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Table of contents

Introduction **8**

Chapter 1
Polycrisis in the global economy and economic analysis **11**
Konrad Raczkowski, Piotr Komorowski, Friedrich Schneider

Introduction 11
1.1. The essence of a polycrisis 12
1.2. Causes of global instability as the beginning of an era of polycrises 16
1.3. Consequences of polycrisis 22
1.4. Index of uncertainty in the global economy 26
1.5. Risks of polycrisis and challenges for economic policy 32
Conclusions 34
Bibliography 36

Chapter 2
Social changes caused by fundamental convergence in the functioning of the world economy **40**
Olha Ilyash

Introduction 40
2.1. Global changes in the world economy in the context of geoeconomic fragmentation 42
2.2. Increasing social crises in the isolation of the global economy and the geopolitical tension 49
2.3. Social threats of the long-lasting Russia's military aggression against Ukraine in the economic security of the partner countries 60
Conclusions 69
Bibliography 71

Chapter 3
Mapping the world's changing technological landscape **74**
Alina Landowska

Introduction 74
3.1. A challenge with the technological gap 77
3.2. The Technological Gap Model 79
3.3. The Product Lifecycle Model 80
3.4. The "Technology Gap" Model of International Trade 83
3.5. Measuring the technological disparities 85
3.7. Narrowing or widening the technological gap? 104
Conclusions 107
Bibliography 108

Chapter 4
Energy, economic growth, and the balance of power in the global economy **112**
Marek Szczepaniec

Introduction 112
4.1. Theoretical background 116
4.2. Literature review 117
4.3. Analysis of economic data 120
4.4. Electricity prices 132
4.5. Innovation 138
4.6. Merchandise exports 141
4.7. The wealth of nations 144
Conclusions 150
Bibliography 152

Chapter 5
The growth of the investment fund industry in the context of economic changes **156**
Dariusz Filip

Introduction 156
5.1. A brief review of the literature on the subject 158
5.2. Description of data 161
5.3. Conceptual issues and results 162
Conclusions 173
Bibliography 174

Chapter 6
The green economy and the circular economy as models for addressing environmental change **177**
Bartosz Stachowiak

Introduction 177
6.1. Climate change: social and economic consequences 180
6.2. Towards new ideas for the functioning of the economy – sustainable development, green economy, and circular economy 190
6.3. The circular economy and its impact on the formulation of economic policies and objectives 196
Conclusions 209
Bibliography 211

Chapter 7
Comparisons of the monetary policy of the central banks of the Federal Reserve Bank and the European Central Bank, and the Central Bank of Poland **213**
Dariusz Prokopowicz

Introduction 213
7.1. Comparison of Fed and ECB monetary policies conducted in the context of the 2008 global financial crisis 216
7.2. Comparison of Fed and ECB monetary policies conducted in the context of pandemic economic crisis 2020 221
7.3. Dominant opinions and theories on the legitimacy and effectiveness of actions taken by the FED and ECB central banks in the context of financial and economic crises 224
7.4. Dominant opinions and theories on the legitimacy and effectiveness of actions taken by the central banks FED and ECB in the context of stabilising exchange rate movements 227
7.5. Dominant opinions and theories on the legitimacy and effectiveness of the measures taken by the FED and ECB central banks in the context of quantitative easing 229
7.6. Dominant opinions and theories on the legitimacy and effectiveness of the FED and ECB central banks' monetary tightening efforts 233
7.7. Dominant opinions and theories on the key macroeconomic factors that are taken into account, factored into the formation of monetary policy, and are the basis for certain interventionist actions taken by the FED and ECB central banks 235
7.8. Key differences and determinants in the monetary policies used by the FED and ECB central banks 239
7.9. Key normative determinants of the differences between the Fed's and ECB's monetary policies 241
7.10. Macroeconomic characteristics differentiating the US and EU economies determining the differences in the monetary policies shaped by the FED and ECB central banks 243
7.11. The Anglo-Saxon model of the financial system and the European model of the financial system vs. monetary policy making by the central banks FED and ECB 245
7.12. Interventionist actions by the Fed and ECB during the 2008 global financial crisis 248
7.13. Evaluation of the legitimacy and effectiveness of interventionist measures taken by the central banks of the FED and ECB in the situation of rising inflation in the period between 2021 and 2023 251
7.14. Determinants of increasing gold reserves at central banks 252
7.15. Monetary policy of the Central Bank of Poland versus the FED and ECB – similarities and differences 254

7.16. The question of the impact of central banks' monetary policies on commercial banks' finances and central banking efficiency against the background of the national economy 259
7.17. The past and future of central banks' monetary policies, including the Federal Reserve Bank, the European Central Bank, and the Central Bank of Poland 263
Conclusions 268
Bibliography 271

CHAPTER 4

Energy, economic growth, and the balance of power in the global economy

Marek Szczepaniec

Introduction

The progress of civilisation has always depended on the ability to use different sources of energy. Fire, wind, sun, and water used by humans ensured gradual economic growth and an improved quality of life. However, the real leap in civilisation came with the massive use of fossil fuels. Fossil fuels enabled the intensification of production processes and the development of transport in the 19th and 20th centuries.

Another breakthrough came with electrification. Electricity began to reach the farthest corners of countries and found more and more applications. Without electricity, it is difficult to imagine modern civilisation. It ensures the uninterrupted operation of key infrastructure components and provides light, cooling, or heat, depending on the demand; it drives rail transport and – recently increasingly – road transport.

Access to large amounts of relatively cheap energy has become one of the key factors in the competitive advantage not only for individual companies but also for entire countries. Widespread use of energy, access to energy, and energy prices affect all dimensions of human economic activity, be it the cost of production and services, inflation, household purchasing power, consumption, investment, market interest rates, exchange rates, etc. A policy of restricting the growth of energy supply generates an increase in energy prices, which leads to a slowdown in production processes and an increase in prices in other sectors of the economy. Higher inflation, in turn, contributes to an increase in interest rates, which increases the cost of external financing (loans, leases) and puts an additional burden on all those who previously used credit (companies, households) (Figure 1).

The role of energy in the economy is a very popular subject in science. There are hundreds, if not thousands, of significant publications in this area every year, especially with respect to sustainable growth. However, despite a great deal of scientific activity and changes in economic policy, including energy policy, none of the key problems associated with energy (pollution, rising global CO_2 emissions, energy shortages, and volatile energy prices, including shock events that disrupt not only national economies, but also the entire global economic cycle) have been resolved.

Energy policy and its impact on the balance of power in the global economy have been often described in academic publications, but new developments, rapid changes in the energy market, and international exchanges make the issue topical and requiring constant adjustments and new insights.

The aim of this chapter is to explore and describe the impact of energy on economic growth processes and the balance of power in the global economy.

A comparative analysis of the 10 countries that played the largest role in the global economy in 2022 has been chosen as the research method. The aggregate value of their GDP was USD 67.4 trillion, representing 66.5 per cent of global GDP[1]. The baseline period of analysis covers the years between 1990 and 2020 or extends to 2022 if more recent data are available. In terms of the thematic scope of the analyses, the focus is on the following parameters: primary energy consumption, electricity generation, electricity prices, economic growth, exports, innovation, and citizens' wealth.

This study formulates the following three hypotheses for the 10 countries analysed:

H1: *There is a positive relationship between a country's share of global energy consumption and its share of global GDP.*

H2: *There is a positive relationship between a country's share of global electricity production and its share of global GDP.*

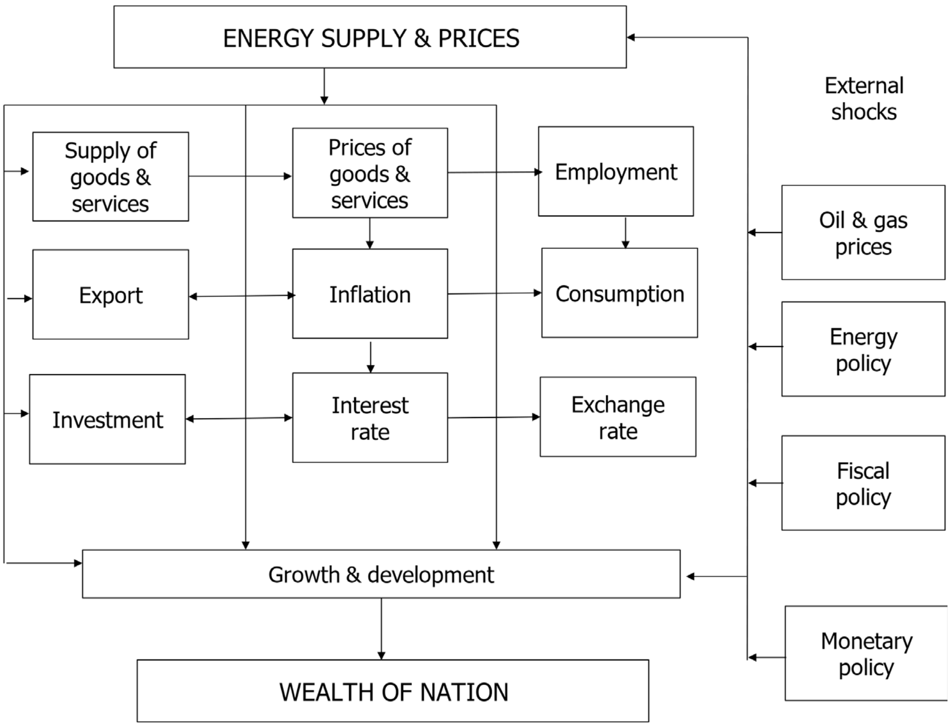
H3: *There is a negative relationship between a country's electricity prices and its share of global GDP.*

1 World Bank (2023), *GDP (current US$)*, https://data.worldbank.org/indicator/NY.GDP.MKTP.CD [19.12.2023].

The rationale for the hypotheses is based on literature studies, the results of fuel and energy sector surveys, and the analysis of macroeconomic indicators.

