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Sustainable Restoration of the Power and Heat Sectors in Ukraine: Implications for Energy Security and Resilience

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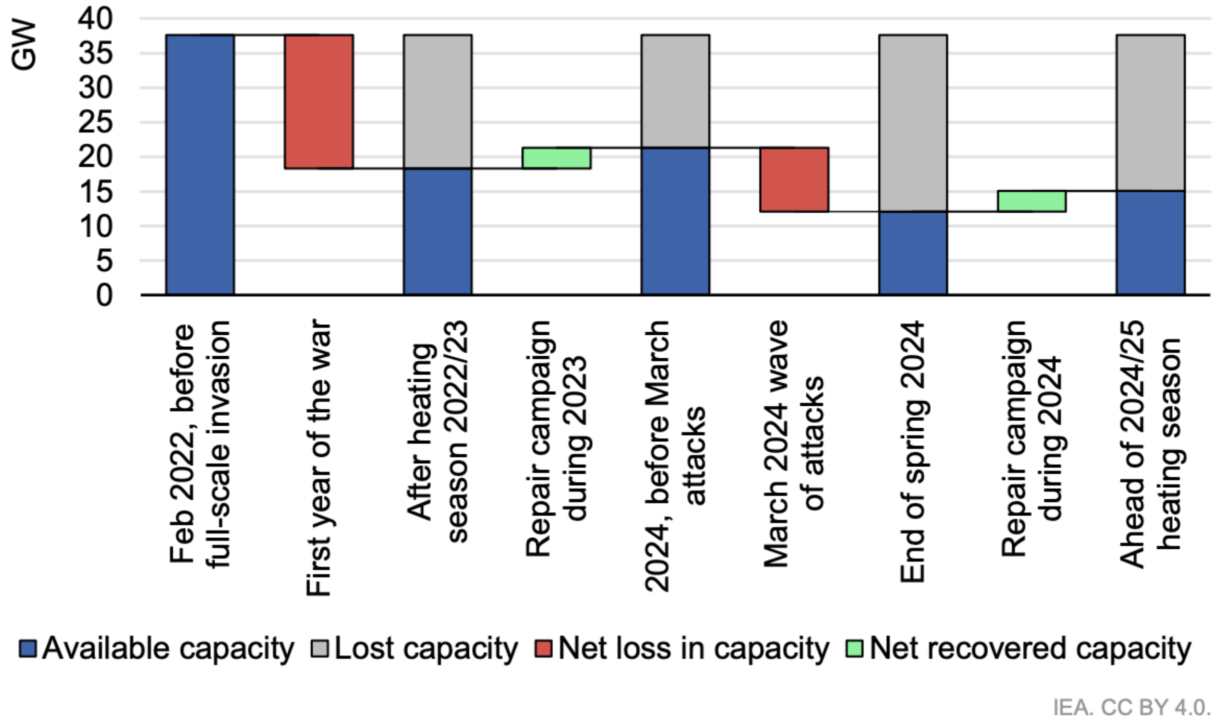
1 Motivation

Russia's unprovoked war in Ukraine created enormous economic and environmental challenges in Ukraine. The first 18 months of war alone resulted in an additional 150 Mt CO2-eq GHG emissions, which may increase considerably as the duration of the war remains uncertain. The ongoing war significantly exacerbates the cost of project financing in Ukraine, severely undermining the economic viability of investments in renewable energy and other climate-neutral technologies.

Nearly two-thirds of Ukraine's dispatchable power generation capacity has been occupied, damaged or destroyed by Russia since the invasion (see Figure 1). Repeated Russian missile and kamikaze drone strikes have triggered widespread rolling blackouts, disrupting daily life for tens of millions and severely constraining access to electricity across Ukraine. Russia's full-scale invasion has drawn a sharp line under Ukraine's past. The country's economic and energy resilience now depends on whether it can reconfigure its electricity sector, the largest source of GHG emissions, into a more decentralised and sustainable system. This is no longer a matter of modernisation but of national security. Rebuilding the power sector on more resilient foundations has become a strategic imperative for Kyiv.

Figure 1. Available installed capacity of dispatchable power generation in Ukraine



Source: IEA, 2024[1].

