Energy Transition to Achieve Carbon Neutrality

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Successful energy transitions, also referred to as leapfrog development, present enormous prospects for EU nations to become carbon neutral by shifting from fossil fuels to renewable energy sources. Along with climate change, EU countries must address energy security and dependency issues, exacerbated by factors such as the COVID-19 pandemic, rising energy costs, conflicts between Russia and Ukraine, and political instability. Central European countries may transition to a clean energy economy and become carbon neutral on economic and strategic levels by locating alternative clean energy supply sources, reducing energy use, and producing renewable energy.

Keywords: energy security ; energy efficiency ; energy transition

1. Introduction

Global energy consumption is estimated to increase by about 80% by 2030, with emerging economies expected to overtake the industrialised world as the leading energy users. Because of the relative availability and environmental sustainability, natural gas is forecasted to be the fastest-growing fuel between 2000 and 2030. Oil consumption will surge further, with the transportation sector accounting for a substantial increase. Renewable energy (RE) will progressively generate electricity, albeit wind and biomass will grow from a minimal base [1]. However, according to the International Renewable Energy Agency (IRENA) [2], RE is projected to provide 90% of all electricity in the world by 2050. In addition, through RE, countries can diversify their economies, protect themselves from price swings, create jobs, and reduce poverty, while easing import dependency [3]. Moreover, RE will significantly contribute to ensuring energy security.

The public debate around decarbonisation, carbon neutrality, and climate policies has gained new impetus worldwide, particularly in the European Union (EU). Droughts, heat waves, heavy rains, floods, landslides, and other extreme weather conditions are becoming more prevalent worldwide, including in Europe. Ocean acidification, rising sea levels, and biodiversity losses are also consequences of climate change [4]. Global greenhouse gas emissions account for over 75%, and carbon dioxide emissions are nearly 90% attributed to fossil fuels. It is essential to reduce greenhouse gas emissions by almost half by 2030 and to reach net-zero by 2050 to avoid the most severe impacts of climate change [3]. Concern over energy security and carbon neutrality, coupled with the rising demand for alternative clean energy, has led EU countries to seek alternative new energy sources. It is possible to reduce carbon emissions and pursue carbon neutrality by reducing emissions in other sectors.

In addition, effectively combatting climate change and achieving carbon neutrality needs an energy transition. This energy transition must ensure a sustainable future and leave the next generation with enough energy to meet needs. Previous research by Jacobson et al. and Delucchi et al. [5][6] has found that transitioning the entire world could be technically and economically possible. Nevertheless, other studies explored similar concerns, but for specific countries or industries, or just carbon emission reductions, in general, rather than reducing air pollution and carbon emissions [7].

The EU energy industry will face significant challenges over the next few decades. As typical cases, new ways of achieving energy security and carbon neutrality transition in CEU countries have been selected for the following reasons: increasing fossil fuel scarcity, combatting environmental degradation, establishing energy security, and transitioning to RE generation to achieve carbon neutrality to meet the EU's expanding energy demand. Contending with the challenges will necessitate significant government intervention, effective energy policy, and industry innovation. In addition, European policymakers must accelerate efforts to enter the carbon neutrality era and reduce greenhouse gas (GHG) emissions to zero by 2050.

2. EU's Energy Performance

Environmental policy researchers and public stakeholders have pushed for "*energy performance*" to be widely used and recognised. Energy efficiency can be better understood by measuring energy performance. Monitoring energy consumption enables users to comprehend and optimise energy usage by making production plan adjustments and behavioural changes that improve efficiency. A growing variety of energy-related regulating mechanisms, such as tradable green certificates [8] and carbon emission permits [9], are being implemented at the firm operations and management levels. Furthermore, energy performance measurement has environmental (diminution of greenhouse gas (GHG) and other pollution emissions), economic (decreased individual utility bills, generates employment, and helps to stabilise electricity prices and volatility), and risk management (fuel price volatility can be stabilised by diversifying utility portfolios) benefits [10].