In the method adopted, the generalisation of results is mainly analytical, but correlation coefficients for key variables have also been counted.

FIGURE 1. The impact of energy supply and prices on the economy.



Source: Internal analysis.

The role of energy in the economy was recognised in the 1970s, when two energy crises occurred. Since then, energy has been accepted as one of the key factors of production, with a multidimensional impact on the functioning of the economy and the international balance of power. Energy security has come to be associated with stable supplies of relatively cheap oil without the threat of embargoes and price manipulation by exporters[2].

After the oil crises, the importance of energy policy and related energy security has clearly increased. Energy policy is a deliberate and purposeful activity of a state or group of states to rationally manage energy resources in order to ensure energy security and improve the quality of life of citizens. Energy policy covers such issues as energy sources, energy efficiency, energy prices, energy exports/imports, energy infrastructure, and the environmental impact of the energy sector.

IEA defines energy security as the uninterrupted availability of energy sources at an affordable price (IEA 2024)[3]. In the long term, energy security is to be ensured by adequate investment in generation capacity, in line with the needs of a growing economy and taking into account the need to protect the environment. According to the World Bank, energy security means ensuring sustainable energy production and consumption at a reasonable price in such a way as to enhance economic growth, reduce poverty, and directly improve people's quality of life by expanding access to advanced energy services[4]. Definitions of energy security have begun to include environmental aspects over time[5].

After the Second World War, a country's position on the international stage was thought to be determined by three areas (with each area including two factors): the military (personnel and expenditure), industry (energy consumption and iron/steel production), and demography (total population and urban population) (Ray and Singer 1973)[6]. These six indicators make up the Composite Index of National Capability (CINC). In subsequent decades, more attention began to be paid to human capital, information, and groundbreaking technologies. In the USA, the Global Power Index (GPI) was created under the auspices of the National Intelligence Council (NIC). The index included the following

2 Colglazier Jr E., Deese D., 1983, *Energy and security in the 1980s*, "Annual Review of Energy", 8(1), pp. 415–49.

3 IEA (2024), https://www.iea.org/topics/energy-security.

4 World Bank (2005), *Energy Security Issues*, The World Bank Group, 2005.

5 UNDP, 2000, United Nations Development Programme, *World energy assessment – energy and challenges of sustainability*, New York.

6 Ray, J. L., Singer, J. D. (1973), *Measuring the Concentration of Power in the International System*, "Sociological Methods & Research, 1(4), pp. 403–437, https://doi.org/10.1177/004912417300100401.

areas: nuclear weapons, international trade, research and development (R&D) spending, government revenue, and working age population[7].

This study measures the global strength of individual countries by relative indicators, such as share of global GDP, share of world trade, share of total patents, and share of total wealth of individuals.

Due to the nature and limited size of this chapter, the focus has been only on the role of energy and innovation, while such issues as military power and the impact of money on international economic processes have been omitted or treated superficially.

4.1. Theoretical background

According to biophysical economics, the production of goods cannot take place without the use of energy (Kummel 1982[8]; Cleveland *et al*. 1984[9]; Kummel and Lindenberg 2014[10]). Energy is recognised as a key source of wealth (Hall and Klitgaard 2018[11]). The use the energy contained in fossil fuels has enabled rapid economic growth and improved the quality of life of the population.

Energy is treated as an important factor in the classical production function, the Solow Growth Model, and the Cobb-Douglas production function (Wang *et al*. 2011[12]; Pandey and Rastogi 2019[13]; Bekun and Agbola 2019[14];

7 Heim J., Miller B., (2020), *Measuring Power, Power Cycles, and the Risk of Great-Power War in the 21st Century*, RAND Corporation.

8 Kummel, R., 1982, *The impact of energy on industrial growth*, Energy, 7, pp. 189–203.

9 Cleveland, C.J., *et al*., 1984, *Energy and the US economy: a biophysical perspective*, "Science", 225, pp. 890–897.

10 Kummel, R., Lindenberg, D., 2014, *How energy conversion drives economic growth far from the equilibrium of neoclassical economics*, "New Journal of Physics", 16, pp. 1–31.

11 Hall, Ch., Klitgaard, K., 2018, *Energy and the Wealth of Nations. An Introduction to Biophysical Economics*, Springer International Publishing.

12 Wang, Y., *et al*., 2011, *Energy consumption and economic growth in China: A multivariate causality test*, "Energy Policy", 39, pp. 4399–4406.

13 Pandey, K.K., Rastogi, H., 2019, *Effect of energy consumption and economic growth on environmental degradation in India: A time series modelling*, 10th International Conference in Applied Energy (ICAE 2018), 22–25th August, Hong Kong, China, "Energy Procedia", 158, pp. 4232–4237.

14 Bekun, F.V., Agboola, M.O., 2019, *Electricity consumption and economic growth nexus: evidence from Maki cointegration*, "Engineering Economics", 30(1), pp. 14–23.

Galadima and Aminu 2019[15]; Munir *et al.* 2019[16]; Akram *et al.* 2020[17]; Lee and Chang 2008[18]).

In the short-run, AD-SAS equilibrium model, an increase in the supply of energy with relatively low energy prices, leads to a rightward shift of the AS curve and to a change in the position of the equilibrium point reached with higher real GDP (Y) and a lower overall price level (P). In the long-run, AD-LAS equilibrium model, an increase in the supply of resources (including energy) with competitive prices, should contribute to a shift of the LAS curve to the right, resulting in higher GDP and lower inflation.

4.2. Literature review

In the last decade, the unidirectional positive impact of energy consumption on economic growth processes has been confirmed by a number of studies, *e.g.*:

- Talha *et al.* (2021)[19], Malaysia (1986–2019);
- Okoye *et al.* (2021)[20], Nigeria (1981–2017);
- Jayasinghe and Selvanathan (2021)[21], India (1991–2018);
- Bashir *et al.* (2021)[22], Indonesia (1985–2017);

15 Galadima, M. D., Aminu, A. W., 2019, *Nonlinear unit root and nonlinear causality in natural gas – economic growth nexus: Evidence from Nigeria*, "Energy", Volume 190, 1 January 2020, http://dx.doi.org/10.1016/j.energy.2019.116415.

16 Munir, Q., *et al.*, 2019, *CO_2 emissions, energy consumption and economic growth in ASEAN-5 countries a cross-sectional dependence approach*, "Energy Economics", http://dx.doi.org/10.10168/j.eneco.2019.104571.

17 Akram, R., *et al.*, 2020, *Heterogeneous effects of energy efficiency and renewable energy on economic growth of BRICS countries: A fixed effect panel quantile regression analysis*, "Energy", http: //dx.doi.org/10.1016/j.energy.2020.119019.

18 Lee, C. C., Chang, C. P., 2008, *Energy consumption and economic growth in Asian economies: a more comprehensive analysis using panel data*, "Resource and Energy Economics", 30, pp. 50–65.

19 Talha, M., *et al.*, 2021, *Impact of oil prices, energy consumption and economic growth on the inflation rate in Malaysia*, "Cuadernos de Economia", 44, pp. 26–32.

20 Okoye, L. U., *et al.*, 2021, *Analysing the energy consumption and economic growth nexus in Nigeria*, "International Journal of Energy Economics and Policy", 11 (2), pp. 378–387.

21 Jayasinghe, M., Selvanathan, E. A., 2021, *Energy consumption, tourism, economic growth and CO_2 emissions nexus in India*, "Journal of the Asia Pacific Economy", 26(2), 361–380, http://dx.doi.org/10.1080/13547860.2021.1923240.

22 Bashir, A., *et al.*, 2021, *Relationships between urbanization, economic growth, energy consumption, and CO_2 emissions: Empirical evidence from Indonesia*, Journal of Asian Finance, "Economics and Business", 8(3).

- Tao *et al*. (2020)[23], China (1990–2016);
- Güriş and Tiftikçigil (2020)[24], Turkey (1990–2015);
- Zhang *et al*. (2020)[25], China (1996–2005);
- Lin and Wang (2019)[26], China (2000–2016);
- Gozgor *et al*. (2018)[27], 29 OECDs, (1990–2013);
- Ghoshray *et al*. (2018)[28], USA (1949–2014);
- Jiang and Bai (2017)[29], China (1987–2007);
- Ito (2017)[30], 42 DCs (2002–2011);
- Dar (2017)[31], India (1971–2011);
- Hamit-Haggar (2016)[32], 8SSAs, (1991–2007);
- Chen *et al*. (2016)[33], 188 countries (1993–2010);
- Işık & Shahbaz (2015)[34], OECD (1980–2010).

Many studies have also found a feedback loop between energy and economic growth demonstrate that increasing energy consumption lead to economic growth, but economic growth also contributes to increasing energy consumption as the population grows richer, *e.g.*:

23 Tao, W., *et al*., 2020, *Energy consumption in China's marine economic zones – an estimation based on partial linear model*, "Energy", 205, 118028.

24 Güriş, B., Tiftikçigil, B.Y., 2020, *The renewable energy consumption-economic growth nexus in Turkey*, "Social Science Research Journal", 9(3), pp. 105–111.

25 Zhang, J., Zhang, Y., 2020, *Spatial effects of economic growth, energy consumption and environmental pollution in the provinces of China – an empirical study of the spatial econometrics model*, "Sustainable Development", pp. 1–12.

