A Critical Analysis of the Impact of the Pandemic on Sustainable Energy Scenarios

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***Abstract*—The energy sector is undergoing a major transformation in the composition of its energy matrix and the new trends detected in different scenarios have been published by institutions and/or organizations in the sector. This document contributes to the search for solutions to the serious problems of environmental pollution and humanity's economic inequality. To achieve this, it examines the reports of energy sources, and carbon dioxide emissions and performs a regression analysis up to the year 2100. The results indicate that a 25% increase in renewable energy is required, compared to renewable energy. that was required before the pandemic, to limit the increase in the temperature of the earth's surface to 1.5°C average, concerning the pre-industrial period. Unfortunately, the planet's energy matrix shows no signs of becoming sustainable and climate change and economic inequality continue to affect humanity.**

Keywords—Sustainability, renewable energy, economic inequality

Abbreviations

EJ	Exa Joules
EEA	European Environment Agency
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IEA	International Energy Agency
IRENA	International Agency for Renewable Energy
OECD	Organization for Economic Cooperation and Development
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Program
WBG	World Bank Group
WEC	World Energy Council
WMO	World Meteorological Organization
WWF	World Wide Fund for Nature
WEC	World Energy Council
WWF	World Wildlife Fund

I. INTRODUCTION

The 2020 COVID-19 pandemic has magnified the great problems that humanity already had, exposing a society that has prioritized the economy over health. As if the above were not enough, the Russia-Ukraine war has contributed significantly to economic inequality, climate change and lack of resources are there to remind us that the sustainability of our planet is in jeopardy and that the meagre The results obtained suggest the need for academia to assume strong leadership, especially in those countries whose economies need to recover and strengthen to provide opportunities for their fellow citizens [1].

Sustainability can be analyzed in three major themes, which group society's major problems: environment, economy and energy [2]. In fact, in [3] it is mentioned that the sustainability of our planet is strongly threatened by the use of energy from fossil fuels, particularly oil. The IPCC in its 2012 special report analyzed 164 potential scenarios for the year 2060 and urged the global community to change the energy matrix by intensifying the use of renewable energy, due to its potential to reduce greenhouse gas emissions [4]. The International Energy Agency (IEA), in its 2021 report after the pandemic, updates its data with projections up to 2100. The various scenarios are quite worrisome and lead one to think about the risks that humanity runs, caused by global warming. The strong recommendations are the same, the urgent need to change the hackneyed energy matrix [5].

Unfortunately, despite the great development of artificial intelligence that has allowed the execution of different renewable energy projects [6,7,8], the change in the matrix has not been possible due to the lack of a low-carbon development model with clear objectives [9], caused by power struggles, by leadership without commitments marked by a conflict of values and by the lack of adequate strategic thinking focused on sustainability [10].

This study contributes to the literature on the energy sector and its impact on climate change and economic inequality, (i) updating the information provided in an article previously published by the authors [1], (ii) exploring the latest reports of IEA, UNEP-IPCC, WEC, Shell, WWF, WBG, IRENA, IMF and, (iii) adding the issue of carbon credits and the compensation fund for climate change damages, discussed at COP29.

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II. Review of the State of the Art

A. Sustainable energy

Sustainability can be analyzed considering the environment, the economy and energy, strongly connected and interdependent issues, so a holistic vision is necessary if good results are to be obtained. In the environment, we must include climate change, the depletion of the ozone layer, toxic pollution, acid rain, the decrease in biodiversity, the extinction of ecosystems, migration and coastal settlements [11]. In the economy, economic inequality, scarcity of resources, water sources, sustainable agriculture, human health and education. Finally, on the subject of energy, primary sources, infrastructure, transportation, storage, energy efficiency, and systems for its operation and control.

The definition of energy sustainability given by the World Energy Council (WEC, www.worldenergy.org) comprises three dimensions: energy security (availability), social equity (access and affordability to energy) and environmental sustainability (climate change) [12].

