Renewable Energy Sources

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Renewable energy sources (RES) have many advantages: (a) increase in RES consumption provides reliability on energy supply and reduces dependence on energy import; (b) larger use of RES is an important measure for the reduction of energy-related greenhouse gas (GHG) emissions; and (c) deployment of RES creates additional employment, stimulates regional economic development, and contributes to the implementation of modern technologies. Various aspects of RES deployment have been analysed in the relevant literature. Currently, the most important aspects are: (a) the role of RES consumption on economic growth; (b) the effect of RES deployment on the decline of energy-related GHG emissions.

Keywords: renewable energy sources ; GHG emissions ; decomposition analysis

1. The Relationship between RES Consumption and Economic Growth

The relationship between RES consumption, economic growth, and other factors has been analysed in many studies employing diverse approaches. A long- term equilibrium relationship between real gross domestic product (GDP), renewable energy consumption, real gross fixed capital formation, and the labour force in twenty countries of the Organisation for Economic Co-operation and Development (OECD) over 1985–2005 was investigated by Apergis and Payne [1]. The bidirectional causality between renewable energy consumption and economic growth in the short- and long-term was based on the Granger-causality test.

The growth of RES consumption in China since the end of the 1970s was an important factor for researchers to examine their role in the country's energy policy and economy. The Granger-causality test was employed to investigate the relationship between renewable energy consumption and economic growth over 1977–2011, and the long-term causality was proved by Lin and Moubarak [2]. The active promotion of RES consumption by increasing investment into production and distribution capacities was recommended for the Chinese governments, considering the impact of the renewable energy deployment. The role of renewable energy consumption in the economic welfare of China over 1978–2008 was examined by Fang [3] using the Cobb–Douglas type production functions. The high correlation between the various variables of economic welfare and renewable energy consumption was proved.

Modelling the relationship between energy consumption and economic indicators in various regions and separate countries is an active area for researchers. Long-term causal relationships between economic growth, renewable and non-renewable energy consumption in 15 developed countries of the EU over 1990–2011 were investigated by Ucan et al. [4]. A positive impact on economic growth from the increase of RES consumption was defined in the study, and, conversely, an increase of non-renewable energy consumption has stipulated a decrease in real GDP. Furthermore, the impact of renewable energy consumption on economic growth in 38 countries with the largest use of RES over 1991–2012 was examined by Bhattacharya et al. [5]. Based on this investigation, it was proven that the consumption of RES positively impacts the economic growth for 57% of the analysed countries.

A long-term equilibrium relationship between economic growth and renewable energy consumption in 29 European countries over 1995–2016 was examined by Kasperowicz et al. [6]. A significant positive impact of RES deployment on economic growth was revealed. Additionally, the favourable effect of promoting RES on economic growth, reducing GHG emissions, and sustainable development was proved. The causal relationship between renewable energy consumption and economic growth in the G7 countries over 1990–2011 was examined, and specific differences for separate countries were revealed by Chang et al. [7]. The long-term relationship between renewable energy consumption and economic growth in Pakistan was examined by Shahbaz et al. [8] using Cobb–Douglas production function and quarterly data over 1972–2011. The positive impact of renewable energy consumption on economic growth was defined. The assessment of the causality relationship by Bobinaitė et al. [9] indicated the positive effect of renewable energy consumption on economic growth in Lithuania.

The econometric analysis by Bersalli et al. [10] confirmed the effectiveness of renewable energy policies in 20 Latin American and 30 European countries over 1995–2015. The positive impact of promotion policies was the main driver for RES deployment in Europe and Latin America. The relationship between renewable energy consumption and economic growth in 25 European countries over 2007–2016 was investigated by Ntanos et al. [11]. Based on the statistical analysis, a correlation between RES consumption and economic growth in countries with high indicators of GDP per capita was found to be higher than in economies with low GDP per capita.

A significant positive long-term equilibrium relationship between renewable energy consumption and economic growth in the 28 EU countries over 1995–2015 was proven by Saint Akadiri et al. [12]. Real gross fixed capital formation, carbon emissions, and other environmental factors were defined as the main determinants of long-term economic growth in the EU. Additionally, a long-term bidirectional causal relationship was identified between renewable energy consumption, economic growth, and other growth determinants.