26 Lin, B., Wang, M., 2019, *Possibilities of decoupling for China's energy from consumption economic growth: A temporal spatial analysis*, "Energy", 185, pp. 951–960.

27 Gozgor, G., *et al*., 2018, *Energy consumption and economic growth: New evidence from the OECD countries*, "Energy", 153, pp. 27–34.

28 Ghoshray, A., *et al*., 2018, *Re-assessing causality between energy consumption and economic growth*, "PLoS", 13(11), e0205671. http://dx.doi.org/10.1371/journal.pone.0205671.

29 Jiang, L., Bai, L., 2017, *Revisiting the granger causality relationship between energy consumption and economic growth in China*, "Sustainability", 9(12), 2299; https://doi.org/10.3390/su9122299.

30 Ito, K., 2017, *CO_2 emissions, renewable and non-renewable energy consumption, and economic growth: Evidence from panel data for developing countries*, "International Economics", 151, pp. 1–6.

31 Dar, J.A., Asif, M., 2017, *On causal interaction between carbon emissions, energy consumption and economic growth: An evidence from India*, "International Journal of Ecology & Development", 32(2).

32 Hamit-Haggar, M., 2012, *Greenhouse gas emissions, electricity production and economic growth in different income levels*, "Energy Economics", 34, pp. 358–364.

33 Chen, P., *et al*., 2016, Modeling the global relationships among economic growth, energy consumption and CO_2 emissions, "Renewable and Sustainable Energy Reviews, 65, pp. 420–431.

34 Işık, C., Shahbaz, M., 2015, *Energy consumption and economic growth: A panel data approach to OECD countries*, "International Journal of Energy Science", 5(1), pp. 1–6.

- Syzdykova *et al*. (2020)[35], CIS (1992–2018);
- Bui (2020)[36], Vietnam (1984–2016);
- Baz *et al*. (2020)[37], Pakistan (1971–2014);
- Zafar *et al*. (2019)[38], APEC (1990–2015);
- Zhang *et al*. (2021)[39], 45 BRI (1990–2015);
- Lawal *et al*. (2020)[40], Africa (1971–2017);
- Churchill and Ivanovski (2020)[41], Australia (1990–2005);
- Ali *et al*. (2020)[42], Pakistan (1961–2015);
- Kirikkalelli *et al*. (2018)[43], 35 OECDs
- Al-Mulali and Sab (2018)[44], GCC (1980–2015),
- Sarwar *et al*. (2017)[45], 210 Global (1960–2014);
- Raza *et al*. (2016)[46], ASEAN (1980–2010).

35 Syzdykova, A., *et al*., 2020, *Analysis of the relationship between energy consumption and economic growth in commonwealth independent states*, "International Journal of Energy Economics and Policy", 10(4), pp. 318–324.

36 Bui, X.H., 2020, *An investigation of the causal relationship between energy consumption and economic growth: A case study of Vietnam*, "International Journal of Energy Economics and Policy", 10(5), pp. 415–421.

37 Baz, K., *et al*., 2020, *Asymmetric impact of energy consumption and economic growth on ecological footprint: Using asymmetric and non-linear approach*, "Science of The Total Environment", 718, pp. 1–10.

38 Zafar, M.W., *et al*., 2019, *The nexus of renewable and non-renewable energy consumption, trade openness, and CO_2 emissions in the framework of EKC: evidence from emerging economies*, "Environmental Science and Pollution Research", 26(15), pp. 15162–15173.

39 Zhang, H., *et al*., 2021, *Electricity consumption and economic growth in BRI countries: Panel causality and policy implications*, "Emerging Markets Finance and Trade", 57(3), 859–874. http://dx.doi.org/10.1080/1540496X.2019.1601551.

40 Lawal, A.I., at al., 2020, *Examining the linkages between electricity consumption and economic growth in African economies*, "Energy", 208, 118363.

41 Churchill, S.A., Ivanovski, K., 2020, *Electricity consumption and economic growth across Australian states and territories*, "Applied Economics", 52(8), pp. 866–878, http://dx.doi.org/10.1080/00036846.2019.1659932.

42 Ali, S., *et al*., 2020, Impact of electricity consumption and economic growth: An application of VECM and ANN, "The Journal of Developing Areas", 54(4).

43 Kirikkalelli, D., *et al*.., 2018, *Panel cointegration: Long run relationship between internet, electricity consumption and economic growth: Evidence from OECDs*, "Investigación Económica", 77(303), 0185–1667.

44 Al-Mulali, U., Che Sab, C.N.B., 2018, *Electricity consumption, CO_2 emission, and economic growth in the Middle East. Energy sources. Part B Economics, planning and policy*, 13(5), pp. 257–263.

45 Sarwar, S., *et al*., 2017, *Electricity consumption, oil price and economic growth: Global perspective*, "Renewable and Sustainable Energy Reviews", 76, pp. 9–18.

46 Raza, S.A., *et al*., 2016, *Electricity consumption and economic growth in south*, "South Asia Economic Journal", 17(2), pp. 200–215, http://dx.doi.org/10.1177/1391561416649721.

4.3. Analysis of economic data

Primary energy consumption

Primary energy consumption is associated with all economic and livelihood processes. Energy enables the production of goods and services and the movement of goods and people, and it improves the quality of life.

Table 1 shows primary energy consumption, which has increased globally by almost 76 per cent over the past 32 years, from 344 EJ in 1990 to 604 EJ 2022. In 1990, the USA (23.6 per cent) and the Soviet Union (10.5 per cent) were the leaders in primary energy consumption. Over the next 32 years, China has gradually increased its share of primary energy consumption, becoming the world leader in this field. In 2022, China accounted for 26.4 per cent of the world's primary energy, ahead of the USA (15.9 per cent), India (6.0 per cent), and Russia (4.8 per cent). The combined share of the four largest European economies (E4: Germany, United Kingdom, France, and Italy) in primary energy consumption decreased from 11.7 per cent to 5.6 per cent.

TABLE 1. Primary energy: Consumption (Exajoules, share)

COUNTRY	1990	2000	2010	2020	2021	2022
World (Exajoules)	344	397	509	566	597	604
World (%)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
United States	23.6%	24.1%	18.4%	15.6%	15.6%	15.9%
China	8.3%	10.7%	20.6%	26.4%	26.4%	26.4%
Japan	5.5%	5.7%	4.2%	3.0%	3.0%	3.0%
Germany	4.4%	3.6%	2.7%	2.2%	2.1%	2.0%
India	2.4%	3.4%	4.4%	5.6%	5.8%	6.0%
United Kingdom	2.6%	2.4%	1.8%	1.3%	1.2%	1.2%

COUNTRY	1990	2000	2010	2020	2021	2022
France	2.8%	2.8%	2.1%	1.6%	1.6%	1.4%
Russian Federation	10.5%	6.5%	5.5%	5.1%	5.3%	4.8%
Canada	3.1%	3.3%	2.7%	2.4%	2.3%	2.3%
Italy	1.9%	1.9%	1.4%	1.0%	1.1%	1.0%
E4*	11.7%	10.7%	8.0%	6.1%	6.0%	5.6%

* Germany, United Kingdom, France, Italy

Source: Energy Institute, *Statistical Review of World Energy, 2023*, https://www.energyinst.org/statistical--review [19.12.2023].

Fossil fuels played a dominant role in the global energy mix in 2022, accounting for a total of 81.8 per cent of primary energy consumed (of which 31.6 per cent – oil, 26.7 per cent – coal, and 23.5 per cent – natural gas). Of the 10 countries analysed, the USA, Russia, and Canada are in the best position. They have abundant fossil fuel resources, which provides them with a high level of energy security and independence. The remaining countries are heavily dependent on imports of energy resources. For China and India, coal is crucial in the energy mix, and they do not intend to give up this raw material in the coming decades.

A different approach is being taken by the EU, which wants to bring about a further reduction in the use of fossil fuels as part of its Fit for 55 policy. The Renewable Energy Directive proposes to increase the overall binding target from the current 32 per cent to a new level of 40 per cent of renewables in the EU energy mix[47].

47 European Commission, 2021, *'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality*, Brussels, 14.7.2021, COM(2021) 550.

TABLE 2. Primary energy: Consumption by fuel (per cent), 2022

COUNTRY	OIL	COAL	NATURAL GAS	RENEW-ABLES	HYDRO ELECTRIC	NUCLEAR ENERGY
World	31.6%	26.7%	23.5%	7.5%	6.7%	4.0%
United States	37.7%	10.3%	33.1%	8.8%	2.5%	7.6%
China	17.7%	55.5%	8.5%	8.3%	7.7%	2.4%
Japan	37.0%	27.6%	20.3%	8.6%	3.9%	2.6%
Germany	34.6%	18.9%	22.6%	19.9%	1.3%	2.5%
India	27.6%	55.1%	5.7%	5.9%	4.5%	1.1%
United Kingdom	36.5%	2.9%	35.4%	18.7%	0.7%	5.9%
France	34.7%	2.6%	16.5%	9.6%	5.0%	31.6%
Russian Federation	24.4%	11.1%	50.8%	0.3%	6.4%	7.0%
Canada	30.2%	2.7%	31.0%	4.2%	26.4%	5.5%
Italy	40.2%	5.0%	38.2%	12.3%	4.3%	0.0%

Source: Energy Institute, *Statistical Review of World Energy, 2023*, https://www.energyinst.org/statistical--review [19.12.2023].

Electricity generation

Widespread electrification has driven development in the 20th and 21st centuries. Over the past 32 years, electricity generation has increased by 144 per cent, from 11,961 TWh (1990) to 29,165 TWh (2022).

As electricity is used in all key production and service processes, countries that increase electricity generation are gaining importance in the global economic cycle.

