# CLEAN ENERGY ROADMAP: FROM RECONSTRUCTION TO DECARBONIZATION IN UKRAINE

## Report for COP28

**Study commissioned and supported by the Ministry of Energy of Ukraine**

Ministry of Energy of Ukraine

NET ZERO WORLD INITIATIVE | Accelerating Global Energy System Decarbonization

Argonne NATIONAL LABORATORY

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## Disclaimer

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| **ANL** | Argonne National Laboratory |
| **BECCS** | bio-energy carbon capture and storage |
| **CCS** | carbon capture and storage |
| **CHP** | combined heat and power |
| **COP** | Conference of the Parties under the United Nations Framework Convention on Climate Change |
| **DAC** | direct air capture |
| **DOE** | U.S. Department of Energy |
| **EBRD** | European Bank for Reconstruction and Development |
| **EU** | European Union |
| **G7** | Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States |
| **GHG** | greenhouse gas |
| **IEF** | Institute for Economics and Forecasting of the National Academy of Science of Ukraine |
| **IFI** | international financial institution |
| **LBNL** | Lawrence Berkeley National Laboratory |
| **NDC** | Nationally Determined Contribution |
| **NECP** | National Energy and Climate Plan |
| **NREL** | National Renewable Energy Laboratory |
| **PNNL** | Pacific Northwest National Laboratory |
| **SMR** | small modular reactor |
| **TIMES** | The Integrated MARKAL-EFOM System model |
| **TPES** | total primary energy supply |
| **TPP** | thermal power plant |
| **USAID** | U.S. Agency for International Development |

# FOREWORD FROM THE MINISTRY OF ENERGY

I would like to express sincere appreciation to Net Zero World Initiative for its unwavering support to inform the reconstruction and future development of Ukraine. Through collaborative efforts, we have conducted extensive modeling and stakeholder research, the culmination of which is presented in this report. This partnership has laid the foundation for strategic and informed decision-making.

The ongoing russian aggression has not only threatened our resilience but has presented unparalleled challenges to our energy security. In the face of this adversity, our specialists have displayed exceptional dedication, expediting emergency repairs, fortifying energy infrastructure, and persistently demining energy facilities. As we navigate these violent times, comprehensive security remains our first priority, addressing physical, engineering, and cyber aspects.

At the same time, this report reflects our strong commitment to international obligations. Beyond reinforcing energy security, our strategic goals align with European Union standards and our commitment to a global sustainable, low-carbon future. As we aspire to EU membership, our vision encompasses the seamless integration of our energy sector with EU markets, harmonizing with climate objectives.

Looking forward to our strategic goals, we are resolute in developing low-carbon and carbon-neutral capacities. This involves replacing outdated thermal coal power plants with modern biofuel or waste-to-energy facilities, solar and wind power, integration of energy storage, and deployment of other innovative flexible generation technologies. Our commitment extends to the development of nuclear generation, ensuring diversity in our energy mix. Similar intentions guide our approach to the broader energy sector, including industry, buildings, and transport. We aim to foster new technologies such as hydrogen and biomethane production and usage.

Decarbonization, as we envision it, necessitates significant investments. In earnest collaboration with our partners, including international financial institutions and other donors, we are engaged in a dialogue to secure the funding and investments essential for these transformative developments.

The recovery of Ukraine and the modernization of our energy system are also opportunities for business cooperation. Our country, with its natural resources, including critical raw materials, and significant human resources, is exploring opportunities to develop its own production and join global supply chains of climate-neutral technologies.

In conclusion, I extend my deepest appreciation to all contributors, researchers, and partners who have dedicated their expertise and resources to this cause. COP28 serves as a pivotal platform for us to collectively shape ideas about a sustainable, resilient, and decarbonized future.

Thank you for your commitment, dedication, and invaluable contributions.

*Sincerely,*
***German Galushchenko***
*Minister of Energy of Ukraine*

# A WORD FROM THE TECHNICAL TEAM

This analysis would not have been possible without the highly responsive and essential support and guidance provided by Deputy Energy Minister **Yaroslav Demchenkov**. We also want to express our appreciation for the work of Deputy Energy Minister **Svitlana Grynchuk** for supporting all COP activities.

**Yaroslav Lytvynenko** provided invaluable everyday support for the study. On behalf of the technical team, we want to express our sincere appreciation for his hard work.

We express our gratitude to the members of the stakeholder consultation group who participated in our discussions between May and September 2023. These include the Ministry of Energy, Ministry for Communities, Territories and Infrastructure Development, Ministry for Environment and Natural Resources, Reform Support Teams of these ministries, National Energy and Utilities Regulatory Commission, Ukrenergo, DTEK, Ukrainian Bioenergy Association, DiXi group, KPMG, EcoAction, EcoClub, U.S. Department of Energy (DOE), DOE national laboratories, United States Agency for International Development (USAID), USAID's Energy Security Project, Energy Community Secretariat, European Bank for Reconstruction and Development, World Bank, International Energy Agency, International Atomic Energy Agency, Danish Energy Agency, Berlin Economics, and many others. We benefited from your contributions to this study.

**Dr. Nazar Kholod**, Net Zero World Initiative country coordinator for Ukraine

**Dr. Oleksandr Diachuk**, team leader of Ukraine's modeling team

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1 Pacific Northwest National Laboratory (PNNL)
2 Institute for Economics and Forecasting of the National Academy of Sciences of Ukraine
3 Argonne National Laboratory (ANL)
4 DiXi Group
5 Lawrence Berkeley National Laboratory (LBNL)
6 National Renewable Energy Laboratory (NREL)

# EXECUTIVE SUMMARY

Under the Net Zero World Initiative, the United States is mobilizing the capabilities of nine U.S. government agencies, led by the U.S. Department of Energy (DOE), to partner with philanthropies and multiple countries to cocreate and implement tailored technical and investment pathways to accelerate the decarbonization of global energy systems. The Net Zero World Initiative, committed to accelerating decarbonization and fostering more inclusive, equitable, and resilient energy systems, is pleased to support the Government of Ukraine in developing decarbonization pathways.

In a collaborative effort to promote the resilience and sustainability of the energy system as part of Ukraine's reconstruction, this project has harnessed the expertise of the leading DOE national laboratories and distinguished Ukrainian research institutes and think tanks. The modeling team used the TIMES-Ukraine model, developed by the Institute for Economics and Forecasting (IEF) of the National Academy of Sciences of Ukraine, and improved in 2023 with the support of the DOE national laboratories to model decarbonization pathways. Together, we have developed scenarios for achieving net-zero emissions in the energy sector, which are aligned with the goals of the Energy Strategy of Ukraine through 2050. The team explored three main scenarios: Reference, Net Zero Base, and Net Zero Intense. Both Net Zero scenarios are designed to achieve net-zero greenhouse gas (GHG) emissions in the energy sector; the Net Zero Intense scenario assumes higher economic growth and clean energy exports.

The modeling results underscore the significant sectoral and technological opportunities for Ukraine to expedite its clean energy transition. Ukraine has a significant potential to reduce GHG emissions through energy efficiency improvements, renewables, phasing out coal, electrification, and low-carbon fuels. Renewable sources make up about half of Ukraine's total primary energy supply in 2050, with nuclear providing the other half in the Net Zero Base scenario. In the more ambitious Net Zero Intense scenario, there is a much greater increase in total primary energy supply driven by faster economic growth and the development of green industry. Nuclear and wind supply are at more than twice the 2050 levels of the Net Zero Base scenario, with solar at more than three times the base recovery levels. Ukraine exports green hydrogen, electricity, and steel to support the decarbonization of the European continent and the rest of the world. Negative CO2 emissions from the power sector balance small remaining emissions from the industry, transport, and supply sectors, achieving net zero in 2050.

The Government of Ukraine used the outcomes of this study to prepare the National Energy and Climate Plan through 2030. The results are also being used to inform policy measures and implementation actions that support Ukraine's long-term decarbonization goals while also prioritizing the country's recovery and energy strategy. At the Ukraine Recovery Conference in London, G7 members pledged support for Ukraine's energy ambitions, emphasizing climate neutrality and a green transition as key recovery principles. The Net Zero World team, together with Ukrainian partners, is dedicated to developing detailed scenarios and policy measures to advance Ukraine's reconstruction and decarbonization objectives.

# THE SITUATION IN UKRAINE

Russia's unprovoked full-scale invasion of Ukraine, which started in February 2022, has led to enormous human suffering and damage to Ukraine's economy. The invasion caused a GDP contraction of around 30% in 2022 and significantly reduced the labor supply. Due to its crucial role in the Ukrainian economy and the functioning of the country, energy infrastructure became a main target of brutal attacks. As of May 2023, Russia had destroyed or damaged 61% of Ukraine's electricity generating capacity, reducing installed capacity from 37.6 to 18.3 GW [1].