The short- and long-term causality relationships between economic growth and electricity consumption from renewable and non-renewable sources for Turkey were investigated by Dogan [13].

Numerous researchers were focused on investigating renewable energy policy instruments. Using panel data in 50 US states during 1991–2007, the effects of state policies on the penetration of renewable electricity sources, including wind, biomass, geothermal, and solar photovoltaic, were estimated by Shrimali and Kniefel [14]. The significant impact of renewable portfolio standards on the penetration of all types of renewable energies and differences of this impact depended on the type of RES was highlighted.

The effectiveness of renewable policy instruments focused on RES, implemented in 27 EU countries and 50 US states over 1990–2008, was investigated by Kilinc-Ata [15]. Feed-in tariffs, tenders, and tax incentives were revealed as effective mechanisms stimulating RES for electricity generation. The effectiveness of feed-in tariffs, tradable certificates, renewable portfolio standards, tax incentives, and production quotas on renewable energy deployment in South Korea, China, the UK, and Germany was analysed by Shokri and Heo [16]. It was revealed that feed-in tariffs were the most effective energy policy instrument in advanced countries. The role of a clean development mechanism to achieve ambitious targets of RES deployment in China was analysed by Wang and Chen [17]. The barriers related to implementing this mechanism and appropriate opportunities for the promotion of RES were identified. A comparison of the effects of feed-in tariffs and renewable portfolio standards as two renewable energy policy instruments implemented in many countries was presented by Sun and Nie [18]. The existing barriers to renewable energy development in the Iranian wind and solar energy sectors were determined and some recommendations to eliminate these barriers were presented by Nasr et al. [19].

A review of articles on sustainable energy policy for promoting RES in Germany, Denmark, China, the UK, and the US was conducted by Lu et al. [20]. Recommendations were provided, and the study's key conclusion was that governments and stakeholders must actively promote the deployment of RES and effective policy incentives and provide appropriate policy control. The evolution of renewable energy policy in Romania, critical analysis of the existing regulatory framework, and the assessment of the impact of policy changes on renewable energy producers was presented by Marinescu [21]. The challenges and shortcomings of policymaking were highlighted, and valuable insights for a more robust renewable energy policy were suggested.

The model for estimating the optimal subsidy for electricity generation from renewable energy in China was presented by Zhang et al. [22]. The stochastic process was used to describe the electricity market price, CO_2 price, and investment cost. The optimal subsidy for solar photovoltaic electricity generation was derived from the project and the threshold values.

The need to perform qualitative and quantitative analysis of RES deployment considering their economic, technological, environmental, and social aspects was discussed by Ilbahar et al. [23]. Based on the detailed analysis of multi-attribute decision-making methods, the reasons, purposes, and factors of their application and the most preferred techniques for evaluating RES deployment were identified. Analytic hierarchy process and additive ratio assessment methods were employed by Štreimikienė et al. [24] to perform an integrated evaluation of technical, economic, environmental, and other aspects. The most suitable electricity generation technologies in Lithuania were identified. Multidimensional analysis methods were employed by Roussafi [25] to study energy transition and regional RES development in France over 1990–2015. Similarities and differences of RES deployment by regions and types of renewable energies were revealed, and several recommendations to promote their regional development and management were identified.

Currently, various aspects related to the growing role of RES in the transition to a low-carbon economy have become increasingly important. Based on the analysis of national plans in 26 countries, accounting for about three-quarters of the global energy demand, the potential to double the global share of RES from 18% in 2010 to 36% in 2030 was identified by Saygin et al. [26]. Three factors with the highest importance were identified to achieve such levels of RES contribution: (1)

further development of technologies, (2) innovations supporting the transition towards renewable energies, and (3) improved cost-competitiveness of technologies. A similar role of RES in the global renewable energy scenario with their share of 34.7% in 2030 and 47.7% in 2040 was foreseen by Demirbas [27].

