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Quantitatively estimating the impact of the European Green Deal on the clean energy transformation in the European Union with a focus on the breakthrough of the share of renewable energy in the electricity generation sector

ABSTRACT: This paper discusses the impact of the European Green Deal policy on the clean energy transformation in the European Union, focusing on the generation of electricity reaching a significant milestone for the EU in 2020 – renewable energy sources for the first time in history surpassing combined fossil fuels in the generation of electrical energy. This achievement, although partially influenced by the exceptional circumstances of the COVID-19 pandemic and the electricity demand shock, is primarily an effect of the Clean Energy for all Europeans Package implementing the European Green Deal strategy designed to position the EU as a global leader in the green transformation, leading by example and turning climate challenges into a growth opportunity, and in doing so presenting an optimistic policy perspective for a global transformation towards a 100% renewable energy world, thus supporting mitigation of the global-warming threats by significantly cutting greenhouse-gas emissions. With the immediate effects of the 2018 recast Renewable Energy Directive (2018/2001/EU) and other related clean-energy policies under the umbrella of the European Green Deal, coal and lignite electric generation has fallen in 2020 by as much as 22% (87 TWh) and the nuclear generation has dropped by 11% (79 TWh), with natural gas to a much lesser extent, yet

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still noting an annual drop of 3%, while renewables grew, surpassing the combined fossil fuels electricity output in the whole of the EU. This is an impressive result confirmed in late 2021 and a hallmark of the European Green Deal initial success, the sustainability of which is yet to be assessed in the coming years, especially in view of the recent international situation of major destabilization. In this context, it should be added that although the newest 2022 Global Energy Review report by the IEA confirmed in 2021, the highest global CO₂ emission level in history (following the post-pandemic economic rebound and also due to the gas-price crisis of late 2021 causing gas-to-coal shifts in electricity-mix, which in the EU, resulted in a 7% relative annual emissions increase), Europe's emission level has remained in a diminishing trend following the European achievements of 2020, with an overall CO₂ emissions decrease of 2.4% in comparison with the level of 2019. Most likely, however, the 2021 gas-price crisis was only a mere prelude to a much more robust long-term perturbation that will be expectedly due to the war in Ukraine and the necessary sanctions policy, especially impacting the energy market and probably further hampering the green-transition process jointly with other economic factors.

KEYWORDS: European Green Deal, EU energy policy, renewable energy, renewable energy sources in electricity generation, clean-energy transformation

Introduction

Europe has a strategic ambition to become the first all climate-neutral continent in history by the year 2050. In previous European climate strategies and goals, the EU has set out on a path to gradually reduce its greenhouse-gas emissions. The most important climate and energy goals were defined in the 2020 climate and energy package and in the 2030 climate and energy framework. These goals were set in order to put the EU on a road to a climate-neutral economy, as described in the long-term strategy for 2050 and proposed in the form of the European Climate Law. The EU is tracking its progress in reducing emissions through regular monitoring and reporting, reviewing and constantly adjusting its policies towards the goal of becoming a climate-resilient society by 2050, fully adapted to the inevitable effects of the climate change driven by greenhouse-gas emissions. The plan to achieve this far-reaching goal of climate neutrality was set out in the EU Strategy on Climate Adaptation. The 2020 policy package defined a set of laws that needed to be passed in order to set the EU on a trajectory to reach its climate goals as well as energy goals for the year 2020. The package contained three main objectives: diminishing GHG (greenhouse gas) emissions by 20% in reference to the 1990 levels, increasing share of the EU energy generation from renewable sources by 20%, and finally achieving at least a 20% improvement in energy-efficiency levels.

These goals were already defined by the policy leadership of the EU in 2007 and implemented into law in 2009. The EU has taken action in a number of areas to ensure that these objectives were successfully achieved. These efforts particularly concerned the establishment of the Emissions Trading System (ETS) with a role of a major instrument for reducing greenhouse-gas

emissions from power plants, large industrial sites and aviation. In 2019, the Emissions Trading System already encompassed around 40% of the total emissions in the EU (not including the aviation sector). In 2020, the new target was set that emissions from energy and industrial sectors should be by at least 21% lower than emissions registered in 2005. Another aspect of this effort was constituted by simultaneously pursued targets of national emission reduction, covering the burden sharing sectors (non-ETS and no agriculture), which constitutes approximately 60% of the whole EU emissions level (again excluding the aviation sector) back in 2019 (these sectors included the non-ETS industry, construction, agriculture, waste management and transport – excluding aviation). As a part of the so-called effort-sharing decision, the European Union countries have jointly defined annual targets for reducing GHG emissions in the mentioned sectors by the year 2020. These goals were set to vary in accordance with national prosperity and wealth levels, ranging from a 20% reduction for some of the richest EU member states, up to even a 20% increase for the least prosperous countries (although these member states will need to make certain efforts on their own in order to limit their GHG emissions) by the year 2020. Progress on NERT is to be monitored every year by the European Commission (including obligations for the member states to individually report their emissions in agreed upon time-frames).

The EU has also included renewable energy targets at the national level. In this initiative, the EU countries have set individual national targets in order to increase shares of renewables in their energy mixes by the year 2020 within the framework of the Renewable Energy Sources Directive. These individual targets varied to account for consecutive different starting points of EU member states in terms of the renewable-based energy generation, as well as their abilities to increase these shares and the time scales required to do so (with one of the most prominent leaders being Sweden, increasing the share of renewables to a level of 49%). The result was generally positive, allowing the European Union to meet its 20% averaged target for the year 2020, i.e. surpassing doubling of its 2010 averaged level which amounted to nearly 10%, as well as achieving a 10% share of renewables in the transportation sector.

The innovation funding programs in the 2020 package have proven to be taking the decisive role. The European Union has supported the growth of clean energy technologies through many programs, e.g. the NER300 program for sequestration (as well as more generally carbon capture and sequestration, CCS) as well as through the Horizon 2020 EU framework program funding for research and development programs in renewables along with several other EU co-funded programs run by dedicated networks, including programs cofounded by European funds at the national level.

Energy efficiency was under a separate focus of these efforts with the Energy Efficiency Directive laying forth steps to improve it. By lowering reliance on traditional energy imports and supporting the establishment of the European Energy Union, the 2020 package aims have also helped to strengthen the EU's energy security (including by creating jobs and promoting green growth, while making Europe more competitive globally in renewable-energy technologies).