The Russia-Ukraine war has exposed Europe's dependence on Russian gas and the little importance that has been given to renewable energy for years. Europe has described both fossil energy (gas) and nuclear energy as renewable energy, even though both are highly polluting and dependent on Russian gas and uranium reserves for approximately 40%. On the other hand, the reserves of fossil fuels, their production technologies and their consumption, are linked to the geopolitical situation of the countries of the Middle East; They are the largest producers and the ones that own approximately 64% of the global reserves of both oil and natural gas; It is estimated that oil reserves can supply world demand until 2045 [13].

As indicated, the energy transition, which is not the end but the means to achieve the sustainability of our planet, requires that renewable energies be competitive against energies from the use of fossil and nuclear fuels, even more so with the high costs and the volatility of fossil fuels.

The main drawback of fossil fuels is that, by generating polluting emissions, they increase the concentrations of Greenhouse Gases (GHG) —gases that trap radiation in the atmosphere— and consequently, the increase in the average temperature of the planet, which could reach 58oC within 100 years, as well as a rise in sea level of almost one meter [13].

Fossil fuels are oil, coal, and natural gas, and renewable sources include wind, solar, and biofuels. Unfortunately, the energies obtained from wind and solar radiation are intermittent [14].

B. Future scenarios of the energy situation

The Covid-19 pandemic in 2020, the stimuli to recover economic activities and the Russia-Ukraine war currently constitute great uncertainties in the energy market, which have additionally caused new records in CO2 emissions [15].

Within this framework, the global energy situation has been analyzed by several internationally renowned organizations such as the International Energy Agency (IEA), the Intergovernmental Panel on Climate Change (IPCC), the WEC, Shell, WWF International, the European Environment Agency (EEA), the World Bank (WBG), the International Renewable Energy Agency (IRENA).

The International Energy Agency (IEA) has been publishing updated annual information related to the energy sector since 1971. Already in 2015, he made projections for 2050 on the sources, uses and pollution produced by energies, with results that invited to change the global energy matrix [14]. In the 2021 post-pandemic report, he updates his data with projections up to 2100 and by 2022, he estimates that 8025 Mt of coal will have been used —equivalent to saying that each inhabitant of the earth generates approximately one ton of coal—, the highest figure since records were kept [15].

For its part, the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) established the Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC has prepared several documents, including special reports, weather reports and technical articles. In its sixth evaluation cycle, its synthesis report was published in March 2023 and the general conclusion is that climate change has affected the entire planet. The least responsible are the most affected and the future risks are greater, due to non-compliance with the agreements. Currently, the mitigation objectives of nations cover 94.9% of the reductions in global CO2 emissions —estimated at 52.6 Gt of carbon dioxide—, of which 90% are clear and quantifiable. The remaining 10% include non-quantifiable strategies, policies, plans, and actions [17,18].

The IPCC in its 2012 special report analyzed 164 potential scenarios for the year 2060 and urged the global community to change the energy matrix by intensifying the use of renewable energy, due to its potential to reduce greenhouse gas emissions [4]. In 2021, it prepared a document that updates its trends up to the year 2100, with various very worrying scenarios that lead us to think about the risks that humanity runs caused by global warming [19] and that in 2022 reaffirms them, since the results obtained do not improve [20].

The WEC, formed in 1923, is an impartial network of leaders who seek the common good of society, promoting the provision and sustainable use of energy to obtain the greatest benefit for all. In his 2013 report, he presented two potential scenarios up to the year 2050 and in the 2019 report, three potential scenarios up to 2060. The scenarios indicated the need to change the global energy matrix to limit global warming and its consequences [21,22].

Shell, a global group of energy and petrochemical companies, whose goal is to become a net zero emissions energy business by 2050, in tune with society, proposed two possible scenarios for 2030, 2050 and 2060, in its reports of the years 2008, 2011 and 2013[23,24] and three possible scenarios in its report for the year 2021 [25], all of them pointing to the need to change the global energy matrix.