The crucial role of renewable energy technologies and energy efficiency was revealed by Gielen et al. [28] to accelerate energy transition to 2050, comply with the Paris Climate Agreement and limit average global surface temperature increase below 2 °C. Foreseen deployment of RES and a significant increase of capacities in the wind and solar power plants can increase their share in the total primary energy consumption by up to 63%. The study's main conclusion—the combined contribution from the rapid growth of RES and energy intensity reduction can guarantee about 94% of total GHG emission reduction.

Based on an analysis of the renewable energy roadmap programme prepared by the International Renewable Energy Agency, valuable findings for the European power sector development were presented by Collins et al. [29]. The possibility of meeting 50% of the gross electricity demand in the EU-28 from RES by 2030 and reducing CO2 emissions by 43% in the power sector, compared to the 2005 level, was confirmed. However, significant operational challenges could be encountered to realise such potential of green electricity generation, and planners should foresee corresponding actions for the power systems.

The growing contribution of renewable energy in electricity generation can cause problems in the power systems to provide a supply and demand balance and maintain continuity of operation in unexpected situations. Solutions to respond to high fluctuation on demand and supply sides and guarantee flexibility of the power systems were discussed by Impram et al. [30]. The solutions for providing flexibility will become more complex. Operational flexibility of the power systems plays a crucial role in integrating the growing capacities of electricity generation from variable RES. Qualitative analysis of the flexibility of the power systems and comparison of different unit types was presented by Ulbig and Andersson [31].

The import of solar electricity from North Africa can be considered as an option to enhance the performance of the European power system and improve the reliability and security of the energy supply. Specific impacts and benefits on the European power system by constructing the cross-Mediterranean High Voltage Direct Current (HVDC) links for transmission of green electricity between North Africa and Europe were discussed by Benasla et al. [32]. The possibilities to improve the European power system's dynamic performance and challenges related to the operation and control of these links were highlighted. The importance of solar power plants in the Sahara region and HVDC links was discussed by Benasla et al. [33].

2. Analysis of Drivers in Reduction of Energy-Related GHG Emissions

The transformation of the global economy from fossil-based to zero-carbon by 2050 requires urgent actions in all countries. To mitigate climate change and ensure continuous reduction of energy-related GHG emissions, investigating the trends and factors influencing these emissions plays a crucial role in formulating energy and environmental policies. Therefore, numerous researchers, policymakers, and international organisations are focused on analysing these issues at the global and regional levels, in separate countries, and economic sectors.

The relationship between historical energy-related CO_2 emissions and influencing factors at the country level has been investigated by many researchers. Several researchers focused their investigation on China as the major contributor to global GHG emissions. A significant decrease in CO_2 emissions in China over 1957–2000 was shown by Wang et al. [34]. Based on the LMDI method, the main factor of this change was energy intensity, and 95% of the total decrease was attributed to this factor. In comparison, 3.2% and 1.6% were attributed to RES penetration and the effect of the fossil fuel composition, respectively.

The LMDI method combined with the (Cobb-Douglas) C-D production function was utilised by Wang et al. [35] to study the decomposition of energy consumption and CO_2 emissions in China and analyse driving factors of their changes over 1991–2011. Changes in final energy-related carbon emissions and carbon emission intensity in China during 1996–2010 and the main affecting factors were investigated by Zhang and Da [36] using the LMDI method. Additionally, the relative decoupling effect between CO_2 emissions and economic growth was analysed.

Changes in energy-related CO_2 emissions in China during 1997–2012 were examined by Li et al. [37]. Based on the application of the IPAT-LMDI model, the influence of CO_2 emissions intensity, energy structure, energy intensity, industrial structure, economic output, and the population was investigated. Over this period, the growth of CO_2 emissions was stipulated by economic output and population growth and due to changes in energy structure. Conversely, reduction of these emissions was achieved due to increased energy efficiency and change in the industrial structure.

A nonparametric meta-frontier approach was employed by Du et al. [38] to estimate the CO_2 emission efficiency and emission reduction potential in 30 administrative provinces of China over 2006–2010. The technology gap (with more than half of the total potential) and managerial inefficiency were identified as the sources of potential reduction of CO_2 emission. Additionally, the differences in potential emission reduction across China were identified—the technology gap is more important in central and western areas, while management inefficiency is critical in the eastern areas.