Following the 2020 package, the European Commission's proposal of reducing GHG emissions by at least 55% by the year 2030, setting Europe on a road to becoming the first climate-neutral continent by the year 2050 and establishing a global leadership position in green trans-

formation. The European Commission suggested expanding the EU's aspirations to further cut GHG emissions and continue on this course for the next ten years. The undertaken evaluations have revealed various ways in which different sectors of the economy might contribute, as well as the policies required to support these actions. Setting a more ambitious and cost-effective path to climate neutrality by the year 2050, promoting the creation of green jobs, maintaining the EU's track record of reducing GHG emissions while still growing the economy in various sectors, and encouraging international partners to share their ambitions for keeping global temperatures below 1.5 degrees Celsius and avoiding the worst effects of climate change are among the goals.

The European Commission's proposed 2030 climate target, which would reduce greenhouse gas emissions by as much as 55% below 1990 levels by the year 2030, was a significant increase above the prior target of at least 40% ([European Commission 2030 climate & energy framework](#)). Such a significant increase in the 2030 ambition provides confidence to political leaders, as well as to investors, ensuring that decisions made in the coming years do not reduce emissions in a way that contradicts the EU's goal of becoming an entirely climate-neutral continent by the year 2050. This proposal fulfilled the pledge made in the European Green Deal communication to present a detailed strategy to responsibly boost the European Union's 2030 target to an ambitious 55% figure. It also aligns with the Paris Agreement's goal of keeping global warming far below the level of 2°C and pursuing efforts to even keep it well below the 1.5°C level. The proposal's impact assessment ([European Commission, Stepping up Europe's 2030 Climate Ambition, September 2020](#)) paved the way for climate and energy policies to be adjusted to support in the decarbonization of the European Union's industries. This includes figuring out what function carbon-based fuel pricing as well as emissions pricing will play in the future and how it will interact with other policies. In this regard, the European Commission has proposed legislative changes to achieve the described above goals. It has also proclaimed that corresponding policy instruments would be reviewed and revised in order to accomplish the increased GHG reduction goals.

The European Commission issued preliminary impact evaluations in late 2020, followed by open public consultations held in November 2020 to prepare these revisions, which included the EU Emissions Trading System Directive ([European Commission, Updating the EU Emissions...](#)), the Effort Sharing Regulation ([European Commission, National emissions...](#)), the Land Use, Land Use Change, and Forestry Regulation ([European Commission, Land use...](#)) and the CO₂ standards for cars and vans regulation also from November 2020. In addition, the Climate Law Regulation has been proposed by the European Commission ([European Commission, Climate Law Regulation...](#)) finally adopted into legal framework in July 2021 ([European Commission, European Climate Law...](#)), aimed to incorporate the 2050 climate-neutrality target as have been set by the EU policy leadership back in December 2019 setting the direction for aligning of all EU policies. The European Commission also suggested in 2020 that the higher 2030 target should be included in the entire mentioned regulation by co-legislation upon the regular legislative proceeding. The novel 2030 objective also served as a springboard for negotiations about adjusting the EU's nationally determined obligations to emissions reduction under the Paris Agreement, originally back in 2015.

Because the 2030 climate and energy framework included EU-wide targets and policy objectives for the years 2021 to 2030, it was an important part of the European Green Deal when the European Commission proposed to raise the 2030 GHG reduction target in September 2020 to at least 55% below the 1990 levels. The European Commission has examined activities required across all sectors, including higher energy efficiency and renewable energy deployment rates, and has begun the process of developing comprehensive legislative recommendations to implement and attain these loftier goals. The aim to transition Europe as a whole to a climate-neutral economy was an important aspect of the Paris Agreement, which was already proven to be encouraging in terms of international collaboration in this area. Beyond the previously indicated 40% reduction in GHG emissions (from the mentioned 1990 levels), the primary 2030 targets included a minimum 32% share of renewable energy and a minimum 32.5% improvement in energy efficiency. The EU Emissions Trading System, the Effort Sharing Regulation with Member States' emissions reduction targets, and the Land Use and Forestry Regulation are deemed to jointly contribute to the 40% GHG reduction target. As a result, all sectors will contribute to the target's achievement by lowering emissions and enhancing efficiency. All these three aspects of climate legislation are planned to be revised by the European Commission on a regular basis in order to assure meeting the proposed net greenhouse gas emission reduction objective of at least 55%.

The EU has developed integrated rules to assure the planning, monitoring, and reporting of progress toward its 2030 climate and energy targets, as well as its international commitments under the Paris Agreement, under the Regulation on the Governance of the Energy Union and Climate Action. Consultations with residents and stakeholders are part of the governance process, which is based on the principles of improving regulation. To summarize, the EU intends to become a 100% climate-neutral continent by the year 2050, i.e., to create an economy that emits no greenhouse gases at all. This goal is central to the European Green Deal and aligns with the EU's Paris Agreement commitment to the action countering global climate change. The transition to a climate-neutral society is both a pressing issue and at the same time a huge opportunity to build a better future for everyone while increasing the European Union's global competitiveness in terms of turning the challenge into a growth impulse. This effort will certainly involve all aspects of social and economic sectors, including power, industry, transportation, construction and buildings, agriculture and forestry. The EU can set the example globally by investing in creative but practical technological solutions for the green transformation, achieving a globally leading position in this field, while simultaneously empowering citizens, and synchronizing actions in important areas such as industrial growth policies, finance, research and development, all while guaranteeing social fairness and especially supporting and encouraging the regions that are lagging behind with regard to green transformation (e.g. coal or heavy-industry regions).

Back in November 2018, the European Commission had already articulated its vision for a climate-neutral Europe ([European Commission, A Clean Planet for All...](#)), which looked through all key sectors and explored possible paths to optimally achieve the objective of green transformation. The European Commission's vision encompassed all EU measures and was completely consistent with the Paris Agreement's goal of limiting global warming to levels well below

2°C and pursuing efforts to keep these levels even below 1.5°C as an important part of the European Green Deal initiative. All parties to the Paris Agreement were asked to submit their long-term, mid-century greenhouse-gas-emission reduction goals by the end of 2020. In March 2019 (cf. the European Parliament resolution of 14th March 2019 on climate change – a European strategic long-term vision for a prosperous, modern, competitive, and climate neutral economy in accordance with the Paris Agreement 2019/2582-RSP, March 2019) and in January 2020 (cf. European Parliament resolution of 15th January 2020 on the European Green Deal), the European Parliament endorsed the net-zero greenhouse-gas-emissions policy goal, and confirmed the path undertaken by the EU.

