Conclusions and Recommendations

EUROPE-UKRAINE
Energy Transition Hub

Roadmap for a climate-neutral, sustainable Ukrainian energy sector and its role in an integrated EU energy market

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Table of contents

Key Results and Messages 1

Introduction 3

1. The Preliminary Studies 3

1.1. Technical 3
1.1.1 Challenges and Opportunities 3
1.1.2 Expert Survey 4

1.2. Financial 5
1.2.1 Financial Structures and Mechanisms 5
1.2.2 International Financial Institutions 5
1.2.3 Platform Approaches 6

1.3. Legal 6
1.3.1 Ukrainian Energy Policy 6
1.3.2 Energy-Market Regulation in an EU Perspective 6
1.3.3 Legal Framework for Energy Generation, Transport and Storage 7
1.3.4 Energy Demand 7

2. Cross-Cutting Sectoral Analysis 7

2.1. Challenges of the Energy Transition 7
2.1.1 The importance of early and comprehensive strategies 7
2.1.2 Energy efficiency 8
2.1.3 Dealing with intermittency 8
2.1.4 Direct intervention by the state 9
2.1.5 Indirect measures 9
2.1.6 Competitive and transparent markets 9
2.1.7 Foreign investment and involvement 9
2.1.8 Independent regulatory agencies 10
2.1.9 Bolstering human resources 10

2.2. Renewable-Energy Generation 11
2.2.1 Solar power 11
2.2.2 Wind power 12
2.2.3 Bioenergy 14
2.2.4 Geothermal energy 16
2.2.5 Hydroelectric energy 17
2.2.6 Funding possibilities 18

2.3. Energy Distribution and Storage **19**
2.3.1 Transmission and distribution 19
2.3.2 Smart grids 21
2.3.3 Storage systems 21

2.4. Industrial Applications **23**
2.4.1 Manufacturing 23
2.4.2 Hydrogen 25

2.5. Transport **27**

2.6. Buildings **29**
2.6.1 Construction 29
2.6.2 Heating 29

Key Results and Messages

Postwar reconstruction in Ukraine will be a long and arduous process. While the country is currently dependent on its partners for its budgetary needs, it has immense natural and human potential that can be unleashed to help it thrive and become a major contributor to European peace and prosperity. Clean and affordable energy will be a key aspect of a successful reconstruction and a richer, safer, and wealthier future for Ukraine and its partners. Achieving this will require great ingenuity, boldness, and commitment to a regulatory system that is fair, transparent, and conducive to sustainable private enterprise.The Ukraine Energy Roadmap, offered by the Europe-Ukraine Energy Transition Hub, analyzed the technical, financial, and legal aspects of this challenge; the detailed results are described in the corresponding three studies. This document summarizes these studies and provides recommendations across six major themes relevant to the energy transition. The key takeaways from the Ukraine Energy Roadmap are described as follows:

The energy transition is key to Ukraine's long-term safety and energy security

The green energy transition in Ukraine is vital to securing independent energy supplies. Many energy carriers and raw materials are still (indirectly) imported from Russia. A clean energy transition is a political, economic, and moral imperative. Without safety there can be no prosperity.

Ukraine can become a pioneer in the deployment of innovative clean technologies

Thanks to its wide-open spaces and capacity for large amounts of wind, solar, bio, and geothermal energy production, Ukraine has access to abundant clean energy to cover all its needs. The existing energy system has been greatly damaged and there is a chance to rebuild based on new technologies at all levels. The country can deploy and scale up innovative technologies, regulations, methods, and mindsets – learning best practices and leapfrogging to cutting-edge technologies wherever possible.

Ukraine has great potential to boost transatlantic energy resilience by exporting energy, services, and raw materials to Europe

The clean transition can help Ukraine evolve from being a fossil-fuel importer to a clean energy export powerhouse. Europe needs more sustainable energy to replace fossil fuels and Ukraine is geographically and institutionally well-placed to fill that gap. Moreover, the country also has an abundance of raw materials. The country has the potential to mine critical raw materials, with many large deposits which have yet to be developed.

Favorable investment and financial environments are necessary components of a dynamic future market

When Ukraine improves the transparency of its markets and bolsters the environment for investors, it will enjoy the benefits from increased foreign and domestic capital in search of safe and profitable investments. A secure legal framework and supportive regulatory and financial instruments will speed up reconstruction and deliver more broad-based prosperity through a vibrant economy.

