, and sustainability. For example, it can be mentioned the offshore wind projects, the Beatrice wind project off the coast of Scotland, the three onshore wind parks in Austria (Energiepark Bruck), or the Belwind project, which currently provides the electricity needed for 160,000 homes in Belgium.

In Romania, the European Investment Bank has financed the energy renovation (thermal insulation) of approximately 65,000 apartments in the last six years. This investment is estimated to result in annual energy savings of over 500 GWh. For the same purpose, the financing of a public-private partnership aimed at renovating some old apartment buildings in the Paris region, three-quarters of which have the status of collective or social housing, built in the 1960-1970 period, was also supported. One of the results of this energy renovation process estimates the possibility of saving up to 75% of the energy of these buildings [3].

Energy security, especially in the case of the use of fossil resources, is influenced by changes in the external environment, such as geopolitical tensions involving the reduction of production/transportation capacities, the closure or destruction of supply sources, and respectively the occurrence of climate changes involving overconsumption (for example, the increase in consumption generated by the decrease in the temperature of the environment). Ensuring the continuity of the supply of these resources must be achieved at competitive prices, estimated for determined periods, through the following methods: the establishment of strategic stocks, the diversification of energy sources on new contractual and infrastructure bases, the signing of long-term contracts with reliable suppliers or even by reducing the consumption of these resources [1]. As a negative example, in France, steep price increases (more than a 200% increase in the price of firewood in 2022 compared to 2021) reveal that energy security, in this case, is not guaranteed. In the case of the countries of the American continent, the main common problems in the energy field are [5]:

- access to modern energy services;
- the link between energy and climate change;
- reliability of energy supply;
- energy price volatility.

In Germany, around 42.9% of electricity now comes from renewable sources, and by the year 2030, a share of 65% is estimated. The expansion and optimization of network capacities must be coordinated according to demand, for this purpose new storage solutions for energy from renewable sources are promoted and developed [7]. Energy security can only be achieved by ensuring the balance between access to energy sources (in as large a percentage as possible from renewable sources), the consequences of climate change, and geopolitical stability.

III. Consumer Protection to Facilitate Energy Sources Access

Access to reliable, affordable, modern, and sustainable energy is essential to increase the quality of life, reduce poverty and sustain economic growth.

The share of people who have access to these sources is therefore an important social and economic indicator.

According to the International Energy Agency (IEA), the minimum electricity consumption for a rural household is 250 kWh/year, and for an urban household, it is 500 kWh/year. In 1990, globally, approximately 71% of the world's population had access to electricity, this percentage increased to 87% in 2016. So 13% of the world's population did not have access to electricity in 2016.

Examples: in India, the percentage increased from 43% to 85%, and in Indonesia from 62% to 98%. At the bottom of the ranking is Chad, with only 8.8% of the population. In terms of the number of people without access to electricity, at the level of 1990, over 1.5 billion people did not have electricity. In 2015, their number decreased to 952 million, and in 2016 it decreased to 940 million (Table I) [8].

TABLE I. Number of the population with access to electricity sources.

Country	1990	2019	The Numerical Difference	The Percentage Difference
Albania	3089027	2854191	-234836	-8%
Armenia	3035831	2957728	-78103	-3%
Austria	7677850	8879920	+1202070	+16%
Bulgaria	8718289	6975761	-1742528	-20%
Czechia	10333355	10671870	+338515	+3%
France	58235716	67248926	+9013210	+15%
Germany	79433029	83092962	+3659933	+5%
Greece	10196792	10721582	+524790	+5%
Italy	56719240	59729081	+3009841	+5%
Kosovo	1700000	1788878	+88878	+5%
Latvia	2663151	1913822	-749329	-28%
Poland	38110782	37965475	-145307	-0,4%
Portugal	9983218	10286263	+303045	+3%
Romania	23201835	19371648	-3830187	-17%
Serbia	7516346	6931345	-585001	-8%
Spain	38867322	47133521	+8266199	+21%
Sweden	8558835	10278887	+1720052	+20%
Switzerland	6715519	8575280	+1859761	+28%

The existing negative results are in Table I. highlight not only the energy phenomenon but also the phenomenon of labor migration to economically and socially developed countries.

In Germany, the effects on the security of supply and electricity prices, generated by the legislative regulations, which ensure the protection of electricity consumers, are to be verified. In the years 2026, 2029, and 2032, it is to be examined whether the shutdown dates of the power plants that are planned for the year 2030 can be brought forward by three years in each case so that coal-based power generation can be phased out as early as 2035. Finally, an adjustment allowance

will be allocated for those employees who are at least 58 years old and who will lose their jobs due to legislative regulations regarding the use of renewable energy sources. The switch from coal to gas is promoted using a so-called coal substitution bonus [7].