In December 2019, the European Council also further supported the goal of transiting the EU to the climate-neutrality by the year 2050 (cf. European Council, conclusions on climate change, the MFF, the Conference on the Future of Europe, EU relations with Africa, the WTO, Turkey and Albania, 12th December 2019). The European Commission has subsequently submitted its corresponding strategy to the UNFCCC (the UN Framework Convention on Climate Change) – cf. United Nations, Long-term low greenhouse-gas-emission development strategy of the European Union and its Member States, 6th March 2020. Under this strategy, all EU Member States must develop their own national strategies for reducing greenhouse-gas emissions in order to meet their Paris Agreement commitments as well as the more ambitious EU objectives (cf. European Commission, national long-term strategies – EU countries' long-term strategies to meet their Paris Agreement commitments and the energy union objectives, 30th September 2021).

The paper aims to quantitatively estimate the early impacts of the European Green Deal on the clean energy transformation in the European Union that we have witnessed especially with regard to the renewable-energy share breakthrough in the electricity generation sector that was achieved in the EU in 2020.

1. Climate change drivers for the European clean energy transformation

In view of the scientific consensus for global warming and induced climate change with the influence of dynamic weather patterns confirmed among others by the scientific evidence based Paris Agreement's declarations of 2015, it becomes clear that the longer no action is taken, the more difficult and more expensive it becomes to reach the emission and climate goals of estimated temperature targets to counter this serious situation.

It has been concluded by multiple analyses that without action taken on the climate change, the EU will experience during the lifetimes of our children, unbearable social and economic costs. Europe notes ca. 400 thousand premature deaths annually because of air pollution ([Air quality in Europe...](#)). With regard to the dynamic shifts of weather patterns the impact is

also overreaching with multiple induced natural disastrous events including unprecedented heatwaves, fires, droughts and floods. In Europe alone, in the past few years there have been noted ca. 90 thousand deaths per annum due to strong heatwaves (cf. European Commission's Joint Research Centre PESETA IV). About 16% of animal species were assessed as being at risk of extinction at a temperate increase of 4.3°C (as estimated by Missirian and Schlenker in 2017). According to the same authors, there has already been a 40% decrease in the amounts of water available in the south of the EU, while as many as 0.5 million people in Europe are now exposed to river flooding each year and as many as ca. 2.2 million people are exposed to devastating floods annually, including the coastal inundations.

With regard to the climate change induced by the global warming, CO₂ levels are forecast to at least double by 2030, with averaged European summer temperatures expected to rise by as much as 2 to even 3°C ([European Environment Agency – Problems – April 2016](#)). According to the same study, Europe is held accountable for about a third of global ozone-depleting gas emissions. More than half of the ecosystems areas of the EU are threatened by climate change impacts. Every year in the EU, about 700 thousand hectares of woods are destroyed in fires, resulting in the deterioration of European forestry as well as in the further diminishing of the CO₂ absorption rates of natural ecosystems. Other studies ([International Resource Panel – Global Resources Outlook – 2019](#)) have found that over the past fifty years, the global yearly extraction rate of fossil energy resources has increased three-fold, and the impact of fossil-fuel burning had eventually resulted in dramatic biodiversity losses of ca. 90%.

The industrial sector in the European Union accounts for roughly 20% of total European greenhouse gas emissions (see [European Commission – EU Climate Action Progress Report – 2019](#)). With almost fifty thousand industrial sites in the EU, up to €190 billion is estimated to be spent on health issues associated with the vast pollution levels arising from the operations of these facilities ([Schaible 2020](#)). The transportation sector accounts for another 25% of the European GHG emissions. The road transportation subsector leads in emissions raking, accounting for nearly 72% of the total emissions level, followed by 14% from aircraft, 13.5% from water transport, and the rest from railways and other branches of transportation ([European Commission – Sustainable Mobility – 2019](#)).

The progress of the electrification of cars, dynamically scaling in Europe is thus a major contribution to the green transformation providing the electricity generation mix and involves a majority share of clean renewable energy sources. In Europe, the demand for electrically chargeable vehicles (ECVs) has grown impressively throughout 2020 despite the pandemic induced crisis, with almost 0.5 million new electric vehicles registered in the EU at large (marking the highest level so far, resulting with an unprecedented 17% market share, which is over twice as high as China and over six times higher than the United States).

The climate system of our planet is complex, strongly interdependent and by no means easily simulated. Decades spanning observations noting unusual weather escalations getting more frequent in the recent years show that global warming might induce a climate destabilization that can possibly scale very profoundly in a feedback loop of complex interdependent factors, which

when set in motion might be difficult to stop. This is a well-known property of very complex, interdependent systems.

The Nobel Prize in Physics for 2021 has been awarded to Princeton University climatologist Syukuro Manabe, Max Planck Institute for Meteorology physicist Klaus Hasselmann, as well as Sapienza University physicist Giorgio Parisi for their contributions to understanding the complex systems in physics, and especially for explaining the complex coupling between different parts of environmental systems, thus for laying foundations for further physical research on the climate and global warming.

Although the sheer economics of climate change, as well as its destabilization is a strong factor driving clean energy change, notably in Europe, it is hard to measure in money values such as the health and wellbeing of mankind's next generations as well as of animals and ecosystems. Beyond such economically unmeasurable threats for the future of the life on our planet, a 3°C increase in the global average temperature level might result in yearly economic losses of up to €190 billion (Ciscar et al. 2014). Globally, the number of people at risk of being displaced from their inhabitation areas by river flooding could rise to even 50 million annually (Internal Displacement Monitoring Centre...) and global warming could cause food prices to rise by at least 20% by the year 2050 (COACCH, The economic cost of climate change in Europe 2018). It is has also been estimated that a 5°C temperature increase will result in approximately 660 thousand additional asylum claims annually in the EU (Missirian and Schlenker 2017). Heat-related mortality might cost more than €40 billion per year in economic expenditure (cf. COACCH). The dominating role of energy in these catastrophic impacts is demonstrated by the fact that over 75% of GHG emissions in the EU are related to energy generation and its usage (European Commission – Clean Energy 2019). As a result, the European Green Deal is primarily motivated by, in addition to clean energy transformation, environmental concerns (including global warming induced biodiversity diminishing, increasing pollution of air and water and ozone depletion), and also as much by their sheer economic consequences. The strategy in continuing Europe's previous sustainable growth assuring clean energy policies of the EU has turned out successfully – with the hallmark of the renewable winning electricity mix share over fossil fuels in the EU being based on the renewable resources providing for almost 18% of the EU's overall gross energy usage in the year 2017, while simultaneously stimulating the economic growth of the EU's green energy sector. The paper discusses progress of the EU's clean energy transformation along with climate change drivers for the European clean energy transformation policy and the European Green Deal implementation, which have recently resulted in the historic achievement for the EU of energy generated by renewable sources dominating the share in the whole electrical energy generation mix for the year 2020.