As recently as in 1990, the United States was the world leader in terms of electricity production, accounting for 27 per cent of global electricity production. The USA was ahead of the Soviet Union (9.0 per cent) and Japan (7.4 per cent).

More than three decades later (in 2022), China was clearly in the lead with a share of 30.3 per cent. The USA dropped to the second position (15.6 per cent) and India rose to the third one (6.4 per cent). During that period, the share of Japan and the European countries in global electricity production declined markedly. The share fell from 7.4 per cent to 3.5 per cent for Japan, from 4.6 per cent to 2.0 per cent for Germany, from 3.5 per cent to 1.6 per cent for France, and from 2.7 per cent to 1.1 per cent for the United Kingdom. The combined share of the four largest European economies (E4) in global electricity production decreased from 12.6 per cent to 5.7 per cent. Following the collapse of the USSR, Russia's role in global electricity production also declined (from 9 per cent to 4 per cent).

TABLE 3. Electricity generation (Terawatt-hours)

COUNTRY	1990	2000	2010	2020	2021	2022
World (Terawatt-hours)	11,961	15,564	21,590	26,986	28,520	29,165
World (%)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
United States	27.0%	26.0%	20.4%	15.9%	15.4%	15.6%
China	5.2%	8.7%	19.5%	28.8%	29.9%	30.3%
Japan	7.4%	7.1%	5.4%	3.7%	3.6%	3.5%
Germany	4.6%	3.7%	2.9%	2.1%	2.1%	2.0%
India	2.4%	3.7%	4.3%	5.9%	6.0%	6.4%
United Kingdom	2.7%	2.4%	1.8%	1.2%	1.1%	1.1%
France	3.5%	3.5%	2.6%	1.9%	1.9%	1.6%
Russian Federation	9.0%	5.6%	4.8%	4.0%	4.1%	4.0%
Canada	4.0%	3.9%	2.8%	2.4%	2.3%	2.3%
Italy	1.8%	1.8%	1.4%	1.0%	1.0%	1.0%
E4	12.6%	11.4%	8.7%	6.2%	6.1%	5.7%

Source: Energy Institute, *Statistical Review of World Energy, 2023*, https://www.energyinst.org/statistical-review [19.12.2023].

Coal (35.4 per cent) and gas (22.7 per cent) played the largest role in the global electricity mix in 2022, but hydropower (14.9 per cent) and renewables (14.4 per cent) were also important.

In 2022, the most electricity was generated from coal-fired power plants (India and China), gas-fired power plants (the USA, Russia, Japan, and Italy), hydroelectric power plants (Canada), nuclear power plants (France), and RES-based power plants (Germany and the United Kingdom).

TABLE 4. Electricity generation by fuel (per cent), 2022

COUNTRY	COAL	NATURAL GAS	HYDRO ELECTRIC	NUCLEAR ENERGY	RENEWABLES	OTHER
World	35.4%	22.7%	14.9%	9.2%	14.4%	3.4%
United States	19.9%	39.9%	5.7%	17.9%	15.8%	0.8%
China	61.0%	3.3%	14.7%	4.7%	15.4%	0.8%
Japan	29.9%	30.9%	7.2%	5.0%	14.7%	12.2%
Germany	31.3%	13.8%	3.0%	6.0%	41.0%	4.9%
India	74.3%	2.5%	9.4%	2.5%	11.1%	0.2%
United Kingdom	1.7%	38.4%	1.6%	14.6%	39.7%	3.8%
France	0.7%	10.0%	9.5%	63.0%	14.5%	2.2%
Russian Federation	16.5%	45.8%	16.9%	19.2%	0.6%	1.0%
Canada	5.2%	12.3%	60.4%	13.1%	7.9%	1.1%
Italy	6.1%	54.4%	9.8%	0.0%	25.1%	4.6%

Source: Energy Institute, *Statistical Review of World Energy, 2023*, https://www.energyinst.org/statistical-review [19.12.2023].

Ways of generating electricity

Coal-fired power plants still play a key role in electricity production. In 2022, they generated 10,317 TWh of electricity, which represented 35.4 per cent of global electricity production.

Over the past 32 years, coal-fired power generation has increased by 131 per cent, from 4460 TWh (1990) to 10,317 TWh (2022). At the same this time, China's share of global coal-fired power generation has increased from 9.9 per cent (1990) to 52.3 per cent (2022). In 2023, China has integrated 47 GW of coal-fired power plants into the system. There are further coal-fired power plants under construction with a total capacity of 140 GW and there are still coal-fired power plants with a total capacity of 268 GW in the announced, pre-permit, and permitted stages[48].

India's share of global coal-fired power generation has also increased markedly, from 4.3 per cent to 13.4 per cent, and more coal-fired power plants with a total capacity of almost 31 GW are under construction. It is worth mentioning that further coal-fired power plants are also under construction in other Asian countries, *i.e.*, Indonesia (9.4 GW), Vietnam (3.9 GW), Bangladesh (3.9 GW), and South Korea (2.1 GW).

Germany and the United Kingdom have opted for accelerated decarbonisation, thus depriving themselves of an important energy source (or reducing its role), which has had an impact on rising energy prices. The combined share of the four largest European economies in coal-fired power generation has fallen from 13.2 per cent to just 2.1 per cent.

Gas is regarded as a better energy carrier than coal due to its lower CO_2 emissions. Over the past 32 years, gas-fired power generation has increased by 270 per cent, from 1,790 TWh (1990) to 6,631 TWh (2022).

By investing in the extraction of gas from unconventional deposits, the USA has become a world leader in both natural gas production and gas-fired power generation, with a 27.4 per cent share of global gas-fired power generation. The abundance and low price of natural gas have enabled the USA to gradually move away from coal.

In Russia, the situation is different. The country has the world's largest identified deposits of natural gas, but its share of global gas-fired power generation has

48 Global Energy Monitor, 2024, *Boom and Bust Coal 2024*.

TABLE 5. Electricity generation from coal (Terawatt-hours)

COUNTRY	1990	2000	2010	2020	2021	2022
World (Terawatt-hours)	4460	5992	8640	9472	10211	10317
World (%)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
United States	38.7%	35.5%	23.1%	8.9%	9.6%	8.8%
China	9.9%	17.7%	37.4%	52.0%	52.2%	52.3%
Japan	2.7%	3.9%	3.6%	3.1%	3.0%	3.0%
Germany	7.0%	4.9%	3.0%	1.4%	1.6%	1.8%
India	4.3%	6.5%	7.4%	12.1%	12.5%	13.4%
United Kingdom	4.6%	2.0%	1.2%	0.1%	0.1%	0.1%
France	0.8%	0.5%	0.3%	0.0%	0.0%	0.0%
Russian Federation	3.5%	2.9%	1.9%	1.8%	1.8%	1.9%
Canada	1.8%	1.9%	1.0%	0.4%	0.3%	0.3%
Italy	0.8%	0.5%	0.5%	0.2%	0.2%	0.2%
E4	13.2%	7.9%	5.0%	1.7%	1.9%	2.1%

Source: Energy Institute, *Statistical Review of World Energy, 2023*, https://www.energyinst.org/statistical-review [19.12.2023].

declined from 13.4 per cent in 2000 to 8.1 per cent in 2022. Gas has been, and still is, treated in Russia as an important export commodity, a source of budget revenue, and a factor that can influence the political and economic situation in other countries (especially European ones).

Energy policy in Europe has led to a dependence on a single gas supplier, Russia. The largest four European economies which imported gas from Russia were hit hard by supply constraints and high gas prices, which was particularly evident after Russia's attack on Ukraine. E4's share of global gas-fired power generation declined from 11.2 per cent in 2000 to 6.2 per cent in 2022.

China has gradually increased its share of gas use for electricity generation from 0.2 per cent in 1990 to 4.4 per cent in 2022. The country is investing heavily in geological research and contracting increasing gas supplies from Russia.

TABLE 6. Electricity generation from gas (Terawatt-hours)

COUNTRY	1990	2000	2010	2020	2021	2022
World (Terawatt-hours)	1,790	2,773	4,884	6,418	6,566	6,631
World (%)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
United States	22.4%	23.3%	21.7%	27.3%	25.9%	27.4%
China	0.2%	0.2%	1.6%	3.9%	4.4%	4.4%
Japan	9.7%	9.2%	6.6%	5.5%	5.0%	4.8%
Germany	2.0%	1.8%	1.8%	1.5%	1.4%	1.2%
India	0.6%	2.0%	2.4%	1.2%	0.9%	0.7%
United Kingdom	0.3%	5.3%	3.6%	1.7%	1.9%	1.9%
France	0.2%	0.4%	0.5%	0.6%	0.5%	0.7%
Russian Federation	28.6%	13.4%	10.7%	7.3%	7.9%	8.1%
Canada	0.5%	1.3%	1.1%	1.1%	1.2%	1.2%
Italy	2.2%	3.7%	3.1%	2.1%	2.2%	2.4%
E4	4.7%	11.2%	9.0%	5.9%	6.0%	6.2%

Source: Energy Institute, *Statistical Review of World Energy, 2023*, https://www.energyinst.org/statistical--review [19.12.2023].

Hydroelectric power plants rank third among the key means of electricity generation. Over the past 32 years, hydroelectric power generation has increased by 101 per cent, from 2,159 TWh (1990) to 4,334 TWh (2022).

China also ranks first in this area. In 2022, it accounted for 30.1 per cent of hydroelectric power generation, compared to only 5.9 per cent in 1990. Several large hydropower plants have been built in China, including Three Gorges Dam (22.5 GW), which is the world's largest power station, Baihetan Dam (16.0 GW), and Xiluodu Dam (13.9 GW). However, the role of the USA, Japan, and European countries (E4) in hydropower is gradually declining.

