ЕКОЛОГІЧНІ ПИТАННЯ В КОНТЕКСТІ ЄВРОІНТЕГРАЦІЇ УКРАЇНИ

UDC 620.9:504:327
DOI https://doi.org/10.32846/2306-9716/2025.eco.5-62.1.34

CASE STUDIES TOWARDS ENERGY TRANSITION IN THE EU, SWITZERLAND, AND UKRAINE

Bilokon A.
GCIP Regional Acceleration Center for Innovation, Technology, and Start-Ups in Mykolaiv Region of Ukraine
alona.bilokon@gmail.com

This paper provides a comparative analysis of energy transition strategies in the European Union, Switzerland, and Ukraine, examining institutional frameworks, policy instruments, and implementation practices. Employing a multi-level case study methodology that combines legislative review, policy evaluation, and best-practice analysis, the study identifies key drivers, barriers, and lessons shaping national decarbonization pathways. Despite differences in governance, market maturity, and geopolitical context, all three cases demonstrate commitments to climate neutrality, renewable energy deployment, and energy efficiency. The EU exemplifies a supranational regulatory approach through the European Green Deal, Renewable Energy and Energy Efficiency Directives, and the Emissions Trading System. Switzerland illustrates the effectiveness of decentralized governance and citizen participation under Energy Strategy 2050, integrating hydro, solar, and efficiency measures supported by carbon taxation. Ukraine is navigating economic transformation, adopting renewable energy, and aligning national legislation with European standards under the Energy Strategy 2035. Highlighted cases of decarbonization in some EU countries (Germany, Denmark, Poland, Sweden), as well as Switzerland, and Ukraine demonstrate successful models of technological innovation, stakeholder collaboration, and policy implementation. Findings indicate that coherent legal frameworks and institutional stability are crucial to accelerating low-carbon transitions. This study offers actionable insights for policymakers and experts, as well as emerging economies seeking resilient, innovation-driven pathways toward sustainable energy systems and climate neutrality. *Key words:* energy transition, decarbonization, renewable energy, EU Green Deal, Swiss Energy Strategy 2050, Ukraine Energy Strategy 2035, sustainable development, comparative analysis.

Тематичні дослідження енергетичного переходу в ЄС, Швейцарії та Україні. Білоконь А.О.
У статті здійснено порівняльний аналіз стратегій енергетичного переходу в Європейському Союзі, Швейцарії і Україні з урахуванням інституційних рамок, політичних інструментів та практик реалізації. Використовуючи багаторівневий метод кейс-стаді, що поєднує аналіз законодавства, оцінку політики та дослідження найкращих практик, дослідження визначає ключові рушійні чинники, бар'єри і успішні кейси, які формують траєкторії декарбонізації держав. Попри відмінності у системах врядування, підходах у формуванні енергетичних ринків та геополітичному контексті, усі три кейси демонструють спільну відданість цілям кліматичної нейтральності, розвитку відновлюваної енергетики та підвищенню енергоефективності. Європейський Союз виступає прикладом наднаціонального регуляторного підходу, втіленого через Європейський зелений курс, Директиви з відновлюваної енергії та енергоефективності, а також Систему торгівлі викидами. Швейцарія ілюструє ефективність децентралізованого врядування та громадської участі в межах «Енергетичної стратегії 2050», поєднуючи розвиток гідро-, сонячної енергетики та заходів з енергоефективності, підтриманих вуглецевим оподаткуванням. Україна, перебуваючи у процесі економічної трансформації, досягла прогресу у впровадженні відновлюваної енергетики та гармонізації національного законодавства з європейськими стандартами в межах «Енергетичної стратегії України до 2035 року». Наведені приклади успішної декарбонізації у деяких країнах ЄС (Німеччині, Данії, Польщі, Швеції), а також Швейцарії та Україні демонструють ефективні моделі технологічних інновацій, міжсекторальної співпраці та реалізації енергетичної політики. Результати дослідження свідчать, що узгоджені правові рамки і інституційна стабільність є критичними чинниками прискорення низьковуглецевого переходу. Дослідження пропонує практичні висновки як для політиків і експертів, так і для країн, що розвиваються, які прагнуть забезпечити стійкі, інноваційно орієнтовані шляхи до формування кліматично нейтральної енергетичної системи. *Ключові слова:* енергетичний перехід, декарбонізація, відновлювана енергетика, Європейський зелений курс, Енергетична стратегія Швейцарії 2050, Енергетична стратегія України 2035, сталий розвиток, порівняльний аналіз.

Problem Statement. The urgent need for global transition to sustainable and low-carbon energy systems arises from challenges related to climate change, energy security, and economic growth. Despite having diverse economic and political backgrounds, the European Union, Switzerland, and Ukraine all strive to achieve energy transition goals. A comparative assessment of their strategies can help identify common features, best practices, and effective tools for policy development.