The World Energy Council (WEC) yearly prepares and publishes the energy trilemma index (ETI), an official indicator for measuring energy performance. Different disciplines and places use the notion of an energy trilemma differently. The ETI has depicted it as a triangle. The complex ‘energy trilemma,’ consisting of the interconnected, but frequently contradictory, aspirations of energy security, tackling climate change and energy poverty, and poses a significant challenge to global energy governance [11]. Using the energy trilemma index, governments and stakeholders can identify areas where energy policy could be improved and determine the most effective options.

WEC’s released ranking is an unrivalled resource and guide for policymakers seeking long-term energy system solutions. Energy security (capability, dependency, and resilience), energy equity (accessibility, affordability, and quality), and environmental sustainability (limiting emissions and degradation, as well as increasing resource efficiency) are the three characteristics on which the WEC rates countries, based on their capability to deliver secure, affordable, and environmentally sustainable energy [12][13]. Their balancing grade represents overall competence in building a sustainable energy mix policy, and the ranking shows how effectively a country balances the trade-offs of the trilemma. Consequently, the selected EU member states were ranked as the most energy-secure countries in the EU in the energy trilemma index in 2021.

The energy security dimension emphasises the need for a robust energy policy to maximise domestic resources, while diversifying and decarbonising energy systems. Czechia (score 9), Germany (score 10), and Hungary (score 12) are among the top three improving countries on the energy security list. Their strategy involves enhancing energy security and tackling its long-term sustainability, while strengthening the EU’s energy mix.

Austria and Slovakia scored the same in energy security, but their approaches differed based on their distinct socioeconomic environments. The two countries do not have particularly strong endowments for domestic energy resources, though the Austrian energy mix is more diverse, due to its hydropower potential. Slovaks rely heavily on coal-based energy and have low resources; however, nuclear power is produced in large quantities, which is politically unsuitable in Austria [14].

Croatia has a significant natural resource endowment, compared to low-performing nations, such as Poland and Slovenia, enabling it to diversify and integrate energy with neighbouring countries to drive good performance. Poland had the highest 90% share of fossil fuels in gross available energy among the selected EU countries in 2019. Furthermore, most of the remaining member states had 60% to 80% [15]. However, to achieve a balanced total trilemma score, decarbonisation and diversification should be prioritised.

The energy equity rankings comprise producer countries with low energy costs for their citizens. The EU region ranked high in energy equity in 2021, but the pandemic has revealed societal vulnerabilities and concerns about energy affordability and accessibility. The implicit subsidies made it increasingly difficult to maintain the current decarbonising environment. Austria (score 10), Germany (score 15), and Hungary (score 24) are the top three achievers, in terms of this component. In either direct or indirect form, price subsidies generally hinder energy supply diversification and reduce the trilemma score on other dimensions. The top three countries have programs to increase energy access and make it more affordable for consumers.

Nevertheless, all the best-performing energy equity nations are developed nations with complex and robust energy infrastructures in Europe. Their energy mix continues to diversify as they move increasingly toward zero-carbon energy sources. Besides the apparent sustainability benefits of zero-carbon energy, other factors are driving the transition, such as countries seeking to harness their local natural resources and declining balancing costs. Energy equity countries are challenged with finding the right balance between affordable energy and ensuring equitable access to energy for all citizens.

In terms of environmental sustainability, Austria (score 20), Germany (score 22), and Croatia (score 24) are at the top of the list, demonstrating strong policy efforts to decarbonise and diversify energy systems. The sustainability of the environment is enhanced with a diverse energy system that is backed up by effective regulatory instruments that significantly reduce greenhouse gas emissions and increase energy efficiency. Despite ongoing efforts to reduce carbon emissions from energy generation, ensuring continuous progress in environmental sustainability proved difficult. Austria is the leading contributor to sustainability, followed by Germany, Croatia, and Slovakia, which have dramatically increased their use of renewables for their electricity consumption.

Nevertheless, the Russian and Ukrainian wars will force reshaping the energy transition in the developed world, since climate protection now requires attention to energy security. It will remain unclear which energy source will prevail until more information becomes available. Despite this, an opportunity seems to be lurking in the shadows. It is an opportunity for the world to create a viable, sustainable development plan with a strong decarbonisation agenda [16].

