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Policies and energy consumption-driven trends facilitating development of the value chain for wind energy component manufacturing in Lithuania

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The paper is aimed at analysing policies and energy consumption related trends motivating the development of the value chain for wind energy component (WEC) manufacturing in Lithuania. A comparative literature review and statistical data (2000–2022) analysis were employed for the purpose. The policy overview revealed that investment, climate and energy policy, and related measures establish the preconditions for the entry of manufacturing enterprises into the value chain for WEC as they are creating the demand for domestic and foreign WEC. The results of statistical data analysis showed that from 2009 through 2019, the annual rate of primary energy consumption (PEC) decreased by an average of 0.5% per year, and in 2020 as much as 8.5% due to the COVID-19 lockdown in the European Union (EU). Though the EU countries are still dominated by fossil fuels and related carbon dioxide (CO_2) emissions are high (2.8 Gt in 2022), over the last decade, the use of renewable energy sources (RES) was growing rapidly, with a tenfold increase in solar energy and a threefold increase in wind energy consumption. As a clean energy technology, wind power plants (PPs) have the highest CO_2 emission reduction potential per MW; also, wind energy is among the cheapest sources of electricity production. Since the EU is a worldwide leader in installations of wind energy capacity and technology deployment, it provides a solid basis for further development. Currently, most of the off-shore plants are operating in the North Sea, but with the new wind parks in the Baltic, Black and Mediterranean seas as well as in the Atlantic Ocean, wind energy could meet more than 80% of electricity demand in Europe. The implementation of wind energy projects requires development of WEC manufacturing activities in EU countries.

Keywords: energy and climate policy; fuel consumption; emissions; energy prices; manufacture; renewable energy; European Union

INTRODUCTION

It is strategically important to invest rapidly and actively in the recovery and growth of the economy of both the European Union (EU) and Lithuania after the COVID-19 crisis, to take advantage of the situation and ensure a sustainable, innovative and high value-added national economies that attract investment, reduce dependence on foreign markets, shorten and diversify strategically important value chains and increase their resilience, create new jobs, ensure the extraction of 'green' energy and supply it to economic sectors. In order to solve the above-mentioned issues successfully in Lithuania, various solutions could be found.

Among them, eight EU member states – Austria, Estonia, Greece, Latvia, Lithuania, Luxembourg, Poland and Spain – appealed to the European Commission (EC) with a proposal to prioritise renewable energy industry not only by solving the consequences of the COVID-19 pandemic, but also by stimulating the EU economy and combatting climate change. The Lithuanian initiative proposed inclusion of the manufacture of two main renewable energy technologies – solar and wind – and energy storage technologies in the EU's strategic value chain. A stable and strong manufacturing sector and research and development efforts are essential for the EU to become a leader in the development of renewable energy technologies. By this initiative Lithuania considers joining wind industry not only as an energy producer but also as a manufacturer of wind energy components (WEC). Therefore, studies on Lithuania's possibilities and prospects in this field are important and relevant not only in the context of the country but also in that of the EU. It is expected that the said studies will give an additional impetus to Lithuanian manufacturers to participate in the value chain of the EU renewable energy industry, allow creating more jobs, and increase the added value created.

Research on WEC is ongoing in the EU and worldwide. Numerous studies analyse the components in the overall context of the value chain for the wind energy [1]. The reports provide an overview of many renewable energy technology supply chains, focusing on the current market for renewable energy technologies and components and the position of EU companies and organisations, as well as on the strengths and weaknesses of the EU, highlighting key EU companies and their competitors outside the EU [2]. The studies also discuss the impact of COVID-19 on the wind turbine supply chain and mitigation strategies for turbine manufacturers and component suppliers [3]. They analyse the conditions under which developers support the growth of wind energy industry by selecting local suppliers rather than selecting suppliers from the global market or from within their own country [4], developing a value chain model for the wind energy industry and comprehensively analysing the factors that have a significant impact on it, using a modified Diamond model [5]. Until [6] and [7] published their research results on the competitiveness of companies manufacturing WEC and on related issues of labour productivity, no research has been carried out on WEC manufacturing in Lithuania. Lithuanian researchers [8–14] focused more on the development of the country's wind energy sector, creating a framework for the development of onshore and offshore wind energy techniques, economy, environment, and policy making. In the context of all these studies, the present research is distinguished by the scope of the scientific problem, the variety of methods used to solve it, and by the originality of the data sources for the explanation of the processes taking place and the identification of patterns. In detail, it focuses on underlying assumptions justifying the need for development of the value chain for WEC manufacturing in the country.

The article seeks to answer the scientific question as to why the Government of Lithuania calls for the development of the value chain for WEC manufacturing in the country and aims to justify the global, regional and national policies and energy demand-driven assumptions for development of the value chain for WEC manufacturing in Lithuania.

Such theoretical methods as systemic analysis, comparison and generalisation, including literature review and statistical data analysis, were applied in this research.

The paper overviews relevant climate and energy policies, discusses the global fuel and energy consumption, presents GHG emission problematics, analyses the trends in global fuel and energy prices, and assesses the prospects for the renewable energy development and the potential of wind energy.

CLIMATE AND ENERGY POLICY

In 2016, the world reached the Paris Agreement [15], whereby 196 countries of the world agreed to take action to keep the global average temperature increase below 2°C (compared to pre-industrial levels) and with the necessary funding to promote development with low greenhouse gas (GHG) emissions. In March 2020, the European Commission (EC) presented its long-term strategy setting out a vision for a climate neutral EU economy by 2050 [16].

In line with the Paris Agreement [15], EU member states endorsed the Climate Change and Energy Framework 2020–2030. It sets out the EU's key objectives for climate change governance and energy as follows [17]:

- to reduce GHG emissions by 40% in 2030 compared to 1990 levels (a 20% target was set for 2020);
- to increase the share of energy from RES by 32% in 2030 compared to 1990 (20% in 2020);
- to reduce energy consumption by 32.5% in 2030 compared to 1990 (20% in 2020).

At the end of 2019, the EC published its communication 'The European Green Deal' [18], which is a growth strategy aiming at transforming the EU society in such a way that resources are used efficiently, the economy is competitive, and growth is decoupled from resource use. Such an economy should have no net GHG emissions, i.e., the EU must become climate neutral by 2050. 'The European Green Deal' includes the 'European Industrial Strategy' (10 March 2020) [19], the 'Roadmap for a Circular Economy' [20], the European Commission communication 'Stepping up Europe's 2030 climate ambition: Investing in a climate-neutral future for the benefit of our people' (17 September 2020) [21], and the 'Marine Renewables Strategy' [22].

The 'European Industrial Strategy' [19] sets out actions that will support all European industrial players to make European industry globally competitive, climate-neutral, and digitally driven. To this end, energy-intensive industries will be modernised by reducing their dependence on fossil fuels, increasing energy efficiency, ensuring low-CO_2 energy supply, reviewing competition rules, and increasing Europe's industrial self-sufficiency. 'The Circular Economy Action Plan' [20] will aim to bring to the EU durable, reusable, repairable, and recyclable products as well as products that use recycled materials instead of raw materials. The focus will be on the electronics and information technology (IT) and plastics sectors. Companies representing these sectors will be required to produce durable products, improve waste collection and management, and meet requirements for the recycled content of materials. The communication on Europe's broader 2030 climate ambition calling for investing in a climate-neutral future for people [21] points out that the EU will not be able to meet its 2050 targets and commitments under the Paris Agreement using the current EU policy framework alone. Continued implementation of the current legislation would allow the EU to reduce GHG emissions by 60% by 2050. Instead of leaving more work to future generations, the EU will follow a different path and aim for a 55% reduction in GHG emissions by 2030 compared to 1990 levels. Renewable energy will play a key role in the implementation of 'The European Green Deal' and in achieving the goal of neutralising climate impacts by 2050. The EU's 'Marine Renewable Energy Strategy' [22] proposes to increase Europe's offshore renewable energy capacity from the current 12 GW to 60 GW in 2030 and to 300 GW in 2050. By 2050, the capacity of ocean energy and other new technologies (including floating wind and solar) should reach 40 GW. All this shows that 'The European Green Deal' supports the formation and development of the value chain for WEC.

Lithuania has agreed to take binding action at the national level to the extent necessary to meet its emission commitments. As part of the Paris Agreement [15], Lithuania has committed to a collective reduction of at least 40% in 2030 compared to 1990 [23] and agreed to publish long-term strategy for low GHG development. In connection with the above-mentioned obligations, Lithuania prepared and submitted to the EC an integrated National Energy and Climate Action Plan [24] in 2018. The plan [24] sets out country's national targets for contributing to the EU's energy and climate objectives in 2030, as well as related policies and measures. Lithuania intends to increase the share of RES in final energy consumption to

45% by 2030. Wind energy is also estimated to remain the main source of electricity generation. The document states that the strategy will 'stimulate investments in technological development, production improvement, technology acquisition and competence centre development for solar, wind, biomass, biofuels, and other RES production by means of tax incentives'. The document discusses the development of electricity generated from renewable energy sources (RES-E) in the Baltic Sea and the need to build a 330 kV substation offshore, a new cable line, and new 330 kV transmission lines in order to connect to the transmission grid the planned RE park in the Baltic Sea.