The energy sector remains the primary source of emissions in Ukraine. Thus, in 2023, it was responsible for 164

[1] Empowering Ukraine Through a Decentralised Electricity System: A roadmap for Ukraine's increased use of distributed energy resources towards 2030

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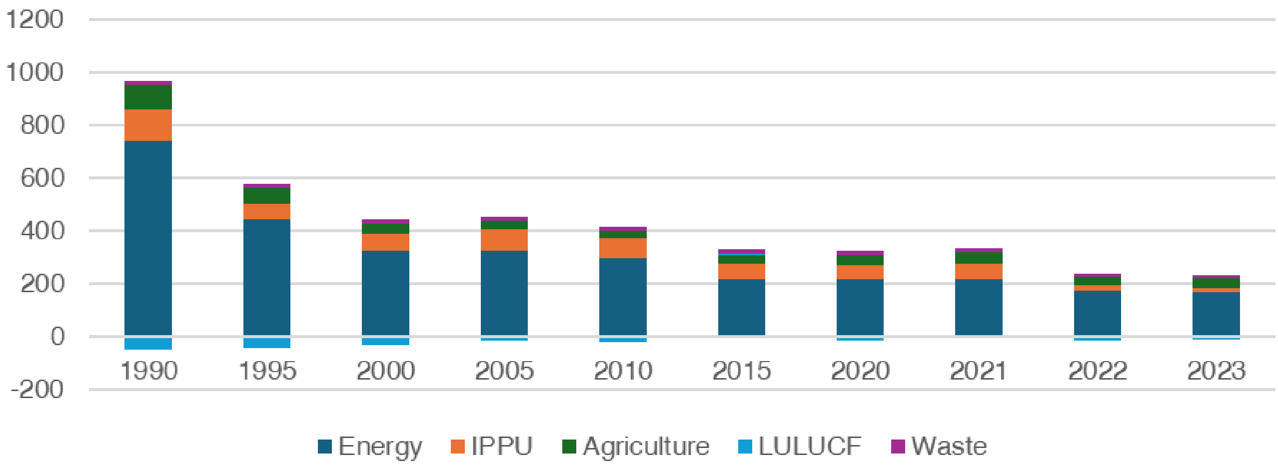
Mt CO2-eq or 74% of total emissions in Ukraine, while the significant share of GHG within the sector is attributed to power and heat generation. Therefore, decarbonizing Ukraine`s energy sector has a high potential to reduce Ukraine`s greenhouse gas emissions.

Figure 2. Total CO2-eq emission by sector



Source: UNFCCC, 2024[2]

The transition to the more resilient and sustainable power sector has already begun. In 2024, the government of Ukraine adopted the Distributed Generation Development Strategy for 2035 and the operational plan of measures for its implementation from 2024 to 2026. Replacement of coal-fired power generation with distributed energy resources (DER), which include variable renewables, biomass, power storage, and ultra-flexible gas generation, will result in a more resilient and secure system, significantly reducing GHG emissions., This is essential for Ukraine to meet its net-zero pledge. Looking ahead, Ukraine will face the complex task of maintaining grid stability as variable renewable energy sources account for a growing share of electricity generation. Meeting this challenge will demand advanced modelling tools, integrated planning, and a cross-sectoral approach. Technologies such as combined heat and power, heat pumps, electric vehicles, and hydrogen production and storage are likely to play a pivotal role in enhancing system flexibility, which is crucial for managing the intermittency of wind and solar systems.

This policy brief addresses the compounded impacts of Russia's war on Ukraine's energy system, presenting scenario-based insights and policy-relevant evidence to inform the reconstruction pathways of the power sector. It contributes to ongoing policy discussions by identifying concrete pathways for enhancing energy system resilience, decentralisation, and decarbonisation. It supports policy design and implementation by identifying options for rebuilding the power sector in line with resilience objectives, decarbonisation targets, and alignment with EU integration and green transition frameworks, offering strategic options for decision-makers tasked with aligning emergency response, infrastructure investment, and long-term climate goals. Therefore, it may assist both Ukrainian and EU's public authorities for planning sustainable restoration of the power sector after the end of the war and established strong peace.