In its 2021 report, Shell proposes three energy transformation scenarios for recovery from the 2020 crisis, Waves, Islands and Sky 1.5. In the Ripples scenario, the initial response is to repair the economy—wealth first. Social and environmental pressures receive less attention until backlash ensues, forcing global society to go to a zero-emission energy system. Late but rapid decarbonization that leads to an increase in temperature to 2.3oC by the year 2100. In the Island's scenario, governments and societies decide to isolate themselves for their safety, generating nationalist movements that threaten the post-war geopolitical order. The development of clean technologies brings progress and with it an energy system with zero emissions. Late and slow decarbonization

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leads to a temperature increase of 2.5oC by the year 2100. Finally, in the Cielo 1.5 scenario, the initial response is to respond to the pandemic —health first. Societies learn and share their best practices, generating responsible behaviour with the environment. In this latter scenario, the pace for energy decarbonization is fast enough to limit global warming to 1.5 °C above pre-industrial levels by the end of the century [25].

Another organization that has made energy projections is the World Wide Fund for Nature (WWF), an independent organization for the conservation of the planet's natural environment, created in 1961. In 2011, it carried out an analysis up to 2050. , whose results call for the concentration of humanity's efforts to replace fossil fuels —the main cause of climate change— with clean and renewable energies [26]. In the year 2021, he mentions the effects of not paying attention to this call, reflected in the species that are disappearing, the loss of homes due to the rise in sea level in the Fiji islands and the intense droughts faced by the Maasai, in Tanzania [27].

The World Bank (World Bank Group, WBG) 2015 made a report on progress towards sustainable energy [12] and set three global objectives: universal access to energy; double the rate of energy efficiency improvement, and double the share of renewables in the global energy mix. The results obtained have been positive, but not enough and the 2020 pandemic poses new challenges that cannot be postponed. By 2021, the WBG is implementing an ambitious agenda in its Climate Change Action Plan 2021-2025, which includes the transition costs of addressing climate change and prioritizes natural capital, biodiversity, and ecosystem services [28]. Something similar has been proposed by the Organization for Economic Cooperation and Development (OECD), through its International Climate Action Program, when visualizing an economy with zero greenhouse gases by the year 2050 [29].

The WBG recognizes that, internationally, the poor suffer the most from the consequences of climate change, despite being the sector that bears the least responsibility for greenhouse gas emissions [28]. With similar conclusions, we can add the periodic reports on the energy issue of the European Environment Agency (EEA) [30], of the International Renewable Energy Agency (IRENA) [29] on the organization's resources for the future [32,33] and from the OECD, stating that the economic and labour or market recovery in emerging and developing economies has been hampered by the lack of access to vaccines. [29].

From the perspective of economic growth and CO2 emissions, the relationship between energy security and equity and environmental sustainability has been investigated using the WEC Energy Trilemma Index (ETI) 2018 [34]. From this work, it is concluded that the adoption of integrated energy policies that can address energy supply and the sustainability of fossil fuel consumption could be the right choice, carbon valuation can reduce greenhouse emissions by economically stimulating companies with fewer emissions, all this will lead to changing energy consumption structures and making it a cleaner option to maximize benefits. The classification of the ten countries with the best results among the energy trilemma indices is carried out by applying principal component analysis (PCA) to reduce the number of variables and subsequently the Fuzzy-TOPSIS method to determine their location; obtaining Denmark and Germany the best results.

Finally, in an opposite vein, research by Pielke and Ritchie [35] finds that the Intergovernmental Panel on Climate Change (IPPC) has misused scenarios for more than a decade for scientific assessments. of climate, including unrealistic extreme scenarios as the world's most likely future, in the absence of climate policy, and the illogical comparison of climate projections across inconsistent global development trajectories. For this reason, the authors consider that a large part of the scientific community dedicated to climate research is currently far from scientific coherence and political relevance.

