DILEMMAS OF ECONOMIC GROWTH

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THE PATH FROM UNLIMITED POSSIBILITIES TOWARDS RESPONSIBILITY?

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The path from unlimited possibilities towards responsibility?

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Reference List: Fifeková, E., Nemcová, E., Nežinský, E. and Studená, I. (2021). DILEMMAS OF ECONOMIC GROWTH. The path from unlimited possibilities towards responsibility? 2021, Prag, Wolters Kluwer CZ, p. 80

The scientific monograph is part of projects VEGA 2/0002/18 "Institutional framework of Slovakia's economic development in the new phase of globalisation" and VEGA 1/0716/19 „Policies evaluation beyond GDP: impact of unequal distribution of socio-economic development".

Reviewers:
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ISBN 978-80-7676-042-4

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ABBREVIATIONS AND SYMBOLS USED

ARE	United Arab Emirates
ARG	Argentina
AUS	Australia
AZE	Azerbaijan
BGR	Bulgaria
BLI	Better Life index
BLR	Belarus
BRA	Brazil
CAN	Canada
CHN	China
CITIES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CO_2	carbon dioxide
DZA	Algeria
EDF	Environmental Defense Fund
EGY	Egypt
EPA	United States Environmental Protection Agency
EST	Estonia
ETH	Ethiopia
EU	European Union
EU SDS	EU Sustainable development Strategy
GDP	Gross domestic product
GWO	Global Warming Potential
IEA	International Energy Agency
IDN	Indonesia
IND	India
IPCC	Intergovernmental Panel on Climate Change
IRN	Iran
IRQ	Iraq
ISL	Iceland
IUCN	International Union for Conservation of Nature
KAZ	Kazakhstan
kWh	kilowatt-hours
KWT	Kuwait
N_2O	nitrous oxide
MEX	Mexico
MYS	Malaysia

NGA	Nigeria
OECD	Organisation for Economic Co-operation and Development
OMN	Oman
OWID	Our World in Data
PAK	Pakistan
PCSD	Policy Coherence for Sustainable Development
QAT	Qatar
RUS	Russia
SAU	Saudi Arabia
SDGs	Sustainable Development Goals
SGP	Singapore
THA	Thailand
TKM	Turkmenistan
TTO	Trinidad and Tobago
UK	United Kingdom
UKR	Ukraine
UN	United Nations
USA	United States of America
UZB	Uzbekistan
VEN	Venezuela
VNM	Vietnam
WMO	World Meteorological Organization
WRI	World Resources Institute
ZAF	South Africa

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INTRODUCTION

The 21st century brought a slowdown in global growth, which has been – inter alia – attributed to reducing the pro-growth impact of globalization, decreasing the position of the middle class, increasing inequalities, decreasing productive investment, and raising environmental costs. The downward trend in economic growth is currently exacerbated by the global pandemic.

The negative development of global growth due to the pandemic and the need to reverse it are currently drawing attention to measures that would bring a recovery and reduce uncertainty in growth forecasts. The focus of measures is mainly on stimulating consumption, which can reverse negative growth development. As a result of economic growth caused mainly by consumption in recent decades, environmental costs have risen enormously; whether in the form of resource depletion, environmental pollution or climate change. These are the facts which are not recognised sufficiently. Efforts to satisfy growing consumption have gradually led to the transformation of natural resources into accumulating waste and increasing pollution. The support of consumption in the form of massive advertising has resulted in artificially induced needs and an increasing share of the so-called *forced products* in both production and consumption. This has had and continues to have consequences in terms of wasting of resources. Consumption is also growing in many developing economies and it is exacerbated by population growth and its dynamics.

Proponents of economic growth often perceive environmental damage as its necessary corollary when taking into account the need for a compromise between economic growth and the environment.

The economically most successful countries are those that can keep pace with global competition. This leads countries that have their competitive advantages based on factor competitiveness to reduce costs. Focus on cost reduction leads countries to underestimate natural resources. The price of natural resources does not reflect environmental damage or the costs of pollution, waste disposal and planetary destruction. On the contrary, the prices of products are falling, which on the one hand stimulates their consumption, but on the other hand leads to a constant increase in the consumption of resources and minerals, and to a reduction in their stocks. So in order to increase the competitive position, production was moved to countries not only with low labour costs, but also with a low level of environmental legislation. This tendency was supported by the reduction of unit transport costs, increasing the reliability of individual modes of transport, and the acceleration and flexibility of the transport of components for processing in various locations. The growing volume of traffic has led to a sharp increase in greenhouse gas emissions; with the carbon intensity of international transport doubling over the last thirty years.

According to Senet *"Humanity lives beyond its means, almost two planets would be needed to meet its needs, we are consuming more resources than the planet is able to offer in a year. Ecological overdraft is increasing every year, although it has at least slowed down over the last nine years"* (Senet, 2019). Environmental boundaries narrow the scope for economic growth. Exceeding them signals far-reaching consequences for the quality of life on the planet and threatens the prosperity that has been built in the development of civilization so far. The destabilization of the planet's ecological system leads not only to accelerating the loss of biodiversity but also to rising sea and ocean levels by increasing their acidity, climate change, water scarcity and many other factors that will limit life on many parts of the planet.

It is therefore clear that the measurement of economic growth through gross domestic product needs to be adjusted. The shortcomings of the GDP indicator are addressed by the European Commission's "Beyond GDP" initiative. It concerns construction of an indicator that would be able to cumulatively capture the quality of economic, ecological and social aspects of development, express the extent of real wealth, the quality of life of people and respect for the planet.

The basic aim of this work is to capture the shift away from the dynamics of growth towards a more complex approach integrating the quality of growth, especially in the field of environmental sustainability and climate change.

Therefore, we focus on examining approaches that highlight the bottlenecks of economic growth measured with the optics of gross domestic product growth. We rely on growth-pessimistic views, drawing attention mainly to environmental and social risks. These approaches are confronted with the views of proponents of economic growth and their arguments that justify the need for economic growth. We pay attention to global initiatives, which have been drawing attention to the need to ensure global environmental sustainability, especially since the last third of the twentieth century. We reflect on the shift in global initiatives towards mitigating and preventing climate change. The EU's strategic objectives in the area of sustainable development and the creation of conditions for achieving carbon neutrality are also assessed.

Considering that the emission intensity of economic growth worsens the climate situation, we point out the causes and consequences of climate change. We study the production of greenhouse gases – carbon dioxide and methane, both on a global scale and from the perspective of the most important contributors to its creation. We also pay attention to the formation of nitrous oxide, which is not essentially a greenhouse gas, but destroys the ozone layer and accelerates climate change.

1 ECONOMIC DEVELOPMENT IN A GLOBAL CONTEXT

The basic civilization challenges of recent decades are associated primarily with the sustainability of economic development. Sustainable economic development emphasizes qualitative changes in the development of human civilization, connects and integrates economic growth with social cohesion, environmental sustainability and the quality of institutions. The subject area of sustainable development is addressed in a large number of policy/strategic documents framing global development, and it is subject to extensive research and analyses.

1.1 When growth dynamics is not enough

The concept of economic growth has been questioned for more than fifty years. In the late 1960s the issue of the environmental sustainability of economic growth was brought to the forefront as a result of industrial development. The first comprehensive approach, which revealed not only the threat of environmental problems in terms of resource depletion and unsustainable growth of environmental pollution, but also social problems (related to demographic change, unequal population distribution and aging populations in economically developed countries), was the concept of zero growth introduced by the Club of Rome.

Despite receiving considerable criticism of the concept (mainly due to the failure to incorporate the impact of technological progress into the model of world economic development) the analyses produced by the Club of Rome drew attention to the environmental and social problems of economic growth for the upcoming decades. Already during this period it began to resonate that traditional institutions and ways of managing society were not able to solve the emerging problems.

The concluding stages of industrial development produced high dynamics of economic growth, but at the same time revealed the many contradictions that economic development had brought about.

The industrial stage brought an increase in living standards and the so-called *society of abundance* (Galbraith, 1967), which was supported by economic growth through highly-developed industrial production and increased labour productivity. However, the industrial optimism, especially from the late 1960s, was beginning to face a reality which drew attention to the fact that industrial development was approaching its limits. The comprehensive critique of economic growth supported by the extensive spread of industrial processes was presented by the Club of Rome

(Meadow et al., 1972). The Club of Rome examined the extensive development of production in the context of its limiting factors, especially the state of the environment, and sought to bring attention to the need for a better interconnection of economic, political, social and natural components of the global system, with an emphasis on environmental aspects.

The warning from the Club of Rome, based on an estimate of growth trends, highlighted the fact that civilizational developments were at a turning point, which could lead to the total collapse of the ecological and socio-economic system if growth trends continued and did not respect the growth limits. The warning about environmental risks associated with high economic growth as well as the identification of problems associated with demographic development and a deepening of income polarization between developed and developing countries, launched a discussion about the need to address not only the dynamics of economic growth but also its quality.

The Club of Rome's scenario did not receive general support and its legacy has been questioned for several reasons. In particular, it was pointed out that the models did not make sufficient use of theories of economic growth (insufficient application of production functions) and that they were not supported by practical research (Nordhaus, 1973). However, the essential objection was to the insufficient consideration of technical progress, the growth of technological efficiency and the substitution effect of technologies. Despite considerable criticism of the concept, the work of the Club of Rome has continued to draw attention to the ecological and social problems of economic growth.

The positive contribution of the initiatives of the Club of Rome is to be seen in the initiation of a discussion about the hitherto unquestioned doctrine of economic growth and its measurement. To what extent the indicator of gross domestic product measured the success of a country's development became the question at the top of the agenda. Kuznets himself, as the author of the construction of gross domestic product (GDP), pointed out that when examining economic growth, it should be defined very precisely as to what should grow and why (Kuznets, 1971)[1] – that is, a distinction must be made between the growth and its quality. It is these facts that have focussed on economic growth itself, regarding its quality and dynamics (determining the so-called appropriate level of growth). Till today, a relatively intense discussion is still going on between the proponents and opponents of economic growth as such, and about the gross domestic product indicator as a growth measure (Stiglitz, 2009; van der Bregh-Pillarisetti, 2008).

The construction design of the GDP indicator allows economic growth to be stimulated by increasing consumption. The long-term maintenance of the growth rate of GDP by high cyclical consumption (amplified by the population growth and

[1] The economic growth perceived in this way has been subject to relatively strong criticism by other authors, e.g., Cobb et al. (1995). They drew attention, inter alia, to the fact that gross domestic product is essentially the result of the adding up of all activities, i.e., that the GDP measure considers any economic activity positively.

its dynamics) leads to significant overproduction and consequently to negative impacts on resource depletion, environmental pollution and climate change. Together with the growth of wealth in developed countries we can observe an increase in the share of so-called forced products in both production and consumption, i.e. products which are produced to meet needs of the population artificially induced through mass advertising. These *forced* products lead to a waste of resources. Uncontrolled consumption of natural resources induced by demand generally leads to the conversion of natural resources into pollution and, in addition to environmental damage, also to incalculable social costs (Ayres, 2008).

For this reason, growth models (e.g. Baker, 2006) have also been criticized for the fact that they mainly stimulate an increase in consumption, while perceiving the destruction of the environment as a necessary consequence of growth. Although advanced economies create legislative and technical preconditions for reducing the environmental burden, the models take into account the need for a trade-off between economic growth and the environment.

Growth-pessimistic views prioritize not only the threat of depletion of natural resources and the unsustainable pace of pollution (Mishan, 1997), but also other socio-economic consequences. Such views in particular point to the fact that the most economically developed countries have reached the limits of their growth[2], and can increase the economic level only through the so-called bubble effect, but at the cost of plundering nature, increasing indebtedness[3], or such an increase in labour productivity, which leads to the limit of technological conditions and exceeds the limit of human possibilities, and in turn has the effect of reducing a population's quality of life. Douthwaite (1999) therefore argues that continued economic growth in the world is finite and cannot be further increased.

On the other hand, there is a large group of proponents of high economic growth who combine the solution of current global and regional problems with the ability to achieve it. In response to the question why we need higher economic growth if it destroys the planet and its forests, pollutes the oceans and rivers, results in such an excess of carbon in the atmosphere that causes climate chaos, Reich (2010) states that a distinction must be made between economic growth and consumption. Economic growth is about the productive capacity of a country, which reflects not only

2 Along this line of arguments, economic growth can only be supported in the economically underdeveloped countries of the world.

3 e. g. Bond (2010) stresses that the world economy has grown by an average of about 4% per year over the last 15 years, which, in addition to the environmental risks of high economic growth, poses risks of macroeconomic imbalances. It states that even if the world economy grew by at least 3% a year, it would be ten times bigger in 2080 than in 2000, which is self-destructive for the global economy even if the world's resources are infinite and there is no threat to the environment. The problem is that maintaining 4% annual economic growth requires a global increase in debt of around 10% per year. As global debt increases exponentially 6% faster than the growth of the global economy, rapidly growing debt is due to disproportionately rising service costs. Bond sees the pressure for continued growth as a cancer that kills its host's unsustainability.

the improvement of the quality of the environment, but also the improvement of health care and the level of education.

Therefore, countries achieving gross domestic product growth are also increasing their capacity. Due to low production capacity, poor countries are unable to provide adequate nutrition, health services and education for the population, and thus do not have the resources enabling them to develop in a sustainable way. Therefore, growth is not accountable for social and environmental irresponsibility, but the use of a country's productive capacity is determined by economic policy decisions. A high production capacity, therefore, makes it possible not only to cover the social aspects of development, but also to ensure environmental sustainability. The impact of economic performance on environmental sustainability is largely confirmed by the *pollution paradise* hypothesis which clarifies the impact of globalization and trade liberalization on the environmental quality (Grether et al., 2012). The hypothesis is based on the fact that as a country's economic performance increases (and with it the income of the population), the demand for environmental sustainability increases, the environmental laws are tightened and the pollution decreases (Dasgupta et al., 2001).

Therefore, in economically developed countries the institutional environment ensures relatively strong environmental regulation, consequently making it less likely that in countries with a high economic level, production accompanied by high pollution will be located. It is more expected that these economies would specialize in the services sector, which have a minimal negative environmental impact. The higher the economic growth, the more likely it is that countries will have sufficient funding and advanced technologies to ensure environmental protection and production processes will not have negative environmental impacts. On the other hand, in economically less developed economies, due to weak environmental regulation, environmentally demanding production will be localized to a greater extent, and this process will be also supported by the relocation of environmentally polluting production from the advanced economies as part of the value chain fragmentation process.

Thus, the lower quality of environmental standards generates comparative advantages for the industry that devastates the environment (Dasgupta et al, 2002). As a result, pollution is declining in countries with high economic development whereas it is increasing in less developed economies. The process of relocation of environmentally harmful productions from developed countries to developing countries due to the tightening of environmental standards is referred to as the effect of pollution paradise (Temurshoev, 2006).

Differences in environmental regulation are not the only factor that affects the ecological quality of a country. As the development of international trade allows for countries to utilise their comparative advantage, it is likely that developing countries will make greater use of factors, such as cheap labour and specialise in clean, labour-intensive production. On the other hand, developed countries will specialize more on the capital-intensive production. The high capital intensity of production in economically developed countries will have a negative impact on the environment. The fact that the developed north is better equipped with capital than the poorer south is well documented in the literature. However, what is usually underestimated is the high correlation between the capital intensity and the pollution intensity. In the process of liberalizing world trade, developed countries will increasingly specialize in capital-intensive production, which will lead to an increase in the environmental burden (*the factor endowment hypothesis*). The factor endowment hypothesis confirms the negative impact of economic growth on the environment in developed countries, despite their potentially tighter environmental regulation.

From the two approaches, it is not clear whether economic growth and globalization processes lead to an increase in negative impacts on the environment. On the one hand, it is correctly assumed that increasing economic performance will lead to increased environmental protection, on the other hand, in most countries, increasing economic performance is accompanied by capital-intensive production. From the point of view of the international fragmentation of production chains, it is therefore questionable whether the comparative advantages of countries are based on weak environmental regulation or factor endowment.

1.2 Sustainable Development Paradigm

The last third of the twentieth century began to uncover the unsustainability of growth dynamics due to deepening global problems related to increasing pollution, nature devastation, access to water, climate change, global warming and other negative phenomena. Consequently, the attention of global authorities is focused on the long-term development model, which would allow to fully grasp the qualitative aspects of the development of human civilization. In this spirit, many initiatives have been taken, gradually introducing the need for sustainable development.

In the early 1970s, in addition to global environmental sustainability (The Stockholm Conference, 1972 – the first international environmental conference), the need to address issues of basic human demands and needs on a global scale came to the fore in connection with the question of the qualitative aspects of economic growth. The Stockholm Conference, with the participation of 112 countries of the world, raised the issue of preserving the existence of the human population on the planet Earth and emphasized that environmental problems were global in nature and must be thus addressed by joint efforts and cooperation. The conference raised awareness of environmental issues, but also increased the competencies of global institutions in developing international environmental standards. Subsequently, the Washington Convention on Trade in Endangered Species of Wild Fauna and Flora (1973) addressed the negative effects of human activity on species diversity. It focused, in particular, on the problem of widespread poaching, large sales of animals, furs and body parts of animals whose species were threatened with extinction. The Convention (called CITIES) is considered to be one of the main instruments for the protection of nature and the creatures living in it, regulating the ways of endangered species of animals and plants that come from the wild, from captivity or are artificially cultivated or raised in captivity. The trade refers to any export, re-export, import and fishing from the sea.

A breakthrough in the perception of the development of civilization was the report prepared by the World Commission on Environment and Development "Our Common Future"[4], adopted by the UN General Assembly in 1987. The report identified the need for sustainable development defined as development allowing to meet the needs of current generations without endangering the same possibilities for the future generations. In essence, sustainable development is a process in which the use of resources, the direction of investment, the orientation of technological development and institutional change are in harmony with each other and increase both the current and future potential to meeting human needs and demands.