Research Relevance. The energy transition constitutes a fundamental pillar of efforts to achieve climate neutrality, sustainable economic growth, and security of energy supply in Europe. A comparative analysis of the experiences of the EU countries, Switzerland, and Ukraine is particularly pertinent in the context of

emerging geopolitical realities and the global drive toward decarbonization. These three cases have been deliberately selected: the European Union, which has established an extensive legislative framework to accelerate the shift toward renewable energy; Switzerland, a non-EU European country that pursues its own distinct energy strategy; and Ukraine, an EU candidate state undergoing energy sector reforms. The comparison of such diverse political and institutional contexts provides valuable insights into the dynamics of the energy transition. This study, therefore, enhances understanding of how variations in institutional arrangements and regulatory frameworks influence both the pace and the effectiveness of energy transformation processes.

Relevance of the Research to Scientific and Practical Objectives. The present research aligns with and advances key scientific and practical objectives in the domain of sustainable energy policy and governance. It contributes to the theoretical development of policy design and the empirical understanding of how institutional arrangements and international cooperation frameworks facilitate the energy transition. By identifying effective mechanisms for integrating renewable energy sources into national energy systems, the study enhances the evidence base for policy formulation. The comparative analytical approach adopted in this work provides policymakers and researchers with context-sensitive insights that support the design of coherent strategies to accelerate decarbonization, strengthen energy security, and promote sustainable economic development.

State of the Art. *Climate Commitments and Policy Framework.* The cornerstone, which is a legally binding international treaty on climate change, is the Paris Agreement [1]. It was adopted on December 12, 2015 by 196 parties at COP 21 in Paris. Its aim is to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels. Moreover, in July 2021, the European Commission (EC), in response to the climate crisis, adopted a set of policies – the European Green Deal [2], which will make Europe the world's first climate-neutral continent by 2050. Besides, the Sustainable Development Goals [3] provided by the UN serve as a tool to prevent climate change. In September 2015, UN Member States adopted the 2030 Agenda for Sustainable Development, which gives the Global Sustainable Development Report [4] a role in the monitoring and reviewing the new Agenda. *Responsibility and the Role of the Human and Social Sciences in Energy Transition.* Since 1987, the planetary boundaries of greenhouse gases have been exceeded and our livelihoods are being endangered due to the ever-increasing pace of climate change. This is where climate justice is critical. It implies two important aspects: One, the emission of greenhouse gases must be reduced to zero, and two, responsibility must be taken for the individual and national CO_2 emissions in the past years [5]. The transformation of the local and national energy systems in democratic countries as Germany or Ukraine is primarily a matter for civil society, which takes actions in economic and state domains – and is often supported by contributions from the Social Sciences and the Humanities, so called „Human Sciences" [6]. Social sciences currently offer roadmaps of solutions for a feasible social transformation in Germany, which includes an extensive structural and economic program with numerous focal points. In view of the global climate situation, the energy transition is currently the highest priority [7]. Therefore, it is important to consider its various layers, ranging from how the energy transition projects came about [8] to the development of anthropogenic climate change [9]. Energy transitions are not sudden revolutionary advances that follow periods of prolonged stagnation, but rather continuously unfolding processes that gradually change the composition of sources used to generate heat, motion and light [10]. In conjunction, Ukrainian scientists are also making important contributions in the nuanced energy conversion of various types of renewable sources in their country [11].

Recent strategic initiatives, such as the EU Green Deal, Switzerland's Energy Strategy 2050 [12], and Ukraine's Energy Strategy 2035 [13], reflect different approaches to energy transition. Prior research has focused mainly on national frameworks and renewable energy promotion but lacks comprehensive comparative perspectives involving both developed (EU, Switzerland) and developing (Ukraine) contexts. This study fills that gap by examining legislative instruments, market actors, and implementation practices across these countries.

Research Gap. Although the significance of the energy transition for achieving climate neutrality and sustainable development is broadly recognized, the literature still lacks a comprehensive understanding of the mechanisms through which policy design, market configuration, and institutional capacity interact to determine transition outcomes. Existing studies predominantly focus on the experiences of the European Union and its member states, while the comparative perspectives of smaller or non-EU economies remain largely overlooked. In particular, the ways in which countries such as Switzerland and Ukraine, characterized by differing levels of economic development, governance structures, and degrees of integration with the EU energy market, can adapt and internalize European transition models have received limited scholarly attention. This study seeks to address this gap by providing a systematic comparative analysis of the EU, Swiss, and Ukrainian cases, thereby contributing to a more nuanced understanding of the institutional diversity shaping energy transition trajectories in Europe.