Driving factors for the change of CO_2 emissions in the G20 countries over 1971–2010 were investigated by Yao et al. [39]. Their differences in the largest developed countries and emerging economies and at different stages of economic development were revealed.

Changes in CO_2 emissions for Indonesia, Malaysia, Philippines, and Thailand during 1971–2013 were investigated by Chontanawat [40]. Using the Kaya identity combined with variance analysis, it was revealed that income and population growth are the main driving factors for increasing CO_2 emissions in these countries. Therefore, national policies to reduce energy and emission intensity and substituting fossil fuels with alternative energy sources were recommended.

The changes of energy-related CO_2 emissions and their driving forces in Ethiopia during 1990–2017 were examined by Taka et al. [41]. Based on the application of LMDI decomposition, the economic growth, population, and fossil fuel share effects were revealed as the main drivers of these changes. The Kaya identity was employed by Brizga et al. [42] to analyse GHG emission changes in countries of the former Soviet Union during 1990–2010. Different roles of energy intensity, affluence, energy mix, carbon intensity, and population during different periods and differences among countries were highlighted.

The drivers of changes in GHG emissions during 2004–2012 were investigated, and the feasibility to implement EU 20–20–20 targets in Estonia, Latvia and Lithuania were assessed by Štreimikienė and Balezentis [43]. The Kaya identity and Shapley value were employed for decomposition analysis. Policies directed to increase energy efficiency were highlighted as the most important drivers for reducing GHG emissions and achieving EU 20–20–20 targets in the Baltic states.

Attempts of numerous researchers were focused on the analysis of CO_2 emissions in manufacturing and separate industries. Therefore, changes in the aggregate CO_2 intensities in manufacturing in China, South Korea, and Taiwan were distributed by Ang and Pandiyan [44] among four causal factors: fuel CO_2 emission coefficients, manufacturing production structure, fuel shares, and sectoral energy intensities. Therefore, it was concluded that the energy intensity effect significantly impacts aggregate CO_2 intensities in all three countries.

An improved non-radial directional distance function was applied by Cheng et al. [45] to construct a new meta-frontier total-factor carbon emission efficiency index. Its dynamic evolution was investigated in industrial sectors of 30 provinces in China over 2005–2015. Different characteristics of the carbon emission performances in different regions and different periods were identified. Significant spatial heterogeneity and period heterogeneity were revealed. An objective for regions to seek the appropriate emission reduction paths according to their characteristics was recommended.

The drivers of carbon dioxide emissions in China's manufacturing industry were identified by Xu and Lin [46], using the panel data of 30 provinces (during 2000–2013) and nonparametric additive regression models. The LMDI method and the extended Kaya identity were employed by Boqiang and Liu [47] to explore the influencing factors of CO_2 emissions in China from heavy industry over 1991–2015. The labour productivity, energy intensity, and industry scale were revealed as the main factors affecting CO_2 emissions. Weak decoupling of CO_2 emissions in the heavy industry was found, and insights on the industry development pattern were presented.

The impact of the key driving factors of CO_2 emissions change in China's iron and steel industry was examined by Xu and Lin [48] using data of 30 provinces over 2000–2013. Certain differences at the regional levels were defined. New insights into regional emissions reduction in China's steel industry were provided. The impact of the main driving factors on the growth of CO_2 emissions in the iron and steel industry, as the largest contributor to China's CO_2 emissions, was investigated by Xu and Lin [49]. The analysis was based on 30 provincial panel data over 2000–2013 and the application of the nonparametric additive regression model. Based on the analysis, important policy implications were derived: (1) to adopt different measures to mitigate CO_2 emissions, (2) to adopt flexible technical measures directed on reduction of energy consumption and CO_2 emissions in this sector, (3) to increase research of energy-saving measures and emission reduction technologies, and (4) to expand the use of new energy sources, such as hydropower, bioenergy and nuclear energy.

Changes in energy consumption and CO_2 emission trends in the Mexican iron and steel industry during 1970–2006 were analysed by Sheinbaum et al. [50]. The decomposition analysis methodology was applied to define the activity, energy efficiency, structural, and fuel share effects. Implementation of new energy efficiency measures was recommended.