Sustainable development is based on the assumption of finite resources being consumed by human society in direct conflict with the speed of consumption and the burden on the environment as a result of pollution through human waste. The ambition of the concept is to create a symbiosis between man and nature and a mutual harmony among people by the means of a sustainable way of life. Sustainable development should favour such values which do not exceed an ecologically acceptable level of consumption and at the same time it should lead humanity to behave ecologically.

The Brundtland report (1987) draws attention to persistent poverty and injustice in many countries around the world, and development strategies must hence ensure the transition from destructive growth processes to permanently sustainable development processes. This was a fundamental change in policy approach across all countries around the world.

The revival of economic growth is intended to address poverty issues in many developing countries and to create the conditions for the rational use of resources and a positive impact on the environment. It should lead to a change in the quality of economic growth, create space for reducing material and energy intensity and it should ensure a fairer distribution of profits. Under the sustainable development initiative, there are demands to ensure the availability of food, water energy and sanitation for third-world populations by creating jobs that will maintain at least a minimum standard of living. At the same time, sustainable development assumes that a sustainable population level will be ensured and that it would correspond to the production capacity of ecosystems.

Changing the quality of economic growth is associated with the preservation and fostering of basic resources (both renewable and non-renewable), with their protection, and the ability of the biosphere to absorb by-products of energy production and consumption. Tackling the problems of sustainable development requires that legal responsibility is assumed, and changes in the legal order and institutional structure are adopted. The social system must therefore interconnect the political system (citizen participation in the decision-making processes), the social system

[4] The World Commission on the Environment (Brudtland Report) links environmental issues to the need to tackle poverty.

(addressing the disharmonious consequences of development), the production system (the obligation to preserve natural resources for further development), the science and technology system (seeking better alternative solutions), the international system (sustainable trade and financial policy), and the administrative system.

The report "Our Common Future" was followed by the Montreal Protocol on Substances that Deplete the Ozone Layer (1987). The protocol requires countries to control the use of ozone-depleting substances and allows them to be used only if they come from stock, or they were recycled or renewed. An exemption is only provided for the use of these substances for laboratory and analytical purposes.

The Basel Convention (1989) addresses the problem of transboundary movements of hazardous waste and regulates the rules for its transport and minimization. An important result of the Convention is that the import, export and transit of hazardous waste is allowed only on the condition that all concerned countries agree to the shipment and that each member state has the right to refuse or completely ban the import (or transit) of the hazardous waste. The Convention sets out the principle that each state should ensure the disposal of the hazardous waste it has produced on its own territory.

In 1991, the Club of Rome issued its second "Boundary Exceedances" report, which pointed out that despite the introduction of new technologies and stronger environmental policies, economic growth is still unsustainable as the use of natural resources and pollutant production have exceeded tolerable levels. They therefore reiterate their call for a comprehensive revision of policies and practices which lead to sustained growth in material consumption and population, and a call for a rapid, substantial increase in material and energy efficiency. In response to a report by the Club of Rome and a document by the World Conservation Union (IUCN) and the Convention on Biological Diversity (Nairobi, 1992), the "Earth Summit" was held in 1992 in Rio de Janeiro. The conference responded to the global problems of natural resources depletion and environmental degradation, which could lead to a halt to the development and transience of life on the planet. The conference adopted several documents on a global scale. The most important was "Agenda 21", which represented opportunities for achieving sustainable development of comprehensive care for the environment stretching into the 21st century. It focused on the economic and social dimensions in the environmental context, and presented the starting points for the protection and use of resources. The Convention covered a wide range of issues in the areas of biodiversity conservation, the sustainable and prudent use of natural resource components and the fair and equitable sharing of benefits arising from the use of genetic resources.

It has become a fundamental principle of the Convention that each State has the right to use its own biological resources, but its actions must not cause damage to the environment of other States. The Convention established framework rules for the provision of financial resources to developing countries to cover at least part of the costs necessary to meet their obligations under the Convention. At the same time, countries and international institutions have committed themselves to developing national programs and strategies for the conservation and sustainable use of biodiversity (biological resources) while ensuring their integration into sectoral policies and concepts, and that they will support research and monitoring of biological and genetic resources and support such programs in developing countries. Furthermore, the countries promised to ensure the "in situ" protection of native and domesticated species, ecosystems and natural habitats; in particular, through an effective system of protected areas and legislation, and that they will build, when appropriate, facilities for the protection and research of plants, animals and micro-organisms "ex situ" with a view to the rescue and eventual restitution of endangered species. The United Nations Framework Convention on Climate Change (1992) aimed to mitigate and prevent climate change as a result of the rapid increase in anthropogenic greenhouse gas emissions. The Kyoto Protocol to the United Nations Framework Convention on Climate Change (which came into force in 1997) provided a framework for tackling climate issues related to increased global levels of production and consumption. It was a response to the global increase, by 25%, in production and consumption which exceeded the ecological capacity of the planet, and endangered all spheres of the environment (forests, water, air, waste, etc.). The Kyoto Protocol outlined options for bringing global warming under control, stabilizing carbon dioxide and other greenhouse gas emissions, and outlined which national strategies and what timeframe should be adopted.

The UN Convention adopted in Buenos Aires (1998) was also an initiative to reduce emissions and tackle issues related to climate change. This was followed by the Johannesburg Declaration on Sustainable Development, which was adopted in 2002; an implementation plan that paid attention to the pillars of economic development (the need to "equalize" the economic, social and environmental pillars).

The study "Economic aspects of climate change" (the so-called Stern Review, 2007) is also aimed at addressing the challenges of climate change, which on the one hand identifies the risks arising from climate change and the consequences of global warming (melting glaciers, declining crop yields, rising sea levels posing a greater threat to people from floods, etc.) and, on the other hand, provides guidance on what else humanity can do to mitigate or eventually halt the negative effects of climate change. As it concerns the largest and the most extensive market failure, the report points to the importance of policies in accelerating the securing of the transition to a low-carbon economy, despite the high costs, so to minimize risks in the future. According to Stern, the growth of global emissions needs to be stopped in the next 10 years, and then emissions would have to fall by 5% a year in order to fall by 70% below the current level by 2050. It is therefore necessary to reduce the demand for high-emission goods and services, increase efficiency, cease deforestation and use low-carbon technologies in energy, heating and transport. The report also draws attention to the need for society to adapt to irreversible climate change.

The Paris Agreement on Climate Change (2015) introduced an action plan aimed at reducing global warming to well below 2 °C (applying to the period after 2020). The signatories of the conference adopted a resolution aimed at significantly reducing the risks associated with global warming. The conference outlined the trajectories to a low-carbon future, mainly by reducing or completely suppressing the fossil fuel industry, which should reduce greenhouse gas emissions. At the forefront of interest became the need for greater transparency and for the assessment of results achieved over five-year. Sanction mechanisms have also been adopted which would be used to penalize producers of fossil fuel emissions. Within the conference conclusions a strategy has been adopted to aid developing countries in their trajectory towards a low-carbon industry (in the framework of the aid strategy, governments of developed countries would provide $ 100 billion each year inlcuding public and private sources in the period between 2020 and 2025). In terms of the Sustainable Development Initiative, it appeared to be a turning point in 2015. This year, the OECD presented the concept of Policy Coherence for Sustainable Development (PCSD), which aims to achieve sustainable development as an integral part of policy-making, both at a national level and on a global level. This means that no public policy in the area of trade, finance, climate change, the environment, migration, security (including food security) and other global challenges should be directed against development at national or global level. In 2015, after many years of preparations, another important document, Agenda 2030, was adopted by the UN. The document followed up on the PCSD and emphasized the need for interconnected, balanced and coherent policies in all areas of sustainable development. The 17 goals (Sustainable Development Goals – SDGs) included individual dimensions of sustainable development, i.e., economic, inclusive, environmental development and institutional quality. SDGs' initiatives are aimed at positively addressing two fundamental global contradictions, namely the mismatch between economic growth and the environment (nature) and the discrepancy between growing wealth production and the deepening inequality of its distribution (the gap between wealth growth and poverty growth, or between the core, periphery and marginalized areas).

The current framework for sustainable development is set out in Agenda 2030, which identifies the key threats and sets global goals in individual areas. It highlights the inclusive and environmental aspects of development as essential parameters of economic growth. Agenda 2030 builds on the Millennium Development Goals[5]. It has the ambition to ensure sustainable development in a balanced and coherent way taking into account the economic, social and environmental dimensions. The Agenda sets global goals for the next decade that focus on people and the environment in which they live, emphasizing their sustainable symbiosis on both sides.

Therefore, the specification of goals presupposes the creation of a socially just and inclusive society that will respect the need for the permanent protection of the planet and its natural resources and will have a positive impact on solving climate problems. It is addressed to all countries of the world and their inhabitants, regardless of the level of socio-economic development of the country. The objectives of the Agenda

[5] These were set out in 2000 with a deadline in 2015. They focused on tackling global challenges; notably poverty, hunger, women's status, child mortality, access to health, population dynamics, access to drinking water, tackling inequality, human rights and climate change.

meet the previous challenges of sustainable development regarding interpersonal, intergenerational and interspecific solidarity, drawing attention to the need for respecting long-term quality objectives, the need to ensure coherence between economic growth, the protection of natural resources and the reduction of pollution. The first group of goals is focused on interpersonal solidarity and social balance of economic development. Their ambition is to eradicate poverty in all its forms and dimensions, eliminate hunger (including ensuring food security), combat inequalities within and between countries, provide basic human needs (education, housing, health care, security), which should improve the quality of life of the inhabitants of the planet. Particular attention is paid to gender equality and the status of women; as women are generally poorer than men they have worse access to education, health and freedom in all their forms, while on the other hand, it is women who have the main responsibility for raising children, passing on cultural and social values to future generations, and they are the crucial link in tackling poverty. The availability of drinking water for all, its sustainable management, as well as affordable and sustainable energy, should also help to improve the quality of life of the planet's inhabitants. As part of improving the quality of life of the population, the objectives of the Agenda also focus on transforming cities and human dwellings so that they become inclusive, safe, resilient and permanently sustainable. It is in particular a matter of improving the living conditions of the poorest people, whose living conditions do not ensure their human dignity. In the context of the global quality of life, the level of inequality both between and within countries is considered to be a serious problem. Despite the fact that inequalities between countries are decreasing, they are deepening within individual countries (both income inequality and wealth inequality are increasing), while in recent years the trend is noticeable mainly in economically developed countries. Therefore, reducing inequality has become one of the goals of the 2030 Agenda.

The 2030 Agenda also pays great attention to measures to support economic growth and change its quality. The goals in this area target inclusive, sustainable economic growth, driven by high labour productivity, while creating quality sustainable jobs that will bring better living conditions and increase dignity to all the inhabitants of the planet. These goals require extensive structural changes in industrial production, take into account the environment, the dynamics of technical progress, apply the latest technologies, and deal with the consequences of automation, digitisation and robotisation on job creation and quality. The development of industrial production is linked to the quality of the physical infrastructure, as well as to the availability and quality of the information and communication infrastructure. These processes are conditioned both by the availability of education for all individuals, as well as by increasing the quality of education. The sustainability of economic growth requires it to be "green growth", i.e., being environmentally friendly and reducing the current ecological footprint. The production (but also consumption) should be focused on reducing the resource intensity, pollution and degradation of natural systems.

Environmental challenges are another priority area of Agenda 2030. It is a complex of measures aimed at combatting climate change and its consequences that would halt land degradation, protect biodiversity, protect the use of both terrestrial and marine and ocean ecosystems. The depletion of natural resources and the negative impact of a deteriorating environment, including desertification, drought, soil degradation, fresh- water scarcity and loss of biodiversity, contribute to expanding the list of challenges that humanity is facing. The biggest challenge today is the prevention of climate change. Sea levels rise, ocean acidification and other impacts of climate change are seriously threatening coastal areas and low-lying coastal and island states.

The institutional framework of the 2030 Agenda calls for the promotion of a life of peace, the provision of justice, democracy, and the strengthening of governance. This means improving the quality of formal and informal institutions and their interconnectedness.

All these goals are addressed to institutions, governments and citizens around the planet. They focus on deepening cooperation between countries, between the private and public sectors, and on increasing transparency and the quality of global decisions.

1.3 Beyond GDP indicators

As we indicated in the previous sections, the emphasis on economic growth, measured by the GDP indicator, which prevails in economic policy approaches, overlaps many imperfections; not only in the way it is measured but also in approaches to its stimulation. The long-term superiority of the dynamics of economic growth, and its quality, has masked many social and environmental risks which pose as acute problems of global development.

As a result, other ways are being sought to combine and measure not only the pace of growth but also its quality, and to find ways to affect economic growth in its complexity. In the new approaches, it is considered how to eliminate as much as possible the negative consequences of increasing economic growth on nature, climate and the quality of life of all inhabitants. Therefore, the professional discussion takes place not only on the issues of the appropriate level of economic growth, but also on the possibilities of capturing its environmental and social impacts.

The low ability of the GDP indicator to capture environmental degradation, resource depletion, public health and growing income inequality has led to the opening of a debate on how to change the assessment of societal progress to reflect not only material progress but also long-term sustainable development.

As early as 2007, the European Commission, the European Parliament, the Club of Rome, the OECD and WWF organized a "Beyond GDP" conference to initiate a political and public debate on how to perceive societal progress through human quality of life and sustainable use of the planet, including the climate[6]. The initiative

[6] The same aim was pursued by a study on new approaches and measures in the field of societal progress (Stiglitz et al., 2009), which would enable economic policy makers to change the basic frameworks of the current assessment of progress towards its long-term sustainability.

called for the development of indicators that would respond to the global challenges of the 21st century.

Subsequently, in the road map GDP and beyond: Measuring progress in a changing world (2009), the European Commission presented a plan containing key measures aimed at improving the necessary qualitative improvement in measuring progress. The basic goal of the initiative was to supplement the aspects of environmental protection, quality of life and social inclusion with GDP.

In particular, the need to complement environmental and social indicators with GDP, which would collectively affect the quality of the environment and social inequalities, was emphasized.

The design of a comprehensive environmental index reflected the need to measure the quality of the environment, climate change and energy consumption, nature and biodiversity, air and health pollution, water use and pollution, as well as waste generation and resource use. At the same time, the need for early monitoring and sharing the information on the state of the environment within the EU was emphasized.

Within the framework of social inclusion, the roadmap focused mainly on the need for a more robust measurement of quality of life, especially on the availability and quality of public services, health, mobility, quality of working conditions, leisure time, and rising living standards. The aggregate indicator should reflect, in addition to progress in these areas, also progress in eradicating poverty, by reducing the number of people at risk of poverty or social exclusion.

The development of clear and measurable indicators to measure medium- and long-term economic and social progress is still relevant. A study was carried out (Aiginger, 2016) which connects the basic strategic framework of the European Union – increasing its competitiveness and the agenda beyond GDP. In a comprehensive strategy a new benchmark was articulated – increasing wellbeing. In pursuit of the latter, guiding principles for intertwined economic dynamics, inclusiveness and sustainability were set. Specifically, decoupling emissions from output was declared one of the main environmental goals. Thus, the three-dimensional assessment becomes a standard in backing policy decision making.

1.4 Integrating development initiatives into the strategic framework of European Union

For the EU, ensuring sustainable development has become a priority in its strategy papers; in which it has gradually incorporated all the initiatives that frame sustainable development and support its implementation. Article 3 of the Treaty on European Union states, inter alia, that “The Union shall pursue the sustainable development of Europe based on balanced economic growth and price stability, a highly competitive social market economy with full employment and social progress and a high level of protection and improvement of environmental quality (Douglas--Scott, S., Hatzis, N., 2017).

The Treaty of Amsterdam (adopted by the EU in 1997) already incorporated into its framework the concept of sustainable development, which framed the formulation of the economic policies of the Community and its members.

EU development strategies have also placed great emphasis on sustainable development. The comprehensive strategy for growing competitiveness, the Lisbon Strategy, 2000,[7] has paid attention to all pillars of sustainable development. Following the aims of the Lisbon Strategy towards ensuring sustainable development in the area of the environment, attention has been drawn to tackling climate change, transport, public health and natural resources. The fight against climate change has involved reducing greenhouse gas emissions and increasing the consumption of electricity produced from renewable sources. Ensuring sustainable transport focused on a set of measures that were intended to lead to the reorientation of trans-European transport networks, regarding noise reduction, a decrease in traffic pollution and a preference for rail, water and public passenger transport, while also emphasizing the need for their inter-connectedness. These measures referred to support for investment in public transport, railways, inland waterways and maritime transport.

The strategy also called for increased public health efforts, which were linked to food safety and quality, the use of safe chemicals and tackling the associated incidence of infectious diseases and antibiotic resistance.

Achieving the economic objectives of the EU and its members has been linked to a responsible and sustainable use of natural resources, with an acceptable volume of waste, the preservation of biodiversity, the maintenance of ecosystems and the prevention of desertification.

Following the objectives of the Lisbon Strategy and the global challenges for sustainable development, the European Council adopted in 2001 the first EU Sustainable Development Strategy (EU SDS). It identified areas that threaten the sustainable development of the EU. Its aim was to improve the quality of life on Earth for present and future generations and to ensure that economic growth was linked to environmental protection and social integration. The strategy created a cross-cutting policy framework for EU policies and strategies. It was revised and updated in 2006.