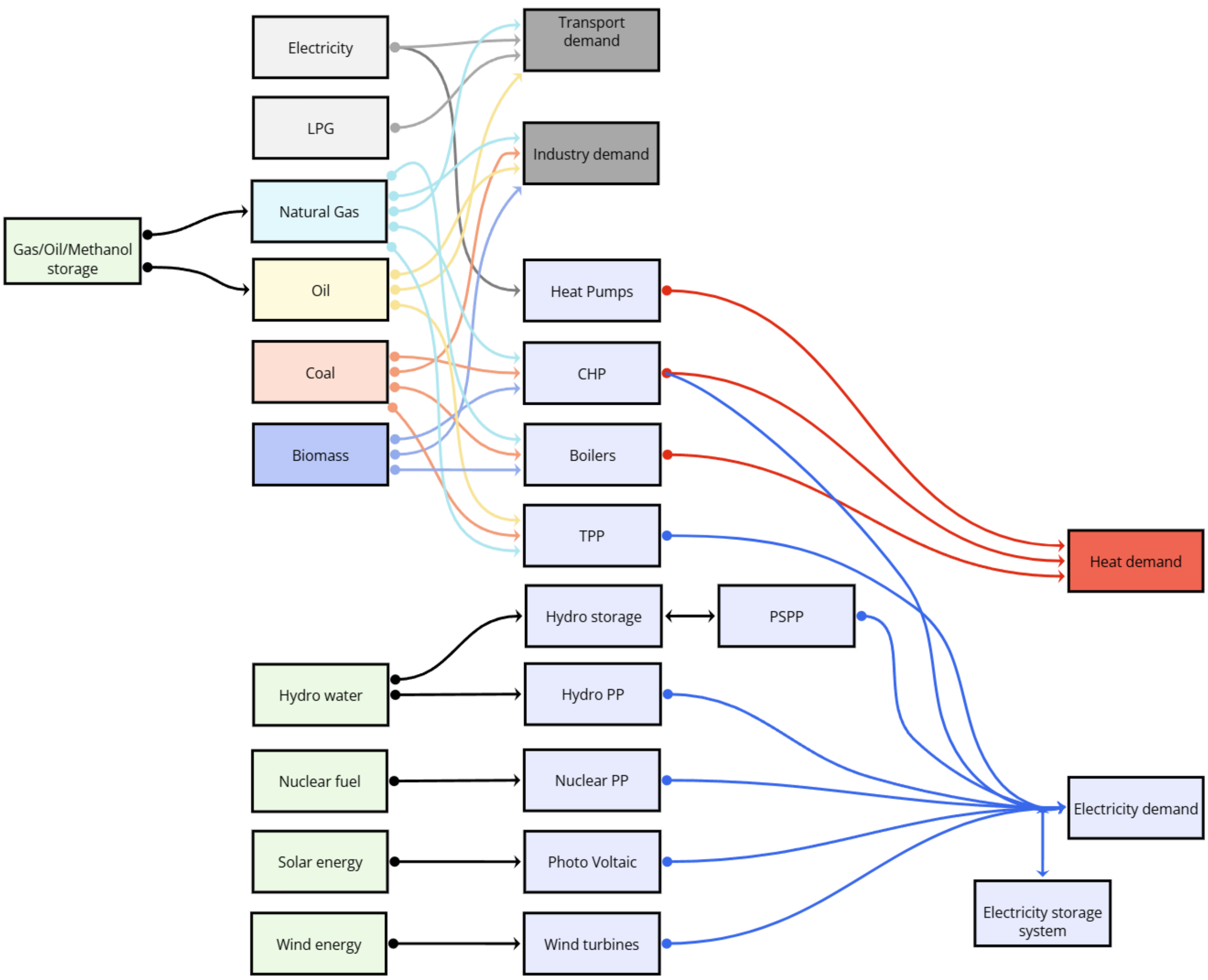
[2] Ukraine Greenhouse gas inventory 1990-2023

2 Scenario Design

KSE Institute employed the EnergyPLAN model, developed by the Sustainable Energy Planning Research group at Aalborg University in cooperation with PlanEnergi and EMD A/S, which enables the study of national energy systems' operation on an hourly basis, including electricity, heating, cooling, and transport, and builds different scenarios for power and heat generation development to meet domestic demand during the modelled sustainable recovery until 2035.

