ARCHITECTURE CIVIL ENGINEERING ENVIRONMENT
The Silesian University of Technology
No. 4/2021

doi: 10.21307/ACEE-2021-038

CLIMATE AGREEMENT. RACE TO CARBON NEUTRALITY FROM RIO VIA KYOTO AND PARIS TO GLASGOW

Nonna PAVLIUK *

[a] Dr Eng.; Department of Heat-Physical Problems of Heat Supply Systems, Institute of Engineering Thermophysics of National Academy of Sciences of Ukraine, 2a, Marii Kapnist, 03057 Kyiv, Ukraine
*E-mail address: *nonna.ipe@gmail.com*

Received: 22.07.2021; Revised: 9.09.2021; Accepted: 18.09.2021

Abstract
This paper demonstrates an influence of the anthropogenic Carbon Dioxide (CO_2) emission trend on climate talks aimed to reduce greenhouse gas emissions. The influence of commitments to reduce greenhouse gas emissions, undertaken by the largest emitter countries within the framework of international treaties (the Kyoto Protocol and the Paris Agreement), on the fossil energy consumption and CO_2 emissions from the combustion of various types of fuel by these countries has been analyzed. Emissions from the European Union (EU), as well as consumption of renewable and alternative energy sources by countries are beyond the subject of this paper.
The paper focuses on the obligations that the largest emitters of greenhouse gas emissions are ready to undertake in order to achieve carbon neutrality by 2050. The impact of the country's choice of the base year on its ambitious climate action to reduce emissions has been evaluated. Challenges that the countries may face in the implementation of the Net Zero by 2050: A Roadmap for the Global Energy Sector, developed by the International Energy Agency (IEA), have been identified.

Keywords: **Climate Change, Greenhouse Gas, Energy Sector, Carbon Dioxide emissions from fuel combustion, Net Zero.**

1. INTRODUCTION

Climate change observed in the recent decades is one of the most important problems of the globe.

The Intergovernmental Panel on Climate Change (IPCC) has discovered that the climate change is caused by a rapid increase in the atmospheric concentration of long-lived greenhouse gases [1], and also pointed to the obvious impact of the human activity on the anthropogenic emissions [2].

In 2019, global annual average ground-level content of the Carbon dioxide CO_2 was 410.5±0.2 ppm = 148% of pre-industrial levels, of Methane CH_4: 1877±2 ppb = 260% of pre-industrial levels, Nitrous oxide N_2O: 332.0±0.1 ppb = 123% of pre-industrial levels, and Hydrofluorocarbons (HFCs) – about ppt [3]. Contribution of these long-lived greenhouse gases into the growing global radiation exposure over the period from pre-industrial levels to 2019 is the following: CO_2 – 66%, CH_4 – 16%, N_2O – 7%, HFC – 11% [4].

In 2019, atmospheric CO_2 concentrations were higher than at any time in at least 2 million years (high confidence), and concentrations of CH_4 and N_2O were higher than at any time in at least 800,000 years (very high confidence) [5].

Measurements of CO_2 concentration carried out in March 2021 by observatory in Mauna Loa, Hawaii, showed a 50% excess in CO_2 concentration of pre-industrial level (Table 1).

Table 1.
Historical (retrospective) changes in atmospheric concentrations of carbon dioxide [6]

Parameters	1750	1860	1990	2008	2012	2015	2016	2017	2018	2019[7]	2020[7]	2021[8]
Atmospheric concentrations of CO_2 (ppm)	278.0	286.2	353.72	384.98	392.6	399.64	402.87	405.19	407.58	411.49	414.01	419.13
Excess concentration of 1750, %		3	27	38	41	44	45	46	47	48	49	51

Table 2.
Primary energy Consumption and Carbon Dioxide emission from the combustion of anthropogenic fuel by the largest world emitters in 1990 [11, 12]

Country	Primary energy Consumption, Exajoules	CO_2 emissions from fuel combustion, million tonnes of CO_2			
		Fuel	Coal	Oil	Gas
United States	80.99	4 803.1	1 837.2	1 951.5	994.9
Russian Federation	36.14	2 163.5	707.2	618.7	837.6
China	28.70	2 122.2	1 814.9	286.6	20.6
Japan	18.61	1 053.9	296.3	645.9	111.6
Germany	15.05	940.0	516.2	303.7	115.2
Ukraine	11.42	688.6	292.9	185.2	210.5
United Kingdom	9.01	549.4	247.1	197.9	104.1
India	8.24	530.1	364.8	151.1	14.2

2. INTERNATIONAL TALKS ON CLIMATE CHANGE MITIGATION

2.1. United Nations Framework Convention on Climate Change

Global society has been trying to curb the growth of GHG emissions since 1992, when the UN summit in Rio adopted the United Nations Framework Convention on Climate Change (UNFCCC). The ultimate objective of the Convention is to stabilize greenhouse gas concentrations "at a level that would prevent dangerous anthropogenic (human induced) interference with the climate system". It states that "such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change" [9].