Energy markets worldwide are undergoing unprecedented change as governments strive to decarbonise and adopt more equitable energy transitions to help the global economy rebound from the pandemic's economic impact. Countries that have not yet decarbonised their energy mix can benefit from minimising energy intensity. However, humanising the energy transition guarantees inclusive decarbonisation, leaving no community behind.

However, those objectives have been deferred by the exorbitant energy prices, particularly natural gas, brought on by Russia's invasion of Ukraine. Russia's energy resources, on which Europe depends, are now not just unreliable, but also unwanted, due to the war [16].

The energy market typically outpaces regulations and policies in the energy sector. However, sometimes they change the game by rethinking energy markets to take advantage of new technologies and industry standards. The energy trilemma index must be adapted to reflect the evolving energy industry and keep up with database and indicator changes to remain relevant and contemporary. Furthermore, the significance of the COVID-19 epidemic must not be overlooked [17]. The challenges and opportunities provided by post-pandemic recovery are expected to change energy policies and the energy transition agenda. The trilemma can be used to guide the conversation toward a more secure, equitable, and sustainable energy future.

3. Energy Transition to Achieve Carbon Neutrality

The transition to a climate-neutral future is driven by several factors, including EU legislation, such as the European Green Deal, state assistance for R&D, and the desire to minimise reliance on fossil fuels [18].

Sustainable bio economies are required for a climate-neutral future and for achieving the 2050 carbon neutrality target. The goal of the bioeconomy is to transition from "old carbon," which has accumulated over millions of years, to "new carbon," which is biological and renewable, during the next one to ten years. Life forms in a natural setting, that is, in harmony with the atmosphere, produce renewable carbon.

The evidence for human-made global warming and its potentially catastrophic effects is undeniable. The International Energy Agency (IEA) [19] acknowledged that around two-thirds of greenhouse gas emissions are caused by energy production and consumption, and an "*energy revolution*" encompassing a shift from a high to a low carbon economy is urgently needed. Enhancing energy security will necessitate a global approach that is far-sighted and cooperative, as well as many specific national and international initiatives and actions. In this regard, two challenges stand out: the threat of global warming and its links to the use of fossil fuels; and a considerable percentage of the world's poorest members' lack of access to clean, healthy, and affordable energy, including electricity, which indicates the need for RE sources.

The energy transition is "*a pathway toward transforming the global energy sector from fossil-based to zero-carbon by the second half of this century*" [20]. The RE revolution will be among the primary characteristics and factors supporting the transition to a low-carbon economy. The RE trajectory will be the primary factor as a critical driving force for the transition to a low-carbon economy. Natural gas must be used instead of coal, and fossil fuels must transform into nuclear and RE sources [21]. Even though nuclear power is a low-carbon energy source, Japan's Fukushima Daiichi nuclear disaster provided a vivid example of shifting from nuclear energy to other RE sources [22].

Recalling Knox-Hayes et al. [23], the definition of energy security indicates the apparent link between RE and sustainability. RE can improve a minimum three of the following dimensions of energy security examined in the study. Moreover, RE significantly increases environmental quality, particularly in resisting climate change and modest energy production. In the context of the dimensions of energy security outlined by Sovacool et al. [24], RE for electricity production allows for fuel diversity, disruption restoration, reduced reliance on foreign sources, reduced price volatility, and environmental sustainability. Furthermore, using RE has multiple benefits, including lower energy costs, lesser environmental pollution, less reliance on fossil fuels, and more efficient energy production and supply [25][26].

The transition to RE occurs at various intensities throughout EU member states. This pattern reflects their diverse national energy security challenges, resulting in divergent foreign energy policy agendas within the Energy Union [27]. However, the energy transition can transform the global energy system from fossil fuel to zero-carbon. Despite the current global energy transition, further measures are required to curb carbon emissions and prevent climate change. Through energy efficiency initiatives and the deployment of RE sources, carbon emissions can be reduced by 90% [28][29]. Furthermore, RE supplies must be essential to achieving energy security and sustainability.

Although the transition towards RE will significantly impact the EU and the rest of the globe, the associated problems, regarding the transition, undoubtedly influenced the EU's clean energy package targets. In contrast, RE impacts the economy, society, and politics.