In Romania, household consumers benefited from a monthly subsidy granted between November 1, 2022, and March 31, 2023. Families with a monthly net income of less than 1,386 RON per member or single persons whose income did not exceed 2,053 RON. The subsidy was granted for a single heating system used in a single home (home or residence), as follows [9]:

- heating system with thermal energy in a centralized system;
- natural gas heating system;
- electric heating system;
- heating system based on solid and/or petroleum fuels.

Facilitating access to sustainable energy sources (reliable, modern, and affordable) is the essential condition necessary for the implementation of a sustainable energy system, which leads to sustainable economic growth (based on increasing food production, reducing poverty, improving public health and education, etc).

IV. Energy sources sustainability

Increasing the ability of modern society to transition to secure, affordable, and sustainable energy. In this context, it was necessary to carry out annual projects to model future energy solutions and the materials needed for this purpose, such as the "Fostering Effective Energy Transition Report", carried out in 2021, which concluded the following [6]: the main factors that influence the energy system are demand growth, technological innovation, geopolitical changes, and effects on the environment; the main measures needed to accelerate the energy transition include decoupling economic growth from energy consumption, especially in emerging economies, integrating technological innovations to increase efficiency and sustainability, and addressing equity and justice in the energy transition; specialized studies and statistics facilitate the identification of the processes necessary for the energy transition and the alignment of policies and market factors specific to each country. The top 10 in the energy transition for 2021 are presented in Table II.

TABLE II. Top 10 Countries Energy Transition Index 2021. Source [6].

Rank	Country	ETI Score
1	Sweden	79%
2	Norway	77%
3	Denmark	76%
4	Switzerland	76%
5	Austria	75%
6	Finland	73%
7	United Kingdom	72%
8	New Zealand	71%
9	France	71%
10	Iceland	71%

Apart from the constant expansion of renewable energy sources, Germany will proceed to phase out nuclear power and coal-based electricity generation processes. The "Growth, Structural Change, and Employment" Commission established in 2019 introduced a bill for sustainable structural development and the gradual elimination of the use of coal by 2038, in parallel with the development of new technologies and solutions for clean energy [7]. In order to obtain the necessary energy, France uses an energy mix consisting of oil, natural gas, biomass, nuclear and solar energy, with proportions that vary from year to year, the main fields of use of which are: 42% for obtaining heat, 30% for transport and 28% for electricity (necessary for domestic and industrial consumption). The French government aims to have 40% renewable energy in its energy mix (the distribution of different energy sources consumed) by 2030, up from 20% currently. According to the multiannual energy program, until 2030, renewable energies must represent 40% of electricity production, 38% of final heat consumption, 15% of final fuel consumption, and 10% of gas consumption [10].

V. Study case

The study aims to identify the components of the energy trilemma (security, affordability, and sustainability) using the "Keywords Everywhere" extension that can suggest relevant "Related Keywords" associated with internet queries. The keywords reported by the extension "Keywords Everywhere" [11,12] are suggested by the search engine and were identified for the Internet search of the phrases: Energy security – Table III, Energy sustainability – Table IV, and Access to Energy - Table V.

TABLE III. Energy security- Related Keywords

Related Keywords	About results in Internet
energy security pdf	751,000,000
energy security ppt	36,700,000
why is energy security important	867,000,000
energy security geography	86,500,000
energy security issues	819,000,000
energy security Europe	451,000,000
types of energy security	776,000,000
short term energy security	436,000,000

TABLE IV. Energy sustainability - Related Keywords

Related Keywords	About results in Internet
energy sustainability ideas	236,000,000
energy sustainability journal	211,000,000
energy sustainability and environment	497,000,000
energy sustainability ppt	15,700,000
energy sustainability pdf	311,000,000
energy sustainability report	500,000,000
energy sustainability masters	146,000,000
energy sustainability projects	569,000,000

TABLE V. Access to Energy - Related Keywords

Related Keywords	About results in Internet
access to the energy newsletter	524,000,000
access to electricity by country	305,000,000
Electric	13,100,000
access to electricity	650,000,000
why is access to electricity important	307,000,000
Africa	600,000,000
lack of electricity in developing countries	63,000,000
energy access explorer	101,000,000

The statistics of the keywords "energy security", "energy sustainability" and "access to energy" were displayed in Fig. 1 represents the estimated number of relevant results for the search on Google. The values of these searches represent an estimate of the total number of web pages, articles, images, or other types of content that could be relevant for "energy security", "energy sustainability" and "access to energy".