Ukraine has lost 43% of its nuclear, 75% of its thermal, and 33% of its combined heat and power (CHP) generating capacities [2] as a result of the war. In the south of Ukraine, many renewable energy facilities were destroyed or are located in temporarily occupied territories. As of February 2023, the Government of Ukraine, the World Bank, the European Union (EU), and the United Nations estimated damage to the energy sector to be above 10 billion U.S. dollars (without accounting for Russia's destruction of the Kakhovka Hydroelectric Power Plant) [3]. The dramatic reduction in generation capacities, coupled with the destruction of transmission and distribution lines, transformers, gas and heat networks, and other crucial energy infrastructure, poses an obstacle to the recovery of the Ukrainian economy.

In June 2023, Ukraine presented its Energy Strategy through 2050 at the Ukraine Recovery Conference in London. This strategy envisions decarbonizing Ukraine's energy sector by 2050. Given the country's ambitions to join the EU, we modeled Ukraine's net-zero greenhouse gas (GHG) emission pathways through 2050. Ukraine is committed to achieving rapid, deep, and sustained reductions in GHG emissions while providing affordable, reliable, and secure energy to all Ukrainians and designing long-term, low-emission development strategies aligned with the EU's goal of net-zero emissions by 2050.

With 68% of Ukraine's coal-generating capacity damaged or destroyed [1], the Government of Ukraine is considering phasing out coal from its power sector by 2035. Ukraine also plans to significantly increase power generation using wind, solar, nuclear, and biofuel technologies [4] and to improve system balancing with robust energy storage capabilities. The country aims to evolve into a prominent European green energy hub focused on the production of carbon-neutral electricity. Currently, Ukraine is actively engaged in the development of commercial energy flow potential and endeavors to seamlessly integrate with the EU energy markets. Additionally, it aspires to play a key role in the emerging hydrogen economy in the EU. Similarly, the country is considering developing certified gas storage to enhance energy security and flexibility in Ukraine and Europe. Further, involvement in the global energy equipment production chains is expected to foster economic growth and technological advancement within the country.

# METHODOLOGY OF THE STUDY

# GOAL OF THE STUDY

The goal of this study is to model several pathways for Ukraine's energy sector to show key sectoral and/or technological changes and opportunities for accelerating the clean and green energy transition through 2050. The scope of the study includes the power sector as well as other sectors of the economy (heat sector, industry, buildings, transport, and agriculture). The team was tasked to estimate investment needs for the pathway implementation to achieve net zero GHG emissions in Ukraine's energy sector. Finally, the Ministry of Energy asked the team to identify the main sources of international financial support for decarbonization in Ukraine.

# MODEL

The modeling team used the TIMES-Ukraine model, developed by the Institute for Economics and Forecasting of the National Academy of Sciences of Ukraine, and improved in 2023 with the support of the U.S. Department of Energy national laboratories (Pacific Northwest National Laboratory, Argonne National Laboratory, and National Renewable Energy Laboratory) under the Net Zero World Initiative. The TIMES-Ukraine model is the primary tool for the system-wide analysis.[1]

TIMES-Ukraine is a linear optimization energy system model of the TIMES (The Integrated MARKAL-EFOM System) model family [5] that provides a technology-rich representation of the energy system (bottom-up framework) of Ukraine for the long-term estimation of the energy dynamics [6]. The structure of the model is harmonized with Eurostat and International Energy Agency methodology with approximately 2050 technologies. The model was used to prepare numerous energy and strategic climate documents for the Government of Ukraine, such as the Building Retrofit Strategy, the National Energy Efficiency Action Plans, the Nationally Determined Contributions [7], the 2050 Low Emission Development Strategy [8], and other documents, and to prepare reports on renewables and climate neutrality for and World Bank [9] and the United Nations Economic Commission for Europe [10]. TIMES models satisfy the methodological recommendations of the Secretariat of the United Nations Framework Convention on Climate Change for the development of energy and environmental forecasts [11].

1 Full description of the TIMES-Ukraine model, socio-economic assumptions, assumptions about the cost of technologies, the scenarios and modeling results is available at http://ief.org.ua/wp-content/uploads/2023/11/NZW-IEF-TIMES-Ukraine-Description_and_Assumption.pdf

# SCENARIOS

The team modeled three scenarios:

1. **The Reference scenario** assumes no fundamental changes will occur throughout Ukraine. Specifically, this includes no additional emission reduction measures or policies. Implementation of energy efficiency improvements, deployment of renewable energy resources, adoption of new technologies, and implementation of environmental and climate commitments are consistent with rates from past years. The purpose of this scenario is to show the energy sector development pathways in the post-war recovery of a severely damaged Ukraine, when the opportunities to attract the necessary investments in the decarbonization of the economy will be limited and the demand for energy services and goods will be covered in any available way. We consider this scenario to be hypothetical and only for comparison with Net Zero scenarios.

2. **The Net Zero Base scenario** includes all technological change capabilities; additional sectoral targets (e.g., in buildings, transport, and industry); developing bioenergy, nuclear, green, and clean energy options; and integrating European energy and climate obligations. This scenario is designed to achieve net-zero GHG emissions in the energy sector in the context of Ukraine's course toward membership in the European Union.

3. **The Net Zero Intense scenario** includes all the technological options and energy and climate obligations of the Net Zero Base scenario, along with greater economic growth driven by green industry and modeled exports of green electricity, green hydrogen, green fertilizers, and green steel. The relevant scenario includes the restoration and development of Ukraine as an energy hub in Europe, considering climate commitments and decarbonization of Ukraine's energy sector. This scenario provides not only the possibility of achieving climate neutrality for Ukraine but also a significant contribution to the decarbonization of the European continent and the rest of the world.

The team also used the TIMES-Ukraine model to estimate the required investment for each scenario.

# SOURCES OF FINANCING

The team explored the financial mechanisms available to facilitate Ukraine's energy transition and contribute to the global discourse on decarbonization and sustainable energy solutions. During September and October 2023, we interviewed representatives from prominent organizations, including the following:

- World Bank
- European Bank for Reconstruction and Development (EBRD)
- European Investment Bank (EIB)
- European Commission and the EU Delegation in Ukraine
- Deutsche Gesellschaft für Internationale Zusammenarbeit
- UK Foreign, Commonwealth & Development Office
- U.S. International Development Finance Corporation
- U.S. Trade and Development Agency
- Export-Import Bank of the United States.

These discussions provided invaluable insights into the multifaceted financial support extended to Ukraine for its energy transition. Sincere appreciation is extended to the participants for generously sharing their time, expertise, and cooperation during these interviews. Their contributions have been instrumental in shaping the content and insights presented in this report.

# MODELING RESULTS

# TOTAL PRIMARY ENERGY SUPPLY

In the Reference scenario, with no new policies, no emissions or energy transition targets, and historical rates of efficiency and fuel switching, the mix of total primary energy supply (TPES) shifts only gradually from 2020 through 2050 (Figure 1). The impact of the war is visible in the sharp decrease in TPES between 2020 and 2025, followed by recovery at a rate of increase that is mitigated by increasing efficiency. There is a gradual shift away from coal toward wind, solar, and biofuels, but fossil sources remain more than half of TPES by 2050.