TABLE 7. Hydroelectricity: Generation (Terawatt-hours)

COUNTRY	1990	2000	2010	2020	2021	2022
World (Terawatt-hours)	2,159	2,647	3,430	4,359	4,289	4,334
World (%)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
United States	13.5%	10.3%	7.5%	6.5%	5.8%	6.0%
China	5.9%	8.4%	20.7%	30.3%	30.3%	30.1%
Japan	4.0%	3.2%	2.6%	1.8%	1.9%	1.7%
Germany	0.8%	0.9%	0.6%	0.4%	0.5%	0.4%
India	3.1%	2.9%	3.2%	3.8%	3.7%	4.0%
United Kingdom	0.2%	0.2%	0.1%	0.2%	0.1%	0.1%
France	2.5%	2.5%	1.8%	1.4%	1.4%	1.0%
Russian Federation	7.7%	6.2%	4.9%	4.9%	5.0%	4.6%
Canada	13.7%	13.5%	10.2%	8.9%	8.9%	9.2%
Italy	1.5%	1.7%	1.5%	1.1%	1.1%	0.6%
E4	5.0%	5.3%	4.0%	3.1%	3.1%	2.1%

Source: Energy Institute, *Statistical Review of World Energy, 2023*, https://www.energyinst.org/statistical-review [19.12.2023].

The fourth key source of electricity is nuclear power, which, unlike RES, provides a stable supply of electricity. However, over the past 32 years, nuclear power generation has only increased by 34 per cent, from 2,001 TWh (1990) to 2,679 TWh (2022). The Fukushima disaster caused a decline in the importance of this mode of electricity generation in the global energy mix and some countries, such as Japan and Germany, have begun to move away from nuclear power for safety reasons.

The United States remains the clear leader in nuclear power (in 2022) with a 30.3 per cent share, ahead of China, which, however, is increasing its share of nuclear power generation from decade to decade (15.6 per cent), followed by France (11.0 per cent) and Russia (8.4 per cent).

TABLE 8. Nuclear: Generation (Terawatt-hours)

COUNTRY	1990	2000	2010	2020	2021	2022
World (Terawatt-hours)	2,001	2,581	2,768	2,689	2,803	2,679
World (%)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
United States	30.4%	30.8%	30.7%	30.9%	29.3%	30.3%
China	0.0%	0.6%	2.7%	13.6%	14.5%	15.6%
Japan	9.7%	12.4%	10.6%	1.6%	2.2%	1.9%
Germany	7.6%	6.6%	5.1%	2.4%	2.5%	1.3%
India	0.3%	0.6%	0.8%	1.7%	1.6%	1.7%
United Kingdom	3.3%	3.3%	2.2%	1.9%	1.6%	1.8%
France	15.7%	16.1%	15.5%	13.2%	13.5%	11.0%
Russian Federation	5.9%	5.1%	6.2%	8.0%	7.9%	8.4%
Canada	3.6%	2.8%	3.3%	3.6%	3.3%	3.2%
Italy	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
E4	26.6%	26.0%	22.8%	17.5%	17.6%	14.1%

Source: Energy Institute, *Statistical Review of World Energy, 2023*, https://www.energyinst.org/statistical--review [19.12.2023].

Among renewable energy sources, wind power, in addition to hydropower, plays a key role. Over the past 32 years, wind power generation has increased 526 times, from 4 TWh (1990) to 2,105 TWh (2022).

In the early days of wind power development, it was the United States and Germany that led the way, introducing groundbreaking technologies and investing the most in this type of energy. China was a late entrant into this sector of power industry but had a significant position in 2010 (14.3 per cent) to become the clear leader in 2022, with a 36.2 per cent share of global wind power generation.

TABLE 9. Renewables: Generation – wind (Terawatt-hours)

COUNTRY	1990	2000	2010	2020	2021	2022
World (Terawatt-hours)	4	31	346	1,594	1,854	2,105
World (%)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
United States	77.5%	18.0%	27.6%	21.4%	20.6%	20.9%
China	0.0%	1.9%	14.3%	29.3%	35.4%	36.2%
Japan	0.0%	0.3%	1.1%	0.5%	0.4%	0.4%
Germany	2.0%	30.2%	11.1%	8.3%	6.2%	6.0%
India	0.0%	5.0%	5.6%	3.8%	3.7%	3.3%
United Kingdom	0.0%	3.0%	3.0%	4.7%	3.5%	3.8%
France	0.0%	0.0%	2.9%	2.5%	2.0%	1.8%
Russian Federation	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%
Canada	0.0%	0.8%	2.5%	2.2%	1.9%	1.8%
Italy	0.0%	1.8%	2.6%	1.2%	1.1%	1.0%
E4	2.0%	35.0%	19.6%	16.7%	12.8%	12.6%

Source: Energy Institute, *Statistical Review of World Energy, 2023*, https://www.energyinst.org/statistical-review [19.12.2023].

In recent years, solar power has seen the greatest growth rate, with the amount of electricity generated by photovoltaic devices increasing 25-fold in just one decade (2010–2020) and 3,307-fold in the last 32 years, from 0.4 TWh (1990) to 1,323 TWh (2022).

The countries that pioneered the development of this sector, the United States, Japan, and Germany, have been overtaken by China, which is also a clear leader in this field, with a 32.3 per cent share of the global photovoltaic panel electricity generation market in 2022.

TABLE 10. Renewables: Generation – solar (Terawatt-hours)

Country	1990	2000	2010	2020	2021	2022
World (Terawatt-hours)	0.4	1	34	854	1,059	1,323
World (%)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
United States	95.5%	48.9%	8.9%	15.5%	15.7%	15.6%
China	0.5%	2.1%	2.1%	30.6%	30.9%	32.3%
Japan	0.3%	32.5%	11.7%	8.8%	8.7%	7.7%
Germany	0.3%	0.0%	35.3%	5.8%	4.7%	4.6%
India	0.0%	0.7%	0.3%	6.9%	6.4%	7.2%
United Kingdom	0.0%	0.1%	0.1%	1.5%	1.1%	1.1%
France	0.0%	0.5%	1.8%	1.5%	1.4%	1.5%
Russian Federation	0.0%	0.0%	0.0%	0.2%	0.2%	0.2%
Canada	0.0%	1.5%	0.8%	0.5%	0.5%	0.5%
Italy	1.0%	1.7%	5.6%	2.9%	2.4%	2.1%
E4	1.3%	2.3%	42.8%	11.7%	9.6%	9.3%

Source: Energy Institute, *Statistical Review of World Energy, 2023*, https://www.energyinst.org/statistical--review [19.12.2023].

Despite the spectacular growth of RES-based power generation in recent years, the total amount of electricity generated by wind power plants (2,105 TWh) and solar power plants (1,323 TWh) in 2022 was three times lower than that generated by coal-fired power plants (10,317 TWh).

The facts given below provide an apt summary of the above discussion. China currently plays the largest role in energy production and consumption and has the largest share of total electricity generation as well as of coal, hydro, wind, and solar power generation. The United States still remains the leader in nuclear and gas power, but its importance in total primary energy consumption and electricity generation is gradually declining. The importance of Japan and the largest European countries (E4) in the world energy sector is clearly declining.

4.4. Electricity prices

Countries with a large amount of the production factor, *i.e.*, energy, have the potential to increase their production of goods and services, but the price of electricity also plays an important role. In this area, China, Russia, and Canada have a clear competitive advantage over the other countries (Table 19). The USA and India have business electricity prices that are clearly higher than those of the three countries mentioned above, but such countries as Italy, the United Kingdom, Germany, and Japan have the highest prices. This has a negative impact on the international competitiveness of these economies.

The correlation coefficient between electricity prices in the 10 countries analysed and their share of global GDP measured at current exchange rates was -0.35 in 2022. The correlation coefficient between electricity prices in the 10 countries analysed and their share of world PPP GDP (taking into account varying purchasing power parity) was -0.45 in 2022. It is important to note that the analysis includes electricity prices from 2023 and not 2022 because 2022 was an atypical year, with a price shock related, among others, to the war in Ukraine (*e.g.*, in December 2022, business electricity prices in Germany amounted to USD 0.91/kWh).

TABLE 11. Electricity prices USD / kWh, June 2023

COUNTRY	ELECTRICITY PRICES FOR HOUSEHOLDS, USD/KWH	ELECTRICITY PRICES FOR BUSINESS, USD/KWH
United States	0.166	0.147
China	0.078	0.090
Japan	0.230	0.276
Germany	0.399	0.289
India	0.079	0.131
United Kingdom	0.443	0.408
France	0.257	0.207
Russian Federation	0.066	0.097
Canada	0.123	0.103
Italy	0.431	0.582

Source: https://www.globalpetrolprices.com/electricity_prices/ [30.01.2024].

Economic growth and share of global GDP

Energy (including electricity) is used in large part in machines and equipment that are more efficient than simple human labour. Furthermore, with the low price of energy, goods can be produced more cheaply and at the same time services can be provided more cheaply, which makes them more attractive on the global market. In addition, the low price of electricity for households inhibits consumer inflation, which translates into high domestic demand.

One of the key indicators showing the global strength of an economy is GDP. Large amounts of energy and its relatively low prices influence the rate of economic growth, which in many countries is driven by industrial production, infrastructure construction, housing construction, and exports.

Of the group of 10 countries studied, the highest average GDP growth rates between 1990 and 2022 were recorded by countries increasing their energy generation capacity while having relatively low energy prices, *i.e.*, China (8.9 per cent), India (6.0 per cent), and the United States (2.4 per cent). Given the average growth rate for the global economy (2.9 per cent), it can be said that China and India have been key drivers of global economic growth in recent decades.