2.2. The Kyoto Protocol to the United Nations Framework Convention on Climate Change

2.2.1. Change of the Primary energy Consumption and GHG emissions by the largest GHG emitters

In 1997, at the third Conference of the Parties to the Convention (COP3) in Kyoto (Japan), the Kyoto Protocol to the UNFCCC entered into force [10].

According to the Kyoto Protocol, over the first commitment period (2008–2012) Annex 1 Parties were to reduce their GHG emissions by 5.2% compared to 1990. Non-Annex 1 Parties did not have quantitative limits for their GHG emissions.

1990 was chosen as the base year because this year GHG emissions exceeded the relatively safe level of 350 ppm (Table 1).

In 1990, 8 countries were the major world emitters of carbon dioxide from the combustion of anthropogenic fuel (Table 2). Six Annex 1 Parties are responsible for 50% of global CO_2 emissions, out of which only Japan (5.1%), Germany (4.6%) and United Kingdom (2.7%) (in the EU) have committed themselves to reducing greenhouse gas emissions. The USA, the major GHG emitter (23.4%), refused from ratification of the Kyoto Protocol. However, the country took voluntary commitments to reduce greenhouse gas emissions at the level of certain companies and municipal authorities.

According to the Kyoto Protocol, emissions from countries with economies in transition – Russia (the world's second-largest air pollutant – 10.5%) and Ukraine (sixth largest – 3.4%) should not exceed the emission level in 1990.

Another 13% of global CO_2 emissions were produced by China (third largest – 10.3%) and India (eighth largest – 2.6%) (Table 2). However, China and India as developing countries did not have commitments to reduce greenhouse gas emissions.

Table 3.
Primary energy Consumption and Carbon Dioxide emission from the combustion of anthropogenic fuel by the largest world emitters in 2012 [11, 12]

Country	Primary energy Consumption, Exajoules	CO_2 emissions from fuel combustion, million tonnes of CO_2			
		Fuel	Coal	Oil	Gas
United States	89.69	4 903.0	1 648.1	1 869.8	1 361.0
Russian Federation	28.98	1 607.9	435.6	327.9	819.6
China	117.05	8 863.5	7 464.9	1 106.0	264.3
Japan	19.92	1 226.6	428.3	524.3	250.3
Germany	13.37	745.1	325.0	240.6	161.1
Ukraine	5.14	274.0	149.4	36.8	87.8
United Kingdom	8.55	461.4	147.9	157.0	152.8
India	25.11	1 805.3	1 287.5	445.9	70.9

By the end of the first commitment period under the Kyoto Protocol, significant changes had appeared in the consumption of fossil fuels and emissions of carbon dioxide from the combustion of these fuels by various countries (Table 3).

The most significant reduction in emissions against 1990 level took place in the countries with economies in transition – in Ukraine (by ~60%) and in Russia (by 25.7%). As a result of the protracted economic crisis, primary energy consumption has decreased in Ukraine by 55%, and in the Russia by ~20%. Emission reduction has been driven by a reduction in the consumption of carbon-intensive fuels (coal and oil) in Ukraine by ~50% and 80% respectively, and in the Russian Federation – by ~38% and ~47%.

Germany has been the most successful in reducing CO_2 emissions from fossil fuels consumption. Its emissions have decreased by ~21%. The country managed to achieve such a success by reducing the primary energy consumption by ~11% and partial replacing of coal with natural gas in the country's fuel mix. The share of CO_2 emissions from coal combustion has decreased by 37%, and from oil combustion - by ~21%. At the same time, the share of emissions from natural gas combustion has increased by 40%. UK emissions are down 16% while primary energy consumption is down ~5%. The share of emissions from the combustion of natural gas has increased by ~47%, while from the combustion of coal and oil has decreased by ~40% and ~1% respectively. In Japan, primary energy consumption has increased by 7%, but CO_2 emissions have increased by ~16%. The share of emissions from natural gas combustion has increased by ~124%, coal by ~45%, but the share of emissions from oil combustion has decreased by ~19%.

In the United States, primary energy consumption has increased by ~11%, but CO_2 emissions have increased by only ~2%, because the share of emissions from the combustion of coal and oil has decreased by ~10% and ~4% respectively, and the share from the combustion of natural gas has increased by ~37%.

Developing countries, which according to the Kyoto Protocol did not have any commitments to reduce greenhouse gas emissions, have instead boosted them.

China confidently takes the global lead, having increased its emissions by ~318% over the last years. Primary energy consumption in China also has increased by ~308%. The share of emissions from coal and oil combustion has increased by 311% and 286% respectively, but natural gas share increased by ~1180% (in 1990, the share of emissions from natural gas combustion was only ~1% from fossil fuels emission). India increased emissions by ~240%, the consumption of fossil fuels in the country has increased by ~205%, the share of emissions from natural gas consumptions has increased by ~400%, coal – by ~250%, and oil – by ~195%.

2.2.2. The Kyoto Protocol results

Parties that committed themselves under the Kyoto Protocol to reduce greenhouse gas emissions were actively implementing mitigation measures: increased the share of low-carbon and renewable fuels, improved energy efficiency, etc. Non-committed parties noticeably increased their emissions (by several times). It can be easily illustrated by the growth of emissions in certain dynamically developing countries (Table 4).