The model is depicted graphically in Figure 3.

Figure 3. EnergyPlan Ukraine energy model



Source: KSE Institute

The developed EnergyPlan model enables the evaluation of the impact of the projected expansion of renewable capacities and other generation assets on the power sector's resilience and security. Three alternative scenarios were developed, each grounded in a distinct combination of key drivers and enabling conditions, e.g. the end of Russian invasion, speed of the EU acquis implementation, implementation of the policy targets and measures, etc., projected to influence the future configuration of Ukraine's power and heat sectors. The selected drivers and enablers underpinning each scenario are summarized in Table 1.

Table 1. Scenario Design

Scenario	Concept
Baseline	• The war ends by 2026, Ukraine retains its pre-2022 territory with strong security guarantees but Russia remains unaccountable for invasion, and a risk of new war persists. • Medium-fast adoption of the EU acquis by Ukraine, Ukraine joins the EU by 2035. • Fast deployment of VRE, energy storage and ultra flexible power generation to ensure the security, resilience and sustainability targets. • Coal-fired power generation fleet was replaced by distributed energy resources. • Phasing out energy price subsidies in gas, heat and electricity sector by 2030. Prices of gas and electricity reflect market value by 2030 which speeds up the heat pumps and biomass deployment in individual and district heating. • The electric vehicles fleet increases to 465 thousand by 2035. • Feasibility studies for hydrogen deployment are completed with the support from the EU funds and H2 capacities are under construction
Optimistic	• The war ends by 2026, Ukraine retains its sovereign territory with strong security guarantees which leads to sustainable peace, and risk of new conflict is minimized • Very fast adoption of the EU acquis by Ukraine, strong EU political will, Ukraine joins the EU by 2032 • Fast deployment of VRE, energy storage and ultra flexible power generation to ensure the security, resilience and sustainability targets • Coal-fired power generation fleet was replaced by distributed energy resources combined with energy storages and peak-load gas generation • Phasing out energy price subsidies in gas, heat and electricity sector by 2030. Prices of gas and electricity reflect market value by 2030 which speeds up the heat pumps and biomass deployment in individual and district heating • The electric vehicles fleet increases to 1,080 thousand by 2035 • First hydrogen capacities were completed, which enables to reach of 0.3 Mt per year (Mtpa) of clean hydrogen production by 2035
Pessimistic	• The war ends by 2027; Ukraine gains only control of 2025 territory but returns control over Zaporizhzya NPP. It gets poor security guarantees from allies, Russia remains unaccountable and militarized, the risk of a new war remains very high. • Slow adoption of the EU acquis by Ukraine, Ukraine still negotiates the EU accession in 2035. • Slow deployment of VRE, energy storage and ultra flexible power generation. • Coal-fired power generation fleet is partially restored (5 GW) and remains operational by 2035. • Residential energy prices continue to be subsidized. Slow heat pumps and biomass deployment. • The electric vehicles fleet increases to 300 thousand by 2035. • H2 not competitive due to high costs and lack of incentives from the state and support from the EU funds

Electricity demand and the generation mix differ across scenarios, shaped by the extent to which a level playing field emerges in the energy sector, the pace of EU integration and associated economic growth, and the degree