The financial instruments with the most promise for a sustainable recovery and future growth include public-private partnerships, green bonds, transitions bonds, and de-risking measures for innovative technologies. They must be accompanied by independent, transparent, and objective agencies which are protected from political interference.

To deliver on its potential, Ukraine will need to enforce clear legal instruments

A just energy transition requires clear and sound legal instruments. This includes emissions trading schemes, guarantees of origin, green finance and investment regulations, energy-efficiency standards, strong buildings codes and circular-economy regulations, to mention a few. Independent bodies with State oversight should transparently draw up rules that are in the public interest and are enforced.

Bioenergy can make the agricultural sector even more productive

Agriculture is Ukraine's largest economic sector, and the country is one of the world's greatest exporters of many staple foods. This can be made even more productive by tapping its potential to produce energy from biomass and agricultural waste. The required technical solutions will need favorable regulatory and legal frameworks, as well as liquid markets and new infrastructure.

Hydrogen is one of the keys to the energy transition

As Ukraine expands its renewable energy generation, it can also look to produce hydrogen and its derivatives, as fuels and energy storage mediums. The pipelines built for the transit of natural gas from Russia to Europe can be potentially adapted for hydrogen transport.

Ukraine can redevelop a greener and more sustainable heavy industry

Ukraine has a long history of complex heavy industry and the steel and iron industry remains the country's second-largest sector. Ukraine can leverage this experience to grade towards greener production for domestic use as well as export. This will require technological as well as regulatory and financial innovations. The government has, for instance, started a Coalition for the Green Recovery of the iron and steel sector, which aims to develop a pipeline of investment projects, address financial and policy issues, and facilitate coordination among stakeholders.

These takeaways and the publications provide food for thought and input for decision-making to stakeholders in both the private and public sectors in Ukraine and its partner countries and organizations. As such, they will also be part of the discussions during a range of events linked to Ukraine's recovery in the years after publication, including:

- EU investment summit with world leaders 2023
- COP28 in Dubai in November 2023
- EU Business summit with UA spring 2024
- Ukraine Recovery Conference in Berlin in 2024
- COP29 in central/eastern Europe in 2024

Introduction

The Roadmap for a Climate-Neutral, Sustainable Ukrainian Energy Sector and its Role in an Integrated EU Energy Market – the Ukraine Energy Roadmap for short – was carried out to analyze Ukraine's energy system today, and envisage a rich, dynamic, and sustainable future for the country after the end of the Russian invasion. Funded by Breakthrough Energy and carried out by the Institute for Climate Protection, Energy and Mobility (IKEM) and its project partners under the auspices of the Europe-Ukraine Energy Transition Hub, this project consists of three studies – technical, financial, and legal – as well as this set of conclusions and recommendations. These conclusions aim to provide a comprehensive snapshot of the current state of the Ukrainian energy sector and chart a course for policymakers, energy experts, and stakeholders to develop a future-proof energy sector in Ukraine.

The concluding analysis is divided into two main parts: a recap of the three underlying studies with their overarching observations, and a visualization of Ukraine's energy sector needs in six segments that are especially relevant to the country's energy future. There are two parallel priorities which reinforce each other: the need for Ukraine's energy sector to quickly advance a green transition that will enable a vibrant economy and broad-based prosperity, and the requirements of EU accession. Both priorities will be shaped by new legislation, regulations, and administration, with concrete actions, such as the construction of physical infrastructure and the deployment of advanced technologies.

1. The Preliminary Studies

This section briefly presents the technical, financial, and legal preliminary studies.

1.1. Technical

The objective of the preliminary technical study was to identify and outline the main technical steps required to rebuild the Ukrainian energy sector in the aftermath of the war in a manner that ensures a flourishing future built on technological progress and innovation. The study looked at the best ways to carry out fast and efficient repairs to war-related damage, followed by a transformation of the country's economy and energy sector that would allow it to catch up with and hopefully leapfrog in terms of productivity, efficiency, and sustainability.

