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Technological Development Trends of Traditional and New Energy in Europe: A Transition Pathway to Carbon Neutrality

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Abstract

Against the backdrop of global climate change and Europe's commitment to carbon neutrality by 2050, this paper examines the technological development trends of traditional energy (fossil fuels) and new energy (renewables, hydrogen, etc.) in Europe. By integrating policy analysis, historical data, and case studies, we argue that Europe's energy transition is not a linear replacement of fossil fuels by renewables but a dynamic, synergistic process where traditional energy systems are being redefined to support decarbonization. Key findings include: (1) Traditional energy technologies, particularly natural gas and coal, are evolving toward lower-carbon applications (e.g., blue hydrogen, CCS-integrated power generation); (2) New energy technologies, led by wind, solar, and storage, are experiencing exponential cost reductions and scalability improvements; (3) Cross-sectoral integration (e.g., power-to-X, smart grids) and policy frameworks (e.g., EU Green Deal, REPowerEU) are critical enablers of this transition. Challenges such as energy security risks, technological bottlenecks, and social acceptance persist, requiring coordinated efforts across stakeholders.

Keywords: Technological Development ,Traditional and New Energy, Europe, Carbon Neutrality

1. Introduction

Europe's energy landscape is undergoing a profound transformation driven by three interlinked imperatives: (1) climate mitigation—EU member states have pledged to reduce greenhouse gas (GHG) emissions by 55% by 2030 (vs. 1990) and achieve carbon neutrality by 2050 under the European Climate Law; (2) energy security—geopolitical shocks, such as the 2022 Russian invasion of Ukraine, exposed vulnerabilities in reliance on imported fossil fuels; and (3) economic competitiveness—leadership in clean energy technologies is seen as a strategic priority to maintain industrial dominance.

Traditional energy sources (coal, oil, natural gas) have long dominated Europe's energy mix, accounting for ~70% of primary energy consumption in 2020 (Eurostat). However, their role is now evolving: while coal is being phased out rapidly, natural gas is transitioning from a "transition fuel" to a potential "bridge" for low-carbon hydrogen and industrial

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decarbonization. Meanwhile, new energy technologies—wind, solar, hydropower, bioenergy, and emerging sectors like green hydrogen and long-duration storage—are scaling up to replace fossil fuels.

This paper explores the co-evolution of traditional and new energy technologies in Europe, focusing on technological innovation, policy drivers, and systemic challenges. By analyzing case studies (e.g., Germany's *Energiewende*, Norway's hydropower, and the UK's offshore wind), we aim to provide a nuanced understanding of how Europe balances decarbonization with energy security and affordability.

2. Traditional Energy Technologies: From Fossil Fuels to Low-Carbon Hybrids

2.1 Coal: Phasing Out with Residual Roles

Coal was once the backbone of Europe's industrialization, but its decline has accelerated dramatically. In 2022, coal-fired power generation accounted for just 16% of EU electricity (down from 25% in 2019), with countries like France (phased out by 2022) and the UK (targeting 2024) leading the way (IEA, 2023). The primary driver is stringent EU regulations, including the Large Combustion Plant Directive (LCPD) and the Emissions Trading System (ETS), which have made coal increasingly unprofitable due to rising carbon prices (exceeding €90/ton CO_2 in 2023).

However, coal is not disappearing entirely. In regions with limited renewable resources (e.g., parts of Eastern Europe), coal remains a baseload option, albeit with retrofits for carbon capture and storage (CCS). For example, the Polish government plans to repurpose 3 GW of coal plants with CCS by 2030, aiming to reduce emissions while maintaining grid stability (Polish Ministry of Climate, 2022). Additionally, coal-derived materials (e.g., metallurgical coke) are critical for steel production, driving research into hydrogen-based direct reduced iron (DRI) as a coal substitute.