Scientific Novelty. The novelty of the study lies in its comprehensive comparative framework that simultaneously analyzes the EU, Switzerland, and Ukraine as energy transition actors with distinct political and economic contexts. The paper identifies shared structural components of successful energy transitions, such as stakeholder collaboration, regulatory consistency, and

technological innovation, that can be replicated in other regions.

Methodological and Theoretical Significance. This study employs a comparative case study methodology that integrates qualitative analysis of policy documents, legislative acts, and national energy transition programs with the examination of exemplary best practices. Such a multi-level analytical design allows for the identification of both structural and contextual factors influencing the effectiveness of energy transition policies. By situating empirical findings within a broader theoretical framework, the research advances methodological approaches to cross-national comparison in sustainability studies.

Introduction

The transition to a sustainable and low-carbon energy system is a global imperative driven by the need to address climate change and ensure secure and affordable energy supplies. In recent years, many countries have embarked on ambitious energy transition journeys, implementing various strategies and policies to shift from conventional fossil fuels to renewable and cleaner energy sources. This article presents a comparative analysis of energy transition case studies in the European Union, Switzerland, and Ukraine, shedding light on the diverse approaches, challenges, and successes experienced by these regions.

The European Union, as a frontrunner in energy transition, has set ambitious targets under the Clean Energy Package, aiming to achieve a 32% share of renewable energy by 2030 and a 40% reduction in greenhouse gas emissions compared to 1990 levels. The EU has implemented a combination of regulatory measures, support schemes, and research initiatives to foster the deployment of renewable energy technologies, improve energy efficiency, and promote a more integrated and interconnected energy market. The EU case study provides insights into the policy framework, market dynamics, and lessons learned from its ongoing energy transition efforts.

Switzerland, a country known for its hydroelectric- and PV power generation, has been actively diversifying its energy mix and expanding its renewable energy capacity. Through a combination of national energy strategies, innovative financing mechanisms and public engagement, Switzerland aims to increase the share of renewable energy sources, improve energy efficiency, and reduce dependence on fossil fuels. The case study on Switzerland highlights the country's unique energy landscape, explores its challenges and successes, and teaches valuable lessons to other nations seeking to embark on a similar energy transition path.

Ukraine, as a country with a significant reliance on fossil fuels, is undergoing a transformative energy transition journey driven by energy security, economic development, and environmental sustainability. Irrespective of the challenges faced, Ukraine has made notable progress in diversifying its energy sources, increasing energy efficiency, and attracting investment into renewable energy. The case study on Ukraine delves into the country's energy transition policies, regulatory framework, and experiences in navigating the complexities of energy transition.

By examining these case studies, this paper aims to identify common trends, best practices, and key challenges encountered by different countries and institutions in their energy transition endeavors. It also seeks to provide valuable insights for policymakers, researchers, and stakeholders involved in shaping the future of sustainable energy systems. In this article, we will comparatively analyze the key priorities between the energy transition strategies of the EU countries, Switzerland and Ukraine respectively, characterize the key players of the European energy market, as well as highlight the best cases in decarbonization of Germany, Denmark, Poland, Sweden, Switzerland as well as Ukraine.

Energy Transition Strategies and Legislation

Energy transition essentially refers to the shift from fossil fuels to renewable sources of energy. This transition is driven by the need to reduce carbon emissions and mitigate the effects of climate change. The key sources of sustainable energy include solar, wind, hydro, geothermal, and biomass power. Energy transition involves the adoption of new technologies, policies, and business models to enable the deployment of renewable power sources at scale. Some of the key drivers of energy transition include declining costs of sustainable energy technologies, increasing public awareness of climate change, and supportive government policies. Moreover, this very transition has significant implications for the global economy, energy markets, and energy-intensive industries. It is expected to lead to the transformation of the energy sector, with the emergence of new players and business models. Energy transition also presents significant opportunities for innovation and investment in renewable power technologies and related infrastructure.

European Union. Energy transition, energy efficiency, and the green economy have been among the top priorities of the European Union as well as a vast number of other countries worldwide. Over the years, several legislative and programmatic initiatives have been put in place to address these issues, with the view of reducing carbon footprint and promoting sustainable development.

The EU has been actively working towards minimizing its carbon footprint and fostering the implementation of renewable energy sources. The European Green Deal, announced in December 2019, aims to make Europe climate-neutral by 2050. With a view to achieve this, the EU has set a goal of reducing greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. In addition, the EU has established several legislative initiatives such as the Renewable Energy Directive [14], the Energy Efficiency Directive [15], and the Energy Performance of Buildings Directive [16] to put forward energy transition.

Simultaneously, energy efficiency has been an integral part of the EU's energy policies. The EU has defined an objective to reduce primary energy consumption by 32.5% by 2030 compared to 2005 levels. The Energy Efficiency Directive, which was adopted in 2012, aims to improve energy regulation by aiming to target 32.5% in energy savings by 2030. The directive requires Member States to establish national energy efficiency goals and to implement measures in order to achieve them.