2. The European Green Deal

The European Green Deal is a package of the European Commission's policies overarching the strategic goal of transforming the EU to become fully climate neutral by the year 2050. Along the lines of the Emissions Gap Report 2020 by United Nations Environment Program, achieving the Paris Agreement target of limiting temperature increase by a level of 1.5°C with a two-third probability level demands a 57% global emission reduction of CO₂ from 2019 to 2030 and therefore well above the preceding policies with 40% of the EU target as described in the previous chapter. In this way, the European Green Deal has been complemented with an impact assessment plan for increasing the EU's GHG-emission reduction target by 2030 to 50% and up to 55% in reference to the levels from the year 1990.

As many as 93% of Europeans consider global warming to be a significant problem posing existential threats for the future and a similar percentage of Europeans have already undertaken certain actions to counter the global warming on their own. Almost 80% agree that an effort against climate change will lead to achieving new innovations and generally support technological and economic development. The European Green Deal is genuinely targeted at climate and energy, and for most, it is a strategic policy set to ensure a fair and inclusive transition for Europe to clean energy, as energy from traditional fossil fuels plays a role in the challenges global warming introduces.

Yet another important objective of the European Green Deal policy resolves to turn climate challenges into opportunities and to base the new dynamic economic growth in Europe on the transformation towards 100% clean energy. The European Green Deal is thus planned to become a growth strategy for the entire European Union. On the way towards this strategic objective, the European Commission has proposed a legal framework called the European Climate Law that makes political engagement transform into a legal obligation and a legal framework of incentives for investments. Achieving this goal requires action from all sectors of the European economy: energy (decarbonizing the sector of energy – taking into account that the generation and use of energy accounts for more than 75% of the European total GHG emission levels), buildings (renovating buildings to support citizens in cutting their energy bills and their energy consumption – taking into account that buildings are responsible for ca. 40% of energy use in the European Union), industry (helping industry to innovate and lead the global green economy), mobility (decreasing transportation-based emissions – taking into account that transport is responsible for ca. 25% of EU emissions).

The investment scale directly under the European Green Deal calls for a public contribution of at least €1 trillion over ten years. It will encompass a combination of the EU's budget and individual member states national initial investments to facilitate and boost private investments in clean energy transformation following the new paths, under properly motivating investing incentives, as well as technological development support. Additional financing sources include 30% of the InvestEU to climate-change-counteracting projects, ca. 25% of the EU's funding for all

climate actions, as well as stimulating green transition funding from the EIB. The Just Transition Mechanism alone will mobilize ca. €100 billion over the period 2021–2027 as a part of the Sustainable Europe Investment Plan to support certain geographical regions and industry sectors mostly impacted by a general clean energy transition. The EU will offer technological aid as well as special funding to those who will be most harmed by this transition, in an approach not to leave anyone behind. For the EU and the pursued transition to a climate-neutral economy on the continental level, it is critical that the political commitment be accompanied by a huge-scale investment. The European Green Deal shows the determination in Europe to fight climate change, which is currently being underpinned with a financing plan. Setting sustainability in clean energy at the center of the EU investments requires joint efforts on the levels of policy and industry. The European Green Deal aims to facilitate this. Another important aspect should be also stressed, namely the need to show solidarity with the geographical regions in the EU that are most involved with the clean-energy transformation policy, such as the regions with highly developed coal-mining infrastructures and other highly industrialized regions, to ensure that the Green Deal offers uniform support and its implementation is a joint success. The Just Transition Mechanism has been designed as a critical instrument to ensure that the clean transformation will be just and will pronounce European solidarity, not leaving any region behind. It provides properly targeted support with the mobilization of ca. €150 billion planned for in the scale of the current financial perspective until the year 2027, and offers special funding for most socio-economically impacted regions by clean energy transformation. The JTM thus addresses the socio-economic effects of green transformation, and not only for regions, but also for impacted industries and the workforce facing significant jobs challenges, mobilizing its funding through a new fund of €40 billion for assuring the just transition generating ca. €90–110 billion investment. The InvestEU Just Transition program is mobilizing a further €30 billion in investment, and EIB loans amount to ca. €10 billion, which is additionally supported by up to €2 billion from the European Union's budget aimed at initially mobilizing a subsequent €30 billion in investment. As part of its Green Deal commitment, the EU is countering the climate change not only with its ambitious internal policy but also through its close cooperation with international partners, as it is well understood that countering global warming must be a global effort. Europe is determined to lead by example (it has already met its 2020 GHG decreasing objectives and presented a schedule to further diminish emissions by 55% before the year 2030 and completely stop GHG emissions by the year 2050) and to motivate other countries to take responsibility, along with providing financial and technological support to developing countries.

Climate protection is the central axis of the European Green Deal, which includes efforts that range from an ambitious reduction in GHG emissions, through achieving high levels of energy efficiencies, to the funding of innovative green-energy research and development projects. The primary climate protection initiatives as part of the EGD include the European Climate Law to anchor the goal of climate neutrality before 2050 within EU law as well as the broadly defined European climate pact to involve European citizens in climate-protection efforts, the intermediate climate targets for the year 2030 in order to further reduce net GHG emissions by 55% before the year 2030, and the novel European strategy on adapting

to climate change, so as to ensure the building of a society that would be climate change resilient before the year 2050, should the widely undertaken efforts fail and the pollution and the greenhouse effect escalate beyond the possibility of control. On the global scale, the European Union aims continuing negotiating efforts with all international actors to further increase joint ambitions and reducing emissions, as has been recently confirmed during the United Nations Climate Change Conference in Glasgow (COP26) with a steady shift towards common international responsibility.

3. Assessing European Green Deal's quantitative impacts

As the European Green Deal has been designed to position the European Union as a global leader, leading by example on global warming and the climate change front and to simultaneously turn the environmental challenge into a growth and economic recovery opportunity for the EU, the question to ask is what are its current results.