The country prepared the 'Roadmap for the Digitisation of Lithuanian Industry during 2020–2030' [25], which is a roadmap for the implementation of industry digitisation initiatives stemming from Industry 4.0 initiatives that respond to the need for a productive and competitive manufacturing sector. Digitalisation is recognised as a way of reducing the country's dependence on outsourcing the production of low value-added goods, the dominance of low-technology small and medium-sized enterprises (SMEs), an unbalanced labour market, etc. The digital transformation is leading to technological breakthroughs in such areas as robotics, the Internet of Things, artificial intelligence, cybersecurity, and energy systems, and at the same time closely related to energy and climate objectives.

Lithuania is implementing the 'Investment Promotion and Industrial Development Programme' [26]. The objectives of the programme, such as the development of free economic zones and industrial parks, improvement of the investment environment, modernisation and development of industry, networking and industrial cooperation, promotion of more efficient use of raw materials and energy, etc. facilitate and could in the future strengthen the participation of Lithuanian manufacturing companies in the value chain for WEC.

In summary, Lithuanian and EU strategies and action plans in the context of 'The European Green Deal' and the related and planned transformations are favourable to the participation of Lithuanian manufacturing enterprises in the value chain for WEC. Although only slightly, recent policy measures are already creating the preconditions for the entry of manufacturing enterprises into the value chain for WEC, as they are creating the demand for domestic and foreign WEC.

GLOBAL FUEL AND ENERGY CONSUMPTION

Energy, which has a significant impact on economic growth rates, economic structure and social well-being, is an integral part of modern society. It is needed not only for the material well-being of industry, trade, and society but also ensures personal comfort and mobility of the population. Global

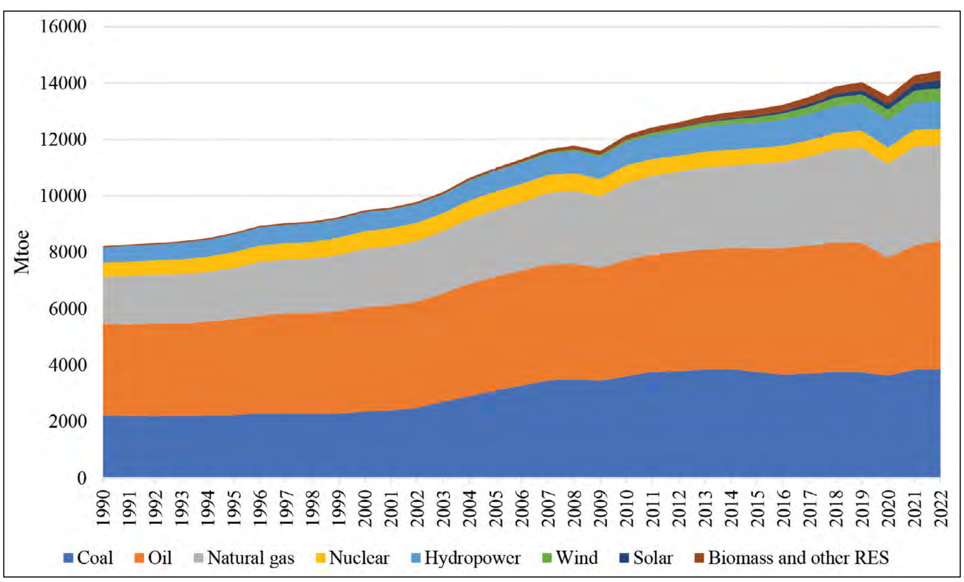

Fig. 1. Trends in global primary energy consumption, 1990–2022, Mtoe [27]

energy consumption is constantly increasing due to the growing population and increasing needs. In the last decade (2009–2019), the average annual growth rate of global primary energy consumption (PEC) was about 2%. In 2020, PEC fell by 4.3% due to the global COVID-19 pandemic, which was the first decrease in energy consumption since 2009. However, in 2021, recovering from the COVID-19 pandemic, the world's energy demand increased by 5.5% and continues to grow. In 2022, global energy demand was 14,430 Mtoe. Global trend in PEC between 1990 and 2022 is presented in Fig. 1.

As shown in Fig. 1, the global PEC structure is dominated by fossil fuels (85%). The production and consumption of fossil fuels poses major environmental problems. One of the main problems associated with the use of fossil fuels is GHG emissions, which cause global warming and climate change. Fossil fuel consumption also results in emissions of air pollutants that harm ecosystems and have a negative impact on human health. In order to reduce environmental problems, the consumption of RES is growing rapidly in the world. Between 2009 and 2022, an average annual growth rate of RES consumption in the world was as high as 5.7%, but fossil fuels still play a major role in the global PEC balance.

In the last decade, the PEC of the EU countries accounted for only about 10% in the global energy structure. The fight against climate change is one of the main priorities of the EU, therefore, in order to mitigate climate change, the EU is implementing ambitious targets for reducing GHG emissions. The first EU climate and energy policy package was adopted in 2008 and set targets for 2020, including a 20% reduction in GHG emissions by 2020 compared to the 1990 level. Already in 2018, the amount of GHG in the EU was reduced by 23.2% [28]. The EU countries managed to achieve this ambitious goal by intensively implementing various measures leading to a decrease in energy needs and promoting the use of RES. So, in the EU countries, the PEC decreased by an average of 0.5% per year between 2009 and 2019, and as much as 8.5% in 2020 due to the lockdown controlling the COVID-19 pandemic. As the total PEC decrease, the use of RES is growing rapidly (on average 5.6% per year), but the EU countries are dominated by fossil fuels too. The trends and prospects of fossil fuel and RES consumption are analysed below.

a. Trends and perspectives of fossil fuel consumption

In the last decade, the consumption of fossil fuels in the world increased exponentially from 10,584.8 Mtoe in 2009 up to 12,302.8 Mtoe in 2019 (Fig. 2). After the global economic crisis, the average annual growth rate of fossil fuel consumption reached 1.7%. In 2020, fossil fuel consumption fell by 5.5% due to a significant reduction in demand during the global pandemic, but returned to pre-pandemic level during 2021. In 2022, 12,379 Mtoe of fossil fuels were consumed.

As shown in Fig. 2, the consumption of natural gas grew the fastest (average annual growth rate of

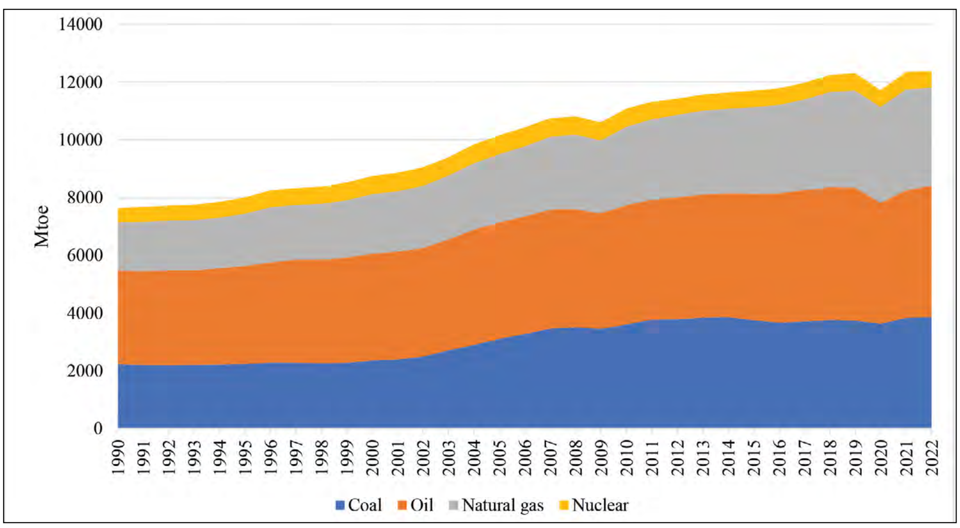

Fig. 2. Trends in global fossil fuel consumption, 1990–2022, Mtoe [27]

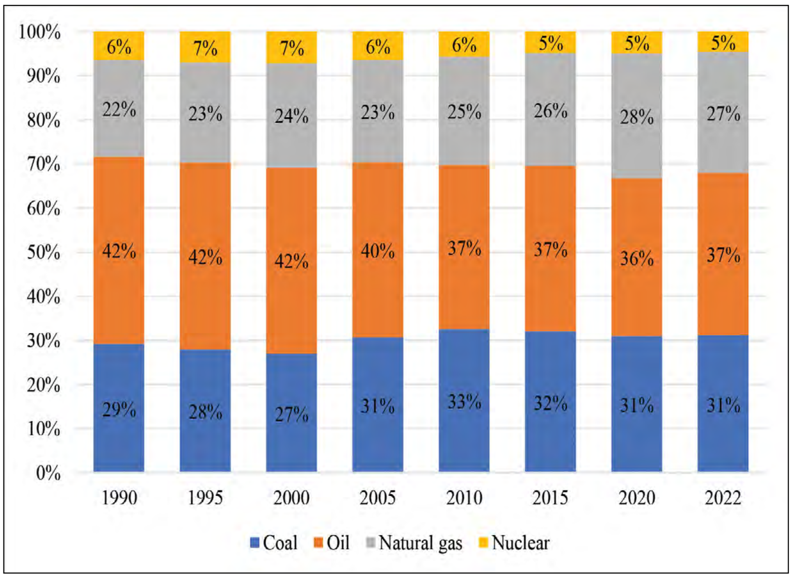

Fig. 3. Structure of fossil fuel consumption in the world,1990–2022, % [27]

3.2%), which was mainly caused by the transition to cleaner fossil fuels, i.e., replacement of coal with natural gas and a significant growth of natural gas demand in China and the United States [29]. In 2020, the demand for oil and its products decreased the most (9.5%), but the structure of fossil fuel consumption in the world is dominated by oil and its products (Fig. 3).