Table 4.
Primary energy Consumption behavior and Carbon Dioxide emission rates from the combustion of anthropogenic fuel in the developing countries [11, 12]

Country	Primary energy Consumption, Exajoules		CO_2 emissions from fuel combustion, million tonnes of CO_2	
	1990	2012	1990	2012
Mexico	4.56	7.71	257.0	459.5
South Africa	3.70	5.14	243.8	422.3
Republic of Korea	3.82	11.54	231.8	575.5
Brazil	5.36	11.69	184.5	424.1
Iran, Islamic Rep.	3.04	9.41	171.2	514.5
Saudi Arabia	3.34	9.76	151.1	463.4
Indonesia	2.20	7.27	131.3	451.1

Table 5.
Primary energy Consumption and Carbon Dioxide emission from the combustion of anthropogenic fuel by the largest world emitters in 2018 [11, 12]

Country	Primary energy Consumption, Exajoules	CO_2 emissions from fuel combustion, million tonnes of CO_2			
		Fuel	Coal	Oil	Gas
United States	95.60	4 921.1	1 270.0	2 031.3	1 600.7
Russian Federation	30.04	1 587.0	411.2	303.0	838.0
China	135.77	9 570.8	7 637.2	1 374.7	525.9
Japan	18.84	1 080.7	431.3	384.1	228.4
Germany	13.44	696.1	273.1	233.3	171.1
Ukraine	3.54	181.8	97.6	28.5	55.8
United Kingdom	7.96	352.4	31.3	157.8	158.0
India	33.30	2 307.8	1 628.0	595.1	83.4
Mexico	7.83	448.5	48.3	243.9	155.8
South Africa	5.30	428.0	350.0	73.5	4.5
Republic of Korea	12.55	605.8	315.3	158.9	114.0
Brazil	12.13	406.3	63.9	274.0	68.4
Iran, Islamic Rep.	11.83	579.6	5.4	191.4	382.7
Saudi Arabia	10.91	491.7	0	318.3	173.4
Indonesia	8.23	542.9	221.9	238.1	82.4

From 1990 to 2012, energy consumption in Iran, Indonesia, Saudi Arabia and the Republic of Korea increased by ~200%. At the same time, CO_2 emissions increased in Iran, Indonesia and Saudi Arabia by ~200%, and in the Republic of Korea by ~150%. Primary fuel consumption has grown significantly in Brazil ~120%, Mexico ~70% and South Africa ~40%. Greenhouse gas emissions in these countries have already exceeded those of the United Kingdom.

Major outcome of the Kyoto Protocol:

1. Efforts taken by the most developed countries in order to reduce greenhouse gas emissions are inadequate, given the global growth of emissions in the non-committed countries having no quantitative limits or goals on emissions.
2. The global problem of reducing greenhouse gas emissions cannot be solved without the commitment of all countries towards such reduction.

2.3. PARIS AGREEMENT

The Paris Agreement was adopted by 196 Parties at Conference of Parties (COP21) in Paris, on 12 December 2015 [13]. This document is a binding agreement bringing all nations to undertake voluntary commitments to reduce greenhouse gas emis-

Table 6.
Dynamics of Methane emissions by the largest world emitters [15]

Country	CH_4 emissions, kt of CO_2 equivalent			
	1990	2012	2015	2018
Russian Federation	929 970	824 270	835 560	849 570
United States	766 550	618 150	617 170	622 590
China	730 340	1 151 100	1 237 520	1 238 630
India	522 740	650 410	652 000	666 510
Indonesia	298 410	251 460	269 470	287 500
Brazil	285 240	414 530	422 280	416 800

sions, based on the principle of differentiated responsibility. The countries independently determine national contributions to reducing greenhouse gas emissions [14].

2.3.1. CO_2 emission reduction after the end of the first commitment period of the Kyoto Protocol

The first results in terms of reduction in fossil fuel consumption after the end of the first commitment period of the Kyoto Protocol are presented in Table 5.

Compared to 2012, the largest reduction in emissions in 2018 was achieved by Ukraine (by 34%). However, the 31% reduction in primary fuel consumption is mainly attributable to industrial restructuring due to the ongoing political crisis.

Significant reductions in CO_2 emissions since 2012 were achieved by the United Kingdom – by 24% with a decrease in primary fuel consumption by ~7%, Japan – by ~12% with a decrease in primary fuel consumption by 5.4% and Germany (by ~7% with an increase in primary fuel consumption by 0.5%). The reduction in CO_2 emissions in these countries was largely due to an increased use of natural gas consumption as a replacement for the part of the high-carbon fossil fuels (in the UK and Germany, coal combustion was curbed by ~80% and 16% respectively, in Japan - oil combustion by ~27%).

The total amount of US emissions remained almost unchanged with an increase in primary fuel consumption by ~6.6%, however, the country is now actively reducing its coal consumption (by ~23%) and increasing the share of natural gas by ~17.6%.