C. *Environmental impact*

The gases emitted into the atmosphere by anthropogenic activities that prevent the return of solar energy received by the Earth to space are called "Greenhouse Gases" (GHG) and include carbon dioxide (CO2), nitrous oxide (N2O) and methane (CH4), among others. Since the industrial revolution, human activity has caused GHG concentrations to increase, which has led to an increase in the temperature of the earth's atmosphere, an event commonly known as "Global Warming". During the last two centuries, the CO2 and N2O in our atmosphere have increased by 31% and 16%, respectively, while the methane concentration doubled in the same period. Of the three gases mentioned, the most abundant is CO2, while the most damaging due to its warming potential is N2O.

To avoid the adverse effects of GHGs, the 2010 Cancun Agreements demanded limiting the increase in global average temperature to 1.5 °C concerning the pre-industrial period, so GHGs must stabilize between 440-490 ppm CO2eq in the atmosphere (1 GtCO2 = 0.133 ppm) and, consequently, CO2 emissions should decrease between 50–85% by the year 2050. a goal that can only be achieved if there is a real commitment from humanity [19,34].

III. Energy Scenarios and Environmental Impact

Taking into account the information from the references mentioned, to carry out this work it has been considered opportune to consider two scenarios, scenario 1 which describes the real situation and that prioritizes the economy and scenario 2 which prioritizes sustainability (Table I and Table II). The reasons for considering these scenarios are more than justified by the report of the United Nations Conference on Trade and Development (UNCTAD) [36] and the International Monetary Fund (IMF) [37] that project a slowdown in the world economy from 5.7% in 2021 to 3.2% in 2022 and 2.7% in 2023, with an extremely uneven rise according to the regions, sectors and income levels, which for many countries in the south has represented a significant impact economic crisis much more severe than that of the global financial crisis and that projects values of carbon dioxide above the estimates [17]. On the other hand, the report from the University of Oxford, as of December 26, 2022, mentions that 68.8% of the world population has received at least one dose of the COVID-19 vaccine [38].

A. *Primary Energy Sources*

For the year 2100, the consumption of energy from primary energy sources, in scenario 1 could reach 768 EJ, and in scenario 2, 1049 EJ. Fig. 1 represents the future scenarios for fossil, renewable and nuclear energy. The dashed lines represent scenario 1, which prioritizes only the economic part, while the solid lines represent scenario 2, which prioritizes

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TABLE I
PRIMARY ENERGY SUPPLY (IN EJ, SCENARIO 1)

Year	1960	1970	1980	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Primary energy supply	**147**	**226**	**303**	**369**	**421**	**537**	**565**	**641**	**667**	**683**	**688**	**691**	**697**	**719**	**768**
Fossil 1	123	195	258	300	339	442	458	510	514	497	456	403	350	295	242
Coal	52	62	76	94	97	153	151	160	154	144	129	108	88	69	54
Oil	52	98	131	136	154	174	172	198	199	192	179	161	142	121	98
Gas	19	35	51	70	87	115	136	152	161	160	148	134	120	105	91
Renewables 1	24	30	38	47	54	65	79	99	128	165	201	245	292	342	405
Biomass	22	26	31	38	42	48	52	58	66	76	83	87	93	103	110
Hydro-electricity	3	4	6	8	9	12	15	16	18	19	19	18	20	21	23
Geothermal	0	0	0	1	2	2	3	5	8	12	17	23	28	32	39
Wind	0	0	0	0	0	1	5	10	13	16	18	21	24	30	42
Solar	0	0	0	0	0	1	4	10	23	40	63	95	124	153	189
Other renewables	0	0	0	0	0	0	0	0	0	0	0	2	2	3	3
Nuclear 1	0	1	8	22	28	30	28	31	25	21	31	43	55	82	120

TABLE II
PRIMARY ENERGY SUPPLY (IN EJ, SCENARIO 2)