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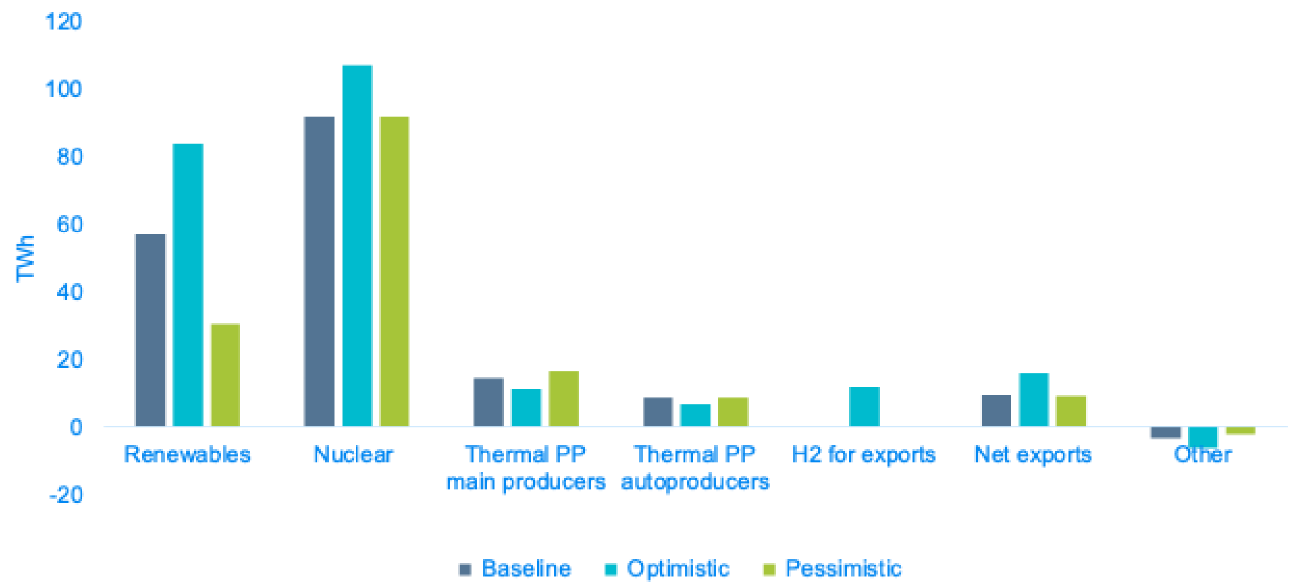
of electrification required to deliver on Ukraine's commitment to net-zero emissions by 2050. The domestic electricity demand in a baseline scenario is projected to return to its pre-war level to 159 TWh. In the optimistic scenario, it is projected to reach 175 TWh, while in the pessimistic one, it may increase only to 136 TWh.

3 Model Results

The results of scenarios are summarized in Figure 4.

Figure 4. Domestic electricity demand and net exports by scenario in 2035



Source: KSE Institute

The share of renewable power in domestic electricity demand increases sharply in both baseline and optimistic scenarios to 37% and 45%, respectively, by 2035, from 13% in 2025. In the pessimistic scenario, rises by just 24%, leaving Ukraine unable to meet its National Energy and Climate Plan (NECP) target, even five years beyond the official deadline. This limited progress reflects a stalled expansion in variable renewable energy sources. Wind power reaches only 8 TWh in this scenario, compared to 29 TWh in the baseline and 54 TWh in the optimistic case. Solar generation grows more modestly across all scenarios, rising from 9 TWh in 2025 to 13 TWh, 20 TWh, and 23 TWh in the pessimistic, baseline, and optimistic projections, respectively.

Nuclear power plants remain the backbone of the electricity sector, accounting for approximately 58% and 61% of domestic demand in the baseline and optimistic scenarios, respectively. This outcome is both technically feasible and consistent with Ukraine's long-term energy strategy.