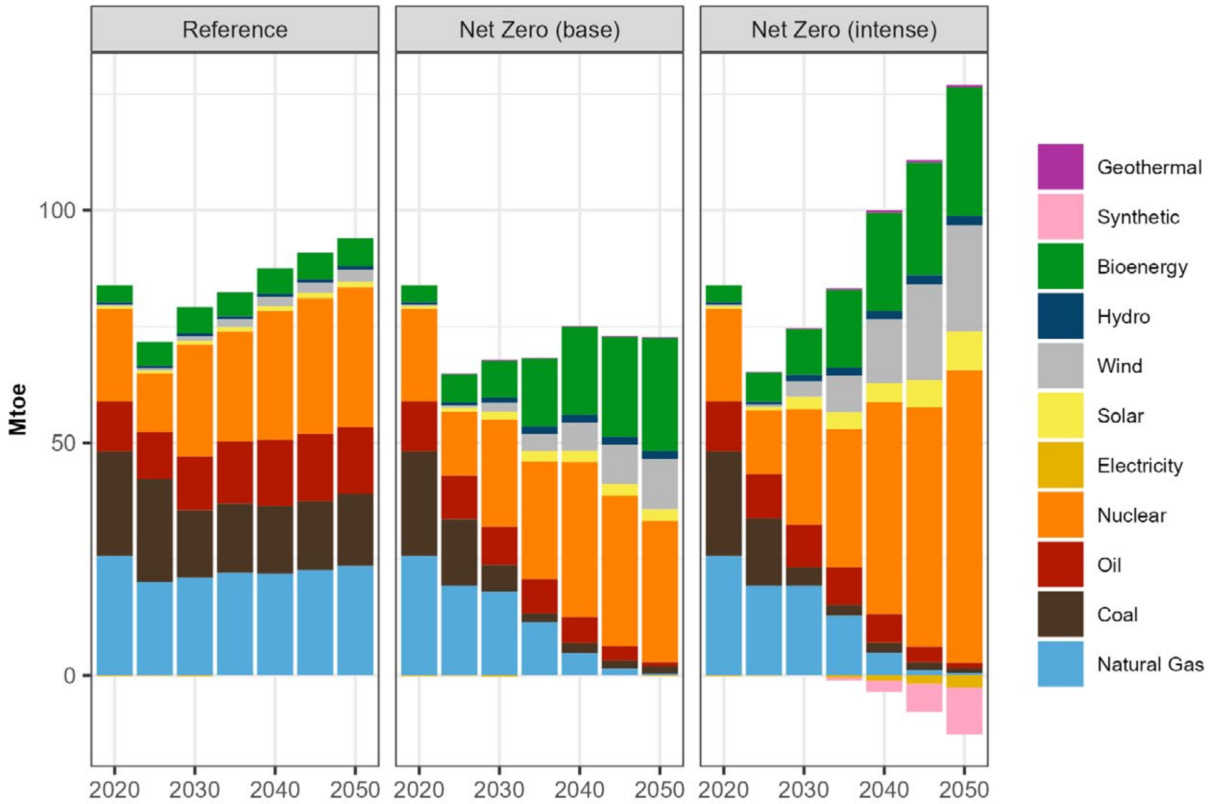


**Figure 1. Total primary energy supply**

In the Net Zero scenarios, on the other hand, there is a rapid phase-out of fossil fuels – first coal, followed by natural gas and oil – and increases in wind, biofuels, solar, hydro, and nuclear. In the Net Zero Base scenario, efficiency gains from investments in end-use efficiency and electrification roughly balance increases in energy service demands, and total primary energy supply remains nearly the same after 2025. Renewable sources make up just over 50% of TPES in 2050, with nuclear providing another 49%. The growth in bioenergy production in Ukraine in 2020-2050 is similar to the historical data for Germany between 1990 and 2020 [12], while Ukraine's bioenergy potential is larger than Germany's.

In the Net Zero Intense scenario, there is a much greater increase in TPES after 2025, driven by faster economic and population growth and the development of green industry.

Exports of green hydrogen and green electricity begin in 2035 and increase rapidly until 2050. The 2050 supply mix is roughly half nuclear and half renewables. Nuclear and wind supply are at more than twice the 2050 levels of the Net Zero Base scenario, with solar at more than three times the base levels.

## ELECTRICITY GENERATION AND CAPACITIES

Electrification is a major decarbonization strategy for the Ukraine economy, so the Net Zero scenarios show substantially increased generation over the Reference case (Figure 2). In the Reference scenario, there is a gradual shift in the electricity generation mix as coal and gas generation decrease and nuclear, bioenergy, hydro, solar, and especially wind power increase over the projection period. Renewables provide just over 25% of total generation by 2050 and nuclear has increased to nearly 60% of total generation in the Reference scenario.

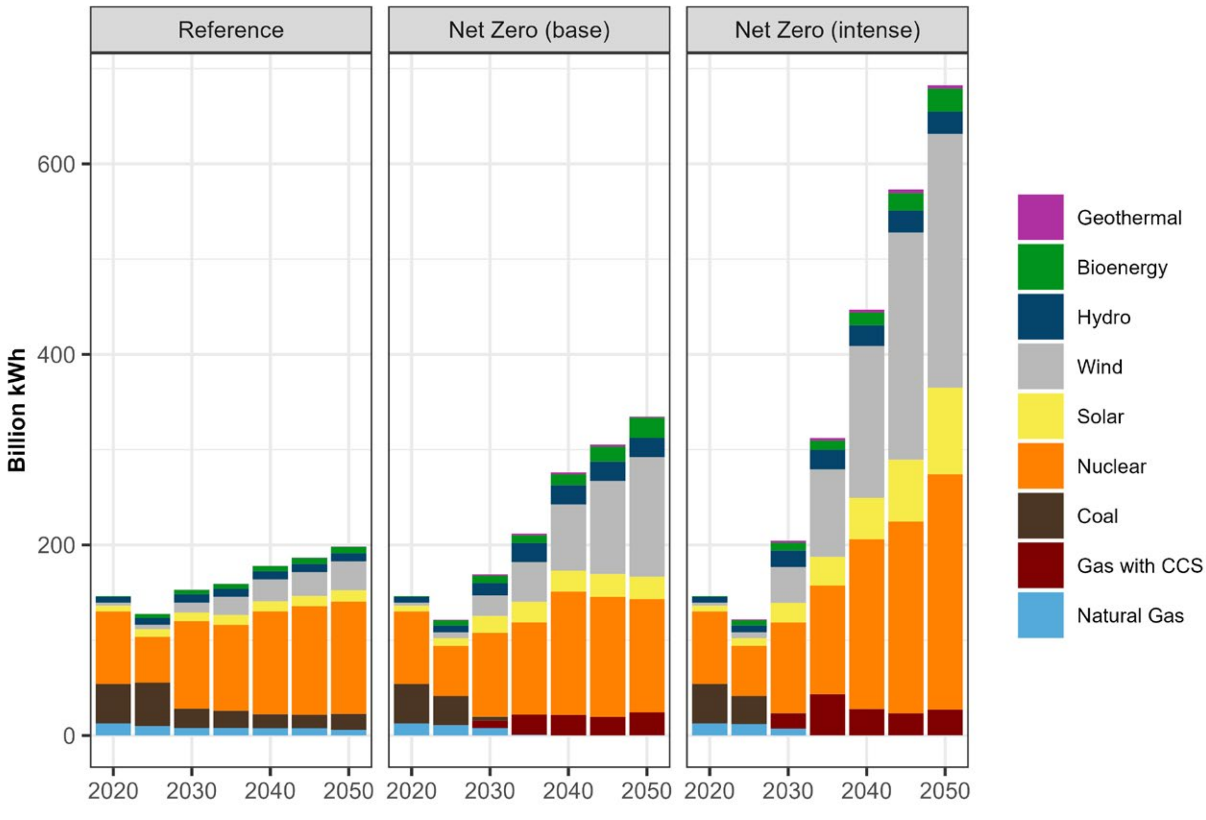


**Figure 2. Electricity generation by technology**

In the Net Zero scenarios, there is a much faster phase-down of coal and gas generation, with no coal electricity generation after 2035. Fossil sources with carbon capture and storage (CCS) provide a small fraction of generation, with most of the increase coming from renewables and nuclear. Some fossil fuels like natural gas are replaced by biomethane after 2035 with a full switch to bioenergy by 2045 at new gas power plants and CHPs equipped with bio-energy carbon capture and storage (BECCS). These new generating facilities provide dispatchable renewable electricity, heat, and negative $CO_2$

emissions. Renewable sources make up roughly 65% of electricity generation in both Net Zero scenarios by 2050, with nuclear comprising just over one-third. However, the total generation is much larger in the Net Zero Intense scenario due to both greater electrification and substantial generation for hydrogen production (see Figure 9). Figures 3 and 4 provide details on renewable and nuclear generation.