The role of the green economy in this context is crucial. Green economy is a type of economy that is low carbon, resource-efficient and socially inclusive. The EU has been encouraging the development of the green economy through several initiatives. The Circular Economy Action Plan [17], adopted in 2020, aims to make the EU's economy more circular by promoting reuse, repair, and recycling of products and materials. The EU also supports the development of a sustainable finance framework, which aims to promote investments that are environmentally neutral.

Moreover, reducing CO_2 footprint is a crucial element of the EU's efforts to combat climate change. The EU has established several programs to cut down on CO_2 emissions. The Emissions Trading System (ETS) [18] is one of the key programs, which puts a price on CO_2 footprint to incentivize companies to lower their release. The EU has also established the Effort Sharing Regulation [19], which sets binding national targets for reducing emissions from sectors not covered by the ETS, such as transport, buildings, and agriculture.

In conclusion, the EU has put in place several legislative and programmatic initiatives to address energy transition, energy efficiency, the green economy, and reducing CO_2 emissions. These initiatives demonstrate the union's commitment to combating climate change and promoting sustainable development.

Switzerland. Switzerland has set ambitious goals for reducing its carbon footprint and has implemented various policies to promote the implementation of renewable energy sources and energy efficient measures. The Swiss Energy Strategy 2050 and the new energy act aim to minimize the country's reliance on fossil fuels and increase the share of renewable energy sources in the energy mix. The strategy includes steps to promote the installation of renewable energy systems, such as ground-mounted PV systems and wind turbines.

The Federal act on a secure electricity supply [20] comprises a number of initiatives to decrease the country's carbon emissions and increase the share of renewable energy sources in the energy mix. One of the key provisions of the law is the introduction of a CO_2 tax on fossil fuels, which will encourage the use of renewable energy sources and energy-efficient technologies. The law also embraces measures to promote the installation of renewable energy systems, such as ground-mounted PV systems and wind turbines.

Switzerland has been extensively incorporating international legislation to prevent climate change, including the Paris Agreement, aimed at limiting global warming to well below 2°C above pre-industrial rates. Switzerland has pledged to reduce its greenhouse gas emissions by 50% by 2030, compared to 1990 levels, and achieve carbon neutrality by 2050.

Ukraine. Ukraine has established an extensive legal and policy basis for sustainable development. National Sustainable Development Goals for 2030 have been defined by the presidential decree. These nationally adopted SDGs are accompanied by a framework for monitoring progress, with annual reports. The State Environmental Policy Strategy (Environmental Policy) [21] and the more recent National Economy Strategy [22] both identify sustainable development as a key goal and principle, comprising references to sustainable development in numerous other national sectoral policy documents. As for renewable energy sources, 2003 was marked by signing the Law of Ukraine "On renewable energy sources" [23]. In 2019, the Law of Ukraine "On Principles of Monitoring, Reporting and Verification of Greenhouse Gas Emissions" [24] and the Law of Ukraine "On regulation of activities using ozone-depleting substances and fluorinated greenhouse gases" [25] were endorsed, followed by the Law of Ukraine "On energy efficiency" [26] in 2021.

Being heavily dependent on fossil fuels, especially natural gas, Ukraine is seeking to diversify its energy mix as well as reduce its carbon footprint. The Ukrainian Energy Strategy 2035, adopted in 2017, aims to increase the share of renewable energy sources in the energy mix to 25% by 2035. The strategy comprises measures to promote the installation of renewable energy systems, namely solar, wind, and biomass.

The analysis of energy transition strategies and legislation in the European Union, Switzerland, and Ukraine demonstrates both shared objectives and context-specific approaches to sustainable energy development. In the EU, comprehensive frameworks such as the European Green Deal, Renewable Energy Directive, and Energy Efficiency Directive reflect a coordinated, supranational effort to achieve climate neutrality by 2050, emphasizing decarbonization, energy efficiency, and the promotion of a green economy. Switzerland, while not an EU member, implements an ambitious Energy Strategy 2050 that prioritizes hydro and solar energy, energy efficiency, and the integration of CO_2 taxation to incentivize low-carbon technologies. Ukraine, facing a fossil-fuel-dependent energy system, has developed its Energy Strategy 2035 to diversify the energy mix, expand renewable energy deployment, and reduce greenhouse gas emissions through a combination of national legislation and alignment with international climate commitments.

These cases illustrate the critical role of legislative and policy frameworks in guiding energy transitions. They highlight how energy strategies must be adapted to specific national contexts, balancing resource availability, technological potential, and institutional capacity. Comparative examination of these approaches contrib-

utes to a deeper understanding of the mechanisms that enable effective transition to sustainable, low-carbon energy systems, offering insights for both policymakers and researchers seeking to accelerate decarbonization and strengthen energy security.