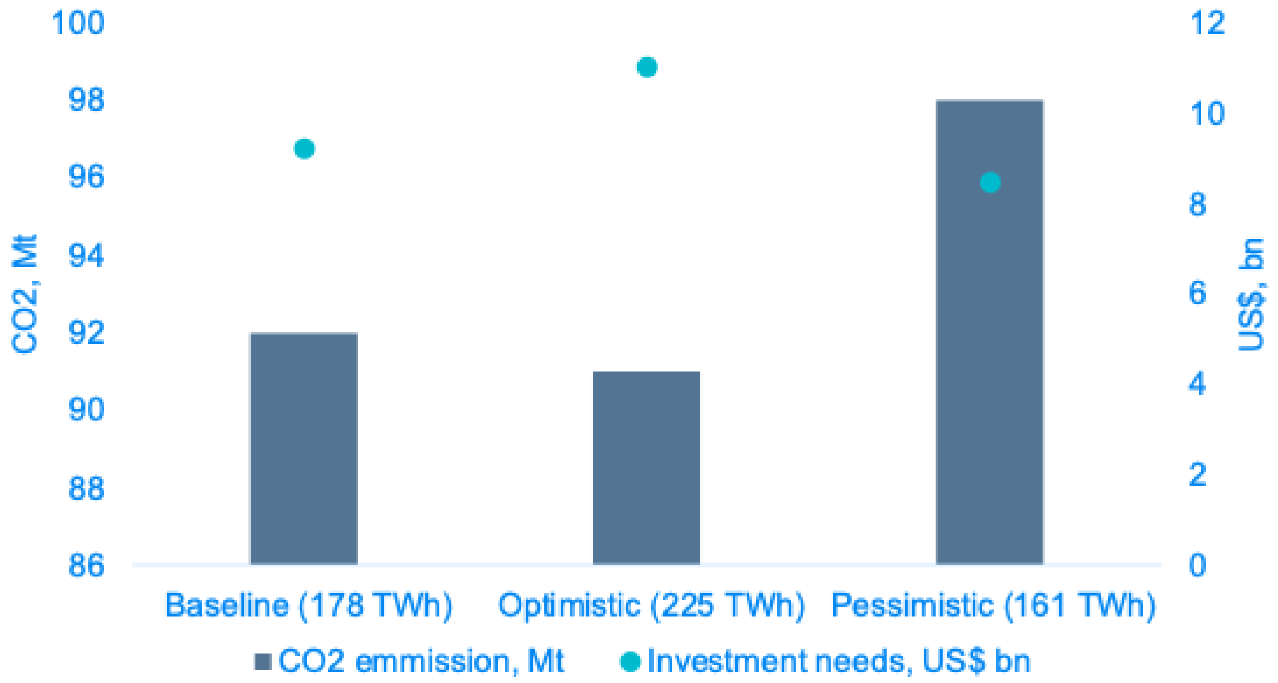
Thermal power plants (TPPs) transition from serving as baseload generators to becoming flexible, load-following units, helping to manage peak loads and system variability. The average annual capacity factor of TPPs drops to 41% and 32% in the baseline and optimistic scenarios, respectively, compared to 84% in 2025. Lower system load not only eases operational strain but also enables more regular maintenance, extending asset lifespans and enhancing long-term reliability and sustainability performance of the power system.

Despite improved system balance, occasional peak-hour reliance on electricity imports requires an upgrade in transmission capacity from the planned 4.9 GW to 5.8 GW in the baseline scenario. This expansion ensures sufficient import/export flexibility, strengthening grid reliability. However, the planned 4.9 GW transmission capacity is sufficient for both imports and exports in the optimistic scenario, enabling a flexible response to peak load conditions. Despite significantly lower demand in the pessimistic scenario and annual electricity imports of less than 1 TWh/year, the available domestic generation capacity is insufficient to meet peak demand. As a result, the required import capacity must increase to approximately 3 GW from the current 2.3 GW. Net electricity exports are projected at 9 TWh, 10 TWh, and 16 TWh in the pessimistic, baseline, and optimistic scenarios by 2035. In contrast, in 2025, a significant share of domestic demand is expected to be met through imports, which could reach up to 10 TWh.

The model shows a reduced reliance on CHP plants, many of which are aged and in deteriorating condition in all scenarios. In response, heat-only boilers and heat pumps assume a larger share of heat production, particularly in baseline and optimistic scenarios. These technologies offer greater flexibility, are more cost-effective to maintain and replace, and contribute to a more resilient heat supply system.

Figure 5 presents annual CO_2 emissions and investment requirements across the modelled scenarios. In the baseline case, emissions reach 92 million tonnes per year, with yearly investment needs rising to US$9 billion (in 2025 constant prices), as total electricity generation, including exports, increases to 178 TWh. In the optimistic scenario, annual CO_2 emissions reach 91 million tonnes, with investment needs rising to US$11 billion (in 2025 constant terms), even as electricity generation, including net exports and production for hydrogen, expands to 225 TWh. By contrast, in the pessimistic scenario, emissions climb to 98 million tonnes, while investment falls to US$8 billion and total generation reaches just 161 TWh.