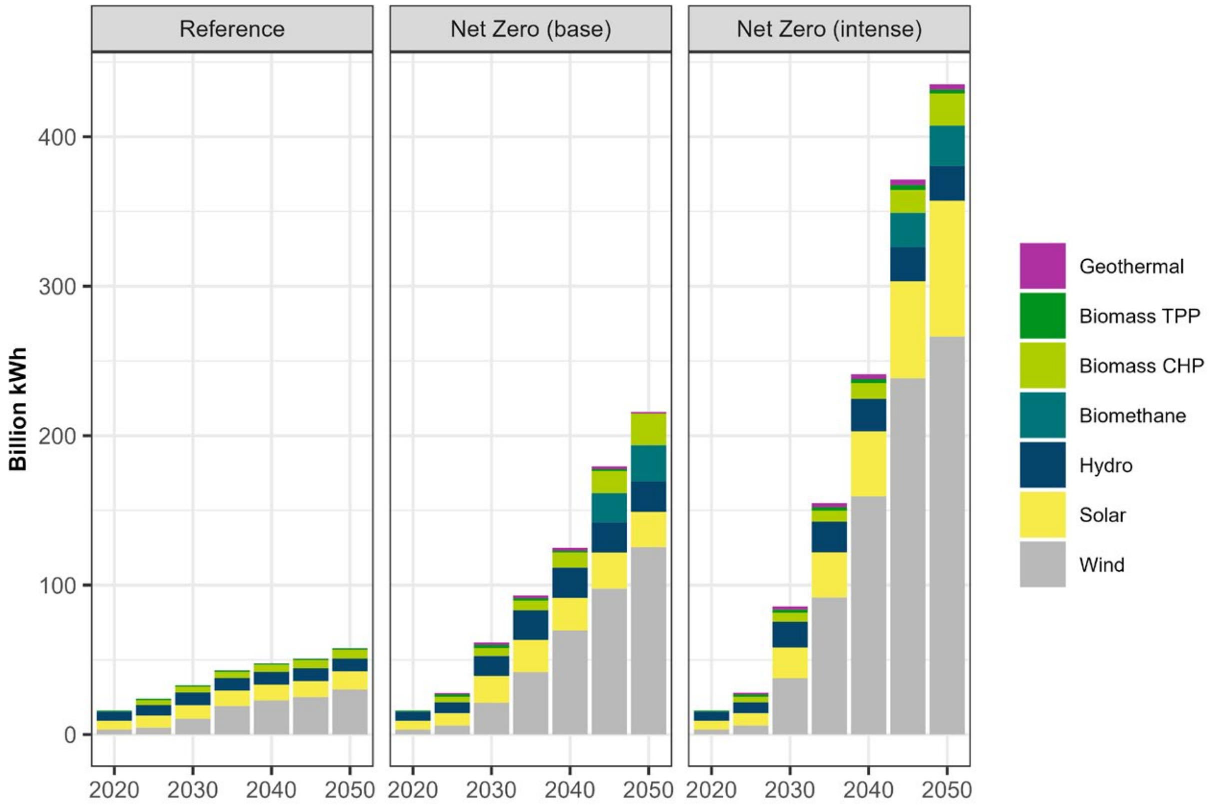


**Figure 3. Electricity generation from renewable sources**

Figure 3 breaks down the production of electricity from renewable sources. In all three scenarios, wind – both onshore and offshore – is the primary source of renewable electricity. The greater demands for renewable electricity in the Net Zero scenarios are met by steady increases in hydro, biomass (primarily CHP), and solar (both centralized and distributed systems), along with small amounts of geothermal generation. The much greater increase in renewable electricity production in the Net Zero Intense scenario is met by scaling up all of these sources, especially through a large investment in offshore wind production.


**Figure 4. Electricity generation by nuclear reactors**

Figure 4 breaks down the production of electricity from nuclear reactors. In all three scenarios, there is a gradual phase-down of generation from existing units after 2035 as these reactors begin to retire. Most of the increasing generation is produced by new large reactors, with smaller investments in new small modular reactors (SMRs) in the Net Zero scenarios. SMRs are defined as nuclear reactors with a capacity of up to 300 MWe.

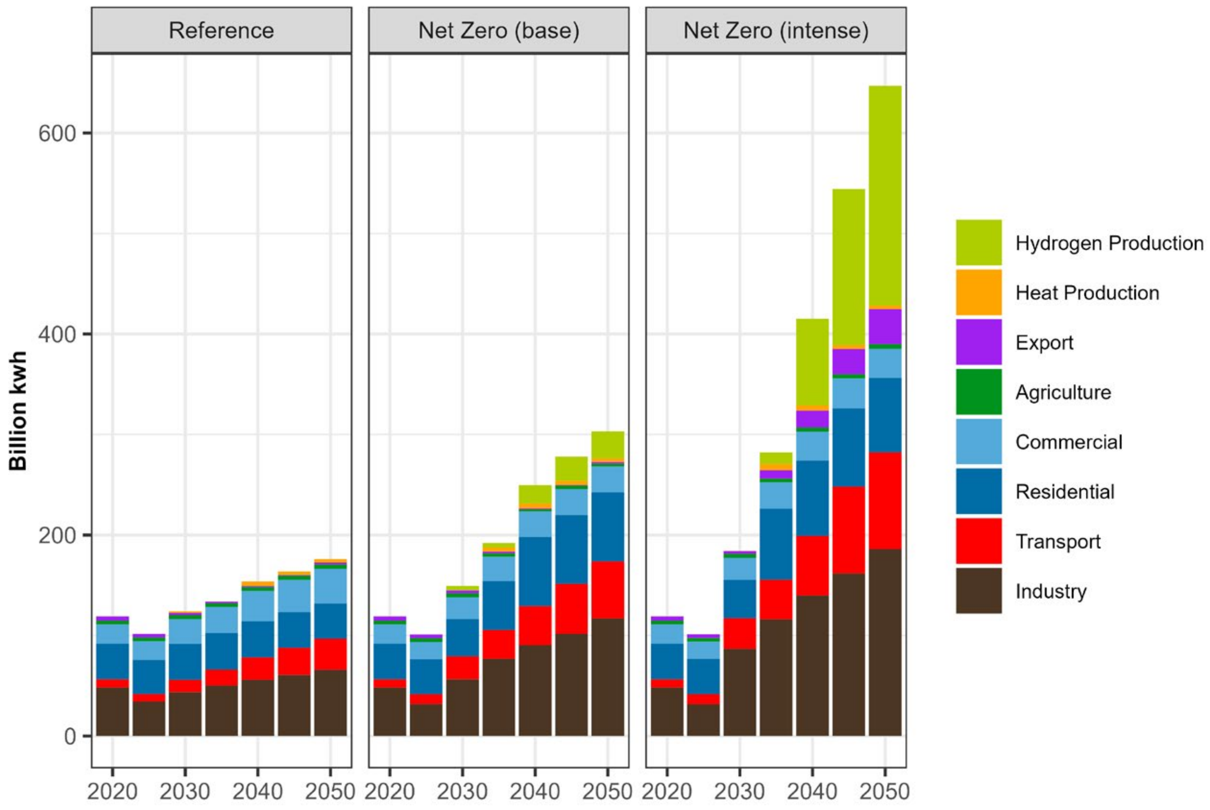


**Figure 5. Electricity consumption by sector**

Figure 5 shows that in the Reference scenario, electricity consumption grows slowly due to electricity use by industry and some electrification of transport – primarily light-duty vehicles and buses. Electrification is much more rapid in the Net Zero Base scenario, with complete electrification of light-duty vehicles by 2050, along with moderate electrification of freight transport, heating, cooking, and water heating in buildings, and both light and heavy industry. There is also increasing consumption of electricity for hydrogen production beginning after 2030. By 2050, total electricity consumption is nearly 2.5 times 2020 levels.

The increase in electricity consumption is much more rapid in the Net Zero Intense scenario, reaching roughly more than five times 2020 levels by 2050. The increase is driven by greater economic growth, greater industrial production, and deeper electrification in transport, building, and industrial uses. There is also rapid growth in electricity consumption for hydrogen production – for domestic consumption and exports – after 2035.