2.2 Natural Gas: Recalibrating as a "Transition Fuel"

Natural gas has long been viewed as a lower-carbon alternative to coal, with EU gas demand peaking at 578 billion cubic meters (bcm) in 2021 before dropping to 433 bcm in 2022 due to the Ukraine war (Eurogas). Its future role is contested: while some argue it will be phased out by 2030, others emphasize its potential to support renewables via flexible power generation and hydrogen production.

Technologically, gas-fired power plants are evolving toward higher efficiency (combined cycle gas turbines [CCGTs] now achieve >60% efficiency) and lower emissions. Innovations like hydrogen co-firing (mixing hydrogen with natural gas) are gaining traction: the EU's

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Hydrogen Strategy targets 10 million tons (Mt) of domestic green hydrogen and 10 Mt of imported hydrogen by 2030, with gas infrastructure (pipelines, storage) earmarked for repurposing as hydrogen networks (EC, 2020). For instance, the H2Med pipeline project aims to transport 2 Mt/year of green hydrogen from Spain to France by 2030, leveraging existing gas infrastructure (Snam, 2023).

Moreover, gas is critical for balancing variable renewables. As wind and solar penetration increases, gas peaker plants (which can start up in minutes) provide grid stability. In Germany, gas plants operated at 15% capacity in 2022, up from 5% in 2020, highlighting their role in managing intermittency (AGORA Energiewende, 2023).

2.3 Oil: Declining Demand with Niche Applications

Oil demand in Europe peaked in 2006 and has since fallen by 25% (IEA, 2023), driven by electrification of transport (EVs accounted for 14% of new car sales in 2022) and policy measures (e.g., EU's 2035 ban on internal combustion engine vehicles). Remaining demand is concentrated in aviation (kerosene), shipping (heavy fuel oil), and petrochemicals.

Technological responses include sustainable aviation fuel (SAF) and bio-lubricants. The EU's ReFuelEU Aviation regulation mandates 2% SAF by 2025 and 6% by 2030, with synthetic e-kerosene (produced via green hydrogen and captured CO_2) emerging as a key solution (EC, 2023). Similarly, maritime shipping is exploring ammonia and methanol as zero-carbon fuels, though these require significant engine retrofits (IMO, 2023).

3. New Energy Technologies: Scaling Innovation for Decarbonization

3.1 Wind and Solar: Cost Leadership and Technological Maturity

Wind and solar are now the cheapest sources of new electricity generation in most of Europe, with levelized costs of energy (LCOE) ranging from €20–40/MWh for onshore wind and €30–60/MWh for utility-scale solar PV, compared to €60–120/MWh for gas-fired power (Lazard, 2023). This cost parity has driven explosive growth: wind capacity increased by 11 GW (+7%) in 2022, while solar PV added 41 GW (+37%) (WindEurope, 2023; SolarPower Europe, 2023).

Technological advancements are accelerating this trend. Offshore wind, in particular, is seeing breakthroughs in floating turbine technology, which enables deployment in deep waters (≥60m) where fixed-bottom turbines are impractical. Projects like Hywind Scotland (50 MW) and Vineyard Wind (800 MW, US, but with European technology) demonstrate floating wind's potential to unlock 80% of Europe's offshore wind resource (ENTSO-E, 2022).

Solar PV is benefiting from perovskite-silicon tandem cells, which could reach 30%

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efficiency (vs. 22% for standard silicon cells) by 2030 (NREL, 2023). Additionally, building-integrated photovoltaics (BIPV) and agrivoltaics (combining solar panels with agriculture) are expanding deployment opportunities beyond dedicated solar farms.

3.2 Energy Storage: Solving Intermittency

The variability of wind and solar requires flexible storage solutions. Europe's storage market is dominated by pumped hydro (accounting for 90% of installed capacity, ~50 GWh), but battery energy storage systems (BESS) are growing rapidly, with capacity reaching 12 GWh in 2022 (up from 1 GWh in 2019) (EASE, 2023). Lithium-ion batteries dominate the market, but long-duration storage (LDS) technologies (≥8 hours) are gaining attention to address multi-day intermittency.