As presented in Fig. 3, oil and its products accounted for 37%, coal for 31%, natural gas for 27%, and nuclear energy for 5% in the structure of fossil fuel in 2022. Coal still remains the world's second largest energy resource. Coal also continues to be the main source of electricity generation in the world (about 36% of electricity is produced using coal), although in 2019 more electricity was produced from RES and nuclear than from coal. The share of natural gas in the structure of fossil fuel consumption is growing rapidly, taking into account the fact that burning natural gas emits half as much CO_2 per unit of energy compared to coal, and about 25% less than burning oil products. Utilising natural gas as a fuel source results in minimal emissions of sulphur dioxide and nitrogen oxides, in addition to lower levels of CO_2.

While the world's total fossil fuel demand grew between 2009 and 2022, fossil fuel consumption in the EU countries decreased by an average of 1.5% a year. Particularly, it decreased by as much as 10.5% in 2020 and amounted to 1,105.3 Mtoe in that year (Fig. 4). The fossil fuel demand almost returned to the pre-pandemic level during 2021, but in 2022 it again decreased by 4.4% to 1,121.7 Mtoe mainly due to climate conditions and the war in Ukraine.

As presented in Fig. 4, coal consumption decreased the most in the EU countries (an average annual rate of decrease was 3.4%), which was largely caused by the implementation of climate change mitigation goals.

Figure 5 presents the structure of fossil fuel consumption in the EU between 1990 and 2022. It shows that the comparative weight of coal decreased the most from 27% in 1990 to 15% in 2022, but the share of natural gas increased from 18% in 1990 to 26% in 2022. Historically, the structure of fossil fuel consumption is dominated by oil and its products (about 44%).

Trends in fossil fuel consumption in Lithuania hardly changed over the past decade and remained stable (about 5 Mtoe a year). In 2020, fossil fuel consumption decreased by only 1.4% compared to 2019. Such a small decline in fossil fuel consumption was caused by a small decline in economic activity. The decline of the Lithuanian economy in 2020 was one of the smallest in the EU countries, which was caused by the small first wave of the pandemic, the successful activity of exporters, and the low dependence of the economy on the most limited and affected activities by COVID-19. In 2022, however, fossil fuel consumption decreased by as much as 10.0%

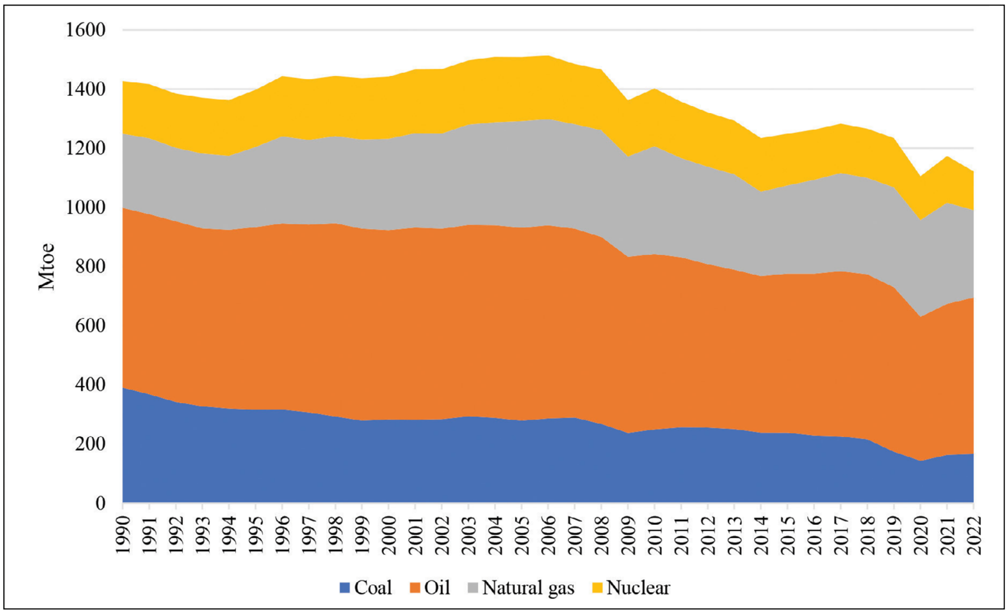

Fig. 4. Trends in fossil fuel consumption in the EU, 1990–2022, Mtoe [27]

compared to 2021 due to significant increase in energy prices following the outbreak of the war in Ukraine and a considerably warmer winter.

The implementation of the Paris Agreement [15] necessitates phasing out from fossil fuels in the energy sector and switching to the use of RES and increase energy efficiency (EE). EE is one of the most important tools for sustainable economic growth worldwide, but to limit global warming to 1.5°C, global fossil fuel production must begin to decline immediately and at a rapid pace.

In summary, it can be stated that, although historically the functioning of the economies of the world, the EU, and Lithuania was based on extensive consumption of fossil fuels, the adopted international agreements in the field of climate change are an important factor that will influence the decrease in the consumption of fossil fuels in the future, which, as the energy needs of society grow, will be changed to the use of environmentally friendly fuels, including wind energy.

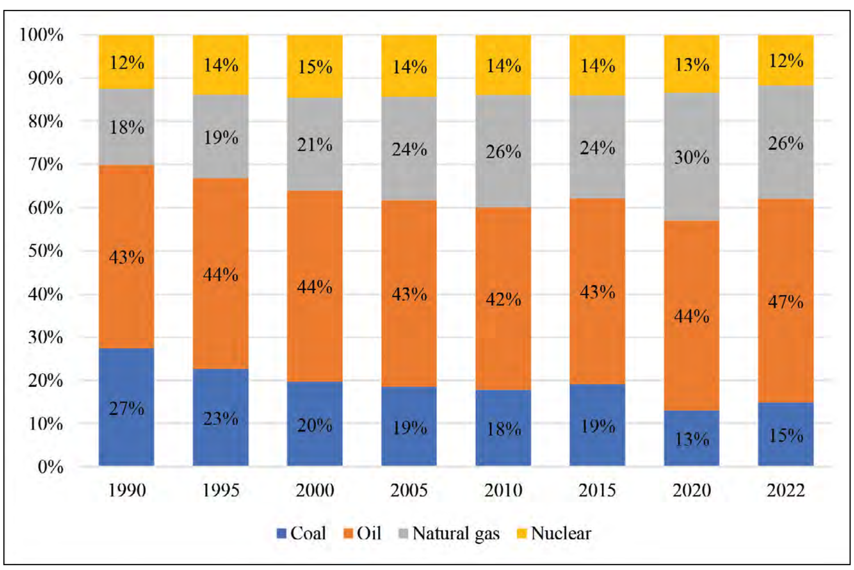

Fig. 5. Structure of fossil fuel consumption in the EU, 1990–2022, % [27]

b. Trends and perspectives of renewable energy consumption

In order to meet the growing energy needs and solve the problems of climate change and air pollution, RES plays an increasing role in the world. In the last decade, the growth rates of RES consumption reached 6.3% per year (Fig. 6).

As shown in Fig. 6, the use of solar and wind energy has seen the fastest growth in the world over the last decade. Solar energy increased by almost 40 times, and wind energy sixfold. The use of biomass and other RES increased by 6.1% a year, and hydropower by 1.4% a year.

Hydropower with a share of 47.0% in 2022 dominates in the structure of RES consumed in the world, but the rapid development of other RES between 2010 and 2022 significantly changes the structure (Fig. 7).

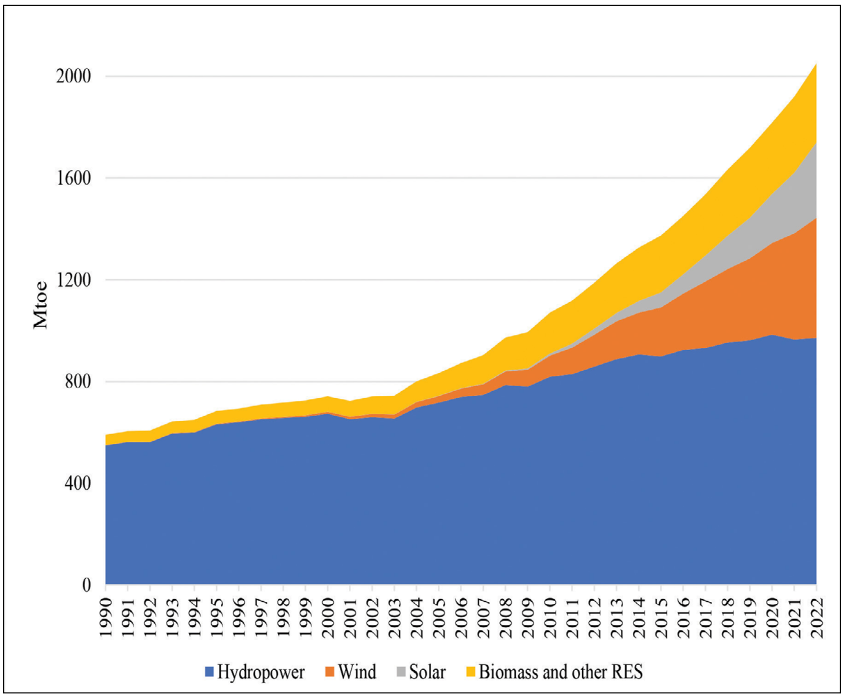

Fig. 6. Trends in RES consumption in the world, 1990–2022, Mtoe [27]