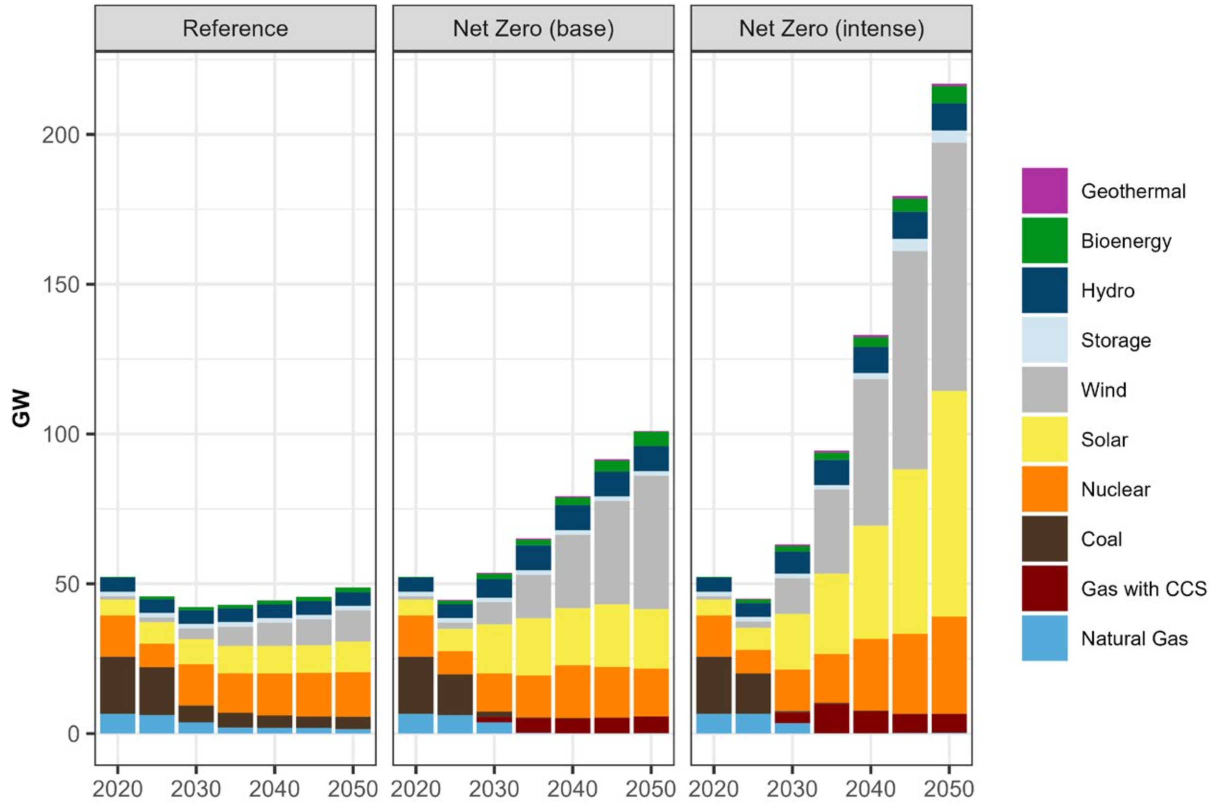


**Figure 6. Electricity generation capacity**

Figure 6 shows the modeled installed capacity to supply electricity. In the Reference scenario, the capacity mix shifts over time from fossil and nuclear dominated to a mix of primarily nuclear and renewables, but the total capacity remains around 2020 levels at nearly 50 GW by 2050. To meet the much greater electricity demand, total capacity grows to over 100 GW by 2050 in the Net Zero Base scenario and over 250 GW in the Net Zero Intense scenario. Because of their lower capacity factors, the capacities of wind and solar grow faster than their contributions to the generation mix (Figure 4). In 2050, there are 44 GW of wind and 20 GW of solar in the Net Zero Base scenario, and over 80 GW of wind and 75 GW of solar in the Net Zero Intense scenario. The nuclear capacity in 2050 is roughly 15 GW in both the Reference and Net Zero Base scenarios and around 32 GW in the Net Zero Intense scenario.

Overall, electrification is the most important factor in achieving net-zero emissions by 2050. With fossil fuels phased out, generation capacity from renewable sources should grow manyfold, especially in the Net Zero Intense scenario to meet the domestic demand and support clean electricity exports to Europe. The share of nuclear in the electricity mix remains one of the highest in the world [13].

# HEAT GENERATION

In the Reference scenario, heat is generated by fossil fuel and bioenergy and supplied by district heat (Figure 7). In the Net Zero scenarios, the share of bioenergy grows fast between 2030 and 2050, and fossil fuels are replaced by electricity and technologies with CCS systems. Note that Ukraine uses heat produced by nuclear power plants and this share increases in the future.

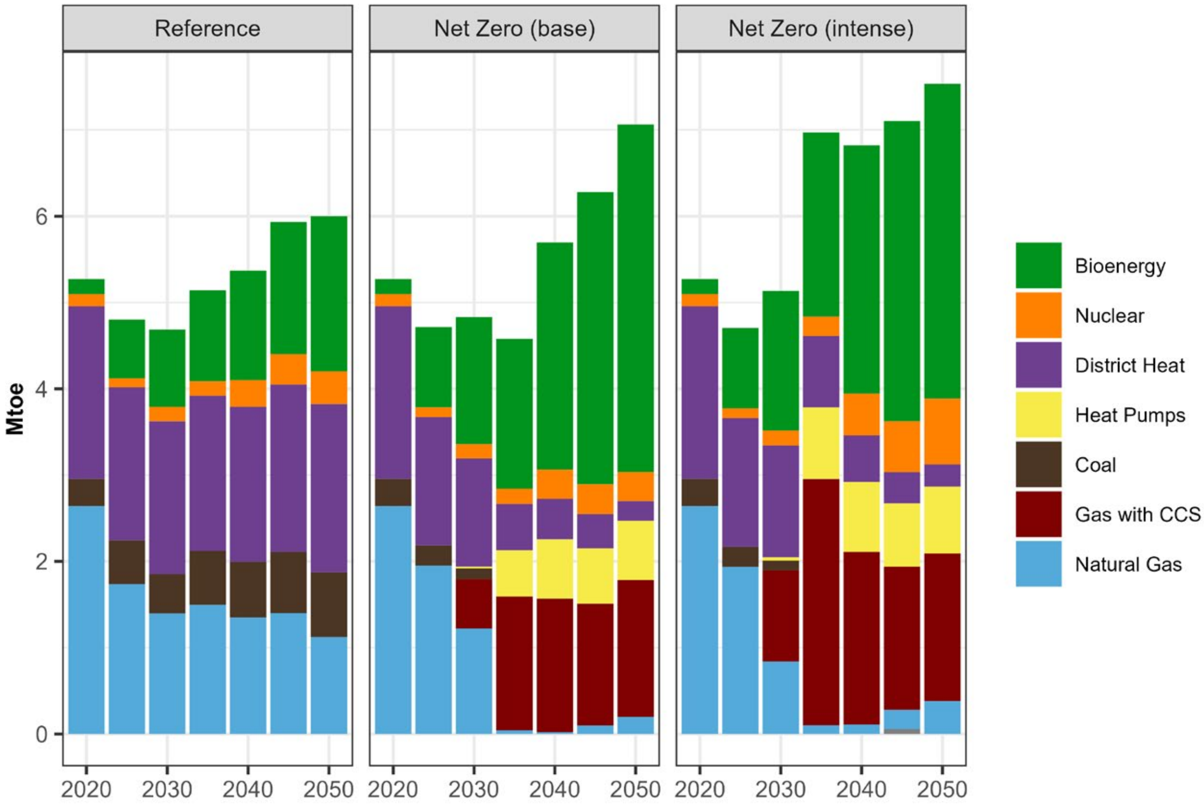


**Figure 7. Heat generation by technology**

Heat pumps as part of the district heat systems play an important role in decarbonizing the heat sector. District heat uses all sources of energy, including biofuels and industrial waste heat. Biogases and synthetic fuels gradually replace natural gas for heat generation in district heat.

# TOTAL FINAL CONSUMPTION

Figures 8 and 9 show final consumption by sector and fuel, respectively. As with primary energy, there is a sharp decrease in final energy between 2020 and 2025 due to the war, particularly for natural gas use in industry. In the Reference scenario, total final consumption expands with recovery. Growth in final consumption slows after 2030 as increasing efficiency of use mitigates the impact of increasing energy service demand. The final consumption mix in 2050 is very similar to the mix in 2020.