China, with a growth in fossil fuel consumption by 16%, has increased CO_2 emissions by 8%, but the share of emissions from natural gas combustion has increased by 99%, and from coal combustion by only 2%.

India has increased its consumption of fossil fuels by 33%, while CO_2 emissions have grown by ~28%.

Fossil fuel consumption in Iran and Saudi Arabia has increased by ~26% and ~12% respectively, but emissions from Iran and Saudi Arabia increased by only 13% and ~6% respectively, due to the replacement of 12% and 4% of oil with natural gas.

In Brazil, fossil fuel consumption has increased by 3.8%, but CO_2 emissions have decreased by 4.2% due to a 10% reduction in emissions from oil combustion and an increase in natural gas emissions by 13.4%. However, emissions from coal combustion also increased by 7.6%. In Mexico, fossil fuel consumption has increased by ~2%, but emissions from oil combustion decreased by ~7% and from coal combustion – by ~5%, while emissions from natural gas combustion have increased by ~6%.

2.3.2. Methane, nitrous oxide, and HFC gas emissions behavior

A brief outlook of the other greenhouse gas emissions behavior is presented below.

Methane emissions

Comparison of methane emissions with the level of base year (1990) is shown in the Table 6.

As can be seen from the Table 6, in 1990, 51.2% of the world's CH_4 emissions was generated by 6 countries, out of which 42.8% by the: Russian Federation (13.5%), United States (11.1%), China (10.6%), India (7.6%), and also 8.4% – by Indonesia (4.3%) and Brazil (4.1%). By 2012 methane emissions by the United States decreased by ~20%, by Russian Federation – ~11%, and by Indonesia – 16%. China's emissions have grown by 58%, India – by 24%, and Brazil – by 45%.

In 2018 methane emissions by China accounted for

Table 7.
Dynamics of Nitrous Oxide emissions by the largest world emitters [19]

Country	N_2O, thousand metric tons of CO_2 equivalent			
	1990	2012	2015	2018
China	312 810	503 970	542 900	538 790
United States	249 360	245 810	242 640	250 060
India	139 570	241 950	246 030	253 790
Russian Federation	104 170	53 090	55 520	58 610
Brazil	106 590	167 660	172 220	179 200

Table 8.
Dynamics of Hydrofluorocarbons emissions by the largest world emitters [20]

Country	HFC, thousand metric tons of CO_2 equivalent	
	1990	2010
United States	29 186	300 896
Japan	9 154	60 318
China	5 970	183 870

15.2% of global CH_4 emission, emission by Russian Federation – 10.4%, by India – 8.2%, and by the United States – 7.6%. In 2021, China's oil and gas companies formed an alliance whose one of the aims is reduction of methane emissions [16].

Although emissions from the United States, Russian Federation and India have decreased compared to global emissions in 2012, emissions growth from other countries have resulted in a 3.9% increase in global methane emissions.

According to the Table 6, methane emissions from the Russian Federation change insignificantly, however, over the recent years, a significant increase in atmospheric methane emissions has been observed which is associated with the thawing bogs in the Siberia permafrost (microbial methane) and deglaciation of rock formations in the Arctic permafrost (thermogenic methane) [17]. In the short term, the damage from methane emissions can be much more serious than from CO_2 emissions, because the global warming potential of CH_4 is 25 times higher than of CO_2 [18]. According to forecasts, active thawing of permafrost which occupies 65% of Russia's territory can start as early as in 2025. The damage from thawing of bogs and rocks can have a global nature and is imponderable to-date.

Nitrous oxide emissions

Comparison of nitrous oxide emissions with the level of base year (1990) is shown in the Table 7.

As can be seen from the Table 7, in 1990, 39% of the world's N_2O emissions was generated by 5 countries, out of which 30% by the: China (13.4%), United States (10.7%) and India (6.0%), and another 9% was produced by Russian Federation (4.5%) and Brazil (4.6%). Collective emissions by Australia, Ukraine, Mexico, Pakistan and Islamic Republic amounted to 8.6%. In 2012 India's emissions increased by 73.4%, China's by ~60%, and Brazil's – by 57.3%. Emissions by Russian Federation reduced by 49%, and by United States – by 1.4%. By 2018 N_2O emissions by Russian Federation have grown by 10% compared to 2012, emissions by China and Brazil – by ~7%, and India – by ~5%. Global N_2O emissions have increased by ~5%.

HFC gas emissions

Comparison of hydrofluorocarbons emissions with the level of base year (1990) is shown in the Table 8.

As can be seen from the Table 8, in 2010 HFC emissions have increased by a factor of 10 in the United States, a factor of 22 – in China, and a factor of 7 – in Japan against the 1990 level. In 2010 aggregate emissions of the United States, China, and Japan amounted to 65.3% of the global emissions.