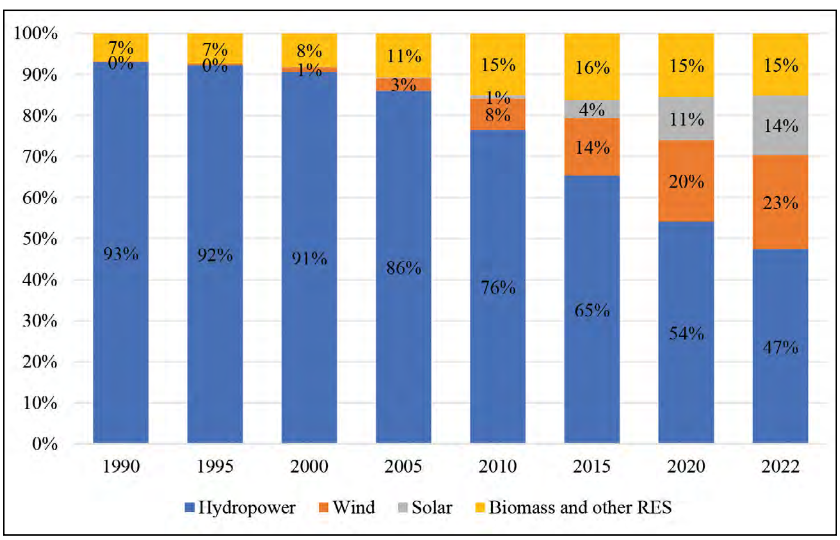

Fig. 7. Structure of RES consumption in the world, 1990–2022, % [27]

As shown in Fig. 7, the contribution of wind energy to the global PEC is becoming more and more significant (23% in 2022). According to the preliminary data of the World Wind Energy Association [30], the world reached a new wind installation record in 2020, i.e., 93 GW of new wind power plants (PPs) were installed, and this is by 50% more than in 2019. The total installed capacity of all wind PPs in the world reached 743 GW. These wind PPs produce 7% of the world's total electricity [30].

In the EU countries, in the last decade, an average growth rate of RES consumption reached about 6% per year (Fig. 8); in 2020, RES consumption increased by 8.3% compared to 2019.

Figure 8 shows that the use of solar and wind energy grew the fastest across the EU. The use of solar energy increased by ten times, and of wind energy by three times. Such a rapid growth changed the structure of RES consumption (Fig. 9).

As shown in Fig. 9, with a share of 66%, hydropower dominated in 2005 in the EU countries, but its share decreased by almost three times to 23% in 2022. The share of wind energy increased to 35%, solar energy to 17%, and biomass and other RES to 24% in 2022.

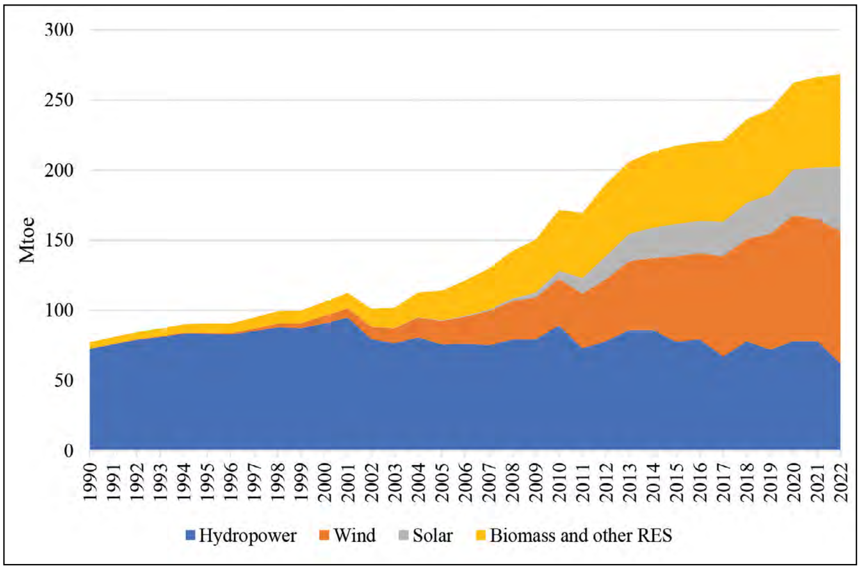

Fig. 8. Trends in RES consumption in the EU countries, 1990–2022, Mtoe [27]

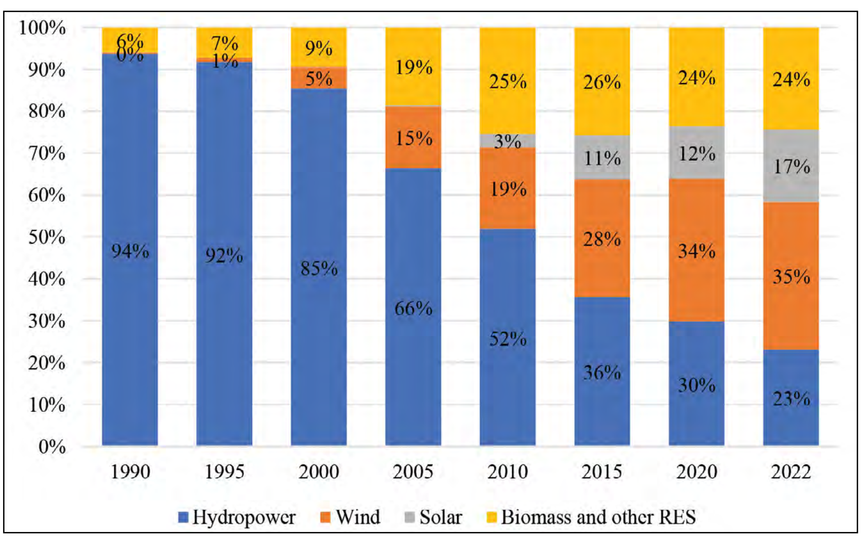

Fig. 9. Structure of RES consumption in the EU countries, 1990–2022, % [27]

The EU is a world leader in installations of wind energy capacity and technology development. Total installed capacity of wind PPs in the EU countries reached 220 MW in 2020, which accounted for 29.6% of the world's total installed capacity in wind PPs [31]. In the EU countries, 10.5 GW of wind PPs was installed in 2020, but this was 6% less than in 2019. The rate of deployment of wind PPs has slowed down due to disrupted raw material supply and strict pandemic restrictions. About 16% of the EU's total electricity is produced by RES.

In Lithuania, an average growth rate of renewable energy consumption reached about 4.4% a year between 2010 and 2022. In 2022, 1,790 ktoe of RES was consumed (Fig. 10).

As in other EU countries, the use of wind and solar energy grew the fastest. The use of wind energy increased by as much as seven times. Such growth is changing the structure of RES consumption in Lithuania (Fig. 11).

According to the information provided in Fig. 11, the structure of renewable energy use in

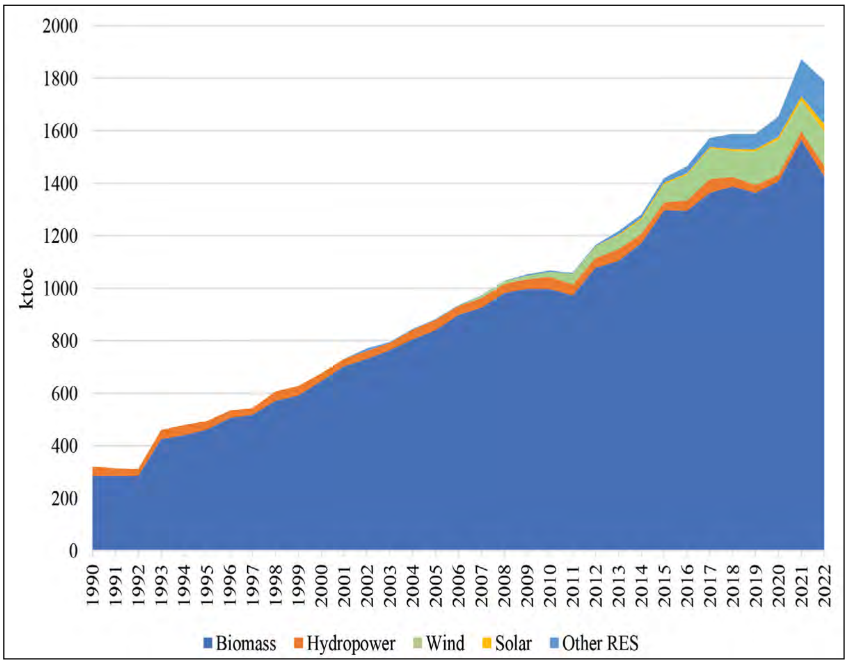

Fig. 10. Trends in RES consumption in Lithuania, 1990–2022, ktoe [32]

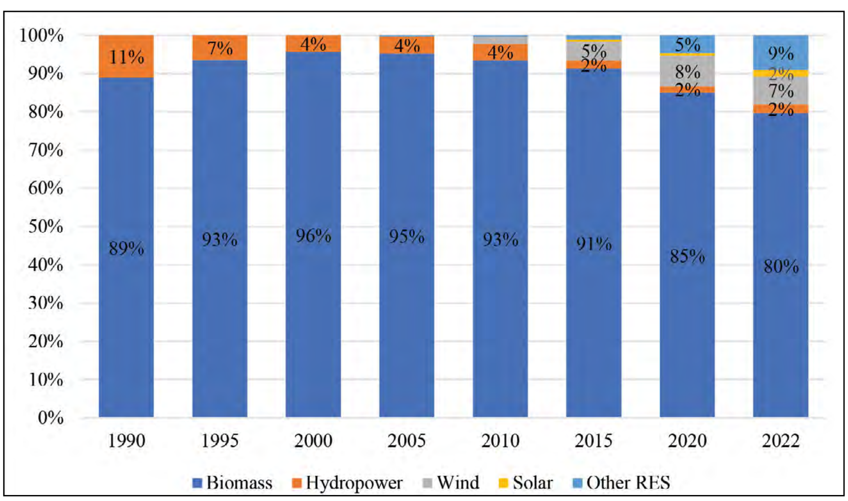

Fig. 11. Structure of RES consumption in Lithuania, 1990–2022, % [32]

Lithuania is dominated by biomass, but the share of wind energy is increasing significantly. In 2022, biomass accounted for 80%, wind energy for 7%, hydropower for 2%, other RES for 9%, and solar energy for 2% of the RES consumption structure.

