

The main drivers of the transition: energy security/economic/political/social drivers

Energy policy is traditionally explained through the “energy policy triangle,” which balances three objectives: sustainability, energy security, and economic efficiency. In practice, a fourth dimension, social justice, must also be considered. Affordability, equity, and the fair distribution of costs and benefits are closely linked to all energy policy decisions.

Sustainability has become a major policy priority because of anthropogenic climate change. The greenhouse effect is a natural process that keeps Earth habitable, but human activities have intensified it by increasing greenhouse gas (GHG) concentrations. Key GHGs include carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and fluorinated gases (F-gases). Their impacts are measured using Global Warming Potential over 100 years (GWP100), where CO₂ equals 1. Methane has a GWP of about 30, nitrous oxide 273, and some F-gases are far more potent. For example, HFC-32, a refrigerant used in air-conditioning and heat pumps, has a GWP100 of 771. Because of these impacts, the European Union’s Regulation 2024/573 aims to phase out hydrofluorocarbons (HFCs) by 2050 and promote natural refrigerants such as CO₂, propane, and ammonia.

Climate change is already producing measurable effects. Global temperatures during 2011–2020 were about 1.1°C above pre-industrial levels (1850–1900). Observed impacts include melting glaciers and ice sheets, sea-level rise, declining sea ice, stronger heat waves, and changes in ecosystems and species distributions. Europe is the fastest-warming continent, with 2024 recording the highest temperatures on record. Recent floods, wildfires, and extreme weather events demonstrate the growing human and economic consequences. Between 1980 and 2023, weather- and climate-related disasters caused an estimated €738 billion in losses across the European Union.

Future warming depends heavily on emissions pathways. Climate feedback mechanisms introduce additional uncertainty. Positive feedbacks amplify warming, such as increased atmospheric water vapor, while negative feedbacks partially offset warming as greater heat radiation into space. Current evidence suggests positive feedbacks are much more dominant than negative feedbacks. Actual warming could exceed some projections because many feedback loops are not understood until today.

The IPCC Sixth Assessment Report concludes that current policies and investments remain insufficient to meet climate targets. Responses to climate change are generally divided into mitigation and adaptation strategies. Mitigation seeks to reduce emissions

through measures such as renewable energy deployment, energy efficiency, electrification, methane reduction, public transport expansion, carbon capture, and reduced food waste. Adaptation focuses on increasing resilience to unavoidable impacts through actions such as strengthening energy systems, improving agriculture, building coastal defenses, and developing early warning systems. However, adaptation has limits, and higher temperatures increase the likelihood of irreversible losses and damages.

The severity of climate impacts grows with each additional degree of warming. At 1.5°C, coral reefs are projected to decline by 70–90 %. At 2 °C, more than 99 % of coral reefs may disappear, while biodiversity loss and permafrost degradation become major risks. At 3 °C, many ecosystems face severe threats from wildfires and water scarcity. At 4°C, virtually all assessed ecosystems experience very high risks, including large-scale tree mortality, carbon loss, and degradation of marine and coastal habitats. Human health risks also increase significantly, particularly in regions where extreme heat and humidity may become dangerous for much of the year.

Energy security is another key driver of the clean heat and cooling transition. Traditional heating systems rely heavily on imported fossil fuels, exposing countries to geopolitical risks, supply disruptions, and volatile prices. Expanding domestic renewable heating technologies, including heat pumps, district heating, geothermal energy, solar thermal systems, waste heat recovery, and thermal storage, reduces dependence on imports and improves resilience. Energy efficiency further strengthens security by reducing overall demand.

Economic efficiency is essential for a successful transition. Although clean heating technologies often require higher initial investment, they typically offer lower operating costs and more stable long-term expenses. Understanding electricity pricing is important in this context. European wholesale electricity markets operate according to the merit-order principle, where power plants are dispatched from the lowest to the highest marginal cost. Renewable energy sources generally enter first because of their very low operating costs. However, the final power plant needed to meet demand (often a gas-fired plant) sets the market price. As a result, gas prices continue to influence electricity prices even in systems with significant renewable generation. Increasing renewable capacity, storage, interconnections, and flexibility can reduce this dependence.

Heating costs vary by technology. Fossil-fuel systems are strongly linked to fuel prices, while heat pumps depend more on electricity prices and their efficiency. District heating systems combine infrastructure, fuel, and operating costs. Advanced fifth-generation district heating and cooling networks (5GDHC) can also provide cooling services, often

at very low marginal cost through waste heat recovery, making them attractive to consumers.

Demand-response mechanisms are becoming increasingly important. Implicit demand response occurs when consumers shift energy use in response to price signals, while explicit demand response involves participation in flexibility markets. Combined with thermal storage, clean heating technologies can move demand to periods of abundant renewable electricity, lowering costs and improving grid stability.

The social dimension is equally important because energy systems provide essential services. Affordable and reliable heating and cooling improve quality of life and help prevent energy poverty. Failure to address climate change could worsen food insecurity, migration pressures, health impacts, infrastructure damage, and public expenditure. Rising temperatures are also expected to increase cooling demand. Therefore, a successful transition supports both energy affordability and broader societal resilience.

The political dimension is closely linked to energy security and social stability. Domestic renewable energy production reduces dependence on imported fossil fuels, increases strategic autonomy, and lowers exposure to geopolitical risks. Decentralized renewable systems are generally more resilient to disruptions than centralized fossil-fuel supply chains. By combining renewable energy, efficiency improvements, thermal storage, and flexible demand management, countries can create energy systems that are more secure, competitive, affordable, and sustainable.

Overall, the clean heat and cooling transition demonstrates that sustainability, energy security, economic efficiency, social welfare, and political stability are deeply interconnected. Effective policies should pursue all of these objectives simultaneously to achieve decarbonization while strengthening long-term resilience and prosperity.