The data presented in the Tables 6–8 confirm the characteristic changes in carbon dioxide emissions trend: developing countries which according to Kyoto

Table 9.
Major Coal Consumers in the world [12, 24]

Country	Coal Consumption, Exajoules		CO_2 emissions from Country Coal combustion/ CO_2 emissions from Country Fuel combustion, %		Coal Consumption/ Primary Energy Consumption, %	CO_2 emissions from Country Coal combustion/ CO_2 emissions from World Fuel combustion, %
	2015	2018	2015	2018	2018	2018
China	80.41	80.09	82.0	79.8	58.8	22.8
India	16.55	18.56	71.0	70.5	55.7	4.9
United States	15.58	13.28	29.7	25.8	13.9	3.8
Japan	5.03	4.99	39.1	39.9	26.5	1.3
Russian Federation	3.86	3.63	26.8	25.9	12.1	1.2
The Republic of Korea	3.58	3.63	53.5	52.0	28.9	0.9
South Africa	3.52	3.76	81.9	81.8	70.9	1.0
Germany	3.29	2.9	43.0	39.2	21.6	0.8
Indonesia	2.14	2.84	35.1	40.9	34.5	0.7
Poland	2.04	2.08	68.4	62.8	47.6	0.6

Protocol did not have any commitments to reduce greenhouse gas emissions, have instead boosted them.

Climate modeling is one of the major tools for climate studies and forecasting future climate changes. Major fine-resolution models: Global Change Assessment Model (GCAM), Integrated Global System Model (IGSM), Asia Integrated Model (AIM), Russian Institute for Numerical Mathematics Climate Model (INM CM) etc. Modeling results are summarized in the IPCC Assessment Reports.

3. RACE TO ACHIEVE NET ZERO BY 2050

UNEP's Emissions Gap Report predicts that the world is rapidly moving towards a near-surface temperature rise of more than 3°C and urgent action is needed to decarbonize the economy [21].

3.1. Net Zero by 2050: A Roadmap for the Global Energy Sector

The International Energy Agency has presented a Roadmap for achieving carbon neutrality for global energy sector by 2050, which outlined an urgent ban on the new unabated coal plants and new projects on gas and oil fields, coal mines or coal extensions [22].

At the G7 Summit, which took place in Carbis Bay from June 11 to 13, 2021, world leaders recognized that the use of coal for power generation represents the main cause of greenhouse gas emissions. The G7 countries have pledged to stop governmental support for coal-fired power generation by the end of 2021 and have appealed other countries to join their pledges, as well as to achieve a meaningful reduction in greenhouse gas emissions in the 2020s and completely decarbonize the power system in the 2030s [23].

3.1.1. Coal consumption

Major coal consumers in the world and CO_2 emissions from coal combustion are presented in the Table 9.

As can be seen from the Table 9, China is burning more than a half of the global coal demand. Another 20% are shared by the United States and India. Complete phase out of coal in these countries may result in reduction of CO_2 emissions from fuel combustion by ~30%.

Aggregate coal consumption by Japan, Russian Federation, The Republic of Korea, South Africa, Germany, Indonesia, Poland equals to ~15%. Complete phase out of coal in these countries may result in reduction of GHG emissions by another ~6%. Without any doubt, this would be a significant contribution to the global decarbonization.

However, coal is responsible for meeting 60% of the primary energy consumption in China, and for 55% – in India, for 70% – in South Africa, for 50% – in Poland, for 30% each in the United States, Japan, the Republic of Korea, Indonesia 30%. Commitments undertaken by these countries to reduce their CO_2 emissions are described in section 3.2.

Table 10.
Primary energy Consumption and Carbon Dioxide emission from the combustion of anthropogenic fuel in the modified base year [11, 12]

Country	Base year	Primary energy Consumption, Exajoules	CO_2 emissions from fuel combustion, million tonnes of CO_2			
			Fuel	Coal	Oil	Gas
United States	2005	96.44	5 703.2	2 179.2	2 316.6	1180.5
China	2005	75.60	5 448.9	4 594.2	776.6	78.0
Japan	2005	22.35	1 181.5	399.9	603.8	169.5
India	2005	16.56	1 075.0	709.8	309.4	55.6
Mexico	2013	7.74	449.6	51.3	257.4	140.6
Brazil	2005	8.86	311.6	45.6	227.9	38.1
Iran, Islamic Rep.	2010	8.94	498.6	2.7	221.6	274.3
Republic of Korea	2017	12.37	600.0	312.8	163.1	102.7
Indonesia	2005	5.17	317.6	87.3	179.3	50.9

According to the Energy Strategy of the Russian Federation, it is assumed that coal supplies to the domestic market may increase by 8% by 2035 compared to 2018 level [25], which contradicts the target set by the IEA. According to the "Draft Strategy for the Long-Term Low-GHG Development of the Russian Federation till 2050", by 2030 the country plans to increase total greenhouse gas emissions by 32% compared to 2017 level, and by 2050 – by 26%, taking into account emissions related to the land use and forestry [26].