In answering this question, the immediate effects of the 2018 recast Renewable Energy Directive (2018/2001/EU) and other related clean energy policies under an umbrella of the European Green Deal should be considered. These include the evolving Emission Trading System with emission caps on the EU level, the EU coal regions in transition initiative, the European Green Deal Investment Plan (with the Just Transition Fund, the InvestEU dedicated scheme of unprecedented scale of € 1 trillion, the Modernisation Fund and the Innovation Fund, supported by Horizon R&D program and the financial mechanisms of the Connecting Europe Facility and the European Investment Bank) influencing the clean energy transition economic and technical factors. These have all led to coal and lignite electric generation falling in 2020 by as much as 22% (i.e. by 87 TWh) and nuclear-based electricity generation dropping by 11% (i.e. by 79 TWh), with natural gas reduction to a much lesser extent, yet still noting an annual drop of 3% (mainly due to its favorable prices in 2020. This drives switching from coal and lignite, the trend reverted from the 2021 onwards and now under a significant new pressure, with the necessity of achieving energy independence from Russian exported gas, due to the unprovoked war in Ukraine by the Russian invasion and the resulting destabilization of the international situation), but still noting an annual drop of 3%.

This is an impressive result and marks the year 2020 as a historical hallmark of the European Green Deal initial success, which is now facing a major new geopolitical challenge.

Meanwhile, the rising renewable share in electricity generation in the EU was supplemented by ca. 30 GW of solar power and wind-power grid deployments in the year 2020 (at levels comparable to those of 2019, proving that the COVID-19 pandemic did not strongly impact the expansion of renewable-energy sources, and as a matter of fact, even supported its historical triumph in the European Union over the combined fossil fuels for electricity generation by causing an overall electricity consumption drop).

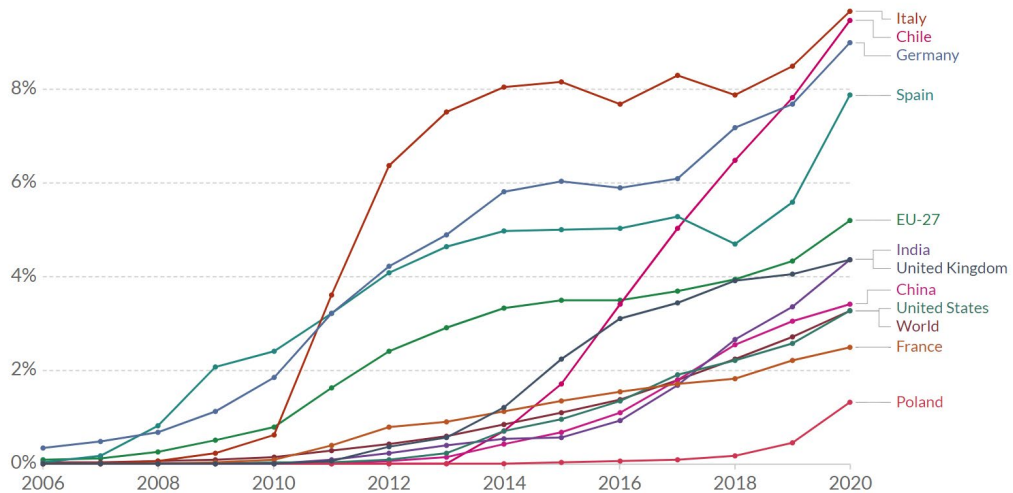


Fig. 1. The solar energy share in the electricity mix of the EU and reference countries in 2020, showing the EU reaching a 5.2% share from just 0.08% share in 2006. Italy, Greece and Germany are leading the solar energy electricity-share race, all reaching 9%, with Spain closely following (at almost 8%). The EU exceeded in this area both the US (3.2%) and China (3.4%)

Source: chart by the author, based on statistical data by BP Statistical Review of World Energy & Ember

Rys. 1. Udział energii słonecznej w miksie elektroenergetycznym UE i krajów referencyjnych w 2020 r., pokazujący, że UE osiągnęła 5,2% udział z zaledwie 0,08% udziału w 2006 r. Włochy, Grecja i Niemcy przodują w udziale energii słonecznej w generacji energii elektrycznej, osiągając podobne wyniki, tj. ok. 9% i mając za sobą Hiszpanię (prawie 8%). UE przewyższyła w tym zakresie zarówno Stany Zjednoczone (3,2%), jak i Chiny (3,4%)

These successes in the clean-energy transition in the EU are certainly due to the current EU strategic policy and other factors, circumstances and actions involving climate-change drivers together with the estimated costs of not taking the action and the perspectives of the progress of the European Climate Law combined with the recall of the European Energy Law (including the European Commission's June 2021 scheduled recast of the Energy Taxation Directive, paying close attention to fossil-fuel subsidies and tax exemptions).

The Directorate-General for Energy of the European Commission (ENER) confirmed in its communication of 9th April 2021 a historical success for the EU and the world at large. The share of electrical energy generated from all renewable sources in the EU for the first time in history overcame the joint share of all combined fossil fuels in the year 2020 (excluding the nuclear energy).

Clean-energy sources dominating the share in the EU's electricity-generation mix reached 39%, exceeding by 4% the combined share of fossil fuels amounting to 36%.

This is an impressive result when taken into account that globally, electricity is generated at 63.3% from fossil fuels (excluding nuclear energy) and at 26.3% from renewables. The breakdown to different renewables in the electricity mix of the EU is presented in Figure 4, showing impressive growth rates of solar energy and wind power vs. a decline of fossil fuels.