Key Players in the Energy Market

European Union Energy Market. The European energy market is a complex and highly competitive domain with a variety of players involved in different segments, featuring such as major energy companies, national energy companies, renewable energy companies, transmission system operators (TSOs), distribution system operators (DSOs), energy traders as well as gas suppliers.

Major energy companies such as E.ON [27], Enel [28], ENGIE [29], and RWE [30] operate in various segments of the European energy market, involving electricity and gas generation, transmission, and distribution. These companies have significant market share, being involved in large-scale infrastructure projects, such as offshore wind farms and gas pipelines. *National energy companies*, such as EDF [31] in France, Iberdrola [32] in Spain, and Vattenfall [33] in Sweden, are state-owned or partially state-owned companies that operate in their respective national markets. These companies play a crucial role in ensuring energy security and implementing national energy policies.

Here is a brief overview of leading European and national energy companies. ENI [34] is an Italian multinational engaged across the entire energy value chain, from exploration and production to refining, marketing, and power generation. EDF (Électricité de France) is a major French utility specializing in electricity generation and distribution, as well as gas and renewable energy. TotalEnergies [35], another French multinational, operates in oil and gas production, refining, marketing, and increasingly in electricity and renewable energy. RWE, a German company, ranks among Europe's largest electricity producers, with operations spanning power generation, gas, and renewables. E.ON, also based in Germany, focuses on electricity generation and distribution, gas supply, and renewable energy development. Shell [36], headquartered in the Netherlands, is one of the world's largest energy corporations, active in oil and gas exploration, refining, marketing, and expanding rapidly into renewables.

Renewable energy companies, such as Ørsted [37], Vestas [38], and Siemens Gamesa [39], specialize in renewable energy generation technologies, including wind, solar, and hydropower. These companies are becoming increasingly important in the European energy mix as the region aims to reduce its carbon emissions and transition towards a low-carbon economy. *TSOs,* such as TenneT [40] in Germany and RTE [41] in France, are responsible for the operation and maintenance of the high-voltage electricity transmission systems in the respective countries. They ensure that electricity is transported efficiently and reliably from the generation sources to the distribution networks. *DSOs,* such as Enedis [42] in France and E.ON in Germany, operate the low-voltage electricity distribution networks that deliver electricity to homes and businesses. They play a critical role in maintaining the reliability and security of the electricity supply. *Gas suppliers,* such as Equinor [43] in Norway, and TotalEnergies in France, supply natural gas to Europe through pipelines or as liquefied natural gas. *Energy traders,* such as Vitol [44], Trafigura [45], and Glencore [46], trade energy commodities, namely crude oil, natural gas, and electricity. They crucially affect the balance of supply and demand in the market and are often involved in large-scale infrastructure projects and long-term supply contracts.

These players, along with many other smaller companies, are active players in the European energy market, which is undergoing significant transformation as the region seeks to reduce its carbon emissions and transition towards a more sustainable energy system.

Swiss Energy Market. Switzerland's energy market is characterized by a diverse array of key players operating across various segments. Despite limited domestic energy resources, the country has developed a robust energy infrastructure, relying on a mix of hydroelectric, nuclear, and renewable energy sources, complemented by strategic imports.

Axpo Holding AG [47] is Switzerland's largest producer of renewable energy, primarily through its extensive hydropower assets. The company manages approximately 60 hydropower plants and holds nearly 60% of the country's nuclear power capacity, including full ownership of the Beznau nuclear plant and significant stakes in the Leibstadt and Gösgen plants. Additionally, Axpo is expanding its renewable energy portfolio to include solar and wind power. Alpiq Holding AG [48] operates a diversified energy portfolio encompassing hydroelectric, nuclear, and renewable energy sources. The company is involved in the planning and construction of new nuclear power stations in collaboration with Axpo and BKW, aiming to replace aging facilities and ensure long-term energy security. BKW Energie AG [49] is a leading utility company engaged in the production and distribution of electricity, gas, and heat. It operates a mix of hydroelectric and thermal power plants and is actively involved in the development of renewable energy projects. BKW also participates in the joint nuclear power initiatives with Axpo and Alpiq. EOS Holding SA [50] is a strategic holding company based in Lausanne, Switzerland. Its purpose is to coordinate and represent the interests of its stockholders, the principal electric companies of French-speaking Switzerland, Romande Energie SA [51], Groupe E SA [52], the City of Lausanne, Services Industriels de Genève, and FMV SA, in activities based on two main axes: the development of renewable energy sources and the optimization of energy distribution networks. Gaznat SA [53] is a Swiss natural gas company that operates in the gas supply and trading segment of the energy market. It is responsible for the import and

distribution of natural gas in Western Switzerland and controls several natural gas storage facilities in the country. Gaznat is actively involved in initiatives to reduce carbon emissions and contribute to a CO_2-neutral energy supply in the region by 2050.