3.2. National pledges of the largest emitters of greenhouse gas emissions

In addition to the collective pledges made by the leaders of the G7 summit [27–28], the countries presented their commitments on the updated NDCs:

- United States: by 2030, reduce greenhouse gas emissions by 50–52% compared to 2005 levels. NDC announced a zero-emission pledge to be achieved no later than 2050. The United States has committed to achieve zero emissions in the energy sector by 2035 [29].
- Japan: by 2030, reduce emissions by 46–50% compared to 2013 level. The NDC specifies that Japan will strive to achieve a "decarbonized society" by 2050 through groundbreaking innovations such as artificial photosynthesis and other CCUS technologies, as well as the implementation of low-carbon hydrogen technologies [30].
- Germany: reduction of emissions by 65% by 2030, and zero carbon emissions by 2045. The NDC contains an interim pledge to reduce emissions by 88% by 2040 [31].
- United Kingdom: reduction of emissions by 68% by 2030 and by 78% by 2035. In addition, phasing-out of coal power plants by 2024, phasing-out of cars with internal combustion engines by 2030, and hybrid cars by 2035 [32].

In order to keep its pledge, the UK is planning to close 7 coal-fired power plants in 2022, and the last coal-fired power plant will be closed in 2024. Italy will phase-out coal in the same year. France has pledged to expedite the closure of coal-fired power plants in 2023 and achieve it as early as 2021. The Netherlands will stop burning coal for electricity generation by 2030, and the first out of five coal-fired power plants is planned for closure in 2021. Sweden intends to stop using coal in 2022, Austria – in 2025 at the latest, and Finland – in 2029. Germany and the Czech Republic are planning to completely phase out coal by 2038.

Developing countries in their iNDCs have also committed to reduce greenhouse gas emissions as follows:

- India: to lower carbon dioxide emissions per unit of GDP by 33–35% from 2005 levels by 2030 [33].
- The Republic of Korea: 24.4% reduction in emissions by 2030 compared to 2017 level [34].
- South Africa: accelerate achievement of the planned 10-year peak emissions (from 2035 to 2025), reduce dependence on coal from current 89% to 59% by 2030 [35].
- China: to lower carbon dioxide emissions per unit of GDP to 65% from the 2005 level by 2030, increase the share of non-fossil fuels in primary energy consumption up to 20%, achieve the peak emissions by 2030 and carbon neutrality by 2060 [36–38].

Table 11.
Influence of the base year on reduction of Carbon Dioxide emissions from the combustion of fossil fuels

Country	CO_2 emissions from fuel combustion, %				
	2018 / 1990	2018 / 2005	2018/ 2010	2018/ 2013	2018/ 2017
Ukraine	-73.6				
United Kingdom	-35.9				
Russian Federation	-26.6				
Germany	-25.9				
United States	2.5	-13,7			
Japan	2.5	-8,5			
Mexico	74.5			-0.2	
Brazil	120.2	30.4			
Republic of Korea	161.3				1
Iran, Islamic Rep.	238.6		16.2		
Indonesia	313.5	70.9			
India	335.4	114.7			
China	351	75.6			

- Mexico: reduction of emissions by 22–36% by 2030 [39].
- Brazil: reduction of emissions by 37% in 2025 and by 43% in 2030 compared to 2005 level [40].
- Russian Federation: reduction of emissions by 30% by 2030, taking into account the maximum possible carbon sequestration capacity of forests [41].
- Ukraine: reduction of emission by 58–64% by 2030 and achievement of carbon neutrality by 2060 [42].
- Saudi Arabia: emission reduction to 130 million tons of CO_2 equivalent annually by 2030 [43].
- Indonesia: reduction of emissions by 29–41% (by 11-14% in the energy sector). Target indicators in the energy sector are: oil share should be less than 25% in 2025 and less than 20% in 2050, coal share – at least 30% in 2025 and at least 25% in 2050; and gas share – at least 22% in 2025 and at least 24% in 2050 [44].

3.3. The impact of the base year on increasingly ambitious countries' climate actions

According to the UN Framework Convention, the predominant priority of developing countries is sustainable development based on economic and social development [9]. Since the emissions of developing countries in 1990 were quite minor (Table 4), a number of countries with rapidly developing economies have abandoned the base year defined by the Kyoto Protocol (1990). The emissions of countries in the modified base year are presented in the Table 10.

A study carried out in [45, 46] has shown the importance of choosing a countries' base year for meeting their commitments to reduce greenhouse gas emissions.

The influence of the base year on the rate (indicators) of reduction of carbon dioxide emissions from the combustion of fossil fuels are shown in the Table 11.

Data in the Tables 10 and 11 demonstrate that the abandonment of the base year 1990 in order to meet the country's obligations to reduce greenhouse gas emissions is more favorable for the countries undergoing fast-paced economic development. Comparison of CO_2 emission reduction levels already achieved in 2018 with the level of base year adopted in the first period of the Kyoto Protocol and with the level of base year modified by countries, shows a clear decline in the ambitions to reduce emissions. This has led to an acceleration of climate change, in particular, to the rapid rise in global temperature. The global average temperature in May 2021 was by 0.26°C higher than the May average over 1991–2020 [47]. The IPCC Special Report on Global Warming by 1.5°C has determined that the average near-surface air temperature over the period 1901–2012 increased by 0.89±0.20°C [48]. The increment of the average near-surface temperature in May 2021 was already 1.11°C [47].