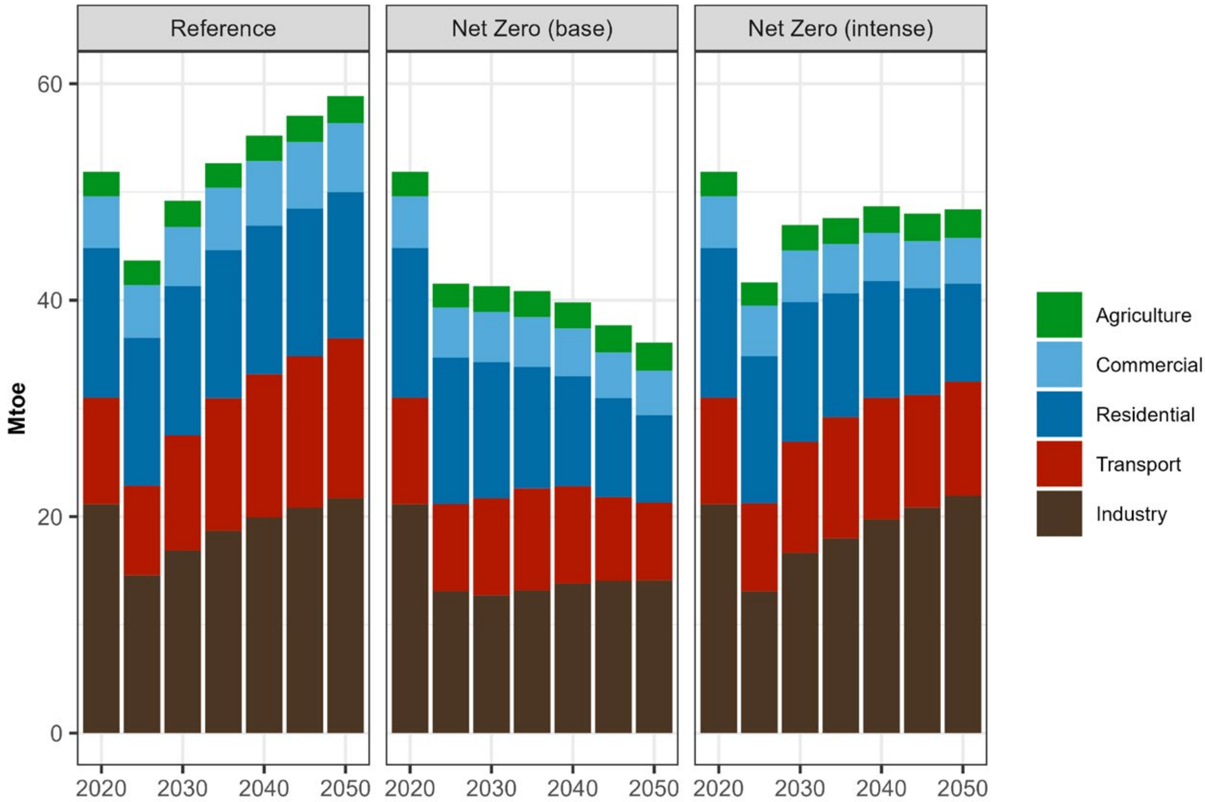


**Figure 8. Total final consumption by sector**

In the Net Zero Base scenario, total final consumption continues to decrease after 2025 due to more intensive investment in efficiency and the greater end-use efficiency of electrification, reaching two-thirds of 2020 levels in 2050. Electricity makes up 60% of the 2050 energy mix (Figure 9), and fossil sources have been almost completely phased out.

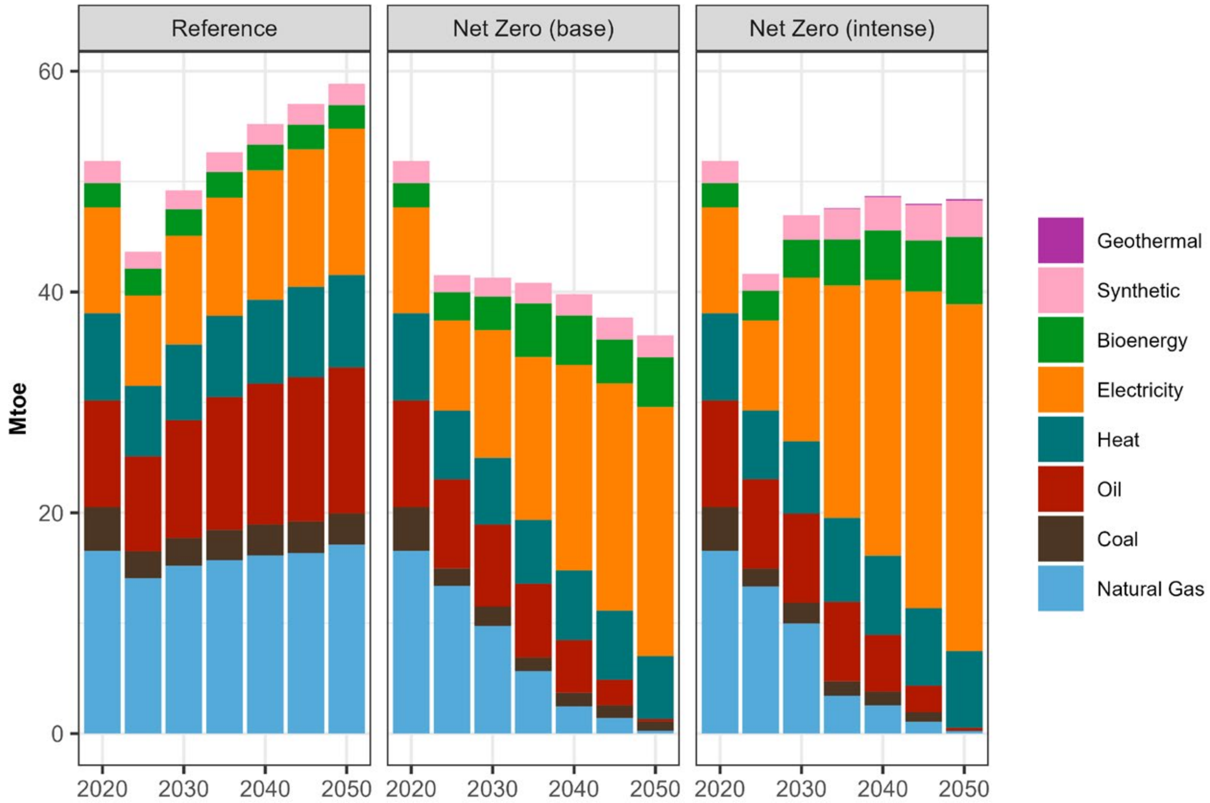


**Figure 9. Total final consumption by fuel**

In the Net Zero Intense scenario, with its greater end demand growth, total final consumption increases more rapidly after 2025 and levels off by 2050 at near 2020 levels. Electricity makes up two-thirds of the 2050 mix, and fossil sources are nearly eliminated. Synthetic fuels include bio- and synthetic methane and hydrogen.

## GHG EMISSIONS

Figure 10 shows the GHG emissions resulting from the modeled shifts in the energy economy. In the Reference scenario, the sharp drop in emissions in 2025 is followed by a leveling out of total emissions. Decreasing emissions from electricity and heat production, as nuclear and renewable sources replace coal power, are balanced by increasing emissions from the industry and transport sectors. In the Net Zero scenarios, steep declines in emissions continue throughout the projection period.

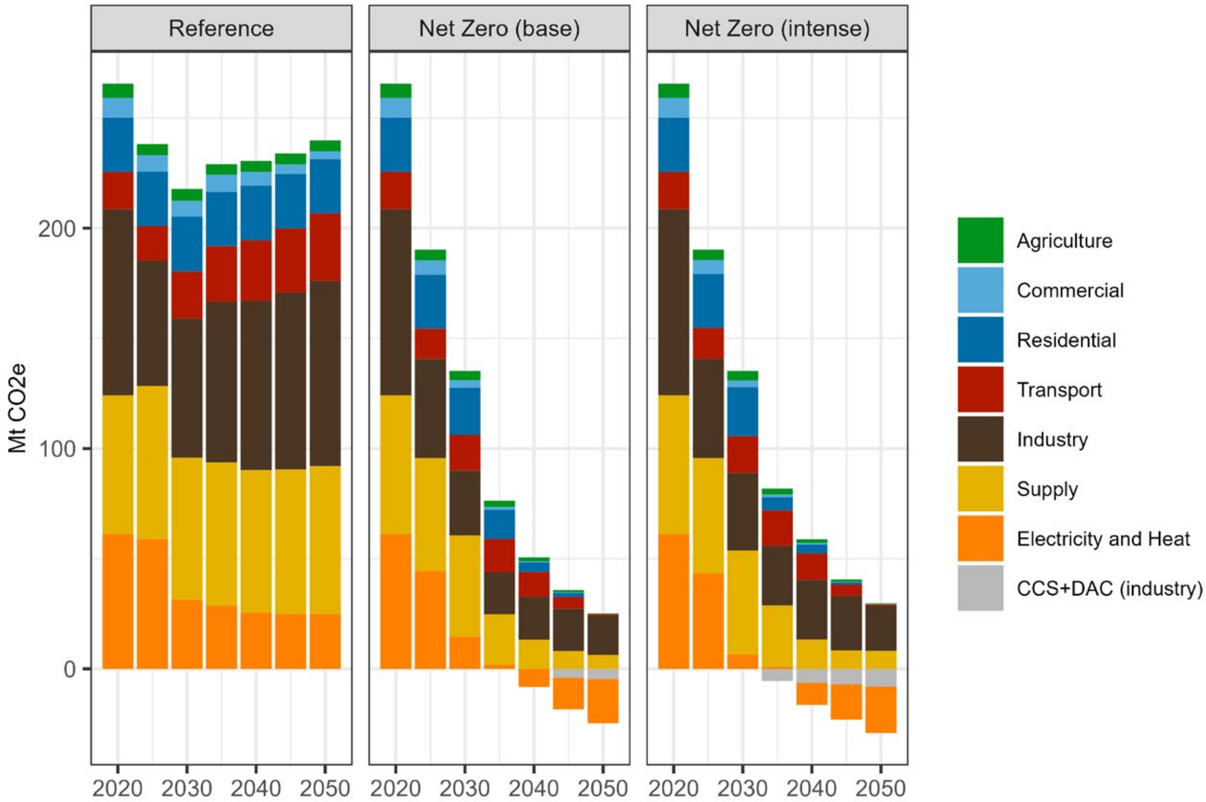


**Figure 10. Ukraine's GHG emissions projections**

The power sector is decarbonized and becomes net negative in 2040. The buildings sectors reach zero emissions by 2045. Negative emissions from the power sector with the help of CCS and direct air capture (DAC) balance small remaining emissions from the industry and supply sectors, achieving net zero in 2050. The negative 'wedge' for power and heat in the TIMES mode is all BECCS facilities. The timeline of total emissions is very similar between the Net Zero Base and Intense scenarios, despite the much greater energy consumption in the Net Zero Intense scenario, because they must both meet the same 2050 net zero target.