Electricity production using RES (RES-E) is growing rapidly in Lithuania (Fig. 12).

Figure 12 shows that the amount of energy produced by wind PPs and its share in the electricity production structure has been steadily increasing. In 2022, power plants using RES produced almost 3 TWh of electricity in Lithuania, more than half of which was produced by wind PPs (1.6 TWh). In 2022, total installed capacity of wind PPs amounted to 671 MW [33]. Wind PPs produced 36% of all electricity produced in Lithuania [34].

In summary, in order to reduce climate change and implement 'The European Green Deal', the transition to the use of RES must be even faster than in the last decade. In Lithuania, it is also necessary to continue to increase the share of RES in the overall energy system, primarily using wind energy.

GREENHOUSE GAS EMISSIONS TRENDS

Although the use of RES is rapidly rising and various other climate change mitigation measures are being applied, the consumption of fossil fuels is growing at the same time, which is caused by the growing energy demand due to economic development and growth in world population. The increasing consumption of fossil fuels in the world affects the increase in GHG emissions (Fig. 13).

In order to stabilise the concentration of CO_2 in the atmosphere, it is necessary to significantly reduce CO_2 emissions; however, as it is presented in Fig. 13, global CO_2 emissions from fossil fuel grew by an average of 1.7% per year between 2009 and 2019. In 2020, global CO_2 emissions fell by 5.5%, but this reduction was short-lived due to the pandemic-induced economic stagnation and reduced energy consumption. During the last several years, GHG global GHG emissions increased by 1–5% a year.

The EU is showing global leadership in the fight against climate change and setting more ambitious climate change mitigation targets in response to GHG emission trends. In the EU countries, an increasing use of RES and various climate change mitigation measures are leading to a downward trend in GHG emissions. As the world's total CO_2 emissions increase, CO_2 emissions due to fossil fuel in the EU countries decreased by 1.5% a year in the years 2009–2019 (Fig. 13). Compared to the 1990 level, CO_2 emissions from fuel decreased by 25% in the EU countries in 2019. On 15 January 2020, the European Parliament welcomed the EU's plan to become climate neutral by 2050 and proposed a legal commitment to reduce GHG emissions by 55% by 2030, compared to the 1990 level (the previous target was 40%). On 30 June 2021, the European Parliament approved the new Law on Climate, which legitimised the political commitments

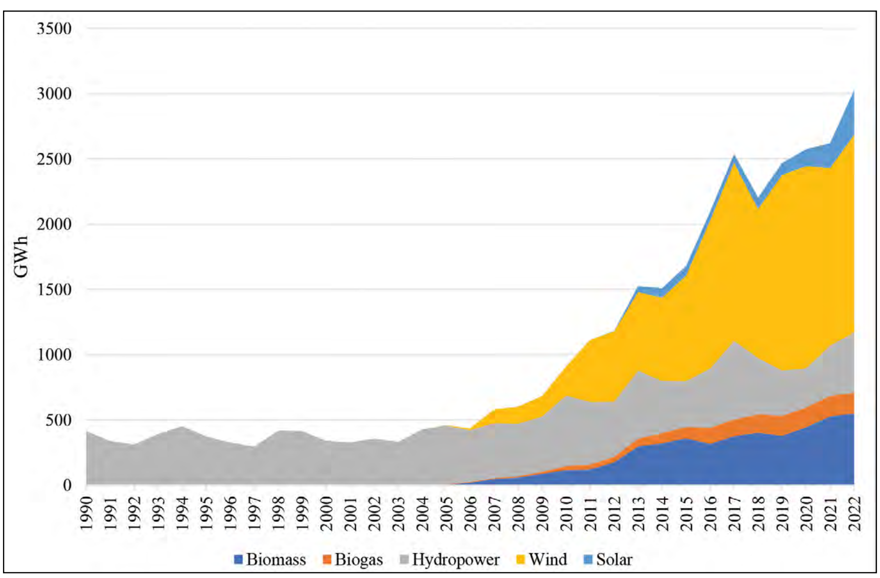

Fig. 12. RES-E production volume in Lithuania, 1990–2022, GWh [32]

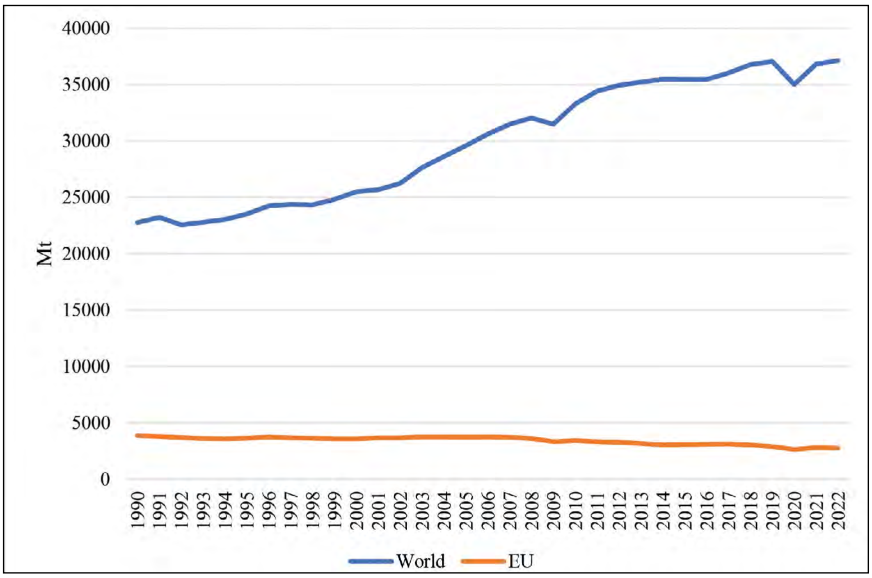

Fig. 13. Trends in CO_2 emissions from fossil fuel in the world and the EU countries, 1990–2022, Mt [27]

of 'The European Green Deal' [35]. The EU has committed to ensure a neutral impact on the climate by emitting not more GHG than is collected or absorbed and will also seek to ensure that after 2050 the EU would remove more GHG from the environment than it emits. The CO_2 emissions from fossil fuels in the EU countries decreased by two times the global average in 2020, i.e., 10%. Such a decrease in figures was caused not only by the strict quarantine due to the global pandemic, but also by other measures to reduce climate change, such as the replacement of coal with gas and the development of the use of RES for electricity production. In 2022, GHG emissions reduced by 1.6% to 2 762 Mt.

Although Lithuania emits a relatively small amount of GHG into the atmosphere, the country's contribution is important in the implementation of international climate change agreements,

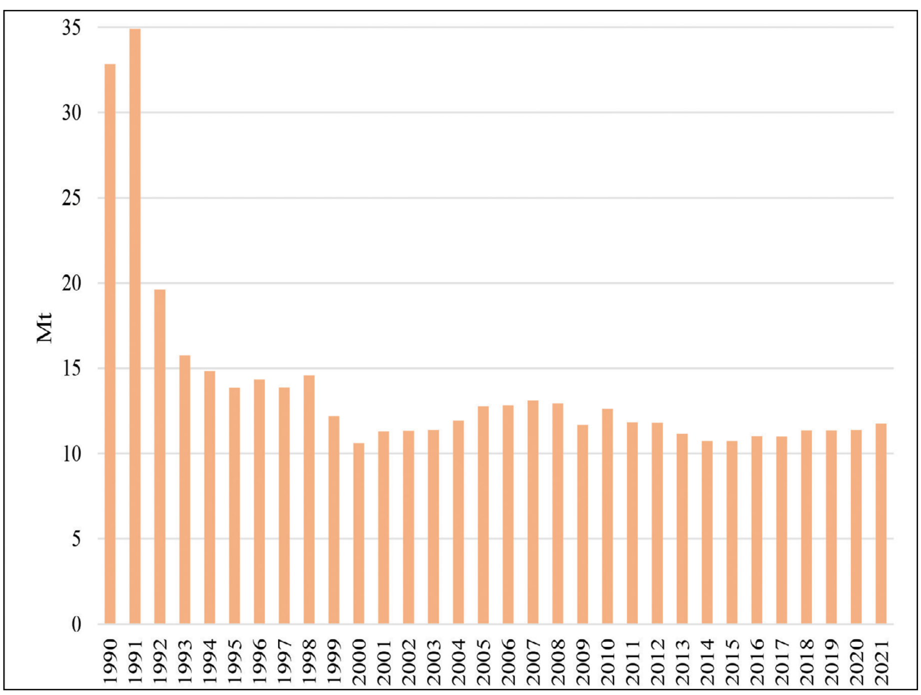

Fig. 14. Trends in CO_2 emission emitted from fossil fuel, 1990–2021, Mt [36]

including the United Nations General Convention on Climate Change (UNFCCC), the Paris Agreement, and the climate change mitigation goals enshrined in EU legislation. Lithuania's CO_2 emissions due to fossil fuel decreased three times compared to the 1990 level (Fig. 14), but this was influenced by economic decline after the collapse of the former Soviet Union, which was accompanied by complex changes in all sectors of the Lithuanian economy, including the energy sector. From 2009 to 2019, CO_2 emissions due to fossil fuel decreased by only 0.3% per year in Lithuania (Fig. 14), but they increased by 0.3% in 2020. In 2020, an increase in CO_2 emissions was caused by increased production of electricity using natural gas and a decrease in the import of electricity, as the significant decrease in the price of natural gas allowed Lithuanian power plants to ensure a competitive price in the electricity market.