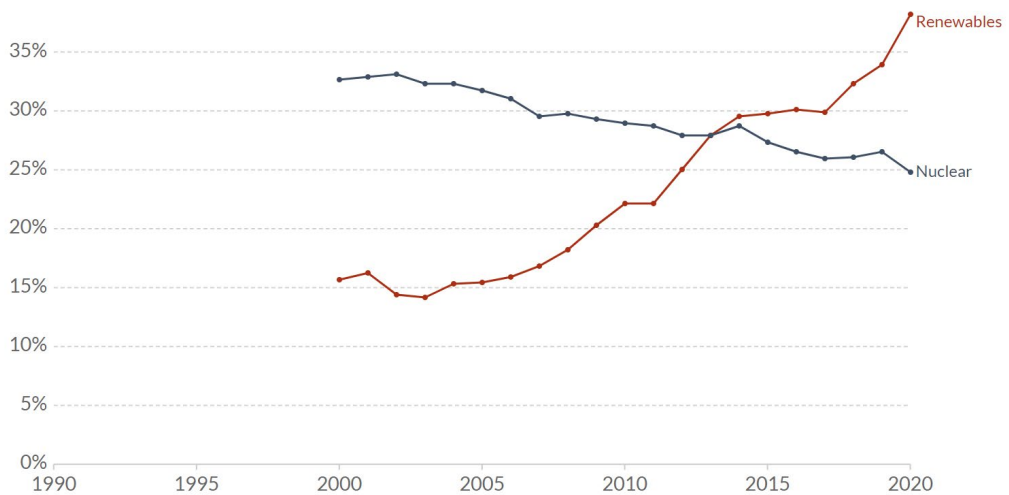


Fig. 2. Competition between renewables and the nuclear-power share in electricity mix for the EU, with a crossing in 2013 (nuclear power is being phased down due to the risk of serious environmental impact in the case of an incident, but is also considerably more expensive, currently estimated at 11 times more costly than photovoltaic energy, mainly due to the necessary security investments – in the EU, only France largely relies its electricity generation on nuclear power, with ca. 70% share stable for decades and renewables at ca. 23%)

Source: chart by the author, based on data by [BP Statistical Review of World Energy & Ember](#)

Rys. 2. Konkurencja udziału OZE i energetyki jądrowej w miksie elektroenergetycznym w UE, z przedstawionym przełomem w 2013 r. (energetyka jądrowa jest wycofywana ze względu na ryzyko poważnego wpływu na środowisko w przypadku awarii, ale jest też znacznie droższa, tj. według obecnych szacunków ok. 11 razy droższa niż energia fotowoltaiczna, głównie ze względu na niezbędne inwestycje w bezpieczeństwo – w UE tylko Francja w dużej mierze opiera produkcję energii elektrycznej na energetyce jądrowej, z ok. 70% udziałem stabilnym od dziesięcioleci i udziałem źródeł odnawialnych na poziomie ok. 23%)

Although it is understood that decisive factors for achieving this breakthrough for the European Union in 2020 partially involved the exceptional situation of the COVID-19 pandemic and its overreaching impact on energy markets (the demand shock lowering the EU overall electric consumption level by 4% in comparison to 2019), combined with the favorable weather conditions for the renewable energy and most notably for solar and hydro power, figures for the fourth-quarter consumption levels (despite continued lockdowns in Europe) were getting closer to their usual values in contrast to the first three quarters of 2020, thus pointing towards normalization. This situation, discussed in detail in the Quarterly Report on European Electricity Markets (cf. EC's Directorate-General for Energy, unit A4, Market Observatory for Energy, April 2021), reports a well-justified expectation that the European Union is able to hold its newly gained ground in clean energy, especially as we observe how the European Commission's Clean Energy for all Europeans Package of policies (cf. CEP in references) gains momentum as the major pillar of the European Green Deal implementation.

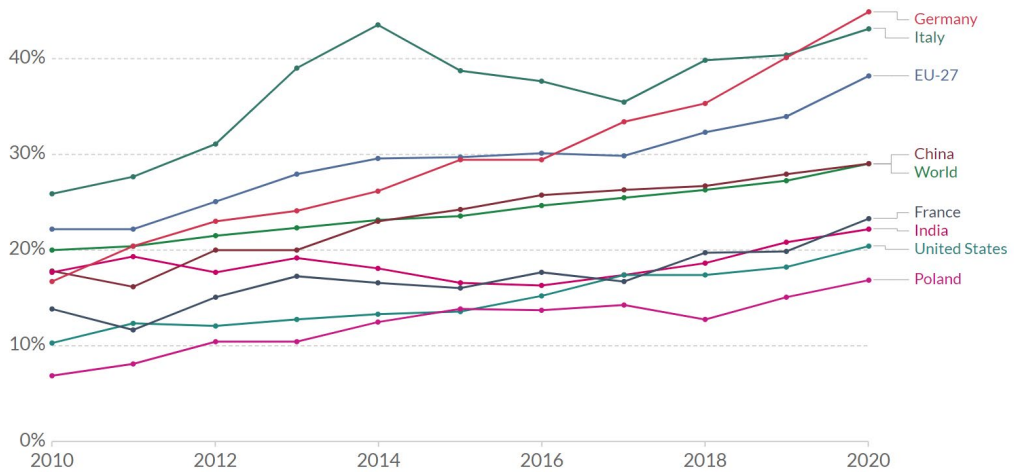


Fig. 3. Electricity mix renewables share for the EU and reference countries in 2020, showing the EU reaching a 39% share from a 22% share in 2010

Source: chart by the author, based on statistical data by BP Statistical Review of World Energy & Ember

Rys. 3. Udział energii ze źródeł odnawialnych w miksie elektroenergetycznym UE i krajów referencyjnych w 2020 r., pokazujący, że UE osiągnęła łącznie 39% udział z 22% udziału w 2010 r.

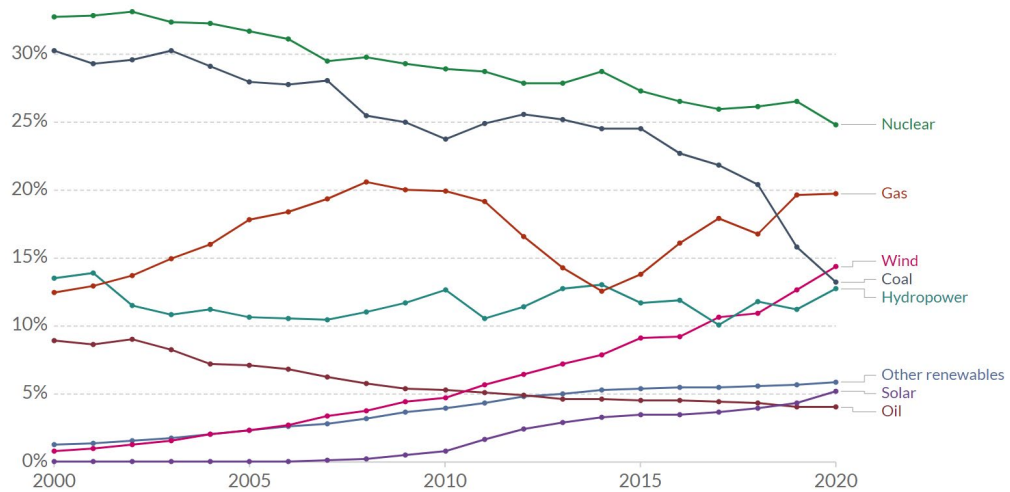


Fig. 4. The breakdown of energy sources in the electricity mix for the EU in 2020 (showing decline in fossil fuels, e.g. the worst CO₂ and pollution emitter – coal from 30 to 13%, oil from 9 to 4%, gas on a stable level of below 20% after averaging – confronted with a steady growth of renewables: notably solar energy from 0.01 to 5.2% and wind power from 0.8 to 14.3%)