These goals also resonated relatively strongly in the Europe 2020 strategy (a strategy to ensure smart, sustainable and inclusive growth). The Europe 2020 strategy defined the EU social market economy for the 21st century and presented a way of forming a knowledge-based society and economy with all the attributes of sustainable development. The key ambition was not only the restoration of economic growth to the pre-crisis level and its subsequent increase, but also (and above all) its qualitative change towards strengthening knowledge-intensive factors, with

[7] The aim of the strategy was to ensure that "the EU becomes the most competitive and dynamic knowledge-based economy, with economic growth that would be sustainable, while supporting more and better paid jobs, greater social cohesion and respect for the environment".

the inter-connectedness of economic, social and environmental aspects of development. The strategic document built on the goals of the Lisbon Strategy set out key priorities, goals and initiatives to increase knowledge-based competitiveness and economic performance.

The strategic framework of the document[8] was defined by three inter-dependently conditioned priorities which are formulated as follows:

- *smart growth* in terms of creating a knowledge and innovation-based economy;
- *sustainable growth*, i.e., growth based on the promotion of a greener and more competitive, resource-efficient economy;
- *inclusive growth*, which means supporting an economy with a high employment rate, and with social and territorial cohesion.

From the point of view of development environmental initiatives, sustainable growth is the crucial initiative. The EU Strategy 2020 defined sustainable growth, as such, that seeks to create a sustainable and competitive resource-efficient economy. European countries and their efforts have focused on securing European leadership in developing new processes and technologies, including green ones which would produce low levels of carbon production, save resources, prevent environmental damage and biodiversity loss. Measures in the area of promoting sustainable growth required that emission reduction commitments were met in a way that maximizes benefits and minimizes costs through a widespread application of innovative technological solutions that would reduce the dependence of economic growth on energy consumption. The strategy identified reducing dependence on foreign sources of raw materials and commodities as one of the competitive advantages of the EU.

The environmental targets were quantified in the strategy as "20/20/20" in the area of climate/energy, which envisaged reducing greenhouse gas emissions by at least 20% compared to 1990 levels[9], increasing the share of renewables final energy consumption by 20% and increasing energy efficiency by at least 20%.

EU strategic goals in the field of sustainable development have been updated in accordance with the goals of Agenda 2030. An implementation strategy was developed, which linked the goals of the 2030 Strategy with the goals of the 2030 Agenda and set out specific measures for their implementation.

In 2019, the European Parliament approved a state of climate and environmental emergency, aimed at achieving carbon neutrality by 2050, and responding to the magnitude and speed of the negative changes in the planetary systems which negate global climate stability. The 25th Climate Conference in Madrid (2019) addressed planetary climate risks and reviewed the implementation of the Paris Conference's commitments. The conference drew attention to the planetary risks associated mainly with the melting of Arctic glaciers, the loss of the Amazon rainforest and many other

[8] Europe 2020. A strategy for smart, sustainable and inclusive growth. Available at: http://ec.europa.eu/eu2020/pdf/1_SK_ACT_part1_v1.pdf

[9] or by 30% under favourable conditions

environmental threats which can gradually cause the collapse of ecosystems and significantly worsen the quality of life on the planet and endanger it in the long term.

At present, initiatives for the EU's sustainable development are set out in the Green Agreement, which emphasizes the objectives of the 2030 Agenda and paves the way for the EU's transformation into a just and prosperous society with a modern, resource-efficient and competitive economy. Like previous strategies, it sets itself the objective of ensuring that the role of the EU in promoting global climate and environmental action, and protecting biodiversity is strengthened. The priority is to protect, preserve and increase the EU natural capital, minimize the negative effects on the environment and the quality of life of EU citizens. At the same time, it draws attention to the need for massive public and private investment in the area of the climate and the environment.

The transformation of the European economy to a permanently sustainable level requires climate neutrality by 2050, which is mainly linked to the further decarbonisation of the energy system, as energy production in all economic sectors account for more than 75% of EU greenhouse gas emissions. The need for neutrality at the same time draws attention to the need to increase energy efficiency and increase the share of so-called clean energy, i.e., renewable energy, while reducing energy production from coal and hydrocarbons. Consequently, the energy system needs to be restructured so that it would be able to ensure a secure and affordable energy supply for businesses and consumers. This requires that the European energy market becomes fully integrated, interconnected and digitized while respecting technological neutrality.

Despite the fact that the EU reduced its greenhouse gas emissions by 23% between 1990 and 2018, significantly more ambitious measures are needed to reduce greenhouse gas emissions. Therefore, energy efficiency is becoming a priority, especially increasing energy efficiency in energy-intensive industries (e.g., steel, chemicals, and cement production). Their decarbonisation and modernisation are among the priority challenges. In the context of sustainable energy, the Green Agreement draws attention to the need to tackle energy poverty.

The transition to climate neutrality requires smart infrastructure emission-based and resource-efficient industrial restructuring. Industry produces around 20% of greenhouse gas emissions; between 1970 and 2017, annual global material extraction tripled and, till today, continues to grow, posing a major global risk as approximately half of total greenhouse gas emissions and more than 90% of biodiversity loss comes from resource extraction and processing of materials, fuels and food. In this regard, the EU, in particular, emphasizes the positive impact of the circular economy.

The EU's industrial strategy calls for a double transformation – green and digital – because digital technologies have the potential to optimize the use of energy, natural resources, monitor air pollution, and thus contribute to reducing climate change and protecting the environment.

Particular attention is paid to the transition to sustainable and smart mobility, as transport produces a quarter of the EU's greenhouse gas emissions, and it keeps growing. The key objective is thus to reduce emissions in all modes of transport – road, rail, air and water – and to significantly support multi-modal transport; in particular, intelligent traffic management systems and the expansion of the production and consumption of sustainable alternative transport fuels should contribute to increasing the transport efficiency.

It is expected that the environmental burden of the agricultural and food sectors will decrease as well. The Green Agreement also aims to protect and restore ecosystems and biodiversity, stop the loss and erosion of biodiversity, caused notably by changes in land and sea use, by direct exploitation of natural resources and by climate change.

The Green Agreement envisages that an investment plan for a sustainable Europe would be created, including financial coverage of individual measures by combining public and private sector funds. A greater use of green budgeting tools in national budgets should redirect public investment, consumption and taxes toward green priorities.

Achieving the objectives of the Green Agreement depends mainly on the level of research and development and the support of innovation. The agreement anticipates the introduction of new key clean technologies and innovative value chains that will support the sustainable development and competitiveness of the EU as a whole and of its individual countries. Four "Green Agreement missions" are defined to bring about far-reaching changes in the climate, oceans, cities and land. This presupposes the creation of partnerships between industry and Member States, universities, research institutes in the area of research and innovation support in transport (batteries, clean hydrogen), low carbon steel production, circular economy and the built environment. Attention must be focused on climate change, sustainable energy, food for the future and intelligent, green and integrated urban transport.

Increased emphasis on research and development in the field of sustainable technologies and their application must be linked to the growing quality of education and vocational training. The development of knowledge, skills and attitudes related to climate change and sustainable development is therefore becoming a priority. It is also necessary to adjust the legal framework to ensure a fair transition to a sustainable future.

The individual objectives and priority areas of the Green Agreement are intended to support the position of the EU as a global leader in sustainable development. In the context of "green" diplomacy, it is essential that the EU positively influences the behaviour of all countries (particularly the EU's trade partners) and influences the attitudes of international organizations and international fora to adopt ambitious environmental, climate and energy policies worldwide. The EU will continue to push for compliance with all international agreements in the area of sustainable development.

The Green Agreement calls for the involvement and commitment of the public and all stakeholders to its implementation by promoting the sharing of information about the threats posed by climate change and environmental degradation and about the ways to combat them. The agreement also presupposes the creation of real and virtual spaces where people can express themselves, present ideas and ways of implementing sustainable activities. At the same time, capacity will be built to facilitate local initiatives in the field of climate change and environmental protection.

The objectives of the Green Agreement are also supported by the Green Recovery Program, which has the ambition to reconcile economic recovery after the crisis caused by the COVID-19 pandemic with the objectives of climate and wider environmental protection. These are massive incentive resources (the volume of assistance from the so-called Union Recovery Program), which are to support environmental investments based on the principles of the European Green Agreement in the form of a combination of loans and grants (including private sector investments).

* * *

Despite many initiatives, sustainable development remains an open question and many problems remain, even at the level of their identification, with a lack of willingness and strength especially on the part of the largest global players. Global development suggests that, despite the immense efforts of the international community, the sustainability of economic development is an acute and increasingly growing problem. The efforts of developing countries to create and expand their development potential run into the problem of depleted natural resources, high pollution and the need to address climate change. Present environmental problems bind the socio-economic development of less developed economies, which do not have the resources built for environmentally friendly activities. The responsibility and help of the developed world are in many ways more declared than real. Economic and power interests still outweigh the need for sustainability. Despite all the initiatives, the economic dimension of sustainable development is superior to the other dimensions. The current view of economic growth increasingly supports its dynamism rather than its quality.

Pressure from the European Commission on green transformation is on the rise, with other initiatives taking on clearer contours and declaring more ambitious carbon neutrality targets. The European Union is taking on the role of climate leader and proposes to reduce greenhouse gas emissions by 2030 from the current 40% to 55% compared with 1990. However, this ambition confronts the reality of industrialized EU countries, who consider the target unrealistic.

2 WHY THE CLIMATE?

2.1 Consequences of climate change

As we stated in the previous chapter, the causes and consequences of climate change have been increasingly communicated in the field of sustainable development since the 1990s. The relatively strong impetus given by the UN Framework Convention on Climate Change and the Kyoto Protocol was amplified by the Stern Review, which highlighted the economic consequences of climate change and global warming. The study sparked a debate among supporters and opponents of pessimistic views on climate change (Nordhaus 2008; Dasgupta 2008; Dasgupta et al., 2009; Mendelson, 2009 and others). In addition to examining the impacts of natural and geophysical phenomena (Rodell et al., 2009; Velicogna, 2009), the focus of climate change research has increasingly begun to focus on their economic consequences. Attention is focused on both the effects of economic growth on climate change and the impact of climate change on economic growth. Critics of proponents of economic growth (Stiglitz, Stern et al., 2017; Maxton, 2012) point out that economic growth has so far not been curtailed in any way, bringing devastation and exploitation of the planet, while the emission intensity of economic growth has a deleterious effect on the climate. A comparison of the current level of resource consumption and the best estimates of the increase in the technological pace shows that humanity has less than a 10 percent chance of surviving a catastrophic collapse. (Bologna, Aquino, 2020).

On the other hand, global warming will slow down global activity and its impact on economic growth will be negative in the long run (Feyen et al., 2020; Wade, Jennings, 2015; Kahn et al., 2019; Lanzi, Dellink, 2019; Fankhauser. S. Tol, R. S. J, 2005, and many others). Short-term measures to address climate change are thought to have the power to tie up the long-term economic growth, in particular, by reducing the pro-growth impact of labour and capital (Wade, Jennings, 2015). Rising temperatures, changes in precipitation patterns and more volatile weather events can have long-term macroeconomic effects (Wade, Jennings, 2015, Feyen et al., 2020) and adversely affect labour productivity, investment slowdown, monetary and financial stability (Kahn et al., 2019; Rozenberg, Hallegatte, 2015; Wade, Jennings, 2015; Batten et al., 2020; Feyen, E. et al., 2020). This will require extensive adaptation approaches, both in changing the structure of the economy and in economic-political approaches (Ruhl, 2009).

Also, the introduction of alternative technologies that would reduce negative impacts of climate change will initially be counterproductive to economic growth, as they will be less productive than existing technologies, while increasing one-off fixed costs and overall adaptation costs associated with tackling climate change. The necessary investments in new technologies, preventing irreversible damage caused by climate change, will ultimately have a positive effect on the quality of economic development (Golub, Toman, 2016). Economic losses stemming from the climate crisis, including the costs of adaptation, will affect the whole world, and will be much higher in less developed countries than in developed countries.

Climate change will affect demographic and socio-economic trends, especially the deepening of poverty due to higher food prices and declining agricultural land, in Africa and Asia (Mendelsohn, 2009, Rozenberg, Hallegatte, 2015) in particular. At the same time, the speed and direction of future socio-economic change will determine the future effects of climate change (Hallegatte et al. 2014).

Deterioration in human health will also be a negative consequence of climate change. Rising global temperatures will bring more deaths than all infectious diseases combined, especially in the poorer and warmer parts of the world. If there is only a low reduction in emissions, global mortality will increase to 73 deaths per 100,000 population by the end of the century. This is almost the same number of deaths as from infectious diseases, which include tuberculosis, malaria, dengue fever, yellow fever and HIV/ AIDS. In poorer and warmer countries (Ghana, Bangladesh, Pakistan and Sudan), mortality can reach up to 200 people per 100,000. In contrast, in richer and colder countries such as Norway and Canada the mortality rate can decrease, as deaths from extreme cold decrease (Carleton, T. A et.al, 2020).

Estimates of the economic costs of climate change vary, e.g., an OECD study (Lanzi, Dellink, 2019) predicts that the long-term economic consequences of climate change will gradually increase. In the case of air pollution of around 1%, climate change damage would reach almost 3% of GDP by 2060, compared to more than 3% of GDP in Asia and Africa and less developed regions, and could even reach as much as around 5%. An analysis of the impact of climate change on economic performance (Kahn et al., 2019) suggests that a sustained increase in average global temperature of 0.04 ° C per year (in the absence of policies to reduce it) could reduce world real GDP per capita by 7. 22% by 2100. The WRI (World Resources Institute) predicts an increase in emissions in the coming years, with global emissions expected to reach historically high levels in 2019 (Levin, Lebling, 2019).

The Global Carbon Project report (Jackson et. al., 2019) states that in 2019 CO_2 emissions into the atmosphere from industrial activities and the burning of fossil fuels will reach approximately 36.8 billion metric tonnes of carbon dioxide and total carbon emissions from all human activities, including agriculture and land use will be around € 43.1 billion tonnes. However, the implementation of the conclusions of the Paris Agreement (assuming that the temperature increase be limited to 1.01 °C per year) will make it possible to substantially reduce the loss to 1.07%.

The Paris Agreement (2015) on climate change set an international target to keep the average global increase in surface temperature (compared to the end of the 19th century) well below 2 °C. This target requires achieving carbon neutrality, i.e., to bring net emissions to zero level by 2050. The IPCC Report (2020) points to a decrease in the average temperature by 1.5 °C by 2050 and by 2 °C by 2070, as raising the temperature above 1.5 °C poses a significant risk. Therefore, a major economic and structural transformation is needed (Stiglitz, Stern et.al, 2017), which would include all aspects of society (including production, consumption, transport and energy).

The European Parliament, which approved a state of climate and environmental emergency in 2019, responded to the speed and scale of negative changes in planetary systems that negate global climate stability. It aims to achieve carbon neutrality by 2050. The Madrid Climate Conference (2019) assessed the Paris Conference's commitments, paying attention to the planetary risks associated with the loss of the Amazon rainforest and the heating of Arctic glaciers, consequently leading to the collapse of ecosystems and to the threat to the life on the planet.

The World Meteorological Organization (2020) states in its last forecast that the average annual global temperature is likely to be at least 1 °C above pre-industrial (1850–1900) levels in each of the next five years (2020–2024) and there is a 20% chance that it would exceed at least 1.5 °C in one year. At the same time, the forecast notes that the last five-year period was the warmest in the entire history of measurement. Stopping the process of climate change requires, above all, in addition to the real fulfilment of the goals of climate initiatives, a change in the quality of economic growth, while the most important area is the reduction of its emission intensity.

2.2 A descriptive view of greenhouse gases

The reversibility of climate change depends primarily on reducing greenhouse gas emissions from natural processes, but mainly from human activity. Therefore, in the next part of the work we will focus our attention on assessing the development of greenhouse gases with an emphasis on the period from the 1990s, as since then global efforts to address climate change have intensified. We adapted the analysis to the availability of data, using the Our world in data (OWID) database, which provides a relatively wide range of data needed to assess the implementation of environmental goals (the World Bank publishes many environmental indicators but only until 2014).

Greenhouse gas emissions have been steadily increasing since the onset of industrial development. At present, they have reached the historically highest levels and are still increasing. Within the total greenhouse gases (calculated on carbon dioxide emissions), carbon dioxide has the largest share, accounting for more than 72% of global greenhouse gas emissions. Economic growth and population growth are key factors that have contributed and continue to contribute to anthropogenic greenhouse gas emissions till now.

The impact of greenhouse gases on climate change is expressed through their Global Warming Potential (GWO). The indicator allows for a comparison of different gases and their effect on global warming. It is a measure of the energy absorbed by the emissions of one tonne of gas over a given period of time in relation to the emissions of one tonne of carbon dioxide. The higher the GWO, the more the gas heats the planet compared to carbon dioxide. The time period used to determine the GWP is usually one hundred years. It follows that carbon dioxide has a GWP value of 1 regardless of the time period, as it is used as a reference unit (EPA2020).

2.1.1 The carbon footprint is regionally differentiated

Carbon dioxide is a gas that is essential for the life of the planet. By consuming it during photosynthesis, plants support the production of oxygen. The problem arises if the emitted amount exceeds the absorption capacity of nature, and nature does not manage to drain its excess amount. Then the gas participates in the so-called greenhouse effect and destroys climate stability. At present, the planet's absorption capacity is twice exceeded by carbon dioxide emissions, and the dynamics of its production is accelerating. The short-term slowdown in emissions due to the COVID-19 pandemic is not sufficient in order to reverse this trend. Reversing the negative trends requires a radical reduction of carbon dioxide production to a level below the current absorption capacity of the planet. It is crucial to realize that each new emission saturates the atmosphere, and that carbon dioxide as such does not disappear, but nature must be able to "absorb" it. CO_2 emissions cause an increase in atmospheric CO_2 concentrations that will last for thousands of years (EPA2020).