Very low growth rates in the period studied were recorded in Italy (0.8 per cent) and Japan (0.9 per cent), which do not have an adequate raw material base in terms of energy carriers. The low average growth rate in Russia over the period studied is mainly attributable to the crisis decade 1990–1999. In the following decade, with rising energy commodity prices, the rate of economic growth was high in the country.

TABLE 12. GDP growth (average annual %)

COUNTRY	1990–1999	2000–2009	2010–2019	1990–2022
World	2.8%	3.0%	3.2%	2.9%
United States	3.2%	1.9%	2.3%	2.4%
China	10.0%	10.4%	7.7%	8.9%
Japan	1.5%	0.5%	1.2%	0.9%
Germany	2.2%	0.8%	2.0%	1.5%
India	5.8%	6.3%	6.6%	6.0%
United Kingdom	2.3%	1.7%	2.0%	1.9%
France	2.0%	1.5%	1.4%	1.5%
Russian Federation	-4.9%	5.5%	2.0%	0.8%
Canada	2.4%	2.1%	2.3%	2.1%
Italy	1.5%	0.5%	0.3%	0.8%

Source: World Bank (2023), *GDP growth (annual %)*, https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG [5.01.2024].

In terms of current exchange rates, the United States is still the economic leader with a 25.1 per cent share of global GDP, but this share has clearly declined since 2000, when it was 30.2 per cent. Over the past 32 years, China's importance in the world economy has clearly increased (from 1.7 per cent to 17.7 per cent), with the decrease in the importance of the following countries: Japan (from 13.9 per cent to 4.2 per cent), Germany (from 7.7 per cent to 4.0 per cent), the United Kingdom (from 4.8 per cent to 3.0 per cent), and France (from 5.5 per cent to 2.7 per cent). India's importance in the global economy has slowly increased from 1.4 per cent in 1990 to 3.4 per cent in 2022.

The correlation coefficients between the share of the 10 countries analysed in world energy consumption and their share in global GDP measured at current exchange rates range from 0.76 (2010) to 0.86 (2021) in each year. The correlation coefficients between the share of the 10 countries analysed in world electricity production and their share in global GDP measured at current exchange rates range from 0.81 (2022) to 0.90 (2000) in each year.

TABLE 13. GDP (bn current US$, share)

COUNTRY	1990	2000	2010	2020	2021	2022
World (bn USD)	22,935	33,899	66,707	85,258	97,530	101,326
World (%)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
United States	26.0%	30.2%	22.6%	24.7%	23.9%	25.1%
China	1.7%	3.6%	9.1%	17.2%	18.3%	17.7%
Japan	13.9%	14.7%	8.6%	5.9%	5.1%	4.2%
Germany	7.7%	5.7%	5.1%	4.6%	4.4%	4.0%
India	1.4%	1.4%	2.5%	3.1%	3.2%	3.4%
United Kingdom	4.8%	4.9%	3.7%	3.2%	3.2%	3.0%
France	5.5%	4.0%	4.0%	3.1%	3.0%	2.7%

COUNTRY	1990	2000	2010	2020	2021	2022
Russian Federation	2.3%	0.8%	2.3%	1.8%	1.9%	2.2%
Canada	2.6%	2.2%	2.4%	1.9%	2.1%	2.1%
Italy	5.2%	3.4%	3.2%	2.2%	2.2%	2.0%
E4	23.2%	18.0%	16.0%	13.1%	12.8%	11.7%

Source: World Bank (2023), *GDP (current US$)*, https://data.worldbank.org/indicator/NY.GDP.MKTP.CD [19.12.2023].

Even greater changes in the global balance of power can be seen if GDP with purchasing power parity (PPP) is taken into account. In terms of PPP, China is the world leader in the GDP category (with its share increasing from 3.8 per cent to 18.4 per cent between 1990 and 2022), with the United States falling to second place (from 20.2 per cent to 15.5 per cent). Table 14 shows an increase in the importance of India (from 3.6 per cent to 7.2 per cent) and a progressive decline in the role of Japan, Germany, Italy, France, and the United Kingdom.

The correlation coefficients between the share of the 10 countries analysed in world energy consumption and their share in world PPP GDP (taking into account varying purchasing power parity) range from 0.89 (1990) to 0.97 (2022) in each year. The correlation coefficients between the share of the 10 countries analysed in world electricity production and their share of global PPP GDP (taking into account varying purchasing power parity) range from 0.95 (1990) to 0.98 (2010) in each year.

TABLE 14. GDP, PPP (current international $)

COUNTRY	1990	2000	2010	2020	2021	2022
World (bn USD)	29,504	49,255	89,840	134,748	148,465	164,533
World (%)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
United States	20.2%	20.8%	16.8%	15.6%	15.7%	15.5%
China	3.8%	7.5%	13.8%	18.0%	18.5%	18.4%
Japan	8.3%	7.0%	5.0%	3.9%	3.6%	3.5%
Germany	5.2%	4.5%	3.5%	3.5%	3.3%	3.2%
India	3.6%	4.5%	5.8%	6.8%	7.0%	7.2%
United Kingdom	3.3%	3.2%	2.5%	2.3%	2.3%	2.2%
France	3.5%	3.2%	2.6%	2.4%	2.3%	2.3%
Russian Federation	4.0%	2.0%	3.3%	3.3%	3.3%	3.2%
Canada	1.9%	1.8%	1.5%	1.3%	1.4%	1.4%
Italy	3.6%	3.1%	2.3%	1.9%	1.9%	1.9%
E4	15.6%	14.0%	10.9%	10.1%	9.8%	9.6%

Source: World Bank (2023), *GDP, PPP (current international $)*, https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD [19.12.2023].

One of the indicators of a country's strength on the international stage is its steel production. Steel is one of the most important materials. It has a wide range of applications, from infrastructure construction, transport, and packaging to engineering, automotive, and precision industries. However, the production of steel requires large amounts of energy, and its price is important. China is the undisputed leader in crude steel production, with a 54.0 per cent share of the global market in 2022.

TABLE 15. Crude steel production (in million tonnes, share), 2022

COUNTRY	CRUDE STEEL PRODUCTION, 2022 (MILLION TONNES)	%
World	1885.4	100.0%
United States	80.5	4.3%
China	1018.0	54.0%
Japan	89.2	4.7%
Germany	36.8	2.0%
India	125.3	6.6%
United Kingdom	6.0	0.3%
France	12.1	0.6%
Russian Federation	71.5	3.8%
Canada	12.1	0.6%
Italy	21.6	1.1%
E4	76.5	4.1%

Source: World Steel Association (2023), *2023 World Steel in Figures*.

4.5. Innovation

Abundant energy resources or the production of large amounts of electricity alone do not guarantee economic growth and development, as evidenced by the examples of Venezuela or Equatorial Guinea and, to a lesser extent, Russia. Energy is only transformed into wealth when it is used in important production processes and when a large part of the added value generated by this energy stays in the country. Even a developed heavy industry is not enough if the country is unable to produce adequate consumer goods.

The best combination is a mix of energy with productive capital and intellectual capital (knowledge, experience, and technology). This ensures the production of high-tech products with original design and relatively low prices. One of the indicators showing the level of intellectual capital in a country and its associated innovation is patent activity. A high number of patent applications and patents obtained is evidence that a country is making technical progress and improving its competitive position.

Companies from the USA, Western Europe, Japan, and South Korea viewed China as a good place for foreign investment because of cheap energy, relatively low labour costs, and a growing domestic market. However, according to the Global Value Chain theory and practice, the vast majority of value added went to highly developed countries[49,50]. To improve their position in global value chains, the Chinese invested in new sectors of the economy, supporting scientific research and their own innovative enterprises, which resulted in the launch of many high-tech products.

Over the past 32 years, there has been a reshuffling of the top of the most innovative economies. China has come out on top in terms of patent applications filed and patents received. China's share of total patent applications has increased from just 1.0 per cent in 1990 to 43.8 per cent in 2022. It is worth mentioning that China has a high level of patent activity in the energy industry, accounting for 51.6 per cent of patent applications in solar energy, 50.7 per cent in geothermal energy, 38.9 per cent in wind energy, and 37.0 per cent in hydropower.

In 2000, the USA accounted for the largest share of patent applications (30.5 per cent), but in the following years the country's share of global patent activity gradually declined to 17.7 per cent in 2022. Table 16 shows a progressive decline in the role of Japan, Germany, Italy, France, and the United Kingdom in global patent activity.

The correlation coefficients between the share of the 10 countries analysed in the total number of patent applications filed and their share of PPP GDP (taking into account varying purchasing power parity) range from 0.71 (1990) to 0.94 (2020) in each year.

49 OECD, 2011, *Global Value Chains: Preliminary Evidence and Policy Issues*.

50 Gereffi, G., Fernandez-Stark, K., 2016, *Global Value Analysis: A Primer. Center on Globalization*, Governance & Competitiveness (Duke University), 2nd Edition, pp. 1–34.

TABLE 16. Patent applications (number, share)

COUNTRY	1990	2000	2010	2020	2021	2022
World (number)	406,582	516,800	915,200	1,596,900	1,754,900	1,823,200
World (%)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
United States	22.2%	30.5%	24.0%	22.0%	18.7%	17.7%
China	1.0%	2.5%	14.8%	33.2%	39.7%	43.8%
Japan	14.6%	24.4%	24.3%	11.2%	10.5%	11.0%
Germany	4.7%	2.8%	1.5%	1.1%	1.2%	1.3%
India	0.4%	0.2%	0.8%	1.7%	1.8%	1.7%
United Kingdom	2.3%	1.6%	0.6%	0.6%	0.6%	0.6%
France	3.2%	2.2%	1.1%	0.8%	0.9%	0.7%
Russian Federation	20.8%	3.4%	3.3%	1.8%	1.3%	1.3%
Canada	3.5%	2.3%	2.1%	1.3%	1.3%	1.0%
Italy	3.0%	1.0%	1.8%	0.6%	0.4%	0.4%
E4	13.2%	7.6%	5.0%	3.1%	3.1%	3.0%

Source: WIPO (2024), https://www.wipo.int/ipstats/en/statistics/country_profile/ [21.02.2024].