Source: chart by the author, based on statistical data by BP Statistical Review of World Energy & Ember

Rys. 4. Podział źródeł energii w miksie elektroenergetycznym UE w 2020 roku (pokazujący spadek udziału paliw kopalnych, np. najgorszy emitent CO₂ i zanieczyszczeń – węgiel z 30 do 13%, ropa z 9 do 4%, gaz na stabilnym poziomie poniżej 20% po uśrednieniu – w obliczu stałego wzrostu OZE: w szczególności energii słonecznej z 0,01 do 5,2% i wiatrowej z 0,8 do 14,3%)

Conclusions

Despite it being difficult to accurately estimate in quantitative terms exactly what contribution to the success in renewables dominating the combined fossil fuels in electricity mix in the EU has been directly due to the immediate results of the European Green Deal policies and what part of it follows from a general economic advantage of renewables, some discussion in this regard is certainly needed. A summary of the most important conclusions in this regard is presented in the bulleted list below.

- ◆ One of immediate effects of the recast Renewable Energy Directive (2018/2001/EU) that is considered to be a part of the current European Green Deal package is certainly related to the increase of funding in renewables-related research and development on many levels affecting the efficiencies of the renewable energy generation. For example, for solar power, multiple industrial research projects funded by the EU resolved to significantly decreasing the costs of fabrication of the increasingly efficient solar-cell devices, driving down the costs per watt of electric energy generated. PV-related research results also include plasmonic enhancements of solar cells (Jacak et al. 2018–2020) which enable cost-efficient increases of energy generated from solar cell devices by surface nano-modifications.
- ◆ Additionally, improvements in smart grids and energy-production decentralization towards enabling the prosumer model indirectly extend potentials and the economic advantages of renewable energy sources and is most certainly driven by relevant Green Deal policies in the EU, such as enabling prosumers to sell their produced energy to the grid (along with the following investments and technological developments in renewables in general).
- ◆ It should be also emphasized that one of major impact factors that makes renewable energy sources more cost efficient than traditional fossil fuels in electricity generation comes from the Emission Trading System which has been imposed upon a climate-related political agreement in the EU and ever since has introduced kind of an artificial (yet justified by climate goals) burden for the fossil fuels, further increased by economic speculation in trading in the emissions market.
- ◆ Other political factors contributing to the economic advantage of renewables in the EU was a German anti-nuclear policy imposed in 2011 after the Fukushima incident, resulting in a complete phasing down of nuclear power in this country, strongly driving the growth in renewables in the EU. Due to a high level of climate awareness already present in 2011, the new energy sector direction in Germany has been shifted towards increasing the share of renewables (along with the controversial increase of dependence on the natural gas supply from Russia in Nord Stream 1 & 2) rather than upscaling polluting electricity generation from coal (which also has a significant share in Germany, but started losing ground to renewables because of the ETS economic pressure, which is, however, directly rooted in the climate policy). On the level of the European Union, these policies are now encapsulated in the European Green Deal package, with new climate-neutrality initiatives and developments that will be surfacing in the upcoming years.

- ◆ Although the funding of the European Green Deal is currently programmed at €1 trillion (as mentioned, the plan involves mobilizing ca. €1 trillion of investments over the period of ten years in the European Union), such a value is nominally rather corresponding to an estimated amount of the necessary annual spending in the EU required to reach the net zero emissions target in 2050 (thus it is by one order smaller from what is actually needed). Certainly, it is an initial investment plan that will require to be further extended and most importantly will trigger an increasingly growing private investment that in total should be at least ten times greater in the scale of a corresponding time frame of ten years (and by a factor of ca. 30 when we consider the almost three decades left until 2050).
- ◆ In September 2020, the European Commission (along the lines of the communication entitled *Stepping up Europe's 2030 climate ambition – Investing in a climate-neutral future for the benefit of our people – Impact assessment*, COM(2020) 562, September 2020) has predicted that meeting the 2030 climate objective would necessitate additional investments of almost €360 billion each year in the EU alone.
- ◆ This increases the relevant investments scale for the EU from an averaged value of ca. €680 billion annually in the previous decade to about €1 trillion annually.
- ◆ The transportation sector accounts for around a third of the required investment, and is by far the greatest component due to a massive combustion-engine vehicles replacement necessity that would facilitate reaching the climate neutrality goal. However, major magnitude upon this investment is on the consumer level, i.e. depending on average EU citizens transiting from buying combustion engine cars to electric vehicles.
- ◆ This transition rate will escalate increasingly in the upcoming decade (even with a discussed ban on the production of combustion-engine cars) but will be closely tied to investments needed for widespread electric-car charging infrastructure (quite differentiated in the EU, and in need of being specifically enhanced in the Eastern European member states).
- ◆ Apart from the transportation sector, the focus is also set on tripling home-heating investments which falls under the scope of building modernization EU policy, while other important components of the EU energy policies (minor in terms of investments magnitudes) such as electricity grids and power plants, must still be increased by at least a factor of two. These estimates were produced by the European Commission only with regard to reaching more modest 2030 targets, while the 2050 target for full carbon neutrality will exceed these costs even further, with a remark that a large part of these investments will be in a transport sector with a consumer-led shift to its electrification.
- ◆ The scale of the global energy investment magnitudes for reaching net zero GHG emissions by 2050 is of course correspondingly larger. In accordance with the International Energy Agency, it currently amounts by rough estimates to well over \$2 trillion annually, which translates to 2.5% of the world's GDP (*Net Zero by 2050; A Roadmap for the Global Energy...*).
- ◆ This is quite an optimistic estimation that only considers the immediate future of up to a few years. After this short term time scale, in order to reach the goal of the net zero

GHG emissions by 2050, according to the mentioned model of the IEA, the investment will have to climb to \$5 trillion globally per year (or ca. 4.5% of the world's GDP) by the year 2030 and to remain at least at this level until the year 2050.