In order to reduce climate change in the near future, global use of RES should be faster and more intensive in changing the use of fossil fuels. As a clean energy technology, wind PP has the highest CO_2 emission reduction potential per MW [37]. Currently, 743 GW of wind PPs installed in the world allows to avoid more than 1.1 billion tons of CO_2. However, the analysis shows that in order to achieve CO_2 neutrality, it is necessary to ensure faster deployment of wind PPs around the world.

In this context, it is important to create, develop, and participate in value chains for WEC, which would contribute to a faster development of renewable energy not only in Lithuania, Europe, but also globally and thus facilitate a path towards climate neutrality for the countries.

TRENDS IN GLOBAL FUEL AND ENERGY PRICES

Demand for WEC is formed and development rate of the value chain for WEC is dictated by prices of fossil fuels (Figs 15–16) and electricity (Fig. 18), which are volatile in short-term and increasing in long-term, as well as low and further decreasing prices of renewable energy, measured by an indicator of levelised cost of electricity (LCOE) (Figs 17–18).

As presented in Fig. 15, between 1990 and 2020, natural gas prices were increasing in many countries around the world, except the United States and Canada. In the countries, the period of low prices began around 2009 due to the development of shale resources and accelerated

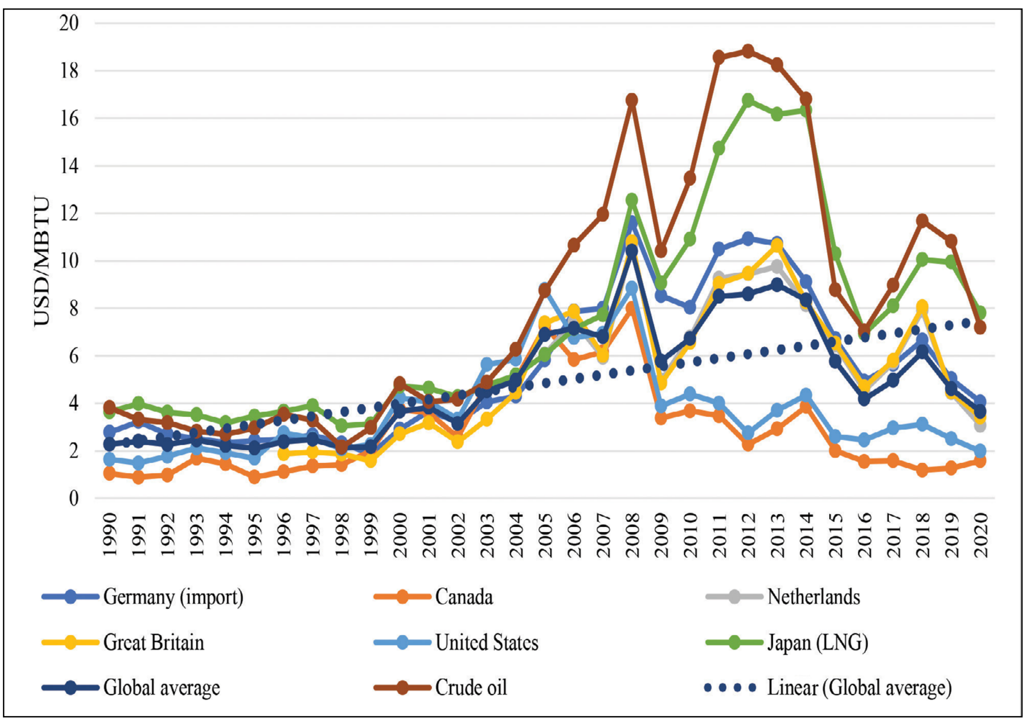

Fig. 15. Trends in natural gas price during 1990–2020, USD/MBTU [27]

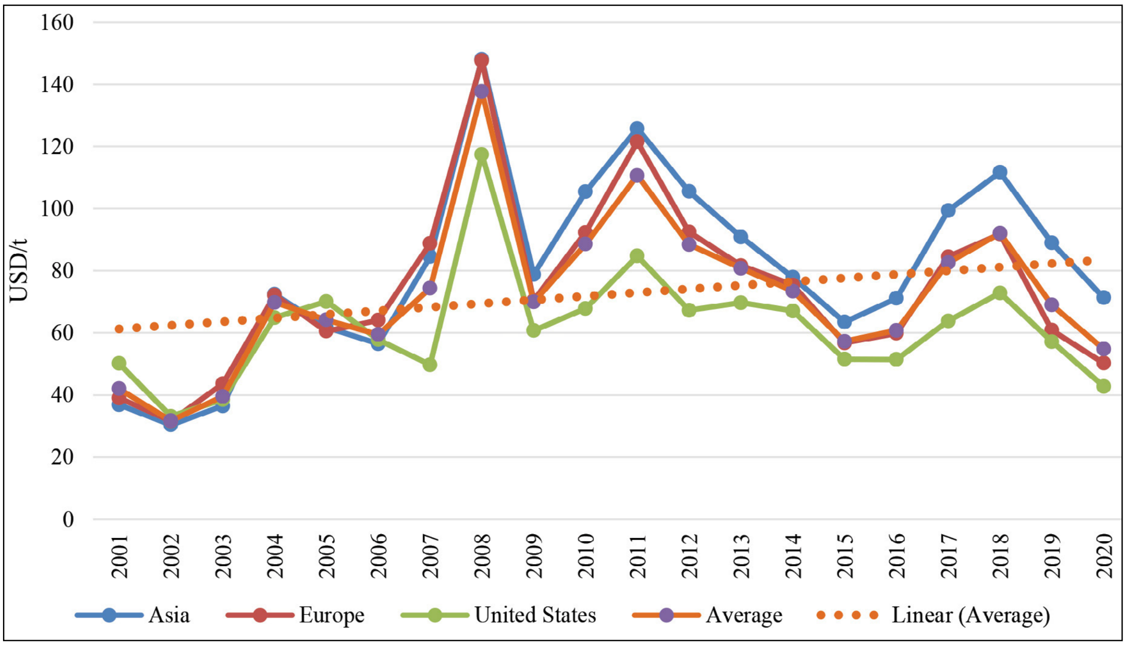

Fig. 16. Trends in coal prices, 2001–2020, USD/t [27]

with low crude oil prices from 2013 continued into 2020 [38]. In Europe and Asia, prices have only started to decline since 2013, when crude oil started to become cheaper, but they remain volatile [38]. High volatility of natural gas prices affects the price of energy for the end user. Prices become unstable.

Coal prices tend to rise (Fig. 16). As can be seen from the information in Fig. 16, the average global coal price increased by about 30% during the analysed period. The price of coal in Asia almost doubled, and in Europe it increased by a third. Over the last three years, the price of coal, driven by falling natural gas prices and efforts to improve air quality and energy efficiency, tended to decline on global markets. Future coal prices will depend on China's structural reform of the coal industry [39].

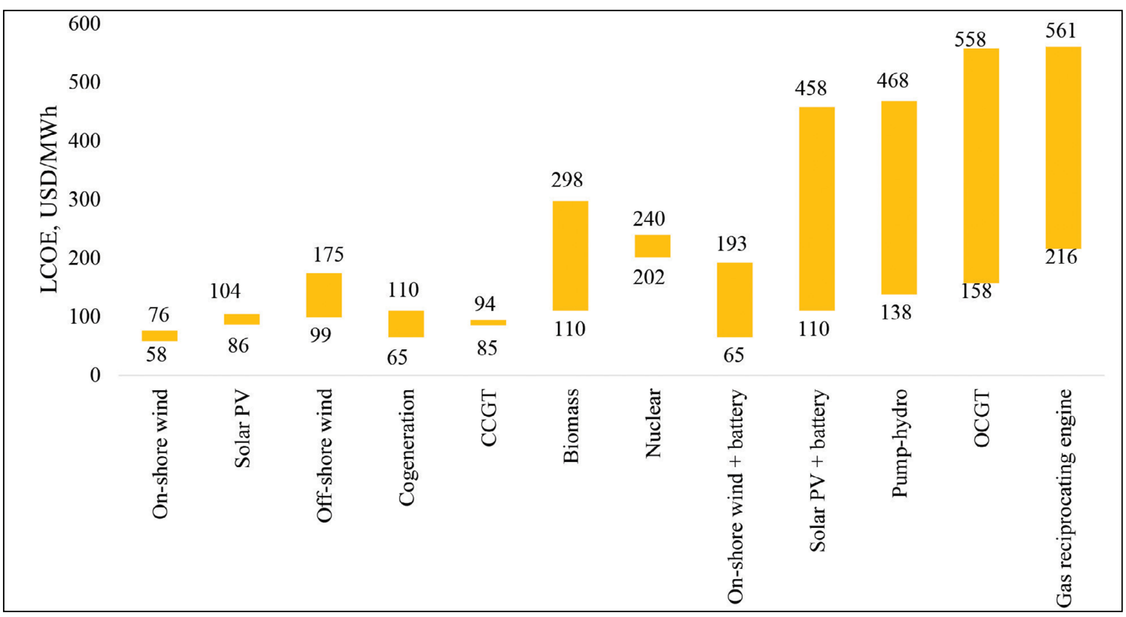

Fig. 17. Levelised cost of electricity in Europe in the first half of 2018, USD/MWh [40]

Today, wind energy is the cheapest source of electricity production in many countries around the world. Unsubsidised on-shore wind energy is cheaper than any other energy source, including traditional energy generation sources such as coal and gas (Fig. 17). According to [40], the LCOE of on-shore wind PP in Europe ranges from 58 USD/MWh to 76 USD/MWh, while the LCOE of electricity produced in cogeneration mode is about 45% higher. In comparison, the LCOE of electricity produced in a nuclear power plant can be even several times higher than the LCOE of onshore wind PP and reach 240 USD/MWh.