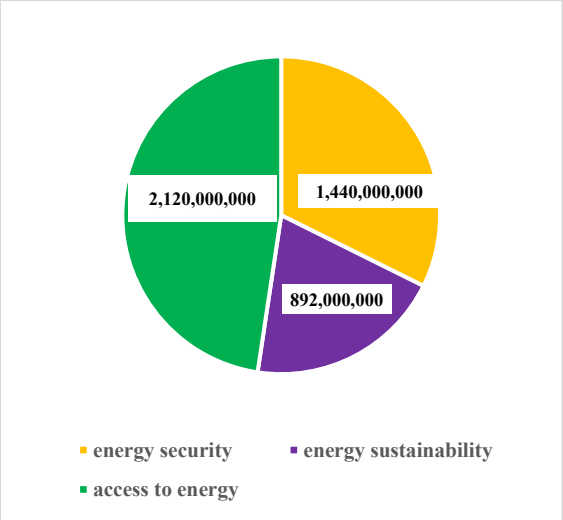

Fig. 1. About results in Google for “energy security”, “energy sustainability” and “access to energy”.

The energy trilemma dynamics was also analyzed at the Web of Science database [13] level for the period 2017-2023, from the point of view of the number of publications by topics, according to Table VI.

TABLE VI. THE NUMBER OF PUBLICATIONS DURING THE PERIOD 2017-2023

Topics in Web of Science	2017-2023	2020-2023	2021-2023	% publications 2021-2023 from publications 2017.2023
Energy security	24,384	13,917	9,998	41.00%
Energy sustainability	32,767	20,540	15,147	46.23%
Access to Energy	38,816	22,973	16,897	43.53%

It is observed that the average percentage of publications from the period 2021-2023 for the three components of the energy trilemma, represents 43.59% of the total publications related to the period 2017-2023.

The main phenomena on which the works from this period are focused are: the use of renewable resources and materials obtained from this category of resources (eg: fibrillated cellulose); the implementation of a new economic model, based on the circular economy and the balance between profit and damage to the environment; the creation of new batteries, with a large storage capacity (ex: Rechargeable aqueous Zn-ion batteries); increasing public spending on education and research-development-innovation in the field of green energy technologies; studying the links between environmental pollution, economic growth and energy innovation; the effects of financial development and the consumption of renewable resources on the sustainability of the environment; analysis of the main factors that contribute to global warming through greenhouse gas emissions; the sustainable increase of energy efficiency through the international sharing of knowledge related to technological innovations; the design of dual-function (semiconductor-mediated) photoredox reaction systems to contribute to the generation of economical and environmentally friendly solar fuel as well as the organic synthesis of value-added fine chemicals; converting biomass into value-added products such as sugars or biofuels.

The dynamics of the number of publications on the Web of Science is highlighted in Fig. 2, where it can be observed that the number of publications for searches in the topics "access to energy" are superior to searches for "energy security" and "energy sustainability", respectively.

This fact is due to the phenomena generated by the lack of and access to energy sources: 3 billion people depend on wood, coal, or manure for cooking and heating, while energy is the main cause of climate change, representing approximately 60% of global greenhouse gas emissions [12].

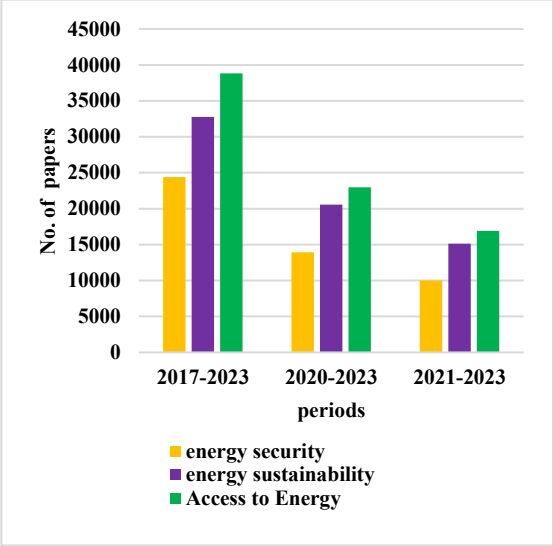

Fig. 2. Number of publications by topics, in Web of Science

The Pearson moment correlation coefficient value between the values of series from Table VI is above 0.98, which indicates a strong linear correlation [14].

VI. CONCLUSIONS

Players in industries that contribute to the ongoing pollution process must reverse their role: the environmental damage must be transformed into ecological processes, based on renewable energy sources, considered inexhaustible on a human scale (an important advantage in times of crisis).

An example of this is the transportation industry, which must develop in two main directions: electric vehicles and innovative battery charging/recycling methods. The best alternatives to fossil fuels are: hydrogen, solar energy, biomass, wind energy, biofuels, geothermal energy, waterfalls or tides. Financial institutions need to identify new methods, opportunities, and long-term investment strategies in the renewable energy.

The balance between "energy security", "energy sustainability" and "access to energy" can be ensured within a green triangle, consisting of educational units, companies active in the field of waste management and companies contributing to the production of clean energy.

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