Figure 5. Total CO2 emission and cumulative investments needs through 2035 by scenario



Source: KSE Institute

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4 Policy Implications

As Ukraine rebuilds its battered energy system and moves toward EU accession, reforms are urgently needed to unlock renewable energy sources, attract investment, and enhance grid resilience. The recommendations below build on existing strategies, highlighting the regulatory and market adjustments needed to translate ambition into action.

1. **Legislation and Regulation**

   Ukraine has adopted a suite of strategic policy frameworks, including the National Action Plan for Renewable Energy, the Strategy for Distributed Energy Development to 2035, and the National Energy and Climate Plan (NECP), to align its energy transition with the objectives of EU accession. These instruments are intended to accelerate the deployment of renewables and reinforce the resilience of a power sector repeatedly targeted and damaged by Russian aerial attacks. Yet strategies alone are not enough. To catalyse further investment, the government must conduct a comprehensive assessment of system needs and dynamics and translate high-level commitments into enforceable legal and regulatory measures. Strengthening investor confidence will depend on de-risking capital flows through targeted secondary legislation that supports the deployment of renewable energy. A clear legal definition of power sector resilience is also needed and should be systematically integrated into planning processes across all levels of government.

2. **Market Design and Pricing Signals**

   Investment needs in the power sector, as projected at 4.3% of GDP in 2025 under the baseline scenario, will remain unmet without a level playing field. Current price subsidies, worth an estimated US$4.2 billion, distort market signals and deter investment. Phasing out subsidies and introducing time-varying, cost-reflective electricity tariffs is essential. The government of Ukraine should develop a roadmap for transition towards the cost-reflective and time-varying electricity prices. A national roadmap for electricity market reform should prioritise smart pricing, targeted support for vulnerable consumers, and grid-friendly demand response mechanisms. Simultaneously, market access for aggregators and energy communities must be improved through simplified participation rules and support for DERs under 1 MW.

3. **Institutional Coordination**

   Coordination across government, regulators, and state-owned enterprises is weak. To mobilise public and private capital, clear mandates and accountability frameworks are needed for Energoatom, Ukrhydroenergo, and Ukrenergo. The National Energy and Utilities Regulatory Commission (NEURC) can take the lead in removing structural market distortions, such as caps in day-ahead, balancing, and ancillary service markets, and enforcing competitive neutrality.

4. **Infrastructure and Digitalisation**

   Modernisation of transmission infrastructure is critical. To enable dynamic pricing and distributed energy resources (DERs), the government must accelerate the rollout of smart meters and digital grid infrastructure. Transmission capacity should be expanded beyond the currently planned 4.9 GW to ensure system flexibility and regional trade integration.

5. **Capacity development and communication**

   Effective reform depends as much on public trust as on technical design. Education campaigns on distributed energy, smart metering, and self-consumption are vital for building trust and enabling informed participation in the energy transition, particularly among households with limited resources, reduced adaptive capacity, or those disproportionately affected by pricing reforms. Households must be able to understand and respond to new, dynamic pricing structures. Clear communication strategies and accessible consumer guidance should accompany tariff reforms. However, capacity development cannot be limited to the household level. Regulators, system operators, local authorities, and market participants all require targeted support to translate policy into practice. This includes developing expertise in grid resilience planning, energy system modelling, tariff design, and market oversight. Aggregators, energy communities, and SMEs also need help navigating shifting participation rules and licensing frameworks, particularly as decentralised energy gains ground.

IAM COMPACT

Policy Brief

Sustainable Restoration of the Power and Heat Sectors in Ukraine:

Implications for Energy Security and Resilience

In a nutshell

IAM COMPACT supports the assessment of global climate goals, progress, and feasibility space, and the design of the next round of Nationally Determined Contributions (NDCs) and policy planning beyond 2030 for major emitters and non-high-income countries. It uses a diverse ensemble of models, tools, and insights from social and political sciences and operations research, integrating bodies of knowledge to co-create the research process and enhance transparency, robustness, and policy relevance. It explores the role of structural changes in major emitting sectors and of political, behaviour, and social aspects in mitigation, quantifies factors promoting or hindering climate neutrality, and accounts for extreme scenarios, to deliver a range of global and national pathways that are environmentally effective, viable, feasible, and desirable. In doing so, it aligns climate action with broader sustainability goals, while developing technical capacity and promoting ownership in non-high-income countries.

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