1.1.1 Challenges and Opportunities

There are plenty of good reasons to transit to green energy as quickly as possible, of which some are universal (like economic advantages or human health) and many (most obviously Russian aggression) specific to Ukraine. Of course, this transition cannot take place overnight. For instance, once the war ends, Ukraine will need to patch up or rebuild infrastructure for many basic services that are based at least partly on fossil fuels, such as the distribution of petroleum products for use as fuel for vehicles or district-heating systems. Even so, wherever possible, the country's policymakers and authorities should be careful to avoid lock-in effects – that is, situations where building or rebuilding physical, technical, regulatory, or administrative structures which reflect fossil-fuel-based business-as-usual will unnecessarily slow down or prevent an ambitious green energy transition.

Reconstructing a destroyed or severely damaged system or structure exactly as it was before may be faster, cheaper in terms of upfront investment, and simpler – all very substantial benefits, especially in a challenging postwar environment – but these advantages are likely to only apply in the short term, especially if Ukraine is serious about catching up with and leapfrogging its European partners where green energy is concerned. Rebuilding a system that will have to be transformed, often beyond recognition, in the medium- and long-term may amount to wasting time, money and expertise on building stranded assets, obsolete skills, and unworkable infrastructure.

Much of this would apply even if the Russian invasion had not occurred: Ukraine's pipelines would probably be used to transport less and less natural gas as demand in Europe falls, and the country's district-heating system would be reduced due to changing population patterns and continued dilapidation of Soviet-era infrastructure. The war provides a double additional impetus. Firstly, so much infrastructure is destroyed and so many people displaced (many perhaps permanently) that major reconstruction and reconfiguration of the energy system will, in one way or another, have to take place in the immediate postwar period – and can lead to a future-proofed new system from the outset. Secondly, the war shows that Russia is likely to remain hostile to Europe and Ukraine for the foreseeable future, underlining the urgency of energy independence from fossil fuels, which are a major source of funding and lever of influence for Russia.

Lock-in effects can be avoided through carefully crafted large-scale strategies on the national level which are in turn translated into detailed and mutually attuned policies on the level of regulations and administration (especially in terms of taxation and subsidies) as well as specific action plans to address bottlenecks such as workforce skills or materials required for the expansion of power transmission and storage infrastructure. These strategies should be defined and put in place as early as possible, and followed up by concrete and coherent secondary legislation and policies with a broad mandate from experts and the body politic. Of course, the government should also know its own limitations, letting Ukraine's people and companies take the lead in creating value when this is more efficient.

1.1.2 Expert Survey

The findings of the expert survey[1] highlight the lack of financing as the major challenge faced by the energy transition in Ukraine, with around 90% of the experts considering this a major obstacle in terms of both private and public investment, and affecting both physical infrastructure and the deployment of innovative new technologies. The experts consistently emphasize the importance of creating an investment-friendly environment to overcome the scars of war and repair the supply chains required for an efficient reconstruction. 80% of them also see public administration as a medium or major obstacle, mainly due to ineffective communication among stakeholders. Around 70% of respondents view national legislation as a medium or major obstacle to deploying green technologies, and stress the need for stronger political will, clearer legal frameworks, and more adaptive legislation to support the energy transition.

1 The results of the survey conducted with experts from the Ukrainian and international energy markets under the auspices of the Ukraine Energy Roadmap project can be read in parallel with the findings of the preliminary technical study, in which the experts are also named. The answers focused less on the material – whether technical or geographical – hurdles to the energy transition in Ukraine, and more on obstacles of a financial, legal, and administrative nature.

1.2. Financial

Developing a comprehensive framework that covers targets for greenhouse-gas mitigation, sustainable infrastructure, and access to carbon financing will be vital in advancing Ukraine's energy transition and climate-mitigation goals. The preliminary financial study aims to identify effective financial mechanisms, funding sources, and potential risks and benefits linked with the significant financial effort required to rebuild Ukraine's energy sector after the war. It emphasizes collaboration with international financial institutions and stakeholders, and alignment with national and European legal requirements and considerations. The results of the study can be divided into sections that describe potential sources of financing and the actual deployment of financing mechanisms.

1.2.1 Financial Structures and Mechanisms

General financial mechanisms that can be deployed to support the energy transition in Ukraine include public-private partnerships, project finance, and sovereign green debt issuance. Clear communication, a stable regulatory environment, and solid risk-sharing mechanisms are essential to attracting private-sector investments and promoting collaboration between public and private entities. Leveraging recovery plans and deploying well tried support mechanisms to engage experienced energy companies can further strengthen Ukraine's energy infrastructure.