These companies, together with several smaller entities, play a vital role in shaping the Swiss energy market and safeguarding the country's energy security. Nevertheless, given Switzerland's limited domestic energy resources, the country relies significantly on imports from neighboring countries while actively investing in and expanding renewable energy sources.

Ukrainian Energy Market Overview. The Ukrainian energy sector is characterized by a mix of state-owned enterprises and private companies, each playing a pivotal role in the country's energy landscape.

Naftogaz [54] of Ukraine is the nation's largest state-owned oil and gas company, responsible for the exploration, extraction, transportation, and distribution of natural gas and crude oil. It operates an extensive pipeline network, including over 4,700 km of oil pipelines, making it the second-largest oil transportation system operator in Europe. In 2024, Naftogaz contributed approximately UAH 104 billion to the state budget, accounting for 7% of total government revenues. DTEK Group [55] is the largest private energy investor in Ukraine. Established in 2005, DTEK operates across various segments, including coal mining, electricity generation from thermal, wind, and solar sources, and electricity distribution. The company has invested over €12 billion in the energy sector since its inception. Ukrtransgaz [56], a subsidiary of Naftogaz, manages the natural gas transmission system in Ukraine. It is responsible for transporting natural gas from production fields to storage facilities and distribution networks, playing a crucial role in maintaining the country's energy infrastructure. Energoatom [57], a state-owned enterprise, operates Ukraine's nuclear power plants, providing approximately 55% of the country's electricity. The company oversees four nuclear power plants with 15 reactors, making Ukraine one of the leading countries in nuclear energy production. Kyivenergo [58], a subsidiary of DTEK, supplies electricity and heat to the capital city, Kyiv. It operates several thermal power plants and district heating networks, ensuring reliable energy services to the city's residents.

Collectively, these entities are integral to the functioning and security of Ukraine's energy market. However, the sector faces challenges due to ongoing geopolitical tensions and the need for modernization to meet future energy demands.

The energy markets of the European Union, Switzerland, and Ukraine exhibit distinct structures shaped by their respective economic, regulatory, and technological contexts. In the EU, a combination of major transnational and national companies (E.ON, RWE, ENEL, EDF, Vattenfall), leading renewable energy firms (Ørsted, Vestas), and regulatory operators (TenneT, RTE) reflects a highly integrated and competitive market environment that drives innovation and facilitates cross-border energy flows. Switzerland's market, by contrast, is dominated by a few large companies, Axpo, Alpiq, and BKW, that manage hydroelectric and nuclear assets while gradually expanding renewable energy portfolios, illustrating a model in which local-scale governance and energy diversification coexist. Ukraine's energy sector is characterized by key actors such as Naftogaz, DTEK, Energoatom, and Ukrtransgaz, which are central to ensuring national energy security, modernizing infrastructure, and supporting the country's ongoing energy transition under complex geopolitical and economic conditions. This comparative overview highlights how different market structures, regulatory frameworks, and strategic priorities shape the implementation of energy transition policies across Europe and beyond.

Best Cases in Decarbonization

Many EU member states, such as Germany, Denmark, Poland, and Sweden, as well as Switzerland, all being leaders in the global energy transition, have implemented various projects to promote the adoption of renewable energy sources and energy efficiency measures. Ukraine, in its turn, also has certain achievements in decarbonization. Here are some of examples of energy transition projects from each country.

Cases of Decarbonization in Some EU Countries. *Germany:* the city of Hamburg has put forward a comprehensive energy transition program, which includes measures to promote the adoption of renewable energy sources, energy-efficient buildings, and sustainable transportation [59]. The Energiepark Mainz, a 6 MW PEM-electrolysis Power-to-Gas facility, demonstrating plant efficiencies based on total power consumption and energy utilization, and highlighting that participation in secondary-control-reserve markets is key to improving economic feasibility. [60]. *Denmark:* the island of Samsø is powered entirely by renewable energy sources, including wind, solar, and biomass. It has become a model for sustainable energy, having attracted many visitors who are interested in learning about its energy transition [61]. The city of Copenhagen has implemented an energy transition program, which includes measures to promote energy-efficient buildings, sustainable transportation, and the adoption of renewable energy sources [62]. *Poland:* the Pomeranian Solar Valley is a cluster of solar energy companies located in the Pomerania region. The cluster has helped to promote the adoption of solar energy in the region, having created numerous new job openings in the renewable energy sector [63]. The GreenEvo program [64], launched by the Polish government, fosters innovative and environmentally friendly technologies. The program has supported the development of many energy-saving and renewable energy projects in Poland. *Sweden:* the approval of the 250 MW Bäckhammar Solar Park in Värmland, Sweden, expected to generate approximately 250 GWh