# INVESTMENT NEEDS

Figure 11 presents the upfront investment needs for each scenario. In implementation, these amounts would ordinarily be financed and thus spread out over time, but viewing the upfront costs can help inform the timeline of investment and financing needs.

Modeled investments include all purchases of energy-producing, -transforming, and -consuming equipment, including power plants and industrial facilities, along with vehicles, cookstoves, refrigerators, and other energy-using appliances. Transportation dominates total investment needs in all three scenarios because vehicles have a much short lifetime than other technology types.

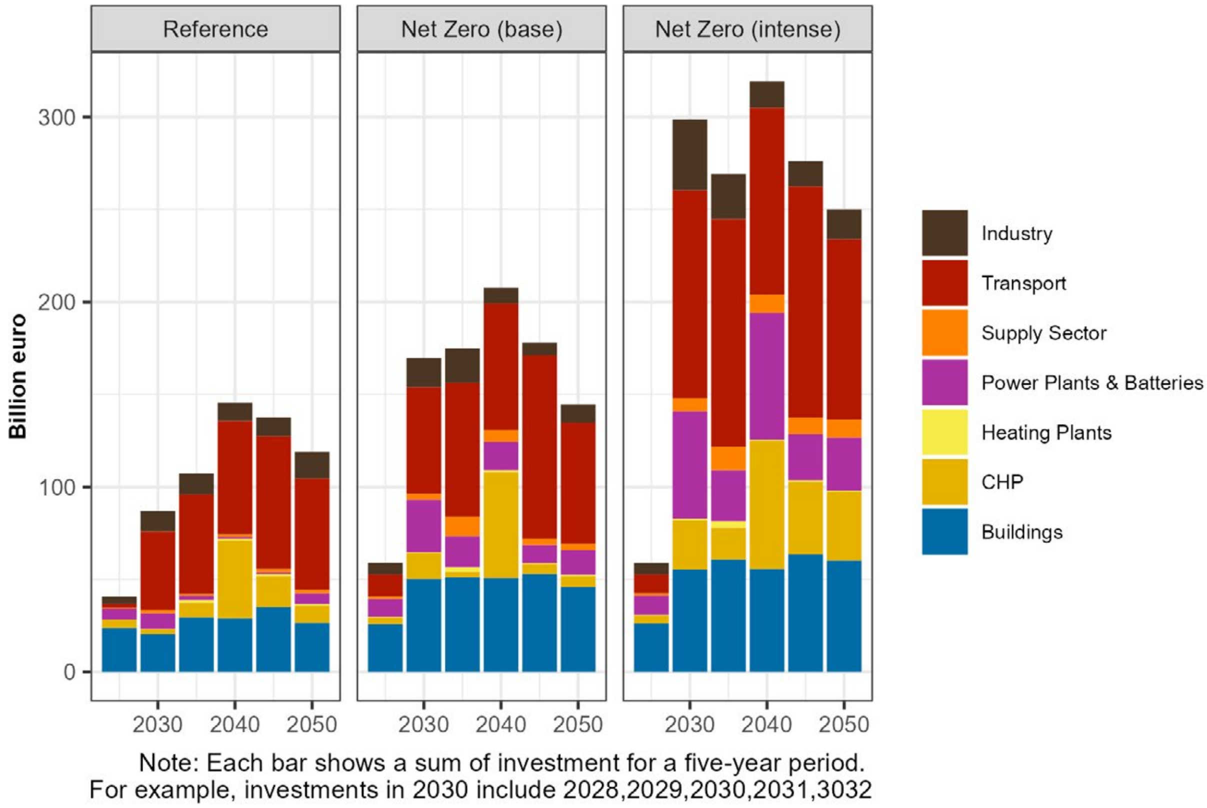


**Figure 11. Total investment needs by sector**

Cumulative investment needs in the Net Zero Base scenario are roughly 50% higher than in the Reference scenario. Major investments include electric and other clean-fueled vehicles, upgrades to buildings, the installation of clean heating systems, and new renewable and nuclear power plants. Investment needs to meet the much higher demand for energy services, industrial facilities, and clean power are significantly greater in the Net Zero Intense scenario, around 300 billion euro for the period of 2028-2032, although they fall gradually as the clean energy economy matures. Investments for clean heating, power, and CHP plants range between 60 and 150 billion euro per a 5-year period.

It is clear that upfront investment needs in the Net Zero scenarios are higher than in the Reference one. At the same time, the total energy system cost (investment, operation and maintenance costs, fuel expenditures, subsidies, etc.) for the Net Zero Base scenario is only 3% higher than the corresponding cost for the Reference scenario. In the case of a significant contribution of Ukraine to the decarbonization of the European continent, the total system costs in the Net Zero Intense scenario are 25% higher than in the Reference scenario.

# INTERNATIONAL SUPPORT OF DECARBONIZATION PROCESSES IN UKRAINE

The section is based on the findings of the modeling approach, which aligns with the core principles of Ukraine's Energy Strategy. The interviews with key partner organizations supporting decarbonization projects in Ukraine offer valuable insights into their ongoing endeavors. While the discussions acknowledge certain challenges, these conversations reveal a mature and sophisticated approach to the complexities of sustainable development. The primary focus is on financial instruments provided or planned by key international donors and partners, their role in supporting Ukraine's energy decarbonization, and the promotion of innovative energy solutions.

## CURRENT ACTIVITIES AND FOCUS SECTORS

Partner organizations are significantly invested in various decarbonization initiatives, with a pronounced emphasis on the energy sector. Their main thrust revolves around public energy infrastructure and private-sector green ventures. The multifaceted approach emphasizes the importance of both emergency support for immediate needs and sustainable project development for long-term recovery and development.

***Emergency Support.*** Responding to the immediate impact of the war, there's a clear emphasis on rebuilding essential infrastructure, including repairing roads, bridges, utilities, and other damaged facilities, to swiftly restore essential services and connectivity in the affected regions. Another key area is ensuring energy resilience in regions affected by the war, involving the deployment of generators to maintain a stable power supply, with a notable focus on transitioning to more sustainable energy sources, such as solar, to reduce the environmental impacts. There is also a commitment to innovative solutions and technical support to enhance emergency response and recovery. This may involve leveraging technology and technical expertise to improve disaster management and recovery efforts.

***Sustainable Project Development***. Sustainable energy solutions take precedence in discussions, with a strong emphasis on initiatives related to renewable energy sources. Solar and wind energy projects are prominently featured, with substantial investments and commitments to scale up their implementation in Ukraine. These investments typically amount to tens of millions of U.S. dollars, with specific projects covering the installation of solar panels, wind turbines, and related infrastructure to harness clean energy. Among the strategies for sustainability, discussions include projects focused on biomass and biofuels, such as support for companies aiming to scale up biomass-to-energy facilities, contributing to cleaner energy generation within the private sector. The anticipated results include reduced carbon emissions, increased reliance on renewable energy sources, and a transition to more environmentally friendly energy production methods. Alongside sustainable energy generation, there's an equally robust emphasis on upgrading energy grids and enhancing energy efficiency. The investments in this sector are considerable, covering the modernization of existing energy infrastructure, including transmission lines, substations, and grid management systems. These upgrades are intended to ensure reliability, reduce energy wastage, and make the entire energy ecosystem more sustainable. The financial commitments here are substantial, often exceeding hundreds of millions of U.S. dollars to revamp and optimize the energy grid. The expected benefit is a more stable and efficient energy supply.

Large-scale contributions to sustainable development mainly come from public sector projects, including investments in state-owned enterprises with a focus on infrastructure development, ensuring the critical sectors of the economy are more environmentally responsible.

Sustainable project development extends to the private sector, with investments in private businesses oriented toward green projects with clearly defined environmental benefits, ensuring ecologically sustainable economic growth. Technical assistance plays a crucial role in developing sustainable projects, advocating for green taxonomy, and facilitating the transition to green bonds and other sustainable financial mechanisms.

## AVAILABLE FINANCIAL INSTRUMENTS

***Grants:*** These are a common financial instrument used for decarbonization projects. Grants often range from a few million to tens of millions of U.S. dollars, providing essential financial support for endeavors related to renewable energy, grid upgrades, and sustainability-focused initiatives in both public and private sectors. These grants serve as a catalyst for project initiation and implementation.