The high patent activity referred to above has resulted in China's share of the total number of patents held increasing from just 1.0 per cent in 1990 to 46.8 per cent in 2022. There has been a clear decline in the share of Japan, E4, and Russia in the global number of patents obtained.

The correlation coefficients between the share of the 10 countries analysed in the total number of patents held and their share of PPP GDP (taking into account the varying purchasing power parity) range from 0.53 (1990) to 0.90 (2020) in each year.

TABLE 17. Patent grants (number, share)

COUNTRY	1990	2000	2010	2020	2021	2022
World (number)	997,500	1,377,600	1,997,500	3,282,200	3,400,500	3,457,400
World (%)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
United States	17.2%	21.5%	24.5%	18.2%	17.4%	17.2%
China	1.0%	3.8%	19.6%	45.6%	46.6%	46.8%
Japan	36.9%	31.7%	17.3%	8.8%	8.5%	8.4%
Germany	3.9%	4.5%	3.0%	1.9%	1.7%	1.7%
India	0.4%	0.6%	2.0%	1.7%	1.8%	2.2%
United Kingdom	2.8%	2.4%	1.1%	0.6%	0.6%	0.6%
France	1.7%	1.3%	0.8%	0.4%	0.4%	0.4%
Russian Federation	11.6%	2.3%	2.1%	1.1%	0.9%	0.8%
Canada	2.7%	2.9%	1.8%	1.1%	1.1%	1.1%
Italy	0.9%	0.7%	0.5%	0.3%	0.3%	0.3%
E4	9.3%	8.9%	5.4%	3.2%	3.0%	3.0%

Source: WIPO (2024), https://www.wipo.int/ipstats/en/statistics/country_profile/ [21.02.2024].

4.6. Merchandise exports

One of the key indicators showing a country's global strength is its share of merchandise exports, and in particular its share of manufactured goods exports. Countries with high amounts of cheap energy, extensive productive capital, and technological innovation can produce and offer, at competitive prices, more attractive products, both for consumption and investment, which gives them an advantage in the international market. There have been major changes in this area over the past 32 years. Between 1990 and 2010, China went from being an exporter with a relatively small share of the world market (1.8 per cent in 1990) to the clear leader (10.3 per cent in 2010) to successively increase its share in the following years (to 15.0 per cent in 2021). During the period analysed, the role of Germany, the USA, Japan, France, the United Kingdom, and Italy in global exports declined markedly.

The correlation coefficients between the share of the 10 countries analysed in world energy consumption and their share of global commodity exports range from 0.65 (2000) to 0.90 (2022) in each year and increase throughout the period analysed.

The correlation coefficients between the share of the 10 countries analysed in world electricity production and their share of global commodity exports range from 0.71 (2000) to 0.91 (2022) in each year and also increase throughout the period analysed.

TABLE 18. Total merchandise exports – annual (bn US dollar, share)

COUNTRY	1990	2000	2010	2020	2021	2022
World (bn USD)	3,490	6,454	15,302	17,653	22,366	24,926
World (%)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
United States	11.3%	12.1%	8.4%	8.1%	7.8%	8.3%
China	1.8%	3.9%	10.3%	14.7%	15.0%	14.4%
Japan	8.2%	7.4%	5.0%	3.6%	3.4%	3.0%
Germany	12.1%	8.5%	8.2%	7.8%	7.3%	6.7%
India	0.5%	0.7%	1.5%	1.6%	1.8%	1.8%
United Kingdom	5.3%	4.4%	2.7%	2.3%	2.1%	2.1%
France	6.2%	5.1%	3.4%	2.8%	2.6%	2.5%
Russian Federation	..	1.6%	2.6%	1.9%	2.2%	2.4%
Canada	3.7%	4.3%	2.5%	2.2%	2.3%	2.4%

COUNTRY	1990	2000	2010	2020	2021	2022
Italy	4.9%	3.7%	2.9%	2.8%	2.8%	2.6%
E4	28.5%	21.7%	17.2%	15.7%	14.8%	13.9%

Source: WTO (2023), *Merchandise exports by product group*, https://stats.wto.org/ [19.12.2023].

The shift in favour of China in terms of exports of manufactured goods is even more pronounced. The country's share of industrial goods exports has increased from 1.9 per cent in 1990 to 21.2 per cent in 2022. In contrast, the share of such countries as Germany, the USA, Japan, France, Italy, and the United Kingdom in global exports of industrial goods has declined.

The correlation coefficients between the share of the 10 countries analysed in world energy consumption and their share of global exports of manufactured goods range from 0.60 (2000) to 0.85 (2022) in each year and increase throughout the period analysed.

The correlation coefficients between the share of the 10 countries analysed in world electricity production and their share of global exports of manufactured goods range from 0.66 (2000) to 0.88 (2022) in each year and also increase throughout the period analysed.

TABLE 19. Total merchandise exports SI3_AGG – MA – Manufactures – annual (bn US dollar, share)

COUNTRY	1990	2000	2010	2020	2021	2022
World (bn USD)	2,391	4,690	9,989	12,142	14,881	15,720
World (%)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
United States	12.1%	13.8%	8.7%	7.5%	7.3%	7.6%
China	1.9%	4.7%	14.8%	19.9%	21.1%	21.2%
Japan	11.5%	9.6%	6.8%	4.5%	4.4%	4.0%
Germany	15.7%	10.3%	10.8%	9.9%	9.5%	8.9%

COUNTRY	1990	2000	2010	2020	2021	2022
India	0.5%	0.7%	1.4%	1.6%	1.8%	1.8%
United Kingdom	6.1%	4.7%	2.9%	2.3%	2.0%	2.0%
France	6.7%	5.8%	4.0%	3.2%	3.0%	2.9%
Russian Federation	..	0.5%	0.6%	0.6%	0.7%	0.6%
Canada	3.1%	3.7%	1.9%	1.5%	1.4%	1.5%
Italy	6.2%	4.5%	3.7%	3.3%	3.3%	3.3%
E4	34.7%	25.3%	21.4%	18.7%	17.8%	17.1%

Source: WTO (2023), *Merchandise exports by product group – SI3_AGG – MA – Manufactures*, https://stats.wto.org/ [19.12.2023].

4.7. The wealth of nations

According to World Bank research, the wealth of nations is influenced by human capital, productive capital, natural capital, and net foreign assets[51]. According to the adopted approach, in which human capital, valued using the income-based valuation method, plays a key role, the countries analysed had the following share of global wealth in 2017: USA (27.4 per cent), China (12.9 per cent), Japan (6.4 per cent), Germany (5.2 per cent), France (3.7 per cent), United Kingdom (3.7 per cent), Canada (3.2 per cent), Russia (2.4 per cent), Italy (2.3 per cent), and India (2.1 per cent).

In another view, wealth is equated with the assets of citizens. The United States has the greatest wealth with a 30.8 per cent share of global assets, but there is a gradual decline in its share (from 36.9 per cent in 2000). The situation is similar for Japan (down from 16.5 per cent to 5.0 per cent) and the four European countries (down from 19.5 per cent to 13.2 per cent). The data in Table 20 show a clear increase in China's share of global wealth from 3.1 per cent (2000) to 18.6 per cent (2022) and a gradual increase in India's importance from 1.3 per cent (2000) to 3.4 per cent (2022).

51 World Bank (2018), *The changing wealth of nations 2018: building a sustainable future*.

The correlation coefficients between the share of the 10 countries analysed in world energy consumption and their share in global wealth range from 0.71 (2010) to 0.84 (2000) in each year. The correlation coefficients between the share of the 10 countries analysed in world electricity production and their share of global wealth range from 0.74 (2021) to 0.90 (2000) in each year.

TABLE 20. Wealth estimates by country (bn USD, share)

COUNTRY	2000	2010	2020	2021	2022
World (bn USD)	117,844	251,885	422,117	463,567	454,385
World (%)	100.0%	100.0%	100.0%	100.0%	100.0%
United States	36.9%	25.7%	29.9%	31.5%	30.8%
China	3.1%	10.1%	17.5%	18.4%	18.6%
Japan	16.5%	11.4%	6.5%	5.5%	5.0%
Germany	5.2%	4.7%	4.3%	3.8%	3.8%
India	1.3%	2.7%	3.0%	3.1%	3.4%
United Kingdom	5.6%	4.5%	3.7%	3.5%	3.5%
France	4.0%	5.4%	3.9%	3.5%	3.5%
Russian Federation	0.3%	0.9%	0.8%	0.8%	1.0%
Canada	2.2%	2.7%	2.5%	2.7%	2.5%
Italy	4.7%	4.6%	2.9%	2.5%	2.4%
E4	19.5%	19.2%	14.8%	13.3%	13.2%

Source: Credit Suisse Research Institute (2010), *Global wealth databook 2010*, UBS Research Institute (2023), *Global wealth databook 2023*, [19.12.2023].

According to an analysis by Swiss bank UBS, in 2022 China had the largest population (168.4 million) of people with wealth between USD 100,000 and

USD 1 million (24.0 per cent of the global adult population with such wealth). The USA remained the leader, with a share of 38.2 per cent, in the wealth group above USD 1 million.