3.4. Challenges for the energy sector of coal-dependent economies

The harsh policies to stop burning coal and gradually phase out the oil and natural gas, as outlined in the Net Zero by 2050: A Roadmap for the Global Energy Sector, require enormous investments in restructur-

ing the economies of the coal-dependent countries. For example, in countries like Ukraine, Poland, or Czech Republic, coal-fired thermal power plants represent a significant part of the country's energy generation.

In Ukraine, 37% of the country's fuel mix are coal-fired TPPs and CHPPs, 53% – nuclear power plants (NPPs), and 7.9% – generation by renewable energy sources (RES) [49]. However, nuclear power plants and renewable energy sources, which generate more than half of the country's electricity, operate in a baseload mode and cannot ensure flexibility according to the demand, while thermal power plants burning steam coal provide such flexibility by following the load curve of generation depending on the fluctuations in demand. The active replacement of coal flexible capacities will be accompanied by a sharp increase in tariffs for industrial users and households. Closure of thermal power plants and coal mines will require creation of new jobs and the re-skilling of the large groups of population.

The G7 leaders emphasized the urgency for other large carbon-dependent economies to find ways towards removing barriers to carbon neutrality and to set more ambitious plans. On October 31 – November 12, 2021, the 26th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC COP 26) will be held in Glasgow. This conference should define specific plans to achieve the goals of the Paris Agreement.

4. CONCLUSIONS

1. The drastic temperature rise has brought the planet closer to the breakpoint of irreversible effects of the climate change.
2. Efforts taken by the most developed countries over the last 30 years in order to reduce greenhouse gas emissions are inadequate, given the rapid growth of emissions in the non-committed countries having no quantitative limits or goals on emissions. Complete decarbonization of the energy system in all countries of the world can stop emissions growth.
3. For decarbonization of the economy, countries require making substantial investments, shifting to the new employment patterns, and starting policy advocacy campaign in order to increase the level of energy and environmental awareness.

REFERENCES

[1] WMO Greenhouse Gas Bulletin (GHG Bulletin) – No.15: The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2018 https://library.wmo.int/index.php?lvl=notice_display&id=21620#.YI_vm7UzZaR

[2] Climate Change 2013: The Physical Science Basis https://www.ipcc.ch/report/ar5/wg1/

[3] The State of the Global Climate 2020 https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate.

[4] WMO GREENHOUSE GAS BULLETIN No. 16 | 23 November 2020 https://library.wmo.int/doc_num.php?explnum_id=10437

[5] The first part of the Sixth Assessment Report, Climate Change 2021: The Physical Science Basis https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

[6] Trends in atmospheric concentrations of CO_2 (ppm), CH_4 (ppb) and N_2O (ppb), between 1800 and 2017 https://www.eea.europa.eu/data-and-maps/daviz/atmospheric-concentration-of-carbon-dioxide-5#tab-chart_6

[7] Mauna Loa carbon dioxide forecast for 2021 https://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/long-range/forecasts/co2-forecast

[8] Carbon dioxide peaks near 420 parts per million at Mauna Loa observatory https://research.noaa.gov/article/ArtMID/587/ArticleID/2764/Coronavirus-response-barely-slows-rising-carbon-dioxide

[9] UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE https://unfccc.int/files/essential_background/background_publications_htmlpdf /application/pdf/conveng.pdf

[10] KYOTO PROTOCOL TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE https://unfccc.int/resource/docs/convkp/kpeng.pdf

[11] IEA (2020), CO_2 Emissions from Fuel Combustion: Overview https://www.iea.org/reports/co2-emissions-from-fuel-combustion-overview

[12] CO_2 Emissions from Fuel Combustion Highlights https://www.iea.org/data-and-statistics/data-product/co2-emissions-from-fuel-combustion-highlights

[13] PARIS AGREEMENT https://unfccc.int/sites/default/files/English_paris_agreement.pdf

[14] NDC Registry https://www4.unfccc.int/sites/NDCStaging/Pages/All.aspx

[15] https://data.worldbank.org/indicator/EN.ATM.METH.KT.CE

[16] China Oil and Gas Enterprises Methane Emission Control Alliance) https://www.cnooc.com.cn/art/2021/5/19/art_6261_15314940.html

[17] Methane release from carbonate rock formations in the Siberian permafrost area during and after the 2020 heat wave https://www.pnas.org/content/118/32/e2107632118

[18] HTTPS://UNFCCC.INT/PROCESS-AND-MEETINGS/TRANSPARENCY-AND-REPORTING/GREENHOUSE-GAS-DATA/FREQUENTLY-ASKED-QUESTIONS/GLOBAL-WARMING-POTENTIALS-IPCC-FOURTH-ASSESSMENT-REPORT

[19] https://data.worldbank.org/indicator/EN.ATM.NOXE.KT.CE

[20] https://data.worldbank.org/indicator/EN.ATM.HFCG.KT.CE

[21] (UNEP) Emissions Gap Report 2020 https://www.unep.org/emissions-gap-report-2020