Year	1960	1970	1980	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Primary energy supply	**147**	**226**	**304**	**369**	**424**	**532**	**570**	**673**	**750**	**828**	**910**	**975**	**1024**	**1040**	**1049**
Fossil 2	123	195	258	300	341	434	458	506	460	375	279	207	176	163	156
Coal	52	62	76	94	100	146	151	155	130	100	73	56	50	51	52
Oil	52	98	130	136	153	173	172	194	180	160	129	97	72	59	50
Gas	19	35	52	70	87	115	135	157	151	115	77	54	53	54	54
Renewables 2	24	30	38	47	55	68	83	124	226	373	535	656	728	753	768
Biomass	22	26	31	38	43	51	56	63	84	110	138	151	181	183	183
Hydro-electricity	3	4	6	8	9	12	15	16	18	19	21	23	23	23	23
Geothermal	0	0	1	1	2	2	3	4	12	28	37	38	39	38	39
Wind	0	0	0	0	0	1	5	15	42	88	120	130	133	129	123
Solar	0	0	0	0	0	1	4	25	70	127	218	313	353	379	399
Other renewables	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
Nuclear 2	0	1	8	22	28	30	29	42	64	80	97	112	120	123	124

sustainability, that is, in addition to the economy, social equity and the environment.

From Fig. 1 it can be seen that the contribution of renewable energies to primary energy between the years 2030 and 2080 has an exponential behaviour and it is estimated that by 2050 its contribution will exceed that of fossil energies, achieving the objective of 1.5°C (scenario 2). with a correlation coefficient R=1.00, the behaviour of renewable energies after the pandemic, as a function of the variable time (t) in scenario 2 is given by the equation:

$$E_{PR2(DP)} = 0.006t^6 - 0.314t^5 + 5.678t^4 - 46.971t^3 + 85.761t^2 - 316.11t + 200.52 \quad (1)$$

And for the year 2050, from (1):

$$E_{PR2(DP)/2050} = 373\ EJ \quad (2)$$

Where $\%E_{PR2}$ is the forced growth of renewable energy after the pandemic. Paraphrasing, after the 2020 pandemic,

On the other hand, the behavior of renewable energy in scenario 2 before the 2020 pandemic, yielded the following results [1]:

$$E_{PR1(AP)} = 0.03t^4 + 0.16t^3 - 3.62t^2 + 19.96t + 5.89 \quad (3)$$

And for the year 2050, from (3):

$$E_{PR1(AP)/2050} = 299\ EJ \quad (4)$$

The results indicate that due to the pandemic —in an optimistic scenario 2—, renewable energies are forced to grow an additional 25% by 2050, if the goal of 1.5°C is to be reached, the only way to overcome the problems at those of us who are already doomed:

$$\%E_{PR2} = \left| \frac{E_{PR1(AP)/2050} - E_{PR2(DP)/2050}}{E_{PR1(AP)/2050}} \right| x\ 100\% = 25\% \quad (5)$$