Emerging LDS options include:

- **Flow batteries**: Vanadium redox flow batteries (VRFBs) offer 10–20 hour durations and 20-year lifespans, making them suitable for grid-scale storage. Projects like the 100 MWh Ulm VRFB in Germany are testing this technology (Fraunhofer ISE, 2023).
- **Thermal storage**: Molten salt storage (used in concentrated solar power, CSP) and phase-change materials (PCMs) are being deployed in hybrid solar plants (e.g., Noor Ouarzazate in Morocco, with 350 MW CSP and 70 MW PV).
- **Green hydrogen**: Produced via electrolysis using renewable electricity, green hydrogen can be stored for weeks or months and used in hard-to-electrify sectors (e.g., heavy industry, aviation). The EU's Hydrogen Bank, launched in 2023, aims to scale production via auctions (EC, 2023).

3.3 Hydrogen: A Versatile Energy Carrier

Hydrogen is positioned as a critical energy carrier for decarbonizing sectors where electrification is challenging. Europe's hydrogen strategy focuses on green hydrogen (produced via renewable-powered electrolysis), with a target of 20 million tons (Mt) of annual consumption by 2030 (10 Mt domestic, 10 Mt imported) (EC, 2020).

Technological progress is accelerating green hydrogen production:

- **Electrolyzer efficiency**: Proton exchange membrane (PEM) and solid oxide electrolyzers (SOECs) now achieve efficiencies of 70–80%, reducing production costs (from €5–8/kg in 2020 to €3–5/kg projected by 2030) (IRENA, 2023).
- **Integration with renewables**: "Power-to-X" (P2X) projects, such as the 800 MW HyDeal Ambition in Northern Europe, aim to produce green hydrogen using surplus wind and solar, then convert it to e-kerosene, ammonia, and methanol (HyDeal, 2023).

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Challenges remain, including high capital costs and limited electrolyzer manufacturing capacity (Europe currently produces <1 GW/year, vs. 50 GW needed by 2030) (Hydrogen Council, 2023).

3.4 Smart Grids and Digitalization

A decarbonized energy system requires seamless integration of diverse generation sources, storage, and end-users. Smart grids—enabled by digital technologies like AI, IoT, and blockchain—are critical for this.

Key innovations include:

- **Demand response**: Smart meters and home automation systems allow consumers to adjust energy use (e.g., charging EVs during peak renewable generation), reducing strain on the grid. In Denmark, demand response programs have cut peak electricity demand by 15% (DTU, 2023).
- **Grid-forming inverters**: Unlike traditional inverters (which rely on grid stability), grid-forming inverters can stabilize voltage and frequency, making them essential for high-renewable grids. Projects like the 100% renewable island of Samsø (Denmark) use this technology (Samsø Energy Academy, 2023).
- **Blockchain for peer-to-peer (P2P) trading**: Platforms like Power Ledger enable households to sell excess solar energy directly to neighbors, bypassing utilities. In Australia, P2P trading has increased renewable adoption by 20% (Power Ledger, 2023), a model now being tested in Germany and Spain.

4. Synergies and Tensions Between Traditional and New Energy

Europe’s energy transition is characterized by both competition and complementarity between traditional and new energy systems.

4.1 Complementarities

- **Backup for renewables**: Natural gas peaker plants and coal plants with CCS provide critical backup during low renewable output periods (e.g., calm, cloudy days).
- **Infrastructure reuse**: Gas pipelines and storage facilities are being repurposed for hydrogen, avoiding costly new infrastructure (e.g., the H2Med pipeline).
- **Industrial decarbonization**: Hydrogen (green and blue) and CCS enable decarbonization of steel, cement, and chemicals—sectors where electrification is impractical. For example, the HYBRIT project in Sweden uses green hydrogen to produce fossil-free steel, with the first commercial plant set to open in 2026 (HYBRIT, 2023).