[22] Net Zero by 2050: A Roadmap for the Global Energy Sector https://www.iea.org/reports/net-zero-by-2050

[23] CARBIS BAY G7 SUMMIT COMMUNIQUÉ Our Shared Agenda for Global Action to Build Back Better https://www.g7uk.org/wp-content/uploads/2021/06/Carbis-Bay-G7-Summit-Communique-PDF-430KB-25-pages-5.pdf

[24] Statistical Review of World Energy 2021 | 70th edition https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-coal.pdf

[25] https://minenergo.gov.ru/node/1026

[26] https://economy.gov.ru/material/file/babacbb75d32d90e28d3298582d13a75/proekt_strategii.pdf

[27] CARBIS BAY G7 SUMMIT COMMUNIQUÉ https://www.g7uk.org/wp-content/uploads/2021/06/Carbis-Bay-G7-Summit-Communique-PDF-430KB-25-pages-1-2.pdf

[28] Statement by the UK Presidency of the G7 The Road to COP https://www.g7uk.org/wp-content/uploads/2021/06/The-Road-to-COP_-Statement-by-the-UK-Presidency-of-the-G7-PDF-418KB-8-pages-.pdf

[29] The United States of America Nationally Determined Contribution https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/United%20States%20of%20America%20First/United%20States%20NDC%20April%2021%202021%20Final.pdf

[30] Submission of Japan's Nationally Determined Contribution (NDC) https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Japan%20First/SUBMISSION%20OF%20JAPAN'S%20NATIONALLY%20DETERMINED%20CONTRIBUTION%20(NDC).PDF

[31] Submission by Germany and the European Commission on behalf of the European Union and its Member States https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/European%20Union%20First/EU_NDC_Submission_December%202020.pdf

[32] United Kingdom of Great Britain and Northern Ireland's Nationally Determined Contribution https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/United%20Kingdom%20of%20Great%20Britain%20and%20Northern%20Ireland%20First/UK%20Nationally%20Determined%20Contribution.pdf

[33] 5 Key Takeaways from India's New Climate Plan (INDC) https://www.wri.org/insights/5-key-takeaways-indias-new-climate-plan-indc

[34] Submission under the Paris Agreement. The Republic of Korea's Update of its First Nationally Determined Contribution https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Republic%20of%20Korea%20First/201230_ROK%27s%20Update%20of%20its%20First%20NDC_editorial%20change.pdf

[35] South Africa's Intended Nationally Determined Contribution (INDC) https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/South%20Africa%20First/South%20Africa.pdf

[36] IEA Executive Director and China's Special Envoy on Climate Change discuss global efforts to reach net-zero emissions https://www.iea.org/news/iea-executive-director-and-china-s-special-envoy-on-climate-change-discuss-global-efforts-to-reach-net-zero-emissions

[37] Enhanced Actions on Climate Change: China's Intended Nationally Determined Contributions https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/China%20First/China's%20First%20NDC%20Submission.pdf

[38] China to control, phase down coal consumption in next decade: Xi http://www.xinhuanet.com/english/2021-04/22/c_139899306.htm

[39] Mexico's Nationally Determined Contributions 2020 Update https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Mexico%20First/NDC-Eng-Dec30.pdf

[40] Paris Agreement. Brazil's Nationally Determined Contribution (NDC) https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Brazil%20First/Brazil%20First%20NDC%20(Updated%20submission).pdf

[41] Nationally Determined Contribution of the Russian Federation https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Russia%20First/NDC_RF_eng.pdf

[42] Updated Nationally Determined Contribution of Ukraine to the Paris Agreement https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Ukraine%20First/Ukraine%20NDC_July%2031.pdf

[43] The Intended Nationally Determined Contribution of the Kingdom of Saudi Arabia under the UNFCCC https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Saudi%20Arabia%20First/KSA-INDCs%20English.pdf

[44] First Nationally Determined Contribution Republic of Indonesia https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Indonesia%20First/First%20NDC%20Indonesia_submitted%20to%20UNFCCC%20Set_November%20%202016.pdf

[45] Sigal, O.I.& Pavliuk, N.Y. (2012) Vuhletsevi perspektyvy: vyklyky dlia Ukrainy Carbon prospects: challenges for Ukraine *Thermophysics and thermal power engineering, 34*(6), 78–85.

[46] Matyukhina, A. & Pavluk, N. (2017) Zmina klimatu jak globalna problema sucasnosti: vyklyky ta slahi virisenna (filosofskij aspekt) (Climate change as a global problem of modernity: challenges and ways of solving (philosophical aspect)) *Proceedings of the National Aviation University, 26*(2), 89–93. DOI: https://doi.org/10.18372/2412-2157.26.12709

[47] Surface air temperature for May 2021 https://climate.copernicus.eu/surface-air-temperature-may-2021

[48] IPCC Special Report on "Global Warming of 1.5°C". https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf

[49] Structure of Electricity Production and Consumption in Ukraine https://kosatka.media/category/elektroenergiya/analytics/generaciya-i-potreblenie-elektroenergii-v-yanvare-avguste-2020-goda