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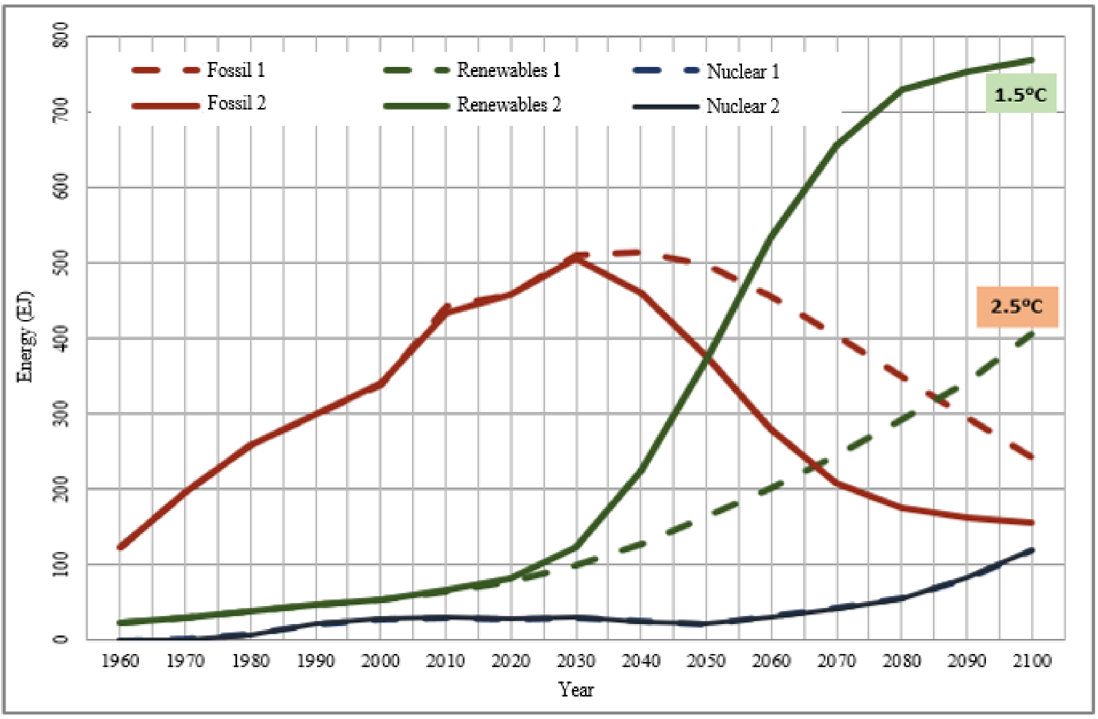

Fig. 1 Primary energy supply (EJ/year)

Our optimistic scenario is less optimistic and after the Russia-Ukraine war, it is even worse.

The main people responsible for environmental pollution are China and North America, who, paradoxically, are among the great beneficiaries of the pandemic that humanity has had to live through. In 2022 China and India became the largest contributors to environmental pollution, due to the use of coal [15].

The 2023 IPCC report [17] concludes that recent climate changes have become widespread and are occurring more frequently and rapidly. Real-time data indicates that by 2022 GHGs have increased. The global temperature of the Earth continues 1.5°C above the reference data of the pre-industrial period 1850-1900. The increase in greenhouse gases, especially the increase in carbon dioxide in the atmosphere, has caused extreme heat, torrential rains, droughts, fires from the weather, warming of the oceans, reduction of sea ice in the Arctic, receding of glaciers, rise in sea level.

To avoid the instability of the earth's system, an immediate and drastic reduction of greenhouse gases is required to limit global warming to 1.5°C. In particular, it is necessary to reduce CO2 —there is a linear relationship between CO2 and the temperature of the earth's surface— and reduce methane CH4, since global warming is mitigated and air quality is improved.

The largest source of CO2 is the combustion of fossil energy, used to power industries, transportation, and residences. On the other hand, the sources of CH4 are wetlands, livestock activity, wastewater, rice cultivation, coal mining, and burning biofuels. Additionally, methane, due to its caloric power, is approximately 23 times more harmful than CO2.

By 2022, the IEA considers an increase in global CO2 emissions above the 2021 values, due to the significant demand for fossil fuels. The spot prices of natural gas and coal reached record levels, which would reverse the drop in emissions by 80% in 2020 [15]. By 2050, renewable energies are expected to contribute to a 32% reduction in CO2, while efficiency improvements do so by 38% [39], values below what is required, that is, a reduction between 50 - 85%.

In the field of nuclear energy, there is an alternative solution and it is the plant called "Natrium", a project designed with the financial support of the US Department of Energy and the companies TerraPower of Bill Gates and PacificCorp of Warren Buffett. Natrium is a new technology capable of producing up to 500 MW —an amount more than enough to supply energy to 400,000 homes—, which would reduce current nuclear waste and would simplify current reactors. Unfortunately, because it is a new nuclear technology, there is concern about its safety and because of the commercial disagreements between the US and China, there are concerns about its construction costs.