TABLE 21. Membership of top wealth groups for selected markets, 2022

MARKET/ REGION	2010				2022			
	USD 100,000 – 1 MILLION		OVER USD 1 MILLION		USD 100,000 – 1 MILLION		OVER USD 1 MILLION	
	NUMBER OF ADULTS (THOUSANDS)	%	NUMBER OF ADULTS (THOUSANDS)	%	NUMBER OF ADULTS (THOUSANDS)	%	NUMBER OF ADULTS (THOUSANDS)	%
World	359,810	100	24,546	100	701,064	100	59,391	100
United States	83,622	23.2	9,940	40.5	132,407	18.9	22,710	38.2
China	17,465	4.9	805	3.3	168,421	24.0	6,231	10.5
Japan	53,246	14.8	2,380	9.7	52,261	7.5	2,757	4.6
Germany	27,931	7.8	1,040	4.3	29,862	4.3	2,627	4.4
India	2,940	0.8	170	0.7	20,114	2.9	849	1.4
United Kingdom	21,869	6.1	1,231	5.1	29,271	4.2	2,556	4.3
France	18,681	5.2	2,225	9.1	29,386	4.2	2,821	4.7
Russian Federation	1,235	0.3	10	0.0	4,437	0.6	408	0.7
Canada	12,709	3.5	905	3.7	16,923	2.4	2,032	3.4
Italy	27,016	7.5	1,415	5.8	25,815	3.7	1,335	2.2
E4	95,497	26.6	5,911	24.3	114,334	16.4	9,339	15.6

Source: Credit Suisse Research Institute (2015), *Global Wealth Databook 2015* and UBS Research Institute (2023), *Global Wealth Databook 2023*.

Thanks to rapid economic development, driven by cheap energy and foreign investment, China has built the world's largest (by volume) middle class. Middle class generates strong demand for cars, smartphones, and other consumer products, which in turn drives product innovation. Now, China is not only the "factory of the world" but also the largest market. China's share of global new car production is 33.5 per cent and its share of new car registrations is 30.8 per cent.

TABLE 22. Car production (in units) and new car registrations (in units)

COUNTRY	CAR PRODUCTION, 2023 (UNITS)	%	NEW CAR REGISTRATIONS, 2023 (UNITS)	%
World	75,615,450	100.0%	72,457,199	100.0%
United States	7,629,525	10.1%	12,327,829	17.0%
China	25,347,593	33.5%	22,320,061	30.8%
Japan	7,734,465	10.2%	3,989,608	5.5%
Germany	3,959,322	5.2%	2,844,609	3.9%
India	4,669,500	6.2%	4,176,522	5.8%
United Kingdom	901,893	1.2%	1,903,054	2.6%
France	959,404	1.3%	1,774,723	2.4%
Russian Federation	491	0.0%	1,015,387	1.4%
Canada	n/a	n/a	n/a	n/a
Italy	542,218	0.7%	1,565,331	2.2%
E4	6,362,837	8.4%	8,087,717	11.2%

Source: ACEA (2024), *Economic and Market Report Global and EU auto industry: Full year 2023* [5.04.2024].

CO_2 emissions and life expectancy

Fossil fuels provide large amounts of stable and cheap energy, but their use has some drawbacks. The production of electricity in coal-fired power stations and to a lesser extent in gas-fired power stations is associated with high CO_2 emissions and environmental pollution.

Until 2000, the United States was the world's largest CO_2 emitter. In the following decade, China came out on top in terms of CO_2 emissions. In 2020, its share of CO_2 emissions was 28.1 per cent. CO_2 emissions in India and other developing countries have also gradually increased.

The share of Western countries and Japan in global CO_2 emissions is declining, but this applies to countries, not corporations. Many large companies have moved production, and thus emissions, to such countries as China, India, Indonesia, Malaysia, and Vietnam. For example, according to the Ministry of Commerce (MOFCOM), by the end of August 2023, a total of 1,150,000 foreign companies were registered in mainland China. In 2023 alone, 33,154 new foreign-invested enterprises were established in China[52]. Most foreign companies in China are engaged in manufacturing, with the top five industries being electronics, machinery, chemicals, textiles, and food processing.

TABLE 23. Total greenhouse gas emissions (kt of CO_2 equivalent)

COUNTRY	1990	2000	2010	2020
World (kt of CO_2 equivalent)	30,629,971	34,208,319	43,442,887	46,120,921
World (%)	100.0%	100.0%	100.0%	100.0%
United States	19.1%	19.9%	14.9%	11.9%
China	10.6%	13.4%	23.5%	28.1%
Japan	3.9%	3.7%	2.8%	2.4%
Germany	3.7%	2.8%	2.0%	1.5%

52 https://www.registrationchina.com/articles/how-many-foreign-companies-in-china/

COUNTRY	1990	2000	2010	2020
India	4.0%	5.0%	5.9%	6.9%
United Kingdom	2.4%	2.0%	1.4%	0.9%
France	1.6%	1.5%	1.1%	0.8%
Russian Federation	9.7%	6.2%	5.2%	5.1%
Canada	1.8%	1.9%	1.6%	1.5%
Italy	1.6%	1.5%	1.1%	0.8%
E4	9.3%	7.8%	5.6%	3.9%

Source: World Bank (2024), https://databank.worldbank.org/source/world-development-indicators/Series/EN.ATM.GHGT.KT.CE# [17.04.2024].

The use of fossil fuels in the energy industry contributes to environmental pollution and can pose a health risk to residents. However, this negative impact is offset by various civilisational benefits. Development processes fuelled by cheap energy contribute to higher wages, improved quality, and increased life expectancy. In this respect, China has made the greatest progress in the last 31 years (an increase of more than 10 years). In 2021, during the COVID-19 pandemic, life expectancy in China (78.2) was clearly higher than in the USA (76.3).

TABLE 24. Life expectancy at birth, total (years)

COUNTRY	1990	2000	2010	2020	2021	CHANGE 1990–2021
World	65.2	67.7	70.7	72.2	71.3	+6.1
United States	75.2	76.6	78.5	77.0	76.3	+1.1
China	68.0	71.9	75.6	78.1	78.2	+10.2
Japan	78.8	81.1	82.8	84.6	84.4	+5.6

COUNTRY	1990	2000	2010	2020	2021	CHANGE 1990–2021
Germany	75.1	77.9	80.0	81.0	80.9	+5.8
India	58.7	62.7	66.9	70.2	67.2	+8.5
United Kingdom	75.9	77.7	80.4	80.4	80.7	+4.8
France	76.6	79.1	81.7	82.2	82.3	+5.7
Russian Federation	68.9	65.5	68.8	71.3	69.4	+0.5
Canada	77.4	79.2	81.3	81.7	82.6	+5.2
Italy	77.0	79.8	82.0	82.2	82.8	+5.8

Source: World Bank (2023), *Life expectancy at birth, total (years)*, https://data.worldbank.org/indicator/SP.DYN.LE00.IN [19.12.2023].

Conclusions

Energy from various sources, both non-renewable and renewable, is the fuel that drives human civilisation. Increasing energy consumption ensures continuous growth and development and contributes to the production of goods necessary for life and those that enhance its quality.

The hypotheses formulated in the introduction, suggesting that there is a growing role for countries in the global economy (measured by their share of global GDP and international trade) that increase their share of global primary energy consumption (H1), increase their share of global electricity production (H2), and provide market actors with relatively low (compared to other countries) energy prices (H3), have been confirmed.

Global influence is shifting towards those countries that are able to produce more energy at a relatively low price (China and India). In contrast, the importance of countries that have high energy prices and are not expanding their energy generation capacity at a sufficient pace (Germany, the United Kingdom, France, Italy, and Japan) is declining. The United States still holds a leading position in terms of GDP in exchange rate terms and the level of wealth of its citizens, but this position is gradually diminishing.

Increased consumption of primary energy may be associated with negative external factors but is most often a sign of increased production, increased population mobility, and improved quality of life.

In recent years, the Chinese economic model has become increasingly attractive to developing countries from South Asia, Africa, and Latin America. The model is associated with rapid economic growth, modern infrastructure, a wide range of attractively priced products and services, internal security, low energy prices, increasing life expectancy, and improving quality of life.

In future, it is likely that human labour will be increasingly replaced by robots, automata, and artificial intelligence, which means that such fundamental factors of production as energy and productive capital will play an even greater role as they will power the economy and determine its competitiveness.

The energy policy pursued in Europe to date has led to a decline in energy security – a far-reaching dependence on imports, limited diversification of energy supplies, high and rapidly fluctuating energy prices, and even energy shortages. There has also been a flight of energy-intensive industries to Asia. Products that are key for the economy, such as steel, aluminium, other metals, cement, lime, glass, ceramics, pulp, paper, cardboard, and chemicals, are largely produced outside the EU. Extending the ETS to further industries will further reduce the competitiveness of companies operating within the EU and, in combination with the Carbon Border Adjustment Mechanism (CBAM), lead to further price increases in EU economies. Unless Western European countries change their energy and industrial policies and attitudes towards underdeveloped and developing countries, they will be pushed out of fast-growing markets, such as Asia, Africa, and South America.

The analysis presented above has some limitations due to the scope adopted. In particular, it does not cover military, financial, and institutional issues. In military terms, the United States remains the greatest power, with second place still attributed to Russia despite its economic weaknesses. However, with economic growth, the military power of China and India grows. In terms of currency, it is the US dollar (USD) that continues to play a leading role, much more so than the US share of world trade would suggest. The global balance of power is also heavily influenced by large corporations and international institutions, such as World Bank, IMF, and WHO.

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