Trajectories of energy-related GHG emissions and the impact of driving factors in the Chinese iron and steel industry over 2001–2010 were investigated by Tian et al. [51]. The production scale effect was revealed as the main driving factor for the increase in GHG emissions. In contrast, the energy intensity and the emission factor change effects had a marginal effect.

The change in energy-related carbon dioxide emissions in the Chinese textile industry over 1986–2010 was examined by Lin and Moubarak [52]. Based on the application of the LMDI method, the impact of energy intensity, industrial activity, industrial scale, energy mix, and carbon intensity on energy consumption and emissions of carbon dioxide was investigated. Industrial activity and energy intensity were identified as the main determinants of change in carbon dioxide emissions. Furthermore, the LMDI method was employed by Lin and Long [53] to explore the most important factors of changes in carbon emissions in China's chemical industry. Output per worker and energy intensity effects were defined as the key driving factors affecting changes in GHG emissions.

To assess energy consumption and CO_2 emissions from China's steel industry over 2010–2050, a system dynamics model and a bottom-up energy system model-TIMES were employed by Chen et al. [54]. Energy efficiency improvements due to energy-saving technologies and structural changes in steel production were the main factors influencing energy intensity and CO_2 intensity reduction.

Linkages between economic growth, carbon emissions, and renewable energy consumption in the EU countries over 1995–2014 were examined by Radmehr et al. [55]. The bidirectional link between economic growth and carbon emissions and economic growth and renewable energy consumption were defined based on the application of panel spatial simultaneous equations models with a generalised spatial two-stage least-squares method.

A multi-level scenario decomposition framework was proposed by Dogan [13] to compare various emission scenarios from business-as-usual to deep decarbonisation and analyse the global GHG emission trajectories and related challenges and potential climate change mitigation opportunities.

The relationship between renewable energy consumption and carbon emissions in China over 1977–2011 was investigated by Lin and Moubarak [2]. However, due to the low share of RES in the country's energy consumption, their contribution to reducing CO_2 emissions was not fixed in this study. Currently, the consumption of RES is growing in all countries due to the need to mitigate climate change by reducing the use of fossil fuels.

3. Integrated Analysis of the RES Deployment and Their Role in Countries of Baltic Sea Region

The literature on the role of renewable energy in reducing energy-related GHG emissions is still limited. An integrated analysis of RES deployment in the Baltic states and other countries of BSR and in-depth analysis of factors influencing the change of GHG emissions over 2010-2019 provided by Miskinis et al. [56] contribute to the existing scientific literature.

Strong points and limitations in consumption of RES by final consumers and their growing role in modernising the energy transformation sector in Estonia, Latvia and Lithuania were revealed based on an in-depth analysis of changes in the RES deployment over 2010–2019. In 2019, the share of RES in the gross final consumption of energy in three countries was higher than the mandatory target (established in Directive 2009/28/EC for the year 2020- Annex I)—by 27.6% in Estonia, 10.7% in Lithuania and 2.5% in Latvia.

The importance of RES consumption for heating and cooling was highlighted. The analysis has revealed that the share of RES in the final consumption of energy for heating and cooling is significantly higher than it was planned for the year 2019—by 35.1% in Estonia, 12.2% in Latvia and 21.1% in Lithuania. Consumption of RES in this sector was also higher than indicators estimated in national plans in other countries of the BSR: by 24.1% in Finland, 22.2% in Denmark, and 7.2% in Sweden. However, it was lower than planned indicators by 1.0% in Germany and 3.1% in Poland.

The contribution of RES in the gross final consumption of energy in the transport sector was growing slowly. In 2019, the share of RES in this sector amounted to 5.15% in Estonia, 5.11% in Latvia, and 4.05% in Lithuania. A target of 10% due to RES in this sector in 2020 was challenging for Poland, Denmark, Germany, and the Baltic States. Radical changes in the energy policy of the transport sector are required. A breakthrough can be related to the deployment of advanced biofuels, the rapid growth of contribution from green electricity, and other priority measures.