IV. Results and Discussion

The data and the analysis of the issue of sustainable energy from the strategic point of view allow us to reach the following analysis and discussion of results:

From fig. 1 shows that, with the data for 2021, updated after the pandemic, fossil fuels tend to stabilize around 500 EJ by 2030 and decrease in both scenarios. If the data had been taken before the pandemic, fossil energies stabilized at 600 EJ in the year 2050 to decrease in an optimistic scenario from the year 2060. Additionally, greater growth of renewable energies is observed, compared to the supplied by nuclear plants. However, this last statement could change due to the new international regulations to consider nuclear energy as renewable energy.

From Fig. 1, with a correlation coefficient R=1.00, the behaviour of renewable energy as a function of time (t) in

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scenario 1, is given by equations (2.4). The projection for the year 2050 is $E_{PR1(DP)/2050)}$ = 373 EJ. The results indicate that —due to the pandemic— renewable energies will be affected by their growth by 25% by the year 2050, if the goal of 1.5°C is to be reached, the only way to overcome the problems we are already facing. doomed That is, to paraphrase a bit, after the pandemic, our optimistic scenario is less optimistic.

The Cancun Agreements of 2010, which demanded limiting the global average temperature to 1.5°C, required that Greenhouse Gases stabilize between 445-490 ppm of CO2eq in the atmosphere and, as a consequence, CO2 emissions decrease to values of 50%—85% by the year 2050. Unfortunately, these goals are far from being met. The latest IPCC report on climate change from March 2023 leaves a bittersweet taste since the agreements of the countries only reflect the contradictions and the lack of political will to prevent global warming from exceeding the 1.5°C goal.

The bittersweet aspect of the agreements is the creation of a fund that compensates for the damage caused by climate change, without specifying who should contribute to the clothes said fund and how much. Additionally, very little progress was made on the issue of reducing carbon emissions, since the main CO2 emitters and fossil energy producers continue not allowing mitigation measures and progressive elimination of this energy source to be taken, wasting time. valuable to reach the 1.5°C goal.

V. Conclusions

The sustainability of our planet is strongly threatened by the use of energy from fossil fuels, particularly oil. The two main problems —climate change and economic inequality— have to be confronted by the academy and in particular by the engineering sciences, not with "lukewarm clothes" but with frontal actions that counteract the contradictions and the lack of political will of the decision-makers.

The problem in Europe related to heating has a solution in renewable methods, but unfortunately, the bloc of fossil energy providers has delayed this change in the energy matrix and consequently, the implementation of real measures to mitigate climate change. Nuclear fission will go its own way and should not distract us from current energy and sustainability needs. As far as Latin America is concerned, Latin America must become more integrated, it pollutes very little and negotiates alone —the 54 African countries negotiate as a bloc. It can contribute to sustainability by providing electricity through renewable energy to 10% of its population that still does not have this service and reducing deforestation in the Amazon and the export of meat and soybean crops.

Although innovation in energy technology helps reduce CO2 emissions, other tools are needed to achieve the global goal of avoiding temperatures above 1.5°C. These tools should be tax support for companies that support climate change mitigation projects and the compensation fund for poor countries that have been affected by climate change.

The article raises several potential works for the future. From the strategic vision of sustainable energy, the economic impact can be determined in the countries that decide to support the development of renewable energies, considering the growth of GDP, GDP per capita and the environmental impact. Along the same lines, scenarios and strategies can be defined to build a new vision of sustainable countries and cities in the future, considering climate change, technology, decarbonization and resilience. Under the same optics, one could investigate the potential impacts of the hydrogen economy industry in solving the serious problems already mentioned and its contribution to the construction of a more just society.

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