From the middle of the 19th century (when the first data was available), Europe (especially its Western part) was involved in global emissions for almost half a century. The gradual industrialization of North America brought increased CO_2 production to this continent, and already by the beginning of the last century, North America produced more than 21% of global emissions, while its share was constantly increasing. This fact gradually reduced the dominance of European emissions which lasted until the mid-1920s, when America took the lead in emissions, with a share exceeding 50%. North America had a significant share in the CO_2 emissions produced by America, which accounted for 94 to 99% of emissions, while in North America it was the USA who was the main emitter, accounting for almost 100% of North America's CO_2 emissions in the mid-20th century. Although the USA share of North American emissions gradually declined, it did not fall below 90% until the mid-1960s. Both continents, Europe and America, shared this rather unenviable record as the major emitters of CO_2 until the early 1990s.

In the early 1990s there was a relatively dramatic increase in CO_2 emissions in Asia, which has dominated global emissions since 1992 and now accounts for almost 55% of them. More than 63% of Asia's emissions are produced by China (50.1) and India (13.2), which accounted for almost 34.8% of global emissions in 2018 (Table 1).

Table 1 **Share of continents and selected countries in global annual carbon dioxide emissions (in percentages)**

	1751	1800	1900	1950	1960	1970	1980	1990	2000	2010	2018
Africa	0.00	0.00	0.12	1.51	1.66	2.04	2.77	2.97	3.63	3.69	3.83
America	0.00	0.91	21.36	49.16	35.91	34.94	31.14	29.70	32.22	24.08	21.21
from which: North America	0.00	0.91	21.20	47.21	33.79	32.66	28.52	27.07	28.93	20.88	18.17
Australia	0.00	0.00	0.52	0.95	0.94	0.99	1.14	1.26	1.43	1.23	1.15
Asia a Oceania	0.00	0.00	2.06	6.26	17.5	19.31	24.09	31.14	38.36	50.81	56.18
Europe	100.00	99.09	44.34	42.71	43.45	42.57	41.54	37.72	25.10	18.47	15.39
USA	0.00	0.90	33.93	43.83	30.69	29.14	24.33	23.09	24.42	17.24	14.81
EU28	100.00	99.09	55.55	29.01	28.15	26.58	23.87	20.16	17.03	11.93	9.42
China	0.00	0.00	0.09*	1.36	8.28	5.19	7.52	10.91	13.64	25.71	27.52
India	0.00	0.00	0.67	1.15	1.28	1.31	1.61	2.78	4.19	5.14	7.26
Japan	–	–	0.99	1.77	2.47	5.17	4.87	5.22	5.15	3.67	3.18
Russia	–	–	–	–	9.43	9.73	11.01	11.39	5.99	4.88	4.68

*year 1903

Source: Our World in Data, 2020, own calculation

Africa gives the impression of a “green” continent, which is somewhat misleading. The data we work with generally includes only carbon dioxide emitted into the air from industrial and agricultural activities and does not include data on CO_2 from soil, which is produced from deforestation and geological activity, and which often accompanies economic growth in many African countries.

Despite warning signals in the form of warming, and accepted challenges and global initiatives on climate change, CO_2 emissions keep rising every year. More than 1.6 trillion tonnes of carbon dioxide have been emitted since the middle of the 19th century up to the present.

The highest CO_2 emitter in the entire period under review was the USA, which produced more than a quarter of global emissions during the entire period under review.

Since 1990, i.e., since intensifying efforts to reduce carbon dioxide emissions, annual emissions have been increasing; the amount of emissions issued annually increased from 22 billion tonnes in 1990 to 36.6 billion tonnes in 2018. On average, this number accounts to more than 28 billion tonnes of carbon dioxide emitted into the air every year.

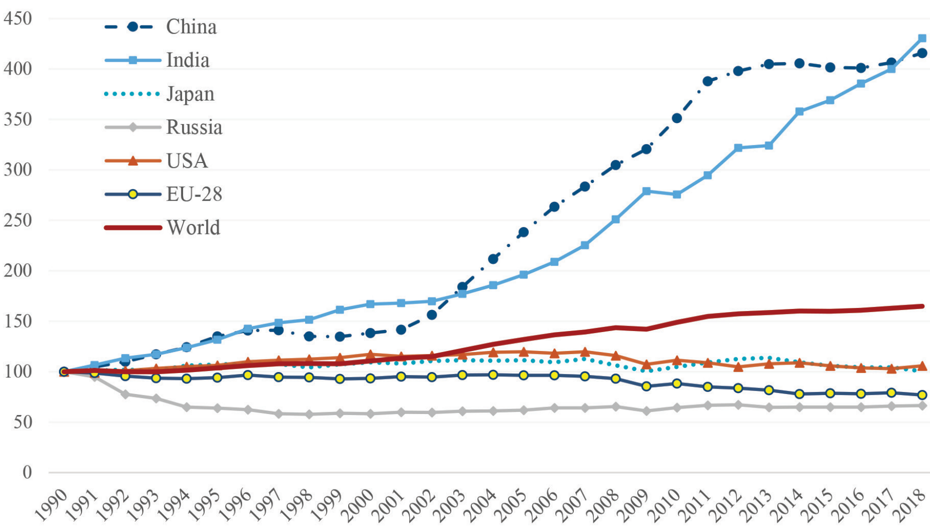
Asia’s high annual growth in global carbon dioxide emissions has been recently affected mostly by China and India, which produced more than € 207.7 billion tonnes over the period 1990-2018 and thus contributed significantly to its global growth. China is currently the largest emitter of carbon dioxide; it produces up to 27.5% of global emissions a year (followed by the USA with production of almost 15%, India more than 7% and Russia almost 5% – these countries produce more than half of the world’s emissions).

Among the key emitters of carbon emissions, there has been a positive development, especially in Russia, which, compared to 1990, produced less than 68% of CO_2 in 2018. Compared to 1990, the annual amount of carbon dioxide has also decreased in the European Union. In the USA and Japan, CO_2 emissions have recently been slightly above 1990 levels (Chart 1).

More than 1.6 trillion tonnes of carbon dioxide have been emitted since the middle of the 19th century to the present (the cumulative amount of global emissions doubled between 1990 and 2018 – increasing from 803.2 billion tonnes in 1990 to 1,611.8 billion tonnes in 2018).

The largest emitter in the entire period under review was the USA, which produced more than a quarter of global emissions during the entire period under review. The distribution of cumulative emissions during this period was uneven, their core shifting to Asia, with China and India contributing to the most significant increase in emissions produced between 1990 and 2018. Although both the European Union and the United States have been able to reduce their share of global emissions (Chart 2), in 2018 they produced by an order of magnitude more tonnes of emissions than in 1990 – the US 1.6 times more and the EU almost 1.5 times more.

Graph 1 **Development of carbon dioxide emissions in selected countries (1990 = 100%)**



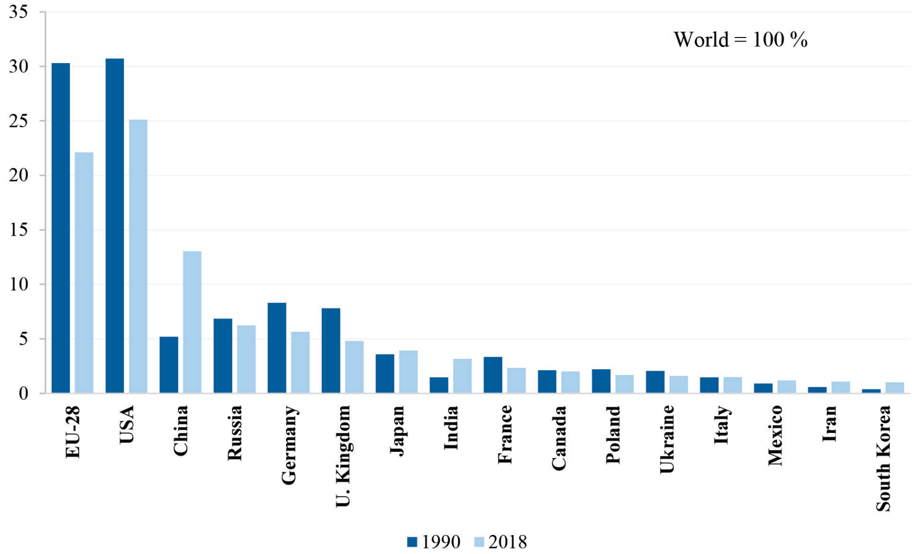
Source: Our World in Data, 2020, own calculation

Stagnant or a declining level of CO_2 production in the developed countries may not objectively reflect a positive reality, as it may have been conditioned to some extent by the relocation of carbon-intensive production to countries where strict compliance with environmental commitments is not required. The decrease in fossil CO_2 emissions in developed countries can thus be replaced relatively quickly by their production in economically less developed countries. At the same time, the reduction in production-induced CO_2 emissions may eventually shift to increasing emissions from freight transport to the point of consumption, as evidenced by the growing carbon intensity of international transport, which more than doubled between 1990 and 2018.

On the positive side, compared to 1990, the emission intensity of gross domestic product decreased, which currently only slightly exceeds the level of 72% in 1990. This fact is due to a significant decrease in the emission intensity of GDP in developed countries, especially the European Union which decreased its emission intensity of GDP by more than a half. Similar developments took place in North America but also China. On the other hand, the emission intensity of GDP in low-income economies and oil-producing countries has increased relatively sharply.

Global pressure to reduce carbon dioxide emissions, especially from economically developed countries is therefore very often criticized by less developed economies, who argue that in terms of the per capita emissions they are much more responsible than developed countries. The less developed countries emphasize that it is the economically developed countries that have historically generated the highest amount of emissions, and which are stifling economic growth of the less developed countries with their climate recommendations.

Graph 2 **Cumulative emissions in 1990 and 2018 (share of selected countries in global emissions in percentages)**



Source: Our World in Data, 2020, own calculation

Indeed, if we were to assess the carbon footprint in terms of emissions per capita, Asia would appear to be one of the most responsible regions due to its high population (Table 2). On the other hand, oil-producing countries would have to be ranked among the largest emitters because they produce the largest amount of carbon dioxide per capita. In reality, however, in terms of their share of annual carbon dioxide emissions, they are not among the largest producers and they only achieve this “primacy” due to their relatively small population. This fact can be very well demonstrated in the emission burden of Australia and China.

Australia produces almost 2.4 times more emissions per capita per year than China, but China’s carbon footprint is almost 24 times higher than that of Australia. From the point of view of the impact of the emission burden on climate change, the total amount of emissions produced by a given country is decisive, but economic policy measures aimed at improving the climate situation must respect the demographic realities of individual countries and regions.

Table 2 **Emissions per capita (2018)**

Country	Annual emissions per capita (in tonnes)	Share in annual world emissions production	Share of the world's population
Qatar	37.97	0.29	0.063
Curaçao	33.68	0.01	0.002
Trinidad and Tobago	31.28	0.12	0.018
Kuwait	23.70	0.27	0.054
United Arab Emirates	21.35	0.56	0.126
New Caledonia	20.56	0.02	0.004
Bahrain	19.79	0.08	0.021
Brunei	18.49	0.02	0.006
Saudi Arabia	18.43	1.70	0.442
Kazakhstan	17.57	0.88	0.240
USA	16.40	14.81	4.328
Canada	15.33	1.55	0.486
Luxembourg	15.86	0.03	0.008
Oman	13.93	0.18	0.063
Estonia	14.78	0.05	0.017
China	7.05	27.52	18.708
India	1.96	7.23	17.725
Russia	11.74	4.68	1.910
Australia	16.88	3.83	0.326
America	9.81	21.21	10.362
Europe	7.51	15.39	9.822
Asia	4.40	54.89	59.749
Africa	1.10	3.83	16.705

Source: Our World in Data, 2020, own calculation

Despite the efforts of developed countries to reduce carbon dioxide emissions, they still remain the largest producers of carbon dioxide, both in terms of production and consumption.

Table 3 **Structure of global emissions in terms of economic maturity (in percentages)**

Income or regional group	**Share of population (%)**	**Share of production--based CO_2 emissions (%)**	**Share of consumption-based CO_2 emissions (%)**
High income	16 %	39 %	46 %
Upper-middle income	35 %	48 %	41 %
Lower-middle income	40 %	13 %	13 %
Low income	9 %	0.4 %	0.4 %

Source: Ritchie, H. – Roser, M. (2019)

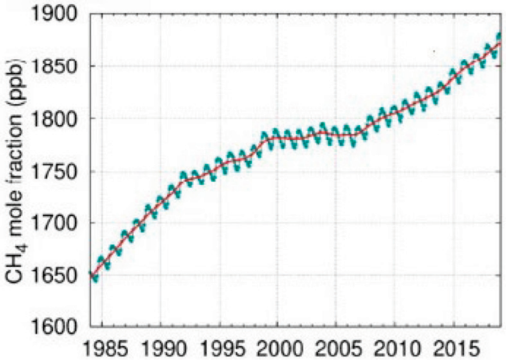
The data in Tables 2 and 3 allow for the possibility of calling into question the prevailing belief in the emissions responsibility of economically developed countries. While it should be borne in mind that within economically developed countries there are countries whose carbon footprint is close to the world average, virtually all developed countries still release more than twice the world average of carbon dioxide into the atmosphere each year.

2.2.2 Devastating methane

In terms of greenhouse gas production, methane is the second most important long-lived greenhouse gas. Methane can come from many sources, both natural and man-made. Up to 64% of methane emissions are generated by human activity (livestock farming, agriculture, fossil fuel use, biomass combustion, landfills, and rice cultivation). The rest is produced from natural sources, (e.g., wetlands). The largest source of artificial emissions is the oil and gas industry.

Methane is a greenhouse gas with a high global warming potential that is comparable to carbon dioxide. Unlike carbon dioxide, methane has a much shorter lifespan, which could imply that the planet deals with it more easily. However, according to the IPCC (2018), on average over a hundred years, each kilogram of methane warms the planet 25 times more than the same amount of carbon dioxide. Methane is, following the first twenty years after its release, 84 times more effective compared with carbon dioxide. EDF (2020) states that about 25% of man-made global warming is the consequence of the methane emissions. Although it does not stay in the atmosphere as long as carbon dioxide, it is much more devastating regarding climate change because it absorbs heat very efficiently. In the first two decades after the release, methane is 84 times more effective than carbon dioxide.

Figure 1 **Methane emissions: a historical perspective**



Source: WMO, 2019

The level of methane in the air has more than doubled in the past 150 years. The World Meteorological Organization reports that new atmospheric methane was recorded in 2018 – about 1.869 parts per billion (ppb), representing 259 % of the pre-industrial level (WMO, 2019).

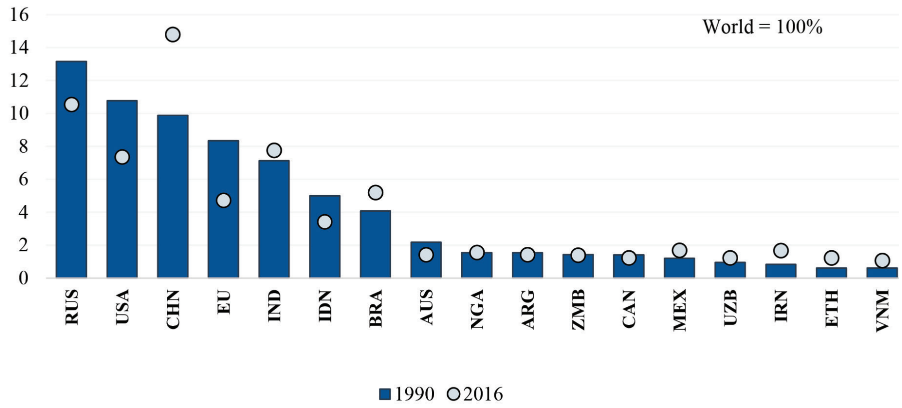
Despite commitments under the Paris Agreement, methane production is increasing worldwide. Compared to 1990, methane emissions increased by 1.13 billion tonnes (converted to tonnes of CO_2 based on a 100-year global warming potential value[10]) in 2016 (OWID has not published more recent data).

Recently, the largest emitters of methane are China, Russia, India, the USA and Brazil. While Russia, the United States, the European Union and Australia accounted for a relatively significant decrease in man-made atmospheric methane between 1990 and 2016, China, India, Brazil, Mexico, Uzbekistan, Iran, Ethiopia and Vietnam increased it.

In terms of the production of methane conditioned by human activity, the European Union has behaved the most responsibly since the 1990s, with a production of 214.5 million tonnes in 2016 less than in 1990. Significant reduction in methane emissions in 2016 compared to 1990 took place also in the USA (by more than 169 million tonnes), Ukraine (by more than 127 million tonnes) and the United Kingdom (by more than 85 million tonnes), Indonesia (by more than 78 million tonnes) and Russia (by more than 73.5 million tonnes). Within the EU, Germany has been the most responsible for decreased methane production (by more than 76 million tonnes), followed by Romania (by more than 27 million tonnes), Poland (by more than 20 million tonnes), France (more than 17.6 million tonnes), Netherlands (by almost 12.9 million tonnes) and the Czech Republic (by almost 11.5 million tonnes). In other EU countries, methane emissions fell moderately in 2016 compared with 1990, with increases in Spain, Portugal, Ireland, Cyprus and Malta.

[10] One tonne of methane equals 34 tonnes of CO_2.