of electricity annually and power some 50,000 households, marks a significant milestone in the country's renewable energy strategy. Developed by Sunna Group AB on reclaimed forest land, the project exemplifies how large-scale solar installations can advance national decarbonization objectives, foster site reuse, and support the transition away from fossil-fuel-dependent power systems [65]. The Gothenburg "2030 Climate Neutrality Action Plan" (Climate City Contract) sets a target of achieving net-zero greenhouse-gas emissions by 2030, with strategic emphasis on decarbonizing transport and mobility, buildings and energy systems, waste, industrial processes and land use. The plan adopts a multi-level governance framework that involves municipal, regional and private-sector actors, commits to periodic monitoring and updates, and includes pathways and portfolios of actions designed to align local systems with the broader EU "Mission Cities" agenda for climate-neutral urban development [66].

The given countries have implemented various energy transition projects to promote the adoption of renewable energy sources and energy efficiency measures. These projects have helped to decrease carbon emissions and increase the share of renewable energy sources in the energy mix, and have become models for sustainable energy in other countries around the world.

Energy Transition in Switzerland: Federal and Cantonal Initiatives. Switzerland's commitment to energy transition is articulated through its national policy framework and reinforced by proactive measures at the cantonal and municipal levels. The Swiss Energy Strategy 2050, established by the Federal Council, outlines a comprehensive approach to reducing carbon emissions, enhancing energy efficiency, and increasing the share of renewable energy sources in the national energy mix.

At the cantonal level, several regions have implemented innovative projects to advance these objectives: *Canton of Basel:* the canton has introduced the "Baselbieter Energiepaket" [67], a strategic initiative aimed at reducing non-renewable heating energy demand and promoting energy-efficient construction. This program is supported through partnerships with financial institutions to facilitate the financing of energy-efficient projects. *Canton of Zurich:* Zurich's Energy Master Plan [68] aligns with the principles of the "2000-Watt Society," targeting a reduction in per capita energy consumption and CO_2 emissions. The plan employs the Building Park Model to assess and optimize energy use across the city's building stock. *Canton of Lucerne:* the canton has committed to decarbonizing process energy by supporting industries in transitioning from fossil fuels to renewable energy sources. The climate-adaptation component of the Climate Strategy for the Canton of Lucerne engaged experts via workshops and group interviews to identify climate impacts, assess risks and opportunities across nine action areas, compile existing measures, and elaborate 49 new adaptation measures [69]. *Canton of Geneva:* the canton has adopted the "Energy Master Plan 2020–2030" [70], setting clear targets for reducing energy demand and optimizing renewable energy use. This plan is integral to Geneva's broader strategy to achieve carbon neutrality by 2050. Additionally, urban centers such as *Lausanne* undertake significant building retrofitting programs [71]. For instance, the city implements energy-efficient renovations in municipal buildings, achieving substantial reductions in energy consumption and carbon emissions.

These cantonal and municipal initiatives exemplify Switzerland's decentralized approach to energy transition, where local governments play a pivotal role in implementing and customizing strategies that align with national objectives. This multi-level governance model enhances the effectiveness of energy policies and fosters innovation in sustainable energy practices across the country.

Leading Renewable Energy Initiatives in Ukraine. Ukraine has made significant strides in advancing its renewable energy sector, with several notable projects and initiatives contributing to its decarbonization efforts: *Tyligulska Wind Power Plant Expansion:* DTEK, Ukraine's largest private energy company, is expanding the Tyligulska Wind Power Plant in the Mykolaiv region. The project aims to increase the plant's capacity from 114 MW to 500 MW, with an investment of approximately €450 million. Upon completion, the expanded facility is expected to produce 1.7 TWh of electricity annually, sufficient to power 900,000 homes. This initiative represents the largest private sector investment in Ukraine's energy sector since the 2022 [72]. *Decarbonization Fund Leasing Project:* the Decarbonization Fund of Ukraine has implemented its first leasing project to support the adoption of renewable energy technologies. This initiative aims to reduce greenhouse gas emissions and promote the development of renewable energy sources by providing financial support for projects that might otherwise lack sufficient upfront investment [73]. *Critical Infrastructure Solar Project in Chortkiv:* September 2025, a solar energy project was completed in Chortkiv to power critical infrastructure. The solar power plants now cover approximately 20% of the facilities' electricity needs, ensuring reliable municipal water services, reducing CO_2 emissions, and lowering costs for the local water utility company [74]. *Rise Solar and Battery Initiative:* DTEK has partnered with Octopus Energy to launch the €100 million "Rise" initiative, aiming to develop 100 solar and battery projects across Ukraine over the next three years. This project seeks to enhance energy security amid ongoing challenges by stabilizing the power grid, reducing costs for businesses, and increasing energy resilience [75].