***Loans:*** In addition to grants, loans play a crucial role in funding decarbonization projects. A notable feature is the strategic conversion of grants into loans in collaboration with international financial institutions (IFIs). While organizations might initially offer grants, they often work with IFIs to transform a portion of these grants into loans. This conversion allows for a more diversified financial approach, mitigating investment risks and making funds available for a broader range of projects. Loan amounts frequently exceed 10 million U.S. dollars.

***Risk-Sharing Mechanisms:*** Collaborations with IFIs are at the heart of creating risk-sharing mechanisms and efficient financial structuring. The risk-sharing mechanisms often involve insurance-based instruments that protect investments in the event of project disruptions or economic uncertainties. The IFIs collaborate on various aspects of the projects, from technical assistance to investment guarantees, further enhancing the attractiveness of decarbonization projects to private investors.

***Combination of Domestic and International Investments:*** While partner organizations allocate significant sums to support green initiatives, they recognize the importance of fostering collaboration with other international donors, investors, and financial institutions. It is important that decarbonization projects are financed through a combination of domestic and international funding. These collaborative financial strategies provide a more diversified funding base for decarbonization projects, ensuring their long-term sustainability and widespread success.

Innovative Financial Instruments: Partner organizations are actively exploring innovative financial instruments for green projects. These instruments go beyond traditional grants and loans and may include environmental impact bonds, green transition bonds, and climate-focused credit facilities. The exact nature and structure of these instruments are continually evolving and adapting to the specific needs of decarbonization projects. Their introduction is aimed at promoting a transition to more sustainable financial practices, driving the green agenda, and providing new avenues for investment in sustainable projects.

## STRATEGY AND PLANS

The IFIs are looking to build partnerships that align with their long-term goals and strategies. While the organizations do have strategies in place, these tend to be focused on the mid-term (approximately 3 years). The organizations support a diverse range of sustainable projects and are open to cooperating with other donors. Looking ahead, the organizations are exploring innovative financial instruments, targeting green projects, and are eager to work with other stakeholders in Ukraine. Long-term financing is a goal, with a vision for its alignment with future reforms and conditions. In summary, the organizations anticipate a shift toward more long-term, sustainable support for decarbonization projects, but recognize the importance of international partnerships and cooperation.

There is unwavering commitment from various organizations to Ukraine's decarbonization efforts. While acknowledging the challenges they face, a prevailing atmosphere of determination, adaptability, and a shared vision of reshaping Ukraine's energy landscape in accordance with global sustainability objectives is evident. Their strategies are designed to provide enduring and sustainable support for decarbonization initiatives, with a forward-looking approach and a positive outlook on a promising future fostered through international collaborations in the fight against climate change.

# CONCLUSIONS

The modeling results from this comprehensive study significantly contribute to a more detailed analysis of the National Energy and Climate Plan through 2030. At the Ukraine Recovery Conference in London, the G7 members collectively expressed a resolute commitment to catalyzing and maximizing investment in support of the National Energy and Climate Plan and Ukraine's National Recovery priorities [14]. The Ukrainian Government has clearly declared the foundational principles of climate neutrality and green transition as essential pillars toward Ukraine's recovery [15]. The Net Zero World team and the partners in Ukraine direct their efforts toward developing comprehensive scenarios, crafting pragmatic policy measures, and tangible implementation actions to advance Ukraine's reconstruction while addressing long-term decarbonization goals.

The G7 countries have notably expressed their appreciation for the united efforts of key financial institutions, including the World Bank Group, the EBRD, the EIB, and our Development Finance Institutions to establish the Support for Ukraine's Reconstruction and Economy Trust Fund at the Multilateral Investment Guarantee Agency. Simultaneously, they have shown strong support for the launch of the Ukraine Investment Platform, aimed at supporting Ukraine's recovery [16].

The current challenging and violent times, coupled with the damage and destruction, necessitate Ukraine's transformation, making it critical to rebuild the energy system. This highlights the importance of making the energy system green and decentralized to strengthen the country's resilience. Importantly, this transformation requires substantial funds and investments to not only repair but to "build-back-better" the energy system.

Investing in Ukraine's energy sector decarbonization and developing clean energy projects emerges as a pivotal opportunity. These investment opportunities allow us to achieve a clean, environmentally sustainable energy landscape, significantly reducing emissions not only in Ukraine but also in Europe and globally. This trajectory aligns with Ukraine's pursuit of reforms and creating a "success story" for Europe's green energy hub, particularly within the realm of European integration. The current landscape reveals unique and unparalleled opportunities for IFIs, lenders, and investors.

Ukraine's Clean Energy Roadmap provides comprehensive data and estimations, inviting global participation and encouraging others to join the transformation of Ukraine's energy sector toward a sustainable, decarbonized future. The adoption of the Energy Strategy of Ukraine through 2050 by Ukraine and the subsequent approval of the National Energy and Climate Plan should play an important role in determining the priority areas of cooperation between Ukraine and international partners and will be key guiding documents for the post-war recovery.

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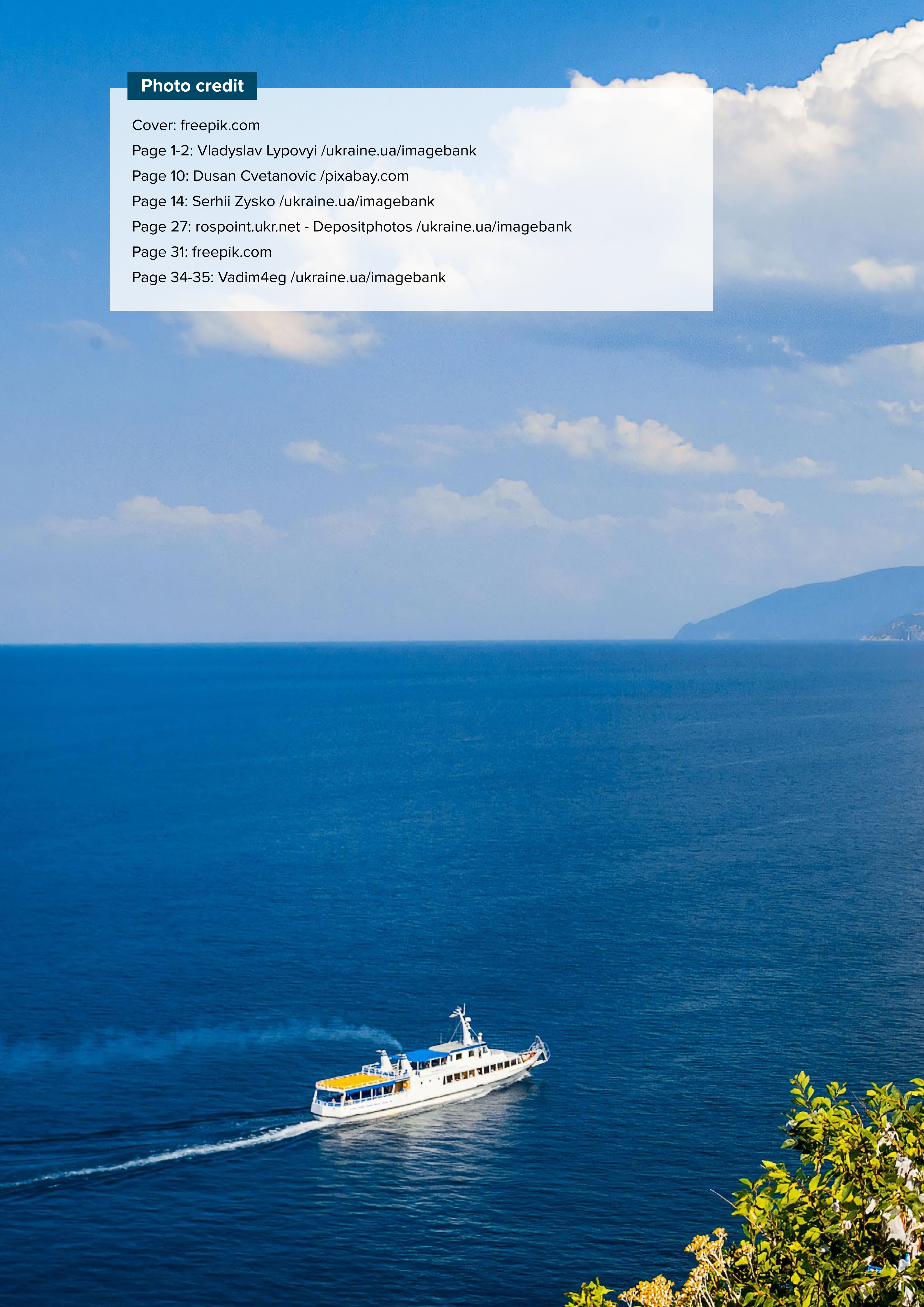


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