Despite so many issues regarding installing renewable energy systems, "*Smart grid*" technology can be used to enable the efficient control and transfer of renewable energy sources, such as solar, wind, and hydrogen. The smart grid connects various distributed energy resources to the power grid. Eco-friendly smart grid technology could provide both invigorating economic growth and improve electricity distribution to customers worldwide, due to the global demand for greener technologies and alternative energies [30].

Furthermore, the RE transition's environmental effects should be lessened, and the prominence of RE projects must be made more acceptable to society to reap the benefits of the change. However, RE sources, such as solar, wind, and water resources, can be ramped up quickly to build a worldwide energy system that runs solely on clean and renewable energy.

Globally, the move away from fossil fuels to RE signals a broader and more profound response to global warming. Low-carbon energy is becoming more popular, and local pollution and climate change issues are interwoven; changes in the energy landscape will affect the relationships between producers and consumers [20][31]. Many European countries have enacted policies aiming to achieve carbon neutrality by 2050, which would have enormous economic, social, and political ramifications. The energy transition has already been recognised as one of the pillars of integrating an endurable energy supply within the Dutch government. They are committed to changing the energy, transportation, and agricultural systems for sustainable development. Discourse and change have been launched, using a transition management paradigm to achieve 'transitions' [32]. Considering this, Barbir, F. [33] highlighted that an energy system based on RE sources would be more sustainable as an alternative to fossil fuel-based electricity and hydrogen systems. Whether a country relies on fossil fuel reserves or access to nuclear energy, RE is likely to provide the best opportunity to achieve energy independence and self-sufficiency, regardless of a country's endowment in fossil fuel resources [34].

As a result of the Russian armed conflict, the energy performance of selected eight EU countries is at risk. The majority of them rely on Russian energy. Nonetheless, the EU must also decarbonise its energy system and manage energy performance to achieve climate neutrality. As a result of the combination of these three components, anthropogenic carbon emissions are offset to a significant extent. The combined implementation of these three components can also lead to carbon neutrality and energy security. First and foremost, the EU needs to diversify the energy supply by putting energy efficiency and RE sources at the top of the priority list. It also complies with the availability and accessibility of energy [35]. EU countries can withstand the use of fossil fuels, such as coal, oil, and natural gas, if they make use of diverse energy sources, including nuclear, solar, wind, and hydrogen energy. Second, the EU must invest in renewable and clean energy technology, improving energy efficiency and ensuring a reliable and inexpensive energy supply [36]. The second component of the illustration shows that investing in clean energy sources, such as solar, wind, and thermal energy, is necessary to ensure that everyone has access to inexpensive energy. At this particular time, fossil fuel prices are rising, due to the conflict in Ukraine, which has crippled the impoverished countries that import energy. Renewable energy sources can assist countries in mitigating climate change, building resilience to volatile price fluctuations, and lowering energy costs. Third, EU people must avoid energy waste and save energy to ensure energy supply stability and environmental sustainability [37]. The final part of the illustration describes an intense relationship between energy savings and environmental sustainability. Making a deliberate choice to consume less energy is known as energy conservation. By using less energy, people can slow down the depletion of fossil fuels and contribute to environmental clean-up. The EU needs to avoid energy waste and emphasise energy conservation as a sustainable strategy for bringing stability and sustainability to the environment.

In order to achieve carbon neutrality and energy security, further strategies are needed. A number of strategies are required to reduce emissions in the production and building sectors, such as the use of renewable energy, shifting fuel, and the utilisation of efficient technologies. Additionally, building sector management needs to be optimised to increase energy efficiency, reduce emissions cost-effectively, and achieve carbon neutrality. Technological advancements can help to achieve this goal [38][39]. In addition, the EU energy market needs to be integrated, networked, and digitalised [40].

In contrast, there are also concerns that RE may not be as reliable as those using fossil fuels heavily. Because RE systems are still in their infancy, fundamental uncertainties and accurate solutions exist. Further, citizens lack adequate knowledge and information about renewable energies and their long-term advantages. Ten strategies and policies are suggested to ensure the future RE transition in the CEU. These policies and strategies align with the Energy Union agenda, which was endorsed in 2015 [41]. In addition, these proposed policies and methods will assist the CEU countries in overcoming four significant challenges, i.e., fossil fuel shortage, environmental degradation, energy security, and the transition, to RE to fulfil future demands.