Based on the analysis performed, the Baltic countries have more energy from renewable sources than their mandatory targets. Moreover, each country has a comparatively high potential for further deployment of RES and can set new objectives. However, analysis shows that their use in Estonia, Latvia, Lithuania and Poland was increasing too slowly over the last few years. Therefore, to contribute markedly to climate change mitigation, new ambitious national targets and more intensive activities from policymakers and governments in Estonia, Latvia, Lithuania, Poland, and Germany are required.

Applying the extended Kaya identity and the LMDI method allowed to assess the role of the main determinants in reducing energy-related GHG emissions in countries of the BSR. The analysis indicates that GHG emissions have decreased in all countries of the BSR and demonstrates absolute decoupling of energy-related GHG emissions from economic growth during 2010–2019.

Rapid economic growth expressed by the GDP per capita was the common feature in the Baltic countries and Poland. This indicator increased over 2010-2019 by 40.9% in Estonia, 47.2% in Latvia, 55.2% in Lithuania, and 38.4% in Poland. The decline of all other driving factors (population, energy intensity, the share of fossil fuels in total primary energy supply, and emission intensity) was another common feature for all these countries. The largest decline was fixed in energy intensity, which strongly impacted the reduction of GHG emissions. This indicator has decreased by 39.7% in Estonia, 25.9% in Latvia, 22.1% in Lithuania, and 26.3% in Poland. Due to the growing integration of renewable technologies, the share of fossil fuels in the total primary energy supply decreased by 19.4% in Estonia, 11.4% in Latvia, 11.1% in Lithuania, and 3.6% in Poland.

Decomposition analysis demonstrates that economic growth and decline of energy intensity, despite their annual variations, had the largest impact on the change of GHG emissions. Economic activities drove the increase in GHG emissions in the Baltic countries and Poland. Reduction of energy intensity in these countries played a major role, explaining 65.3% in the total reduction of GHG emissions in Estonia, 57.7% in Latvia, 46.4% in Lithuania, and 79.2% in Poland. Implementing policies promoting RES deployment and growing their share in total primary energy supply has stimulated decreasing use of fossil fuels. However, these policies' contribution to reducing energy-related GHG emissions was moderate and amounted to 27.7% in Estonia, 23.4% in Latvia, 22.0% in Lithuania, and 9.4% in Poland. The positive effect from the decrease of emission intensity has had different contributions in reducing GHG emissions – by 6.6% in Estonia, 1.2% in Latvia, 12.3% in Lithuania, and 10.9% in Poland. The effect of population decline was also positive and relatively high with 17.7% in Latvia and 19.2% in Lithuania, but its role was minor with 0.4% in Estonia and 0.5% in Poland.

Based on the period-wise analysis, the increasing energy-related GHG emissions in other countries of the BSR and, on average, in the EU-27 were mainly driven by economic and population growth. The decreasing energy intensity was the major factor contributing to reducing GHG emissions—by 81.7% in Germany, on average, by 64.6% in the EU-27, 61.7% in Norway, 52.4% in Denmark, 42.0% in Sweden, and 32.8% in Finland. The contribution of RES deployment due to the substitution of fossil fuels was another important factor. Its share in the total reduction of GHG emissions amounted to 55.2% in Finland, 46.8% in Sweden, 38.3% in Norway, 38.1% in Denmark, and 3.1% in Germany. Therefore, the positive impact of the emission intensity effect was moderate in all BSR countries.

The main energy policy recommendations of the research are summarised as follows: (1) policymakers in all countries are encouraged to focus on improving energy efficiency and faster deployment of renewable energies as two major factors contributing to reducing energy-related GHG emissions; (2) policies directed to increase energy efficiency are effective in all countries of the BSR, but progress in RES deployment is insufficient considering current aspirations of climate change mitigation; (3) policies promoting the growing contribution of RES in Finland and Sweden are more effective in energy-related GHG emission reduction than the impact from the decline of energy intensity; (4) the contribution of RES in mitigating climate change must be increased markedly in Germany, Latvia, Lithuania, Poland, and, on average, in the EU-27, considering the slowdown of their deployment in the last five years; and (5) implementing radical energy policy changes in the transport sector in Denmark, Germany, Poland, particularly in the Baltic States, is urgently required.

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