- ◆ A significant amount of this investment will also need to go towards electric energy generation, as well as to related infrastructure in order to enable new progress in terms of electrification and to further evolve the electric grid to become more capable of dealing with increasing electric energy volumes and variability coming into the grid from renewable energy sources (e.g. in regard to daily intermittency of the photovoltaic energy), and especially concerning the widescale electrification of transport. The International Renewable Energy Agency along the lines of the World Energy Transitions Outlook: 1.5°C Pathway, International Renewable Energy Agency, June 2021, projects similar estimates in terms of the required expenditures to be made in the current decade, resulting in annual spending of \$5.7 trillion until 2030, with an expected minor decrease in the period between 2030 and 2050.
- ◆ Finally, according to the Bloomberg New Energy Finance ([New Energy Outlook NEO, July 2021](#)), global investment needs will range from \$3.1 trillion to \$5.8 trillion each year until 2050. In accordance with these estimations, the goal of achieving climate neutrality globally by 2050 will also require an increase of ca. 2% of GDP in additional investments in energy and transportation infrastructure from the current levels (i.e. close to a figure of 2.5% estimated by the IEA). Because of the size and scope of the required investments, they will have major macroeconomic effects, both on a global scale as well as in the EU. These policies will thus be strongly conditioned by the macroeconomic situation in the world. In this regard, it is certainly crucial to point at major risks looming on the horizon.
- ◆ It should be also added that in accordance with the IEA Global Energy Review, CO₂ Emissions in 2021, the use of coal-fired energy generation was exacerbated by that time by a record-high natural-gas price surge in 2021. For most of the year 2021, the costs of operating existing coal plants in the European Union (and globally) were significantly lower than the costs of operating gas-fired power plants, which resulted in a strong economic pressure to shift from gas to coal in electricity generation, which has significantly increased global CO₂ emissions in Europe by as much as ca. 7% (in terms of coal-only generated energy, the output of CO₂ emissions rose in 2021 in Europe by ca. 16%, which was just by 1% smaller growth than witnessed in the US – yet this growth was still much less than the 21% decline in coal-energy generation that took place in 2020 in Europe).
- ◆ Furthermore, it should be stressed that Europe's total CO₂ emission has remained on a diminishing trend trajectory (despite the 2021 gas-price crisis and post-pandemic economic rebound), following the European hallmark achievements of 2020 of RES domination over all combustion fuels in the energy-mix (marking also a year in which advanced economies joint CO₂ emissions were for the first time lower than those of another single country – China), with an overall decrease in CO₂ emissions of 2.4% noted in 2021 in the EU in comparison to the level of 2019. The approximate levels for the overall CO₂ emissions in the EU were as follows: 2.8 GtCO₂ in 2019, 2.5 GtCO₂ in 2020 and 2.7 GtCO₂ in 2021, showing an obvious

post COVID-19 rebound in 2021 along with the gas-prices crisis but still below the emissions level of pre-pandemic 2019.

- ◆ It is widely expected, however, that the 2021 gas-price surges were of a minor scale if compared to potential and longer-term increases that may be caused by the war in Ukraine and the expanding of the necessary sanctions policy, which obviously mainly impact the energy market and will likely hamper further progress in the clean-energy transformation jointly with other negative economic factors. Western economic sanctions (significantly increased by the EU on 27th February 2022 and expanding towards a possible complete elimination of Russian hydrocarbons from the European energy system) may strongly impact gas prices far beyond the market situation observed in late 2021 and thus become a major factor in the necessity to rescale the climate policy in view of the dire challenges the world now faces with Russian aggression and risks for the conflict to upscale, along with strong global economic impacts that have only just begun. The European Commission, as well as national governments, are aware of these risks and develop adequate policies to minimize impacts of the global crisis triggered by the 2022 invasion of Russia on Ukraine (which already directly impacts global energy sector, but indirectly also other sectors such as, for example, agriculture that will further drive global inflation).

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Ilościowe szacowanie wpływu Europejskiego Zielonego Ładu na transformację energetyczną w Unii Europejskiej ze szczególnym uwzględnieniem przełomu w zakresie udziału energii odnawialnej w sektorze elektroenergetycznym

Streszczenie

W artykule omówiono wpływ polityki Europejskiego Zielonego Ładu na transformację energetyczną w Unii Europejskiej, która w 2020 roku osiągnęła historyczny przełom w zakresie produkcji energii elektrycznej – po raz pierwszy odnawialne źródła energii pokonały paliwa kopalne w miksie elektroenergetycznym. Osiągnięcie to, choć częściowo wynikające z okoliczności pandemii COVID-19 i szoku popytowego na energię elektryczną, jest przede wszystkim efektem Pakietu Czystej Energii dla wszystkich Europejczyków wdrażającego strategię Europejskiego Zielonego Ładu, mającą na celu lokowanie Unii Europejskiej jako światowego lidera zielonej transformacji, z ambicjami przekształcenia wyzwań klimatycznych w szansę na wzrost ekonomiczny oraz ustanawiania przykładu dla globalnej transformacji w kierunku neutralności klimatycznej w celu łagodzenia zagrożeń związanych z globalnym ociepleniem poprzez znaczące ograniczenie emisji gazów cieplarnianych. Bezpośrednimi skutkami znowelizowanej w 2018 r. Dyrektywy w sprawie odnawialnych źródeł energii (2018/2001/UE) i innych powiązanych polityk dotyczących czystej energii objętych Europejskim Zielonym Ładem, produkcja energii elektrycznej z węgla kamiennego i brunatnego spadła w 2020 r. aż o 22% (tj. –87 TWh), a produkcja energii jądrowej o 11% (–79 TWh), przy czym w mniejszym stopniu dotyczyło to gazu ziemnego (3%), podczas gdy odnawialne źródła energii dynamicznie rosły, przewyższając łączną produkcję energii elektrycznej z paliw kopalnych w całej UE. Wynik ten wskazuje wstępnie na sukces Europejskiego Zielonego Ładu, jednak trwałość tego rezultatu będzie podlegać weryfikacji w nadchodzących latach, zwłaszcza w świetle niedawnej poważnej destabilizacji sytuacji międzynarodowej, jak również wzrostu emisji w post-pandemicznym odbiciu gospodarczym.

SŁOWA KLUCZOWE: odnawialne źródła energii, transformacja energetyczna, Europejski Zielony Ład, polityka energetyczna UE, odnawialne źródła energii w sektorze elektroenergetycznym