First, CEU citizens and industries should be educated and informed. Having a wide range of stakeholders involved is crucial to the long-term success of the RE strategy. A proactive approach to educating and informing the public and the business community helps build public acceptance and support. Because local opposition to energy infrastructure can pose significant barriers to achieving 100% RE and carbon neutrality, policymakers must educate citizens, foster engagement, and improve public outreach.

Second, transitioning to “zero-carbon” necessitates prudent comprehensive and long-term planning. Transition technologies, such as improving the efficiency of existing fossil fuel-based energy systems and switching from coal-powered energy to natural gas, can help reduce CO_2 intensity. Despite being a fossil fuel, natural gas emits 50–60% less CO_2 than coal-based energy power and can be used to offset the variability of solar and CO_2 power [42]. The EU needs to develop a roadmap with three milestones and timelines for achieving net-zero emissions: reducing the CO_2 intensity from GDP, minimising overall CO_2 emissions, and achieving carbon neutrality [43].

Third, annual RE investments must triple to USD 800 billion by 2050, from around USD 300 billion in recent years, to meet necessary global decarbonisation and climate goals [44]. The EU Commission recognizes the need to entice private investors to fund low-carbon initiatives; sustainable investments must be made appealing. Encouraging actors to establish and fund “green” ventures entails translating environmental benefits into monetary terms [45]. Investing in research and innovation, as well as transmission, are essential for a development sustainability transition. According to IRENA [46], 90% of RE projects were privately funded in 2016. As risks diminish and technologies develop, private investment is projected to have a greater share in future estimates.

Fourth, assign a high priority to energy efficiency. Prioritising energy efficiency is a fundamental step toward a sustainable energy future. Investing in more efficient energy infrastructure allows countries to construct, develop, and integrate the required infrastructure to meet their energy demands with locally accessible RE sources. Thus, it may be possible to decouple economic growth from greenhouse gas emissions growth and lower total investment requirements, while supporting economic growth decoupled from greenhouse gas emissions.

Fifth, make RE readily available to meet variable energy demands during all seasons. A diverse portfolio of RE sources will provide a more secure energy system than energy storage technologies alone.

Sixth, the selected EU countries analyzed the heating/cooling industry, and the transportation sector should be electrified. In the coming decades, governments should prioritise the transition of the heating and transportation sectors to a greater reliance on electricity. Integrating the electricity, heating/cooling, and transportation sectors is vital to reaching 100% RE, so renewable electricity can be deployed in various dispatchable uses, such as for thermal systems and charging electric vehicles [47].

Seventh, as energy systems transition from highly integrated and centralised complex networks to decentralised and local smaller frameworks that optimise supply, demand, and control by enabling efficient energy supply options at the household scale, they will be less vulnerable to potential power shortages [48]. Energy systems’ ability to handle unexpected circumstances, minimise their impacts, respond quickly to their consequences, swiftly recuperate, and restore power can all be improved with digital technologies.

Eighth, regional cooperation among the analysed EU countries effectively ensures the European integrity of energy systems. A standard grid must connect eight EU countries to transfer RE. At the national level, energy interconnection can only be achieved incrementally. In each selected EU member state, the construction of national grids and interregional connections should be followed by community-based microgrids.

Ninth, researchers need to conduct more research in this field to minimise concerns about future risks posed by some renewable energies.

Tenth, the EU countries analysed must increase RE and safe nuclear energy in their national energy portfolio to mitigate climate change and its consequences. It incorporates the concepts of usability, adaptability, and accessibility of RE to encourage citizens' energy-efficient behaviour.

Implementing these suggestions would address the viability of RE sources and the Sustainable Development Goals, such as SDG-7 (affordable and clean energy) and SDG-13 (climate action). In addition to fighting climate change in the selected CEU member states, these initiatives aim to make modern energy accessible, reliable, and sustainable across Europe.

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