Graph 3 **The largest methane emitters (share of global volume in 1990 and 2016 in percentages)**

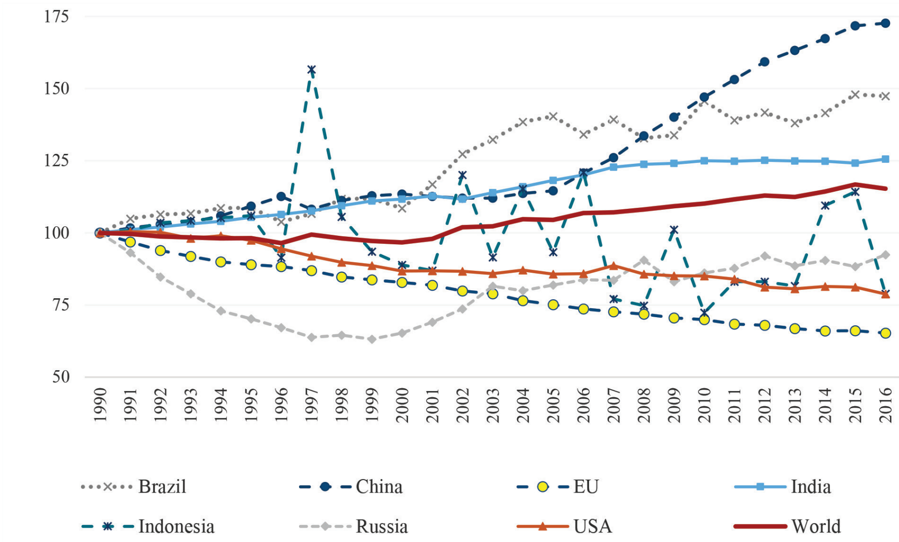


Source: Our World in Data, 2020, own calculation

Between 1990 and 2016 the most significant increase in atmospheric methane was recorded by China, where the amount of methane in the atmosphere increased by more than 532 million tonnes (from 732.5 to 1,264.9 million tonnes). Compared to 1990, the amount of methane emitted in India increased by 135 million tonnes, in Brazil by 143 million tonnes, in Ethiopia by 60.5 million tonnes and in Mexico by 55 million tonnes. Although Pakistan and Afghanistan do not belong to the largest polluters in terms of their current share of annual global emissions, they can be ranked among the countries that have increased the amount of methane in the atmosphere relatively sharply compared to 1990. Pakistan increased the amount of atmospheric methane by almost 73 million tonnes while Afghanistan by more than 69 million tonnes.

The dynamics of methane production (Graph 4) shows an upward trend from a global perspective, with the largest emissions being driven mainly by China, Brazil and India. These countries, despite being among the largest methane polluters, have not achieved the highest growth in recent years compared to 1990. In this regard the most dynamic producers include Ethiopia, Vietnam and Iran, which more than doubled methane production between 1990 and 2016.

Graph 4 **Dynamics of methane production of the largest polluters (in percentages, 1990 = 100%)**



Source: Our World in Data, 2020, own calculation

The global warming potential of methane is estimated at 28–36 in 100 years. Today, the methane emitted lasts on average about ten years, but within the first half of this period it is converted into carbon dioxide. Methane also absorbs much more energy than carbon dioxide. The net effect of a shorter lifetime and higher energy absorption is reflected in its GWP value, which also includes some indirect effects.

2.2.3 Insidious nitrous oxide

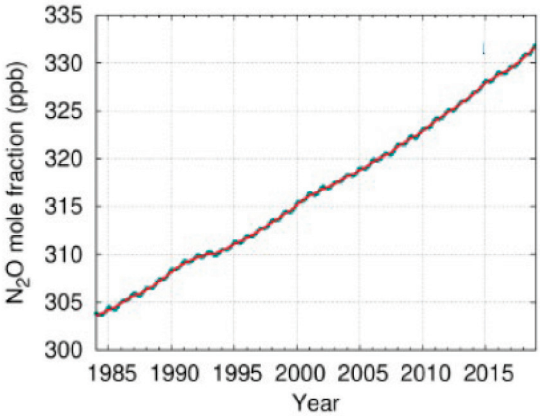
Nitrous oxide (N_2O) is one of the gases which deplete the planet's ozone layer, cause climate change and it is, therefore, generally classified as a greenhouse gas, despite the fact that it is not essentially a greenhouse gas. It is the main component of nitrogen oxides, in which it makes up more than 90%.

Nitrous oxide (N_2O) is emitted into the atmosphere from both natural (about 60%) and anthropogenic sources (about 40%), including the oceans, soil, biomass combustion, fertilizer use, and various industrial processes (WMO, 2019). Its emissions are mainly due to road and air transport (fuel combustion), electricity and heat production. Within the natural environment, the greatest risk for the increase in nitrous oxide emissions is posed by Arctic peatlands, which are a rich source of this gas.

The atmospheric concen-tration of nitrous oxide in 2018 was 331.1 parts per billion (ppb). This is 123% of the pre-industrial level. The increase from 2017 to

2018 was also higher than the increase recorded from 2016 to 2017 and the average growth rate over the last ten years (WMO, 2019).

Figure 2 **Nitric oxide emissions: a historical view**



Source: WMO, 2019

The data provided by the OWID database on nitrous oxide emissions are measured, as in the case of methane, in tonnes of carbon dioxide equivalent, based on the centennial value of the global warming potential[11].

As can be seen in Figure 2, nitrous oxide emissions have been steadily rising over the last thirty years, increasing by 593.5 million tonnes worldwide, with China contributing 245 tonnes million to this increase. Other significant contributors to nitrous oxide emissions are India (almost 106 million tonnes), Brazil (over 70 million tonnes), Cameroon (57.5 million tonnes), Pakistan (31 million tonnes), Ethiopia (more than 26 million tonnes), Indonesia (almost 23 million tonnes) and Iran (almost 20 million tonnes).

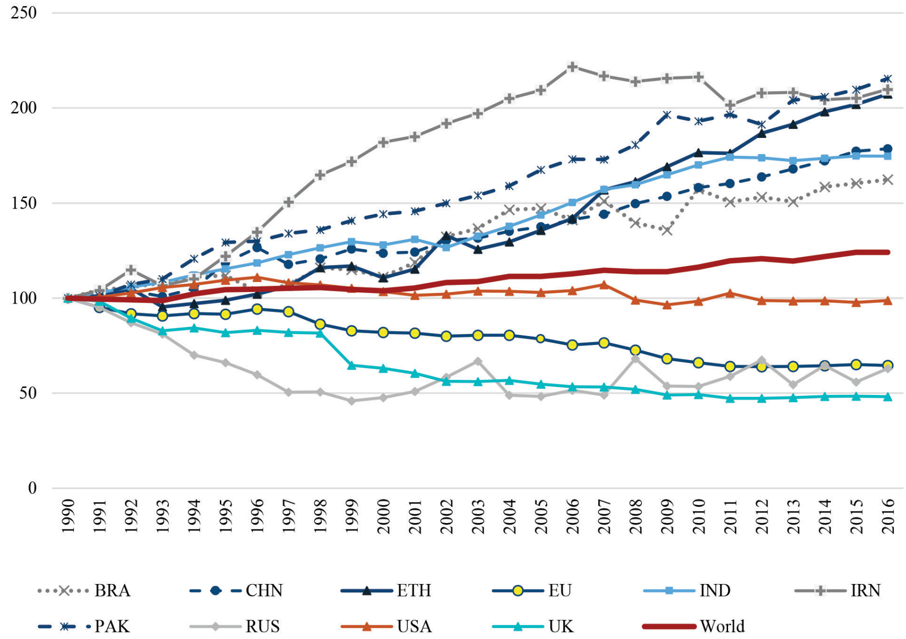
The dynamics of nitrous oxide emissions in selected countries compared to 1990 are shown in Graph 5. A warning signal for the global community is that one hundred and ten countries in the world have increased their production of nitrous oxide.

The most significant decrease in nitrous oxide emissions was achieved by the countries of the European Union (more than 118 million tonnes), mainly thanks to Germany, which reduced its nitrous oxide emissions by more than 30 million tonnes compared to 1990, followed by France (-23.6 million tonnes), Italy (-10.5 million tonnes) and Romania (-9.9 million tonnes). Other countries responsible for emissions include Russia, which reduced nitrous oxide production by almost 44 million

[11] One tonne of N_2O equals up to 298 tonnes of CO_2.

tonnes compared to 1990, the United Kingdom (-30.6 million tonnes), Ukraine (-18.3 million tonnes) and Japan (-10.2 million tonnes).

Graph 5 **Dynamics of nitrous oxide emissions (in percentages, 1990 = 100%)**



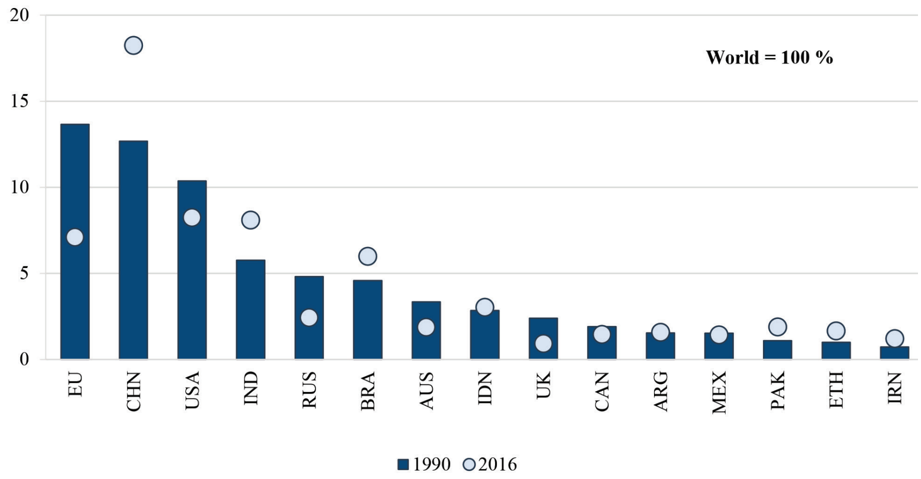
Source: Our World in Data, 2020, own calculation

However, the USA reduced the production of nitrous oxide only to a very limited extent, by less than 3.3 million tonnes. The resumption of coal mining and support for steel production, as well as the development of transportation in the USA, contributed to this fact.

The development of nitrous oxide emissions between 1990 and 2016 brought about a change in the position of individual countries in the global amount produced (Chart 6). The European Union lost its top position in 1990 and was replaced by China, the USA and India.

The insidiousness of nitrous oxide is that it is almost 300 times stronger than carbon dioxide. Nitrous oxide has a GWP 265 – 298 times higher than CO_2 on the time horizon of 100 years, i.e., that the nitrous oxide emitted today remains in the atmosphere for an average of more than 100 years (EPA2020).

Graph 6 **Largest emitters of nitrous oxide (share of global quantity in 1990 and 2016 in percentages)**



Source: Our World in Data, 2020, own calculation

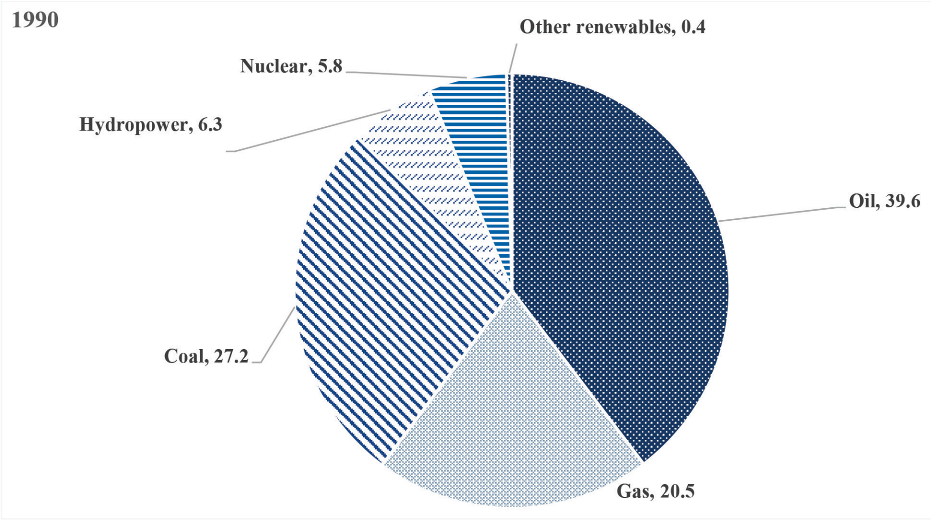
A serious problem in terms of greenhouse gases, is that warming will release huge amounts of greenhouse gases stored in the world's peatlands in the north of the planet which are, so far, largely frozen. This is a natural factor but largely conditioned by human activity. Large amounts of carbon and nitrogen have accumulated in these peaty areas, which has so far helped to cool the planet. Gradual warming is causing the frozen soil to thaw in the north of the planet, as a result of which these gases will be released much faster than previously expected. Another factor that influences the change in the temperature of the planet is the tropospheric ozone, which is formed from factors, such as a result of temperature traces of aircraft or soot from large fires. However, not all human activities cause the planet to warm. Aerosol particles, for example, which are produced by industrial production and some vehicles, have the ability to reflect sunlight and temporarily prevent the planet from overheating due to greenhouse gases.

2.3 Energy consumption

Energy efficiency is one of the factors that would help reduce greenhouse gas emissions and mitigate the effects of climate change. From an environmental point of view, however, it is not only the quantity produced and consumed that is important, but also the source from which it is produced. In the past, but also in current energy systems, fossil fuels (coal, oil and gas) dominate, which produce carbon dioxide and other greenhouse gases (Ritchie, Roser, 2019). Meeting the climate goals is, therefore, not only about saving energy, but also about changing the sources from which it is produced, with the emphasis on low-carbon resources.

Despite strong pressure to change the energy mix from 1990 to the present, the share of energy consumption from fossil fuels (predominantly oil and coal) in total world energy consumption has fallen by only 3.1 percentage points; namely from 87.4% to 84.3% (graphs 7 and 8). In absolute terms, however, energy produced from fossil fuels had increased more than 1.4 times in 2019 when compared to 1990 (from 83,070.3 to 136,761.6 terawatt hours).

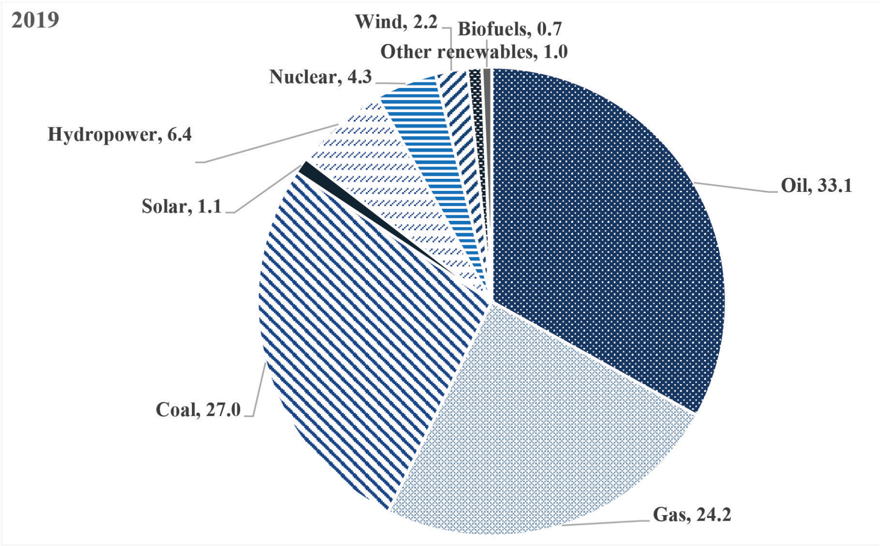
Graph 7 **Structure of world energy consumption in 1990 (in percentages)**



Source: Our World in Data, 2020, own calculation

Although the demand for renewable energy is currently growing, its share of the total energy consumption has increased much less globally than would be desirable. At present, energy consumption from renewable sources (energy from biofuels, water, solar, wind and other renewable sources) covers only 11.4% of total world consumption (Graph 8).

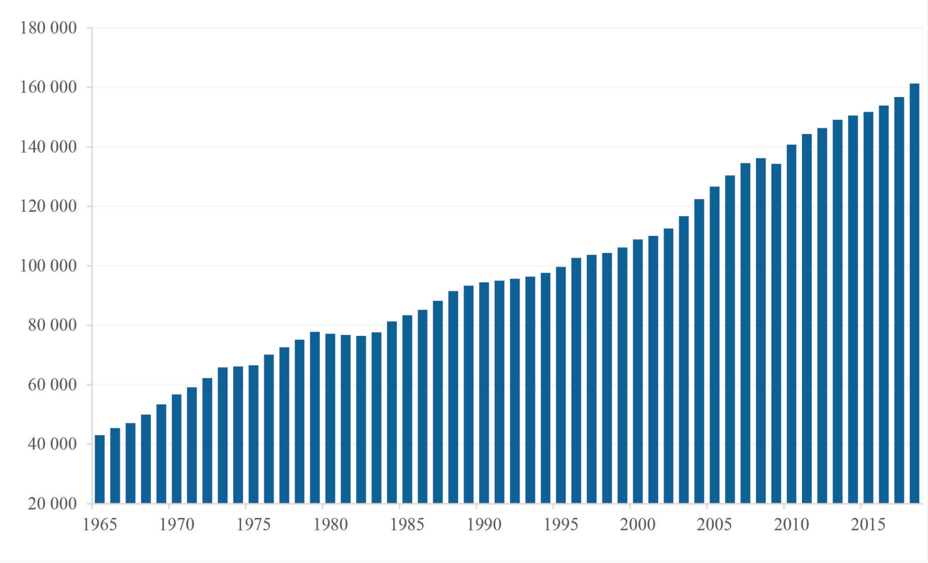
Graph 8 **Structure of world energy consumption in 2019 (in percentages)**



Source: Our World in Data, 2020, own calculation

Electricity consumption has been gradually increasing since 1965, with a more significant decline occurring only at the end of the first decade of this century due to a slowdown in economic activity related to the financial and economic crisis (Graph 9). Between 1965 and 1990, the world's primary energy consumption increased more than 1.7 times, which, given the already mentioned structure of the sources from which it is produced, represents a big environmental and climatic burden.