As the prices of RES technologies decrease (USD/kW), RES becomes cheaper (USD/kWh) (Fig. 18).

Figure 18 shows that the LCOE of solar PV is decreasing the fastest, although such electricity remains more expensive than electricity produced by on-shore wind PP. The latter LCOE halved over the decade and can reach around 0.039 USD/kWh. LCOE of off-shore wind PP is currently among the highest (0.084 USD/kWh), but trend suggests that LCOE could continue to decline in the future.

In summary, changing and increasing prices of fossil fuels and such electricity, as well as relatively low and further decreasing costs of electricity produced by RES, justify the need for the value chain for WEC creation and development in the world, including Lithuania.

PERSPECTIVES OF THE DEVELOPMENT OF WIND ENERGY AND ITS COMPONENTS

According to the data of the European Wind Energy Association, an additional 105 GW of wind PPs should be installed by 2025 in the EU countries, which would implement the goals set out in the National Energy and Climate Action Plans. Of this capacity, 70% should be installed on-shore [31]. In order to reduce GHG emissions in the EU countries by 55% compared to the 1990 level, the development of wind PPs should be even faster. There should be faster development of wind PPs both on-shore and off-shore.

Off-shore wind energy is considered one of the main instruments for the Paris Climate Change Agreement and for the implementation of goals of 'The European Green Deal' until 2050 [42]. In 2020, total installed capacity of off-shore wind PPs amounted to 25 GW in EU [31]. The off-shore wind energy market is currently concentrated in the territorial waters of several countries in the North Sea, including the UK (44% of total capacity), Germany (34%), Denmark (7%), Belgium (6.4%), and the Netherlands (6%).

Europe dominates in terms of technology development and production volumes; therefore, the EU's total off-shore wind PP capacity accounts for about 80% of the global wind PPs

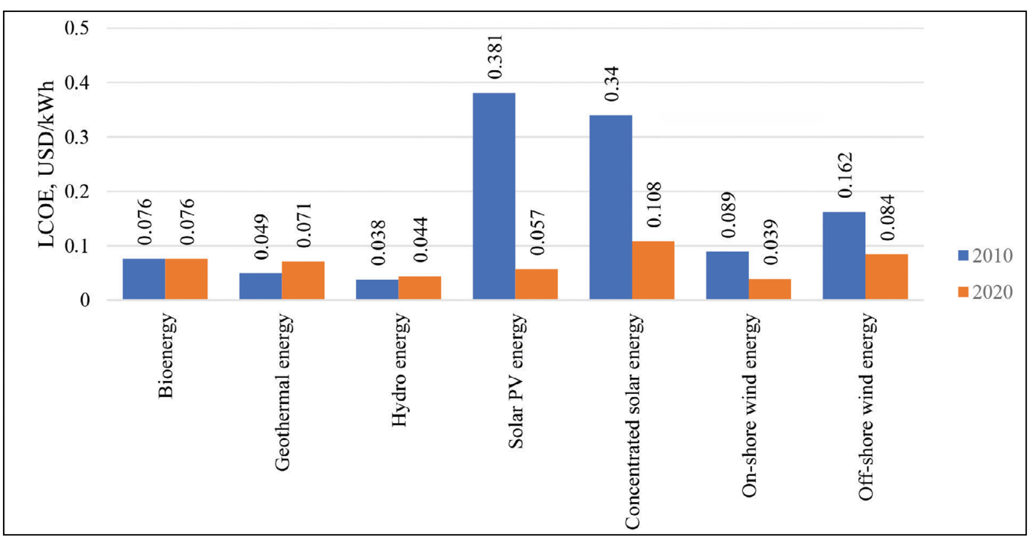

Fig. 18. Levelised cost of energy produced by RES technologies, 2010–2020, USD/kWh [41]

capacity. European companies are leaders in the development of various technologies, including floating sea wind PPs, ocean (wave and tidal) energy technologies, and floating solar PPs.

In order to implement the EU goal to become climate neutral by 2050, in 2020 the European Commission adopted the Marine RES Strategy [22], which defines the goal of increasing the power of off-shore wind PPs to at least 60 GW by 2030 and up to 300 GW in 2050. In addition, the EC seeks to increase floating wind and solar power capacity up to 40 GW by 2050. Currently, all commercial off-shore wind farms are built using bottom-mounted wind technologies, but in future, rapid development is foreseen in floating wind technologies, as most of European off-shore wind energy potential lies at depths greater than 60 m.

In the Marine RES Strategy [22], the highest deployment targets are set for commercially advanced off-shore wind technologies (both bottom-mounted and floating). In these sectors, EU countries have acquired technological, scientific, and industrial experience and have created a capable value chain for WEC from the production of devices to their installation. In the EU's off-shore wind energy sector about 210 000 qualified jobs were created already in 2018 [43]. Their number should grow rapidly, implementing the goals and attracting investments.

Most of the off-shore wind (about 80%) are currently operating in the North Sea, but new wind parks are already planned in the Baltic, Black, and Mediterranean Seas as well as in the Atlantic Ocean. Theoretically, off-shore wind energy could meet more than 80% of electricity demand in Europe if the full economic potential was used (cost of electricity produced is up to 65 EUR/MWh), and about 25% if wind PPs were built only in the most favourable offshore areas (cost of electricity produced is up to 54 EUR/MWh) [44].

Various studies [45] and market analyses [46] show that the natural environment of the Baltic Sea is favourable for development of wind energy because of relatively shallow depth and low waves. These circumstances lead to a relatively low cost of energy production, which is why large-scale off-shore wind PPs projects are planned to be implemented in future.

At present, the total capacity of off-shore wind turbines installed in the Baltic Sea reaches 2.2 GW. More than one Baltic Sea country has announced plans for the development of off-shore wind parks. According to the estimates of industrial representatives, total wind PP capacity should increase to 9.5–14 GW by 2030. Until 2030, Germany plans to increase capacity form current 1 GW to 3 GW in the Baltic Sea, while Denmark plans to invest also in the construction of 2 GW of off-shore wind PPs. Sweden's capacity should increase by 0.5 GW, and Finland plans to expand one of the wind PP parks to a total capacity of 0.5 GW. Latvia and Estonia planned to build an off-shore wind park with a capacity of up to 1 GW in the Gulf of Riga by 2030. Poland has the most ambitious plans: at the beginning of 2021, the country's Parliament approved the Off-shore Wind Energy Act, which regulates the development of offshore wind PPs in the Polish part of the Baltic Sea. The plans are to develop offshore wind PP parks of up to 28 GW capacity.

A study prepared during the Baltic Energy Market Interconnection Plan (BEMIP) project [47] identified a total wind energy potential of 93.5 GW in the Baltic Sea (Table).

Table. **Off-shore wind energy potential in the Baltic Sea [47]**

State	Potential, GW
Denmark	19.5
Estonia	7.0
Finland	8.0
Germany	8.0
Latvia	14.5
Lithuania	4.5
Poland	12.0
Sweden	20.0
Total	93.5

In September 2020, these eight Baltic Sea countries signed the Baltic Sea Wind Energy Declaration, which emphasises the need for the development of off-shore wind energy, the available potential, and sets out the vision for the development of off-shore wind energy in the Baltic Sea.

In pursuit of long-term climate neutrality goals, Lithuania is one of the EU countries with the most ambitious RES development prospects. It is expected that most of the electricity produced using RES will be produced by wind PPs, so the development of wind PP parks in Lithuania is expected to be faster in the next decade than until now. For Lithuania to self-supply by 100% with RES-E by 2050, the amount of electricity produced by wind PPs should triple as early as by 2030. Until 2025, the transmission network operator LITGRID sees additional opportunities to connect about 140 MW of RES to the 110 kV grid, and after the system synchronisation with continental European grids and the expansion of the transmission grid are completed, there will be opportunities to connect an additional 960 MW to the 110 kV transmission grid on land in 2025. This will require total investments of about EUR 1.38 billion [48]. LITGRID predicts that by 2030, the total installed capacity of on-shore wind PPs will increase by about 2 860 MW to reach 3 400 MW, and a 700 MW wind PP park will operate off-shore. LITGID plans that already in 2030, the transmission grid will be ready to connect RES PPs, which generate 90% of all electricity consumed in the country. It is worth noting that the preparation of RES projects takes several years, the provisions of the RES regarding the issuance of permits are not always implemented, therefore, this creates an obstacle for business and RES production companies to plan activities, investments and intellectual potential.