These projects exemplify Ukraine's commitment to advancing renewable energy and decarbonization efforts, contributing to a more sustainable and resilient energy future.

The examined cases illustrate the diversity of strategies and approaches employed by European countries and Ukraine to advance energy transition and decarbonization. Germany, Denmark, Poland, and Sweden have implemented large-scale renewable energy projects, energy-efficient infrastructure programs, and innovative policy instruments, positioning themselves as global leaders in sustainable energy. Switzerland's decentralized model, combining federal frameworks such as the Energy Strategy 2050 with proactive cantonal and municipal initiatives, demonstrates the effectiveness of multi-level governance in achieving energy efficiency and renewable energy targets. Ukraine, despite facing significant structural and geopolitical challenges, has made notable progress in expanding renewable energy capacity through projects such as the Tyligulska Wind Power Plant expansion, the Decarbonization Fund Leasing Project, the Chortkiv solar infrastructure, and the Rise Solar and Battery Initiative. These cases highlight that successful decarbonization requires a combination of robust national policies, local implementation, financial mechanisms, and technological innovation. They provide valuable lessons for countries at different stages of energy transition, illustrating how tailored strategies can support the integration of renewable energy, reduce carbon emissions, and enhance energy security. Furthermore, these examples underscore the importance of public-private partnerships, local community engagement, and targeted investments in renewable technologies as critical drivers of a sustainable and resilient energy future.

Conclusions

The comparative analysis of energy transition strategies in the European Union, Switzerland, and Ukraine reveals the complex interplay of policy, institutional frameworks, and market dynamics in shaping sustainable and low-carbon energy pathways. Despite substantial differences in governance structures, economic contexts, and energy system maturity, all three cases demonstrate a commitment to decarbonization, renewable energy deployment, and improved energy efficiency.

Key Priorities in Energy Transition Strategies. The European Union emphasizes large-scale renewable energy deployment, energy efficiency, and the integration of energy markets across member states, supported by legislative instruments such as the European Green Deal, Renewable Energy Directive, and Energy Efficiency Directive. Switzerland, leveraging its abundant hydroelectric resources, combines national and cantonal strategies to diversify its energy mix, promote energy efficiency, and implement innovative financing and citizen engagement mechanisms. Ukraine, in contrast, focuses on energy security, diversification of energy sources, and attracting private investment in renewable energy, while progressively aligning national legislation with European standards under its Energy Strategy 2035.

Key Players in the Energy Market. The study highlights the critical role of multi-level stakeholder engagement in successful energy transition. In the EU, national governments, regulatory authorities, energy companies, research institutions, and civil society actors coordinate to implement policies, deploy technologies, and integrate energy markets. Switzerland illustrates the efficacy of decentralized governance, where cantonal authorities, municipal administrations, and public-private partnerships actively participate in energy planning. Ukraine's energy market demonstrates the importance of state-owned and private entities, such as Naftogaz, DTEK, and Energoatom, in driving infrastructure modernization, renewable energy deployment, and systemic resilience under challenging circumstances.

Best Cases in Decarbonization. The analysis identifies exemplary projects that provide practical lessons in renewable energy adoption, energy efficiency, and stakeholder collaboration. Germany demonstrates comprehensive urban and solar initiatives; Denmark showcases fully renewable islands and district heating systems; Poland illustrates emerging solar clusters and innovation programs; Sweden combines nuclear and bioenergy to reduce emissions; Switzerland implements cantonal renewable projects and building retrofits; and Ukraine has achieved progress with large-scale wind and solar developments, including the Tyligulska Wind Power Plant expansion, the Chortkiv solar infrastructure, and the Rise Solar and Battery Initiative. These cases underscore the significance of integrating robust policy frameworks, financial mechanisms, technological innovation, and community engagement to accelerate decarbonization effectively.

Synthesis. The findings reveal that successful energy transition requires a context-sensitive combination of regulatory clarity, institutional stability, technological advancement, and stakeholder collaboration. Comparative insights from these cases highlight the importance of adapting strategies to national circumstances, while drawing lessons from international best practices. These insights are relevant not only for advanced economies but also for emerging energy markets seeking to develop resilient, low-carbon systems.

Prospects for Future Research. The results of this study provide a foundation for policymakers and researchers to design adaptive and scalable energy transition strategies. Future research should focus on further developments in EU and Ukrainian energy markets, the role of digitalization and smart energy systems, the expansion of the hydrogen economy, and the scaling of community-based renewable energy initiatives. Sector-specific analyses, particularly in battery energy storage system, grid stabilization, and hybrid renewable technologies, offer additional avenues for advancing sustainable energy governance.

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Дата першого надходження рукопису до видання: 28.10.2025
Дата прийнятого до друку рукопису після рецензування: 28.11.2025
Дата публікації: 15.12.2025