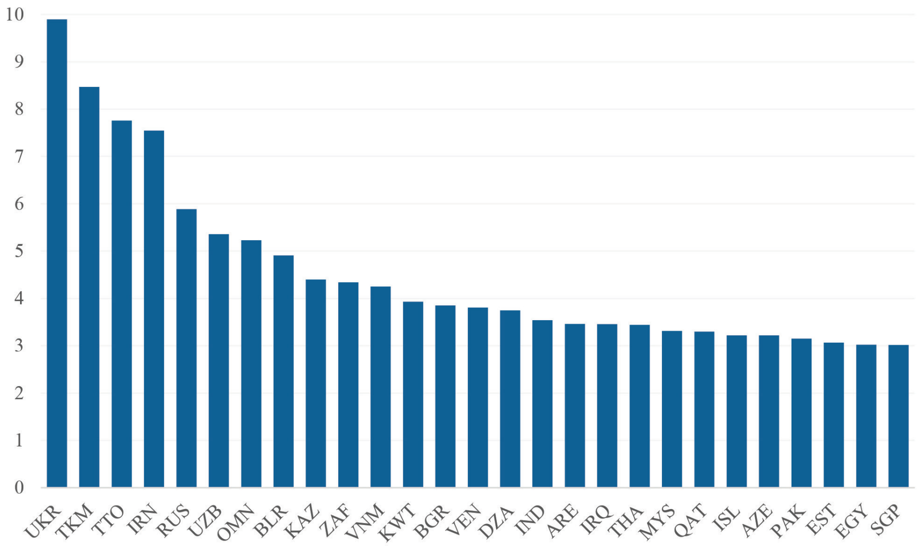
Graph 9 **Primary electricity consumption in the years 1965 to 2019 (in terrawatt hours)**



Source: Our World in Data, 2020, own calculation

A positive development trend is that energy consumption has lower growth dynamics than gross domestic product, as a result of which its energy intensity decreases, i.e., the amount of energy needed to make a unit of gross domestic product decreases. Global energy intensity has fallen by a third since 1990. While 2.63 kWh of energy was needed in 1990 to create one unit of gross domestic product (2015 prices), in 2018 consumption fell to 1.97 kWh. At present, the energy intensity of individual economies varies significantly across the world; while Ukraine needs 9.9 kWh of energy to create one unit of GDP, Switzerland needs only 0.4 and the United Kingdom 0.7 kWh. The vast majority of oil-intensive producers are oil-producing countries (Graph 10).

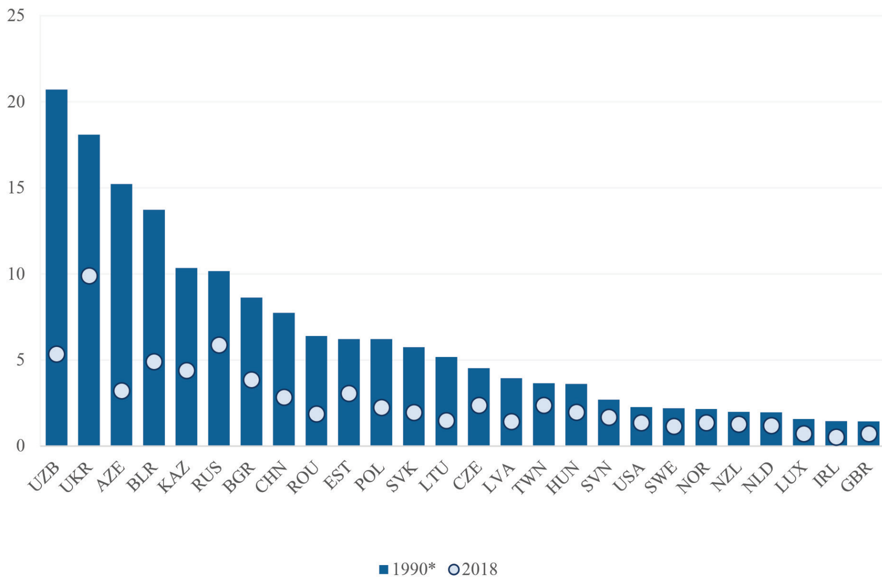
Graph 10 **Countries with the highest energy intensity of GDP (2018)**



Source: Our World in Data, 2020, own calculation

Energy intensity decreased between 1990 and 2018 in the post-Soviet republics, mainly in Azerbaijan (4.7 times), Uzbekistan (almost 4 times), Kazakhstan (2.4), in the Baltic countries (Estonia 2 times, Lithuania 3.5 times, Latvia 2.8 times), but also in Belarus (2.8 times) and Russia (1.7 times). A significant decrease in the energy intensity of GDP was also achieved by Romania (by more than a third), Bulgaria (2.2 times). Among the countries of Central Europe, Slovakia, notably, reduced its energy intensity (2.9 times), but also Hungary and the Czech Republic, which recorded a decrease by more than 1.5 times. China also contributed to the reduction of global emission intensity (2.7 times), increasing its energy intensity due mainly to the high dynamics of economic growth, increasing its total energy consumption by almost 4.8 times between 1990 and 2018 (Graph 11).

Graph 11 **Change in energy intensity between 1990 and 2018**



* Energy intensity of the countries Azerbaijan, Belarus, Bulgaria, Czechia, Estonia, Hungary, Kazakhstan, Lithuania, Poland, Romania, Slovakia, Slovenia, Russia is calculated for the year 1993 due to absence of the GDP data for 1990.

Source: Our World in Data, 2020, own calculation

The countries of the European Union, with the exception of Portugal, have reduced the energy intensity of GDP. Following Romania, Ireland achieved the highest reduction by up to 2.7 times. The new Member States, in particular, contributed to the decline in the energy intensity of GDP, both by reducing energy consumption and by increasing economic growth. The original EU member states achieved a decrease in energy intensity only due to economic growth, while their energy consumption increased slightly.

In general, economically advanced countries behave more responsibly in terms of energy, but this is also conditioned by the structure of their economies, in which services dominate in their industrial structures. Less developed economies have higher shares of industrial production, with sectors dominated with lower rates of added value and higher levels of intermediate consumption, which also includes energy consumption.

*   *   *

Very modest dynamics of global growth in carbon dioxide production and stagnation, or eventual decline in developed countries in recent years, creates room for a slight dose of optimism, but the reality is much more pessimistic. Each new emission of carbon dioxide saturates the atmosphere, while the current rate of emissions is twice as fast as nature is able to absorb. Therefore, even a slightly declining rate of carbon dioxide production in recent years does not create the preconditions for reducing its amount, but, on the contrary, its amount is increasing, but only at a slower pace. A more substantial reduction in carbon dioxide in the atmosphere would require a more drastic reduction that would last for several decades. For a reversal of the current situation, global carbon dioxide emissions would have to fall by almost a half compared to current levels by 2030.

Expectations associated with a decrease in global emissions due to the COVID-19 pandemic (estimated a year-on-year decrease of 4 to 7%) may not have a long-term effect in terms of reducing air pollution. The main reason is that the decline is due to a slowdown in economic activity (restricted production, transport, travel and other economic and social activities) and not by systemic and structural changes towards sustainable development. Short-term reductions in greenhouse gas emissions may not affect either their long-term concentration in the atmosphere or emission reductions in a particular country or region, unless there is a global reduction in traffic, emission-intensive production and diversion of energy production from low-carbon sources.

The slowdown in economic activity has also reduced energy demand and consumption. The IEA (2020) predicts that global energy demand will fall by 6% in 2020, wiping out the last five years of demand growth. This is a decline that has not been recorded in the last 70 years. In the event of a second wave of the pandemic, the agency expects a sharper decline in energy demand.

3 EMISSION EFFICIENCY

The relationship between energy consumption and economic growth, as well as economic growth and environmental pollution, has been the subject of intense research in the last three decades. (Acaravci & Ozturk, 2010).

Three research strands in literature on the relationship between economic growth, energy consumption and environmental pollutants. The first strand considers economic growth and environmental pollutants nexus that are closely related to testing the validity of the so-called environmental Kuznets curve (EKC) hypothesis. The second strand relates energy consumption and economic growth. Ozturk (2010) provides an extensive survey of the country-specific studies on the empirical results from causality tests between the two. In the third strand, dynamic relationships between the energy consumption, pollution and economic growth are examined.

Regardless of the prospective downward trends in absolute demand for energy, from the perspective of sustainable environment, ensuring less pollution per unit of production remains the key determinant of meeting Kyoto commitments. For two decades, China has been leading the empirical investigation in the domain tracked by the applied research OECD or European countries. Due to the nature of the data to be analysed – no free market prices, multidimensionality of inputs and outputs – a non-parametric approach prevails in empirical literature as long as the performance measure is in focus.

Global awareness of energy security and climate change has created much interest in measuring, usually in the form of an efficiency index. A multitude of approaches has been developed for constructing an efficiency index capturing energy utilization and carbon emissions. The routines comprise of the ratio approach (Wang et al., 2011), material flow analysis (Yue et al., 2014), or an ecological footprint based on the extended input-output Leontief model (Cerutti et al., 2013). Due to its advantages – objectiveness and comprehensiveness – as well as the ease of use, DEA (data envelopment analysis) has attracted much attention for its performance assessment methods.

A large part of research concentrates on the most developed countries – OECD or European union members. This enables a conclusion to be drawn from the results "on the frontier". While most developed countries constitute technological frontier benchmarks, empirical studies either focus on the static determination of the sources of ecologic inefficiency in the spirit of Kuosmanen and Kortelainen (2005) or attempt to draw conclusions from intertemporal analysis on a macro-level (Mahlberg et al., 2011, Mahlberg and Luptáčik, 2014). Within the EU, a regional perspective is suggested by Bianchi et al. (2020) while a sector-specific investigation was carried out by Tenente et al. (2020).

The aim of the following analysis is to provide an intertemporal comparison over a long period and assess European emission efficiency with respect to world best practice.

3.1 Eco-efficiency and emission efficiency

As a quantitative assessment concept, eco-efficiency was coined and widely publicized by Schmidheiny (1992), expressing the concern of the business community for environmental issues in realizing its responsibility and potential for contributing to a sustainable future. Schmidheiny´s *Changing course* claimed that there was no trade-off between the economy and the ecology, and eco-efficiency has since developed into a workable concept assessment tool, and even a competitive factor.

A multitude of methods to assess environmental impact with respect to economic performance has been proposed. Most of the indicators are based on simple ratios of the two types. Firstly, environmental intensity of production and its inverse, environmental productivity, relate to the production domain, while the second one considers environmental cost-effectiveness. Indicators on the micro-level are far more precisely defined and elaborated, whereas there is quite a lack of well-established eco-efficiency indicators accepted by decision-makers at the macro-level.

Multi-dimensionality of the decision problems warrants the use of non-parametric decision tools in eco-efficiency framework. For dealing with multi-input and multi-output datasets simultaneously, a variety of data envelopment analysis (DEA) models pioneered by Charnes et al. (1978) have been developed. Refraining from assuming the functional form of the relationship between inputs and outputs, DEA models are capable of tackling broadly-defined transformation processes without even requiring price information. A wide family of models deals with undesirable outputs as a by-product of the economic production process. Due to the *curse of dimensionality* and the established positive correlation of the volume of pollutants and the economic activity, in most of the recent studies environmental damage is proxied by (greenhouse gas) emissions. The more specific term emission efficiency is apt in this context.

3.1.1 Measuring emission efficiency

For an empirical investigation of emission efficiency, the "world emission efficiency frontier" is first determined. European countries as a subsystem within the world scale dataset will be analysed later. In DEA models, efficiency is defined by relating aggregated outputs (outcome) to aggregated inputs (resources). Focusing on the ecological impact of production, the evaluation method leaves aside technical inputs, however relevant from a production perspective. We measure economic outcome in a standard manner by GDP and relate it to the aggregated emission measure composed from three types of gas pollutants – CO_2, N_2O and methane – measured in physical units (tonnes), acting as inputs in the DEA efficiency model. This approach is justified by Korhonen and Luptáčik (2004). Their economic reasoning exposes "bads" as incurring additional cost contributing negatively to overall efficiency. Alongside that, as noted before, emissions are positively correlated with the GDP, which is in line with the production theory underpinning the DEA approach. In the latter, more of an efficiency is ascribed to the country with more economic value per aggregated emission.

3.1.2 Static approach

In the first step we build a one-period emission efficiency model. Due to the design of DEA models, the resulting efficiency score ranges between 0 and 1 (100%), the latter value is only achieved by the best-practice subjects. Computation takes the form of a linear program, whose objective evaluates the efficiency and constraints representing the technology of transformation of inputs into outputs. The detailed results may provide additional information on the subjects under assessment. Exploiting the dataset from Our World in Data (2020), we compile the data on a world scale on GDP and three pollutants. The sample is restricted, based on the criterion of data availability for all four variables as well as GDP value above $1,500 which left 165 DMUs in our sample[12]. The threshold was set to negate very small economies with an unbalanced structure from acting as potential benchmarks for standard ones. To some extent, we prevented this by imposing variable returns to scale (VRS) on our technology which require similarity in size for the countries to be compared.

Since there is a multitude of DEA model types used in eco-efficiency or emission efficiency studies, we first investigate the performance of radial and non-radial models in our dataset aiming to select the most parsimonious approach. This may save up computational resources in the future. As can be seen in Table 4, we employed three DEA models. In all of them the technology is modelled in the same manner expanding the convex hull of the datapoints by allowing for a weak disposability assumption. VRS is implemented by including the convexity condition.

Starting with the BCC model (Banker et al., 1984), we determine radial efficiency for world countries. From Table 4 one can see that despite the presence of input and output slacks s^- and s^+ the latter do not enter the objective function and therefore are not penalized in the total measure of efficiency. This drawback is compensated for by the simplicity, computational speed, and the easiness of interpretation for decision makers.

12 Subjects under evaluation (countries) are termed decision making units (DMUs) in the DEA context.

Table 4 **DEA optimization programs**

	objective (min)	constraints	decision variables
BCC	θ	$\theta x_{i0} = \sum_{j=1}^{n} x_{ij}\lambda_j + s_i^-$ $y_{r0} = \sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+$ $1 = \sum_{j=1}^{n} \lambda_j$	$\lambda_j, s_i^-, s_r^+ \geq 0$
SBM	$\dfrac{1-\frac{1}{m}\sum_{i=1}^{m} s_i^- / x_{i0}}{1+\frac{1}{s}\sum_{r=1}^{s} s_r^+ / y_{r0}}$	$x_{i0} = \sum_{j=1}^{n} x_{ij}\lambda_j + s_i^-$ $y_{r0} = \sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+$ $1 = \sum_{j=1}^{n} \lambda_j$	$\lambda_j, s_i^-, s_r^+ \geq 0$
EBM	$\dfrac{\theta - \varepsilon_x \sum_{i=1}^{m} w_i^- s_i^- / x_{i0}}{\eta + \varepsilon_y \sum_{r=1}^{s} w_r^+ s_r^+ / y_{r0}}$	$\theta x_{i0} = \sum_{j=1}^{n} x_{ij}\lambda_j + s_i^-$ $\eta y_{r0} = \sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+$ $1 = \sum_{j=1}^{n} \lambda_j$	$\lambda_j, s_i^-, s_r^+ \geq 0$ $\theta, \eta \geq 0$

Source: Authors´ elaboration

As proposed in the later developments (Tone, 2001 and Tone and Tsutsui, 2010), slacks could be accounted for directly in the efficiency score. A slack-based model (SBM) penalizes relative detected slacks. Focusing on maximizing the sum of relative slacks may though lead to determining benchmarks, in a statistical sense, "too far away" from the original data point. The problem is partly alleviated in the epsilon-based model. The EBM takes into account the diversity and relative importance of the data exploiting an affinity index between inputs or outputs. Introducing two parameters connecting radial and non-radial features, the EBM involves a computationally intensive two-stage routine. There is an apparent trade-off between the complexity and informational content of the results. Intending to carry out intertemporal analysis, we seek the most parsimonious option and therefore analyse the results from the three models.

Although the construction of efficiency scores precludes direct comparison of the magnitudes, the focus is placed on the ranking generated by individual models. Specifically, the set of efficient DMUs, i.e. countries with efficiency values equal to 1, are of interest. In the case of nearly identical ranking one would prefer a simpler model.

For the sake of comparison, alongside the efficiency scores from BCC, SBM and EBM models, we correlate the respective rankings labelled *rBCC*, *rSBM*, and *rEBM*. All cross-correlations are displayed in Table 5. All correlations are significant at the 1% level.

Table 5 **Score and rank correlations**

	BCC	rBCC	SBM	rSBM	EBM	rEBM
BCC	1	-0.897	0.939	-0.860	0.999	-0.897
rBCC		1	-0.778	0.939	-0.894	0.999
SBM			1	-0.804	0.943	-0.779
rSBM				1	-0.858	0.939
EBM					1	-0.894
rEBM						1

Source: Authors´calculation

Naturally, any ranking is negatively correlated with the underlying score. The results show that the nature of the model, i.e. (non-)radiality, does not imply a resemblance in the results. A very close correspondence between BCC and EBM models is suggested both due to magnitudes of the efficiency scores and the generated rankings on average. Individually, slack-based models tend to identify more slacks than radial models. In Table 6 we expose relative differences in slack detection in BCC and EBM models in three input dimension and the output for European countries. Overall, singular output slacks only emerged in case of the DMUs Bhutan, Lesotho, and Djibouti in BCC and for Somalia in slack-based models. The SBM model, as expected, identified slacks in all three “bads”.