The rapid development of on-shore and off-shore wind energy is leading to a growing demand for RES and raw materials worldwide. The annual production capacity of European original equipment manufacturers is still higher than the annual capacity of wind PPs installed in EU countries (Fig. 19). As mentioned, in 2020 the capacity of wind PPs installed in the EU countries amounted to 10.5 GW.

The largest production capacities in the EU are concentrated in the sectors of control systems and generators, as these components are not exclusively used for wind energy production. Supply chain disruptions that could hold back wind energy development in the EU are unlikely, and if maximum European generation capacity remains stable over the next decade, it should exceed annual order volumes.

National energy and climate action plans show positive prospects for the development of wind energy in Europe. Installed capacity in wind PPs will increase by 105 GW by 2025. This indicates that there will be additional demand for WEC in the region. During the implementation of 'The European Green Deal', the scale of wind energy development will be even greater, taking into account the utilisation of the potential of offshore wind energy. In summary, in response to European trends, rapid development of the wind energy sector is taking place in Lithuania, and in the context of growing ener-

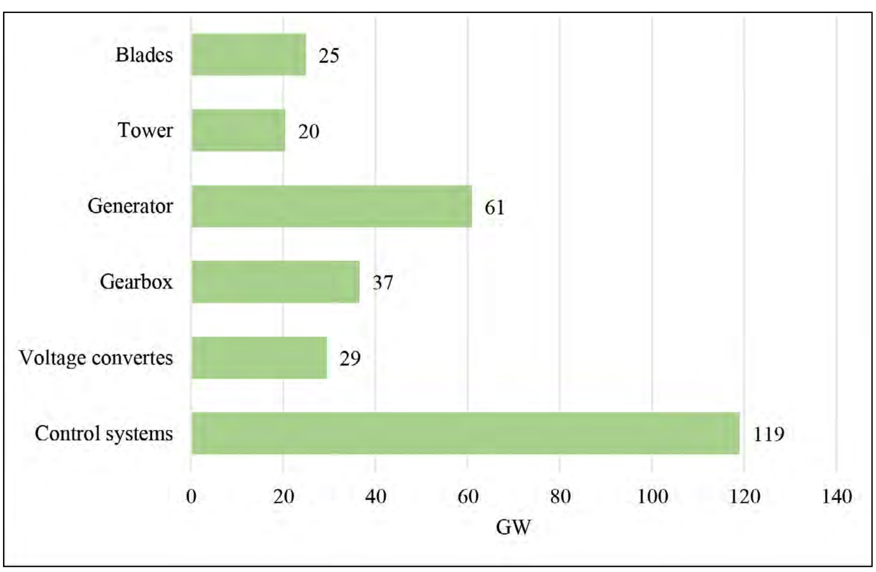

Fig. 19. Annual wind PP production capacity in Europe, by component [49]

gy needs and climate commitments, the country has one of the most ambitious RES development goals in the EU. It is expected that a significant part of electricity in Lithuania will be produced by RES, so the expectations are that in 2030 wind PPs will have a total installed capacity of 3.4 GW on-shore and 0.7 GW off-shore. The development of wind energy is an important factor in the demand for WEC. The capacity of European original equipment manufacturers is still higher than the annual capacity of wind PPs installed in the EU countries. The current availability of manufacturing capacity suggests that supply chain disruptions are unlikely as wind energy expands in Europe.

CONCLUSIONS

This paper provided a broad overview of policies and their targets, global fuel and energy consumption trends, and presented the problematics of GHG emissions, increasing global fuel and energy prices and LCOE of different technologies to establish the underlying assumptions for development of the value chain for WEC manufacturing in Lithuania.

The overview of the policies showed positive prospects for the development of wind energy and the value chain for WEC manufacturing in the country; however, the progress of installing both on-shore and off-shore wind PPs should become much faster.

The results of analysis of fuel and energy consumption revealed that because of growing human needs and population, the PEC was increasing about 2% a year between 2009 and 2019. However, the COVID-19 pandemic demonstrated that people were eventually capable to accept and implement more sustainable practices in their daily lives, allowing to reduce the PEC by 4.3% globally. Still, the global PEC structure is dominated by fossil fuels (85%). Despite the noticeable transition to cleaner fossil fuels such as natural gas, the consumption of fossil fuels was increasing by 1.7% annually, except in 2020, which was a turning point in the history of energy consumption towards energy sufficiency. An extensive use of fossil fuels results in GHG emissions and causes global warming and climate change. The trends in fossil fuel consumption appeal to the fact that is necessary to search for advanced solutions, including being energy sufficient, energy efficient, and using RES for energy production. The trends in the use of RES revealed that the consumption of RES increases fast (by 6.1% a year) in service of the economic sectors with energy. Nowadays, hydropower prevails in the RES structure(over 60%), but wind and solar energy rushed forward in the last decade. The contribution of wind energy to the global PEC is becoming more and more significant (22.6% in 2020). Inevitably, this demands the assistance of the manufacturing industry in supplying energy production sector with components, including WEC.

The results of the GHG emission analysis shows that the EU is a worldwide leader in the fight against climate change. Its GHGs reduces by 1.5% annually. Nevertheless, to achieve climate neutrality by 2050, the use of RES should be faster and more intensive. As a clean energy technology, wind PPs have the highest CO_2 emission reduction potential per MW; also, wind energy is among the cheapest sources of electricity production. Currently, most of off-shore plants are operating in the North Sea, but with the new wind parks in the Baltic, Black, and Mediterranean seas as well as in the Atlantic Ocean wind energy could meet more than 80% of electricity demand in Europe. As the potential of wind energy is high, this supports development of the value chain for WEC manufacturing. The largest production capacities in the EU are concentrated in the sectors of control systems and generators as these components are used not only for wind energy production.

It is recommended to introduce policy measures that would ensure a fast-rate development and implementation of renewable energy technologies, especially those oriented to wind energy both at the EU and national member state levels. These measures comprise an increase of foreign market demand for green products, financial support for businesses, mitigation of inflation, promotion of public education about sustainability and renewable energy, and high-level state of production facilities. Also, it is proposed to overview the current challenges in the business environment: taxes and strict requirements for management and disposal of waste generated in the production process, brain-drain, and a lack of skilled employees.

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POLITIKOS IR ENERGIJOS VARTOJIMO TENDENCIJOS, SKATINANČIOS VĖJO ENERGETIKOS KOMPONENTŲ GAMYBOS VERTĖS GRANDINĖS PLĖTRĄ LIETUVOJE

Santrauka

Darbo tikslas buvo išanalizuoti aktualias politikas ir energetikos tendencijas, skatinančias plėtoti vėjo energetikos komponentų (VEK) gamybos vertės grandinę Lietuvoje. Tam panaudota lyginamoji literatūros apžvalga ir statistinių duomenų (2000–2022 m.) analizė. Įgyvendinamų politikų apžvalga parodė, kad investicijų, klimato ir energetikos politika, apsibrėžti ambicingi tikslai bei susijusios priemonės formuoja VEK poreikį ir sudaro prielaidas gamybos įmonėms plėtoti VEK gamybos vertės grandinę. Statistinių duomenų analizės rezultatai parodė, kad pirminės energijos suvartojimas pasaulyje didėja vidutiniškai po 2 % per metus. Iškastinio kuro kiekvienais metais suvartojama 1,7 % daugiau. Tai turi įtakos anglies dioksido (CO_2) išmetimams, kurie vidutiniškai kasmet didėja po 1,7 %. Nors Europos Sąjungos (ES) šalyse pirminės energijos suvartojimas vidutiniškai mažėjo po 0,5 % per metus 2009–2019 m., o 2020 m. dar 8,5 % dėl COVID-19 apribojimų, šalys, suvartodamos apie 10 % viso kuro ir energijos, ir yra vienos didžiausių CO_2 teršėjų. ES šalių kuro suvartojimo struktūroje vis dar dominuoja iškastinis kuras, kurį deginant į atmosferą išmetama apie 2,8 Gt CO_2 emisijų kasmet. Atliepiant CO_2 emisijų problemą, per pastarąjį dešimtmetį atsinaujinančių energijos šaltinių naudojimas sparčiai augo – 10 kartų padidėjo saulės energijos ir 3 kartus vėjo energijos suvartojimas. Vėjo jėgainės, kaip švarios energijos technologija, turi didžiausią CO_2 emisijos mažinimo potencialą vienam MW, be to, vėjo energija yra vienas pigiausių elektros gamybos šaltinių. ES yra pasaulinė vėjo energijos pajėgumų įrenginių ir technologijų diegimo lyderė; tai suteikia tvirtą pagrindą tolesnei vėjo energetikos pramonės, taip pat VEK gamybos, plėtrai. Šiuo metu dauguma atviroje jūroje esančių elektrinių veikia Šiaurės jūroje, tačiau Baltijos, Juodosios ir Viduržemio jūrose bei Atlanto vandenyne vėjo energijos parkai galėtų patenkinti daugiau nei 80 % Europos elektros poreikio. Įgyvendinant vėjo energetikos projektus, reikalinga VEK gamyba ES šalyse.

Raktažodžiai: energetikos ir klimato politika, degalų suvartojimas, išmetamųjų teršalų kiekis, energijos kainos, gamyba, atsinaujinantys energijos ištekliai, Europos Sąjunga