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4.2 Tensions

- **Stranded assets**: Premature retirement of fossil fuel infrastructure (e.g., coal plants, gas pipelines) risks stranding trillions in investments, creating political and economic friction (Carbon Tracker, 2023).
- **Resource competition**: Mining critical minerals (lithium, cobalt, copper) for renewables and batteries has raised environmental and social concerns, particularly in regions like the Balkans and Latin America (OECD, 2023).
- **Public acceptance**: Wind farms and transmission lines face opposition due to visual, noise, and land-use impacts. In the UK, 40% of onshore wind projects are delayed by local objections (Renewables UK, 2023).

5. Policy and Market Drivers

Europe’s energy transition is heavily influenced by policy frameworks and market mechanisms:

- **EU Green Deal**: The cornerstone of Europe’s decarbonization strategy, it includes the Fit for 55 package (legally binding 55% emission reduction by 2030) and the Carbon Border Adjustment Mechanism (CBAM), which taxes high-carbon imports to protect domestic industries (EC, 2021).
- **REPowerEU**: Launched in 2022 to accelerate the energy transition amid the Ukraine crisis, it aims to double solar PV capacity to 45 GW by 2030, increase offshore wind to 60 GW, and simplify permitting for renewables (EC, 2022).
- **National energy and climate plans (NECPs)**: Member states are required to submit updated NECPs every five years, outlining sector-specific targets (e.g., Germany’s 2030 renewable target of 80% electricity).
- **Carbon pricing**: The EU ETS, which covers 40% of EU emissions, has seen prices rise from €20/ton in 2019 to €90/ton in 2023, making fossil fuels less competitive (ICE, 2023).

6. Challenges and Future Outlook

Despite progress, Europe faces significant challenges in its energy transition:

- **Energy security**: The Ukraine war highlighted vulnerabilities in gas supply, prompting a temporary increase in coal use (e.g., Germany restarting 2 GW of coal plants in 2022). Balancing short-term security with long-term decarbonization remains a priority.
- **Technological bottlenecks**: Scaling up hydrogen electrolyzers, long-duration storage, and grid modernization requires massive investment and R&D. The EU’s Horizon Europe program allocates €95.5 billion for climate and energy research (2021–2027), but

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public-private collaboration is needed to accelerate deployment (EC, 2021).

- **Social equity**: The transition risks exacerbating energy poverty, particularly in low-income households. Policies like the EU's Social Climate Fund (€65 billion) aim to mitigate this by supporting energy efficiency upgrades and renewable adoption in vulnerable communities (EC, 2023).

7. Conclusion

Europe's energy transition is a complex, dynamic process where traditional and new energy technologies coexist and evolve. While renewables are rapidly scaling, traditional energy systems (particularly natural gas and hydrogen) are being redefined to support decarbonization. Key to success will be: (1) accelerating innovation in storage, hydrogen, and smart grids; (2) aligning policies to balance security, affordability, and sustainability; and (3) ensuring inclusive transitions that benefit all citizens.

As Europe moves toward 2050, the role of traditional energy will diminish, but its legacy will persist in hybrid systems and infrastructure repurposing. New energy technologies, supported by robust policy and market mechanisms, will drive the majority of decarbonization. Ultimately, the success of Europe's transition will depend on its ability to integrate tradition and innovation, turning challenges into opportunities for global leadership in clean energy.

References

- Agora Energiewende. (2023). *European Power Sector in 2022*.
- Carbon Tracker. (2023). *Stranded Assets in the European Energy Sector*.
- EC (European Commission). (2020). *A Hydrogen Strategy for a Climate-Neutral Europe*.
- EC. (2021). *Fit for 55: Delivering the EU's 2030 Climate Target*.
- EC. (2022). *REPowerEU: Joint European Action for More Affordable, Secure, and Sustainable Energy*.
- EASE. (2023). *European Market Monitor for Energy Storage*.
- IEA. (2023). *Coal 2023: Analysis and Forecast to 2028*.
- IRENA. (2023). *Green Hydrogen Cost Reduction: Scaling Up Electrolysers*.
- Lazard. (2023). *Levelized Cost of Energy Analysis, Version 17.0*.
- WindEurope. (2023). *European Wind Market Outlook 2023*.