Table 6 **Slack detection in BCC and EBM models**

DMU	CO_2	N_20	MET	GDP
Austria	0.0%	0.0%	0.0%	0.0%
Belgium	0.0%	0.0%	0.0%	0.0%
Bulgaria	0.0%	0.0%	0.0%	0.0%
Cyprus	0.0%	100.0%	0.0%	0.0%
Denmark	0.0%	30.5%	100.0%	0.0%
Estonia	0.0%	0.0%	0.0%	0.0%
Finland	0.0%	3.8%	0.0%	0.0%
France	0.0%	0.0%	0.0%	0.0%
Germany	0.0%	0.0%	0.0%	0.0%
Greece	0.0%	0.0%	0.0%	0.0%
Iceland	0.0%	0.0%	0.0%	0.0%
Ireland	0.0%	57.9%	100.0%	0.0%
Italy	0.0%	0.0%	0.0%	0.0%
Latvia	0.0%	22.9%	100.0%	0.0%
Lithuania	0.0%	18.9%	100.0%	0.0%
Luxembourg	0.0%	100.0%	0.0%	0.0%
Malta	0.0%	0.0%	0.0%	0.0%
Netherlands	0.0%	0.0%	0.0%	0.0%
Norway	0.0%	0.0%	0.0%	0.0%
Poland	0.0%	00%	00%	0.0%
Portugal	0.0%	0.0%	19.0%	0.0%
Romania	0.0%	100.0%	71.9%	0.0%
Slovakia	0.0%	0.0%	0.0%	0.0%
Slovenia	0.0%	0.0%	0.0%	0.0%
Spain	0.0%	0.0%	0.0%	0.0%
Sweden	0.0%	0.0%	0.0%	0.0%
Switzerland	0.0%	0.0%	0.0%	0.0%
United Kingdom	0.0%	0.0%	0.0%	0.0%

Source: Authors´calculation

For the subset of European countries as well as in the complete sample, the BCC and EBM models show quite a similarity. The heat-map-coloured values represent the relative magnitude of a slack with respect to the data. The 100% value in Table 6 implies the absence of a slack in the BCC as opposed to the EBM. Based on the comparison of the results, the BCC model is earmarked for further analysis.

3.1.3 Efficiency scores allowing for uncertainty

After opting for the BCC model on the ground of parsimony we put the modelling through a simple robustness check routine.

A sample is repeatedly drawn with a replacement, the BBB optimization program is run given the sample, and the results are collected into a new dataset. Based on the bootstrapped distributions, standard errors and confidence intervals are determined.

Table 7 **Bootstrapped BCC efficiency**

		50 re-sampling rounds				200 re-sampling rounds			
DMU	eff	bootstrap SE	p-value	95% confidence interval		bootstrap SE	p-value	95% confi-dence interval	
Austria	**0.412**	0.326	0.207	-0.227	1.052	0.317	0.193	-0.209	1.033
Belgium	**0.395**	0.317	0.212	-0.226	1.017	0.312	0.205	-0.216	1.006
Bulgaria	**0.082**	0.314	0.795	-0.534	0.698	0.337	0.808	-0.579	0.742
Croatia	**0.201**	0.295	0.496	-0.377	0.779	0.326	0.538	-0.439	0.841
Cyprus	**0.397**	0.331	0.231	-0.252	1.047	0.315	0.207	-0.220	1.014
Czech Republic	**0.116**	0.330	0.724	-0.530	0.763	0.316	0.713	-0.504	0.737
Denmark	**0.490**	0.327	0.134	-0.151	1.130	0.317	0.123	-0.132	1.112
Estonia	**0.275**	0.310	0.375	-0.333	0.884	0.325	0.397	-0.362	0.913
Finland	**0.397**	0.316	0.209	-0.222	1.015	0.324	0.221	-0.239	1.033
France	**0.930**	0.335	0.006	0.274	1.587	0.307	0.002	0.328	1.533
Germany	**1**	0.309	0.001	0.393	1.607	0.319	0.002	0.376	1.624
Greece	**0.164**	0.327	0.617	-0.478	0.805	0.317	0.606	-0.457	0.785
Hungary	**0.166**	0.319	0.604	-0.460	0.791	0.328	0.613	-0.476	0.807
Iceland	**0.520**	0.330	0.115	-0.126	1.166	0.326	0.111	-0.119	1.159
Ireland	**0.440**	0.339	0.195	-0.225	1.106	0.311	0.157	-0.169	1.050
Italy	**0.860**	0.329	0.009	0.215	1.504	0.337	0.011	0.199	1.521
Latvia	**0.320**	0.334	0.337	-0.334	0.974	0.336	0.341	-0.339	0.979
Lithuania	**0,239**	0.319	0.453	-0.386	0.865	0.307	0.435	-0.362	0.841
Luxembourg	**1**	0.332	0.003	0.350	1.650	0.317	0.002	0.378	1.622
Malta	**1**	0.313	0.001	0.386	1.614	0.325	0.002	0.363	1.637
Netherlands	**0.378**	0.329	0.249	-0.265	1.022	0.334	0.257	-0.276	1.032

Norway	**0.561**	0.320	0.079	-0.066	1.188	0.328	0.087	-0.081	1.203
Poland	**0.087**	0.337	0.796	-0.573	0.747	0.313	0.781	-0.526	0.700
Portugal	**0.240**	0.301	0.426	-0.350	0.830	0.309	0.438	-0.366	0.846
Romania	**0.147**	0.339	0.665	-0.517	0.811	0.314	0.640	-0.468	0.762
Slovakia	**0.173**	0.331	0.600	-0.475	0.821	0.310	0.576	-0.435	0.781
Slovenia	**0.226**	0.310	0.467	-0.382	0.834	0.321	0.482	-0.404	0.855
Spain	**0.477**	0.345	0.167	-0.200	1.153	0.331	0.149	-0.171	1.125
Sweden	**0.767**	0.333	0.021	0.115	1.420	0.312	0.014	0.156	1.379
Switzerland	**1**	0.302	0.001	0.408	1.592	0.314	0.001	0.384	1.616
United Kingdom	**1**	0.334	0.003	0.346	1.654	0.330	0.002	0.352	1.648

Source: Authors´calculation

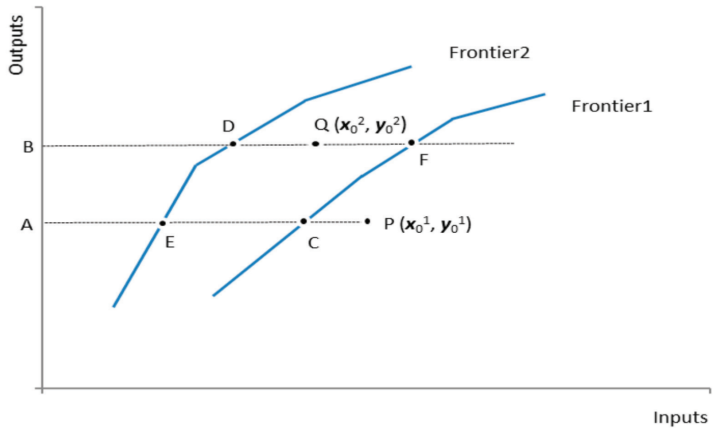
In Table 7, the results for two variants of bootstrapping are presented – with 50 and 200 repetitions. Particular attention should be paid to efficient DMUs with the unit efficiency score – Germany, Luxembourg, Malta, Switzerland, and the United Kingdom. Notwithstanding the fact that standard errors could deteriorate with altering number of re-sampling cycles, all five countries appear to have a highly significant efficiency score and may be considered an established reference set of benchmarks.

3.1.4 Intertemporal analysis

Having verified the non-parametric approach in a static setting we proceed to the main goal of the analysis. The analysis of two time periods requires accounting for the reference set change itself. Comparing efficiency scores computed for two periods would be misleading. To provide an appropriate picture of the performance change, a productivity index should be employed. In the DEA framework, non-parametric analogues of productivity indexes are used – Malmquist or Luenberger, most commonly. In our analysis we opt for the former due to the radiality of the BCC measure. In Figure X1 we depict measuring the productivity change over time. In the figure, DMU_0 is exposed in two periods of time. Schematically, aggregated inputs are represented in the horizontal axis. Similarly, outputs are put on the vertical axis. In the first period, the activity is characterized by the input and output mix $(\mathbf{x}_0^1, \mathbf{y}_0^1)$ – simplified to $(\mathbf{x}_0, \mathbf{y}_0)^1$ – represented by the data point P.

Productivity change results in the input-output change, now represented by the point Q $(\mathbf{x}_0, \mathbf{y}_0)^2$. In a simplified way, productivity growth would be symbolized by the “steeper” ray 0Q compared to 0P.

Figure 3 **Technology change – input orientation**



The technology is represented by empirical (efficiency) frontiers as described in the previous section. Efficiency is measured with respect to Frontier 1 in the first period. Geometrically, the input-oriented measure is determined by the ratio of the lengths of the segments AE and AP. In a similar manner, the input-oriented efficiency with respect to the Frontier 2 in the period 2 is given by the ratio BD/BQ. A simple efficiency change is then termed *catch-up (C)*.

$$C = \frac{\text{efficiency of } (\mathbf{x}_0, \mathbf{y}_0)^2 \text{ w.r.t. Frontier 2}}{\text{efficiency of } (\mathbf{x}_0, \mathbf{y}_0)^1 \text{ w.r.t. Frontier 1}} \tag{3.1}$$

Using the labelling from the Figure X1, we have $C = \dfrac{BQ/BD}{AP/AC}$.

Obviously, C may be any positive value in magnitude, C > 1 meaning improvement in relative efficiency. The magnitude of C is only informative as to whether the DMU is catching up with the best DMUs that constitute the frontier. The more the benchmark moves forward, the more effort is required from the DMU to keep in contact with the frontier. The movement of the frontier can be estimated in two ways, altering the reference point. Projecting activity P onto the two frontiers and labelling intersection points (projections) as E for frontier 1 and C for frontier 2,

an estimate of the technology improvement can be determined as $\phi_1 = \dfrac{AE}{AC}$.

Using Q as an alternative reference yields $\phi_2 = \dfrac{BD}{BF}$. *Frontier-shift* effect could then be calculated as geometric average:

$$F = \sqrt{\phi_1 \phi_2} = \sqrt{\frac{AE}{AC} \cdot \frac{BD}{BF}} \tag{3.2}$$

Frontier-shift estimates how the *best practice* improved over time. Best practice could be defined by a different set of DMUs. Similar to C, the magnitude of F is any positive number with F > 1 interpreted as technology improvement. Adopting the Färe et al. (1994) approach, the total productivity change is captured by the Malmquist index (M). In non-parametric setting the calculation routine follows the formula

$$M = C \times F = \frac{d^2(\mathbf{x}_0,\mathbf{y}_0)^2}{d^1(\mathbf{x}_0,\mathbf{y}_0)^1}\left[\frac{d^1(\mathbf{x}_0,\mathbf{y}_0)^1}{d^2(\mathbf{x}_0,\mathbf{y}_0)^1}\times\frac{d^1(\mathbf{x}_0,\mathbf{y}_0)^2}{d^2(\mathbf{x}_0,\mathbf{y}_0)^2}\right]^{1/2}, \qquad (3.3)$$

where *d* stands for efficiency score from the static DEA model as defined before and the superscript indicating reference frontier. One may recognize four distinct models in computation of M. There are two standard static models for periods 1 employed in the calculation of C term. Alongside, two cross-period models $d^2(\mathbf{x}_0, \mathbf{y}_0)^1$ and $d^1(\mathbf{x}_0, \mathbf{y}_0)^2$ are involved in computation of F. For each DMU are thus four efficiency models to be computed to determine M and its decomposition.

For empirical analysis we used a panel of data for the DMUs from the static model. To embrace the long-term we set the span to 1990 – 2016. Over the time two processes have been taking place. The worldwide economic growth was accompanied by an ever stronger pursuit of eco-efficiency in developed and emerging economies. Green technologies have also spread rapidly. The Malmquist index enables us to have a look at how eco-productivity changed over time in individual countries. The expected average growth (M > 1) rests upon the assumption that more production is coupled with less emission per unit due to improved technology.

Table 8 **Eco-productivity change (selected countries)**

	C	F	M		C	F	M
China	*3.634*	*2.690*	*9.773*	Liberia	2.362	0.178	0420
Armenia	8.598	0.641	5.508	Haiti	0.475	0.874	0.416
Moldova	6.303	0.839	5.289	Equatorial Guinea	1.000	0.388	0.388
Latvia	3.885	1.274	4.950	Benin	0.668	0.515	0.344
Lithuania	3.476	1.407	4.891	Nepal	0.358	0.878	0.314
Georgia	4.485	1.077	4.829	Cameroon	0.244	1.120	0.273
Slovakia	2.479	1.638	4.059	Namibia	0.215	1.035	0.222
North Korea	3.117	1.280	3.988	Laos	0.367	0.497	0.182
Uzbekistan	2.590	1.454	3.767	Libya	0.101	1.456	0.146
				average (total)	***1.592***	***1.262***	***1.662***

Source: Authors' calculation

In Table 8, results for selected countries are shown. In 26 years, an on average increase by 66% in eco-efficiency is estimated. Huge differences between the countries are indicated by the standard deviation 1.25 in magnitude. The ten countries that made the most progress is led by China, followed by a group of post-communist countries along with North Korea.13 At the other end of the ranking mostly African developing countries whose performance deteriorated by 58–85% are placed. Decomposition of the overall index M provides additional information as to the sources of either growth or regress. Four countries have been defining best practice over the period – the United States, Switzerland, the United Kingdom, and Japan14. For those DMUs, efficiency is of unit value in both periods, therefore C term is a unit as well. The variance of F for the sample is small, relative to the one of the catch-up effect. The latter represents the individual effort of the country and the standard deviation (1.46) is nearly equal to the value of C. The average frontier-shift of 1.26 suggests the "greening" of technology over time as 26% more of economic value is produced at the unit environmental cost. As can be seen from the table, Slovakia made a noticeable effort and ranks 7th with over a fourfold increase from the initial performance. Individual effort underpins eco-productivity growth in most countries. Technology absorption or institutional change will explain a large portion of the progress. In the following section, we analyse European countries in more detail.

3.2 EU countries

3.2.1 Emission efficiency of European countries

In analysing EU countries within the global dataset, the idea of Thanassoulis and Portela (2001) can be used aptly. We model a subset of the European countries (EU)[15] in a separate model providing *within-group* efficiency (BCC-EU). The global world frontier and the emission efficiencies (BCC-W) were determined in the previous section. In Figure X2, a comparison of the systems within the DEA framework (Cooper et al., 2007) is depicted.

Schematically, inputs are represented on the horizontal while outputs on the vertical axis. Input-oriented projections onto EU and world frontiers are labelled E and W respectively. The efficiency of the activity (DMU) A with respect to the global (World) frontier, eff_W (A), is then represented by the ratio of lengths CW/CA, whereas efficiency within the EU subsystem eff_{EU} (A) = CE/CA. For the country A, ratio CW/CE presents efficiency of the EU w.r.t. the world. The value cannot

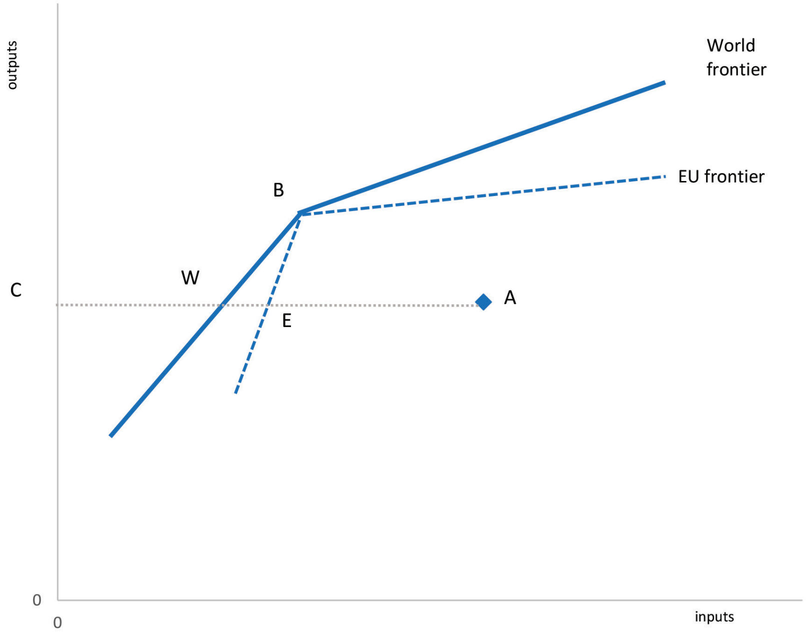
[13] Although for China values are affected by the infeasibilty of cross-period linear programs.

[14] Extracted from the results of component models $d^2(\mathbf{x}_0, \mathbf{y}_0)^1$ and $d^1(\mathbf{x}_0, \mathbf{y}_0)^2$.

[15] We label EU with a wider set of European countries, including Switzerland, UK, and Norway.

exceed 1, equality holding solely in case a country belongs both to the EU and the world frontier line. The latter case is exemplified by the country B whose efficiency $eff_W(B) = ef_{EU}(B) = 1$.

Figure 4 **Efficiency of a subsystem**



Source: Authors´ elaboration

We construct two empirical efficiency frontiers – (i) global world frontier by *BCC-W* model acting as a reference boundary and (ii) EU frontier modelled by *BCC-EU* that only comprises EU countries and providing *within-group* efficiency. The overall DEA efficiency is determined which cannot exceed the *within-group* score attributable to an individual country. Efficient units of individual groups may prove inefficient relative to some global units. Dividing an overall score by the group´s one yields component attributable to group, thus

BCC-W (overall) score =
BCC-EU score (attributable to country) × ***EU/W*** (attributable to EU)

In this way, best practice of the subsystem is compared to the one of the superior systems. Graphical representation of the merit of the decomposition for the output-oriented model is depicted in Figure 4.

In Table 9, EU scores from two models are displayed. BCC-W refers to the result of BCC estimation within the complete world sample. EU countries are then evaluated in a separate model within the EU-subsample. As discussed earlier, the score from the latter could not be worse. Values in BCC-EU column are identical to efficiency scores from Table 5 (Bootstrap). Compared with the rest of the world, two European countries could not retain their efficiency; the efficiencies of Germany and Luxembourg dropped by 10.6% and 14%, respectively. The average deterioration is 7.3%.

Table 9 **EU and World efficiencies**

	BCC-W	BCC-EU	EU/W
Austria	0.4027	0.4123	0.9769
Belgium	0.3816	0.3954	0.9651
Bulgaria	0.0712	0.0818	0.8697
Croatia	0.1739	0.2008	0.8658
Cyprus	0.3243	0.3970	0.8167
Czech Republic	0.1131	0.1164	0.9720
Denmark	0.4812	0.4900	0.9821
Estonia	0.2166	0.2755	0.7863
Finland	0.3819	0.3968	0.9623
France	0.9304	0.9305	1
Germany	0.8043	1	0.8043
Greece	0.1584	0.1637	0.9679
Hungary	0.1565	0.1656	0.9453
Iceland	0.4050	0.5200	0.7789
Ireland	0.4291	0.4403	0.9744
Italy	0.7514	0.8599	0.8739
Latvia	0.2502	0.3203	0.7813
Lithuania	0.2016	0.2395	0.8417
Luxembourg	0.8606	1	0.8606
Malta	1	1	1
Netherlands	0.3513	0.3784	0.9284
Norway	0.5533	0.5612	0.9859
Poland	0.0866	0.0870	0.9946
Portugal	0.2323	0.2397	0.9690
Romania	0.1413	0.1469	0.9616
Slovakia	0.1634	0.1732	0.9433
Slovenia	0.2138	0.2257	0.9476
Spain	0.4767	0.4767	1
Sweden	0.7591	0.7673	0.9893
Switzerland	1	1	1
United Kingdom	1	1	1
average	0.4346	0.4665	0.9272

Source: Authors´ calculation

On the other hand, Malta, Switzerland, and the United Kingdom kept their frontier position. Detailed examination of the results could reveal the fact that efficiencies of the countries benchmarked against the European peers did not drop – the examples being Spain and France (benchmark countries Luxembourg, Malta, Switzerland and the United Kingdom). In contrast, Germany or Latvia benchmarked to Japan or Cape Verde respectively, saw their scores worsen.

3.2.2 Ecologic and social dimension of welfare

Emission efficiency presents one important dimension of social welfare. In the European union, another dimension is attached great importance. Social dimension is even harder to encompass or measure. The *Stiglitz report* (Stiglitz et al., 2009) provides dozens of indicators in its attempt to capture the social benefits or losses from economic activity. We complement our analysis of emission efficiency of European countries with a wide proxy for social welfare – a measure of income inequality. Such a one-sided view is justified by empirical evidence of certain correlations between income distribution and other social welfare phenomena, e.g., health or crime. We, therefore, investigate whether the substantial improvement in emission efficiency shown on average by European countries is associated or traded off against the other domains of social life.

In the first step we examine the productivity growth computed from the intertemporal model. We set up a model in the spirit of convergence regression

$$M = \beta_0 + \beta_1 g + \beta_2 GDP_{1990} + \gamma EU,$$

where M is eco-productivity change (Malmquist index from the previous section), *g* is average growth – both indicators between 1990 and 2016, GDP_{1990} is initial GDP and EU is European country dummy. As displayed in Table 10, economic growth shows no significant effect of the eco-productivity except for the EU dummy which reveals a highly significant difference of 0.97 in M for EU countries compared to the rest of the sample.

Table 10 **Eco-productivity change determinants**

Dependent variable: M					
	coeff.	st.error	t-ratio	p-value	
const	1.381	0.287	4.814	0.000	***
g	1.599	8.428	0.190	0.849	
GDPpc	0.000	0.000	5.746	0.000	***
EU	0.971	0.211	4.592	0.000	***
R2 = 0.13					
F(3. 159) = 36.6 (p-value = 0,00)					

Source: Authors´ calculation

While two EU countries are clustered nearby the world emission efficiency frontier and some of them even define the latter, in a further step we examine how a technology shift in those countries is determined. Rather than the individual effort towards the frontier, we examine the F factor in Malmquist index decomposition. In regression models the frontier-shift effect is conditioned by the initial wealth and average growth as economic variables. Moreover, we complement the potential determinants by the general inequality measure – Gini coefficient in the latest period. We thus seek to find out the association between the environmental improvement and social sphere achievement. Regression model is formulated as

$$F = \beta_0 + \beta_1 g + \beta_2 GDP_{1990} + \delta_1 Gini + \delta_2 Gini^2 .$$

In Table 11, estimated coefficients from the OLS regression with robust standard errors in parentheses are displayed.

Table 11 **Frontier-shift determinants**

Dependent variable: F		
	(1)	(2)
const	-2.803	-2.871
g	-21.42***	-21.46***
	-7.177	(-7.431)
Gini	0.3499*	0.3547*
	-0.1741	(-0.1871)
sq_Gini	-0.006*	-0.0061*
	(-0.003)	(-0.003)
GDPpc	2.56E-08	
	(-2.3E-07)	
obs.	29	29
Adj R^2	0.227	0.194
lnL	-7.994	-7.992
Significance levels: *- 10%, **- 5%, ***- 1%		

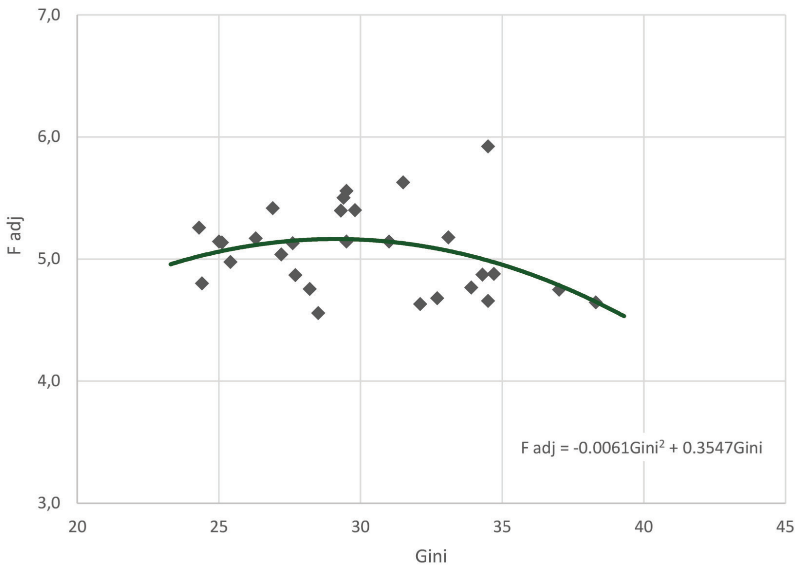
Source: Authors´ calculation

The results suggest a strong negative relationship of the green technology improvement with pure economic growth. There is an apparent trade-off between the speed of the economic catch-up and potential greening. The result could be viewed as empirically aligning to the increasing section of the environmental Kuznets curve.

The initial wealth does not matter and the resemblance to eco-productivity determinants has dissipated in this framework. While the magnitude of M is determined by the catch-up effect, a certain "convergence narrative" might apply in explanation. The development of the frontline countries is fuelled by other sources of growth. In model (2) initial GDP is excluded which changes the results only negligibly.

As regards income inequalities, a non-linearity is allowed for in the regression model by quadratic form specification. The magnitudes of the coefficients of Gini-related variables suggest the inverted U-shaped relationship with the dependent variable. As exhibited in Figure 16, the frontier-shift effect is adjusted. F_{adj} is determined as a residual from regressing F on controls from the models (1) and/or (2) containing thus information not explainable by initial wealth and economic growth. Since Fadj represents the potential for individual countries, higher income inequality appears to hamper the potential for improvement up to a point. Beyond the threshold of Gini to the value of about 30, the explanatory power of the quadratic relationship declines due to the increase in variance. Though the results are only significant at 10% level, we consider it to be sufficient evidence given the sample size.

Figure 16 **Adjusted frontier-shift and income distribution**



Source: Authors´ elaboration

A number of procedures[16] has been suggested for the second-stage regression analysis of DEA scores. We stick to OLS inasmuch as the frontier-shift value is theoretically not bounded as contrasted to the conventional efficiency score.

* * *

DEA modelling has proved useful in emission efficiency analysis suggesting results that could provide the basis for informed decision making. Competing variants of DEA models could be discriminated on the grounds of parsimony. Radial models offer comparable results at far less computational cost. Based on the intertemporal BCC model, the world has experienced a huge ecological technology shift. The distribution of the eco-performance is, though, at an immense variance. While China has achieved enormous improvement with a nearly tenfold increase in the eco-productivity from 1990, static analysis only reveals the average level as to emission efficiency performance. The analysis of European countries confirms a substantial role of the developed European countries in defining cutting-edge environmental technology.

The emission analysis is subsequently complemented by a second-stage regression exploring potential determinants of eco-productivity growth worldwide. The initial wealth of a country proved to determine the latter, much in line with the economic convergence narrative. European countries manifested themselves as a high-above-the-average group.

Proxying social dimension by an income inequality measure, the frontier-shift in EU eco-productivity is shown, to a certain extent, to be constrained by income distribution in individual countries. This sets the investigation in a broader social welfare framework.

[16] e.g. Tobit linear of Simar and Wilson (2007) routine.

CONCLUSIONS

A civilizational shift is not possible without economic growth. Economic growth is a fundamental pillar of sustainable development but measuring economic growth should reflect the environmental and social costs that accompany its achievement. The dynamics of economic growth must be confronted with the sustainability of natural capital, which reflects the quality of ecological systems and social capital in terms of cultivating interpersonal relationships, not deepening inequalities.

The assessment of the success of development based on the growth of gross domestic product has major shortcomings and negatively affects individual areas of sustainable development. Therefore, for almost half a century initiatives have emerged that highlight not only the rising environmental costs of economic growth (depletion of non-renewable and renewable resources, growing environmental pollution) and social risks, but also the lack of capacity of traditional institutions to address these issues.

Prioritizing economic growth is justified by the need to address the current global and regional challenges. The pursuit of economic growth overshadows the warning about its unsustainability due to the deepening of global problems related to increasing pollution, the devastation of nature, the availability of water, sand (and other resources necessary for life and development) and climate change. Development initiatives have, therefore, for a long time focused on finding a development model that could fully grasp the qualitative aspects of the development of human civilization. Growth-pessimistic views not only prioritize the environmental threats and socio-economic consequences of stimulating gross domestic product growth, but also draw attention to the fact that economically advanced countries have moved closer to growth and can only increase economic performance by placing a disproportionate burden on our planet and reduce the quality of life of all of us, its inhabitants. They emphasize that environmental and social sustainability must be global in nature and must be addressed through joint efforts to increase the capacity of global institutions for setting international standards, as the transition from destructive growth processes to sustainable development processes requires fundamental changes in policy approaches across all countries. The fundamental shift must therefore aim at increasing the quality of economic growth, reducing its material and energy intensity, while at the same time ensuring a fairer distribution of profits.

In the context of sustainable development, climate change mitigation and prevention initiatives have been stepped up since the 1990s. The risks arising from climate change and the consequences of global warming are being identified, and ways are being sought to control it and to reduce the rapid increase in anthropogenic greenhouse gas emissions associated with increasing global levels of production and consumption. Efforts to achieve carbon neutrality can be a real way out of the state of climate and environmental emergency.

The achievement of the carbon neutrality target and the consequent avoidance of climate change depends on the extent and speed of the reduction of greenhouse gas emissions. Climate initiatives focus mainly on man-made greenhouse gases, and within greenhouse gases, carbon dioxide dominates; accounting for almost three quarters of their production. Although it is a gas that is needed for the life of the planet, its current production is twice the absorption capacity of nature, as a result of which it creates a greenhouse effect and disrupts climate stability.

Despite efforts to reduce the carbon footprint, CO_2 emissions released into the air keep rising every year. Achieving a level where carbon dioxide production is lower than the planet's current absorption capacity is a major challenge for the future. It requires not only to control the nature of economic growth, but to control global population growth as well.

The largest producer of carbon dioxide today is Asia, mainly due to China and India, which produce more than a third of the greenhouse gas. However, the largest emitter of carbon dioxide in the reference period remains the USA, which has so far produced more than a quarter of global emissions.

Like carbon dioxide, methane is produced by both nature and humans, with human activities accounting for up to 64% of methane emissions. Methane is a greenhouse gas with a significant impact on global warming, as it absorbs much more energy than carbon dioxide. As in the case of carbon dioxide, artificial methane emissions are increasing worldwide, mainly due to the oil and gas industry. Recently, the largest emitters of methane have been China, Russia, India, the USA and Brazil.

In recent years, emissions of nitrous oxide, which contributes to climate change, have also been steadily increasing. Its insidiousness rests in its strength and the long time it remains in the atmosphere. As in the case of carbon dioxide and methane, the most significant producers of the nitrous oxide emissions include China, India and Brazil.

The efficient use of energy, energy saving and a change in the structure of the energy production would undoubtedly contribute to the improvement of climatic conditions. It is necessary to make a shift from fossil fuel-based energy to energy produced from low-carbon sources. At present, energy consumption from renewable sources covers only 11.4% of total world consumption. A positive phenomenon in energy consumption is the declining global energy intensity of gross domestic product. Oil-producing countries are usually among the most energy-intensive producers.

The integration of ecological and economic efficiency into business philosophy and social development strategy was articulated in the early 1990s after the global summit in Rio. The new approach denied the trade-off between economics and environment. As a principle of evaluation of economic activity, eco-efficiency has been built into internal business evaluation systems and is also included in the concept of sustainability.

The practical implementation of the principle of eco-efficiency required development of measurable indicators for the needs of feedback and control. Most of them schematically relate the measured economic value to the environmental burden in various ways. Simple ratios dominate the micro-level evaluation. A more comprehensive view requires the aggregation of a number of sub-indicators from the economic and ecological dimensions, while in the absence of market prices for environmental variables, the problem of aggregating weights also appears. These problems are methodologically solved by the non-parametric procedure of relative comparison and benchmarking of data envelopment analysis (DEA), which dominates empirical research in this area. Current studies are geographically focused on fast-growing industrialized countries; those countries subject to analyses are China, OECD or EU countries. The result of static models is not only the ordering of the compared subjects – companies, industries, regions, countries – but also specific recommendations based on quantitative benchmarking applicable to economic policy decisions. When making decisions with a longer horizon, it is possible to use the results of interim analysis. Productivity indices based on the DEA methodology can comprehensively describe the development of a multidimensional phenomenon. In the presented work we specifically understood the environmental component of eco-efficiency as the burden on the environment caused by the emissions of the three most polluting gases, and we approximate the economic benefit through GDP. European countries were evaluated in a wide sample of countries around the world. The choice of the final radial type of model was motivated by economy, simplicity and robustness of the results. The large variance in the size of the compared countries required a variant with variable economies of scale. Some degree of uncertainty in the deterministic model was taken into account by bootstrapping, and the model provides a robust estimate of the reference effective subjects. The static analysis found that Europe, as a subsystem, defines best practice in ecologically-oriented technological progress, through the large emission-efficient countries of Germany and the United Kingdom. From the smaller emission-efficient economies, Luxembourg, Malta and Switzerland, only Switzerland may serve as a benchmark, given its standard structure of economy. The interim analysis using the Malmquist index of eco-productivity in the period 1990–2016 took into account the long-term development of all components of emission efficiency. We see huge differences in eco-economic performance worldwide. Lagging at the tail of the ranking with a several-fold decline are the poorer African and Asian countries of Namibia, Laos and Libya. At the opposite end, China is leading by a long way, followed by the countries of the former USSR and Slovakia. More sophisticated modelling techniques can distinguish the type of technological progress – in the case of Slovakia and the European Union it is about environmental saving as opposed to input saving technological progress, which we assume in the case of other leading countries. The regression analysis confirmed "narrative convergence" in determining the improvement in eco-productivity at the initial economic level, and specifically a more significant improvement in European countries. Emission efficiency was further embedded in the broader framework of "beyond GDP" development assessment. The social component of development was simply represented by the indicator of income inequality, which, however, is empirically associated with other indicators of social well-being. An examination of the growth factors of the eco-productivity of European economies has shown an inverted U-shaped dependence of the effect of shifting the technological frontier on the income inequality index, with the critical frontier being inequality at 0.29. Thus, a certain degree of inequality is associated with greater growth potential.

Overall, global sustainable development initiatives are putting strong pressure to mitigate climate change, preserve and improve the quality of life and, ultimately, save the planet. However, the slowdown in global economic growth over the last decade and its decline due to the current pandemic increase the risk that the focus will be on supporting economic activity, which may imply that measures to promote sustainable development will not be strong enough and their implementation will be shifted to the future. Institutions will play an irreplaceable role in this process. It will also depend on them whether the world will perceive challenges, such as the decarbonisation of industry, as an opportunity for the sustainability of life for future generations. The climate crisis is a reality that needs to be addressed immediately. If we procrastinate, we may not be able to reverse the devastation of the planet.

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DILEMMAS OF ECONOMIC GROWTH

THE PATH FROM UNLIMITED POSSIBILITIES TOWARDS RESPONSIBILITY?

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Vydává Wolters Kluwer ČR, a. s.,
U Nákladového nádraží 10, 130 00 Praha 3
v roce 2021 jako svou 4263. publikaci.
Odpovědná redaktorka Marie Novotná
Stran 80, vydání první
Sazba a tisk SERIFA®, s. r. o.
Jinonická 80, 150 00 Praha 5

ISBN 978-80-7676-042-4