Some of the most important financial mechanisms include transition and green bonds, which represent a promising avenue for funding the gradual phase-out of coal-fired power plants and fostering more sustainable energy sources. Coupled with a regulatory framework for transparency and reporting requirements, they ensure accountability and boost investor confidence, mitigating the risk of "greenwashing". Public-private and other energy partnerships are another promising form of financing. Crowdfunding has been a very effective way for Ukraine to raise funds during the war, but this may not be as easily available in peacetime. Given its circumstances, Ukraine can also consider a tailored war-insurance program to mitigate risks associated with investment and bolster investor confidence. Such programs are used in Spain and Israel, for instance.

1.2.2 International Financial Institutions

Given the geopolitical risks likely to persist after the war and the resulting hesitance of private-sector investors to enter the Ukrainian market, the postwar reconstruction of the country's energy sector will depend heavily on the support of international financial institutions, which can play a crucial role in mobilizing funds, attracting private-sector investment, and ensuring the efficiency and sustainability of energy-infrastructure development.

International financial institutions can provide fiscal and current account support, loan guarantees, and technical assistance to ensure macroeconomic stability. To ensure that funding is utilized effectively, it is crucial that Ukraine have the capacity to absorb it. International financial institutions typically have stringent requirements for project design, implementation, and monitoring, and they require recipient countries to have the necessary institutional capacity, technical expertise, and construction-sector capacity. This helps maintain a pragmatic and sensible approach to new projects and investments.

1.2.3 Platform Approaches

The financial study examines approaches that have already been employed in Ukraine as well as new approaches to create a favorable financial environment and manage efficiently the financial flows during the rebuilding of the energy sector. The study focuses on several concrete approaches to supporting Ukraine's postwar reconstruction and development in the energy sector.

One is international funding platforms such as the Ukraine Reconstruction Platform and Ukraine Facility, which coordinate international support and funding for reconstruction plans while emphasizing the need for rule of law reforms and local ownership for sustainable recovery, or the Reconstruction and Energy Efficiency Fund, which aims to promote energy-saving measures and the use of sustainable energy while exploring new funding sources and capacity building. Another concept is the Digital Restoration Ecosystem for Accountable Management (DREAM), an electronic platform run by Ukraine's government which manages reconstruction projects transparently and efficiently.

1.3. Legal

The legal study looks at the substantial legal transformation required to help Ukraine implement an energy-market design that will facilitate a prosperous, just, and decarbonized future. This refers heavily to EU membership, with adoption of the EU acquis expected to go some way towards enabling many of the reforms required for a net-zero Ukraine by 2050. The study analyzes Ukraine's existing energy policy and strategies, including international obligations, considers the EU perspective, and then looks at the specific legal environments relevant to the generation, transport, and storage of energy, finishing with an analysis of different energy-demand sectors.

1.3.1 Ukrainian Energy Policy

Ukraine's energy policy rests upon several legislative pillars that reflect the complexity of the energy sector as well as the depth of its international obligations. They range from domestic legislation, which is partly influenced by the country's membership in the Energy Community and its EU candidate status, to international treaties such as the Paris Agreement. Moreover, there are a range of plans, declarations, regulations, and strategies that are legal instruments in their own right.

1.3.2 Energy-Market Regulation in an EU Perspective

The second part of the preliminary legal study focuses on the energy markets in Ukraine and the EU. This section looks at European laws and regulations as well as the rules specific to Ukraine's energy markets and the ways in which these rules are affected by EU obligations. It provides a list of the substantial number of EU regulations that Ukraine has already adopted. Another field of focus are state-aid rules in Ukraine, especially as they relate to postwar reconstruction and current and future EU frameworks. The section also analyzes Ukraine's electricity and gas markets at large and provides recommendations for energy-market regulation in the postwar period, looking especially at energy generation, stability, trade, and transport.

1.3.3 Legal Framework for Energy Generation, Transport and Storage

The third section of the study looks at the Ukrainian and European laws and regulations relevant to the production and handling of energy in Ukraine. It covers a range of energy-related topics, such as renewable energy (renewable electricity, hydropower, bioenergy, and green hydrogen), nuclear power, the coal phase-out, energy distribution, and energy storage. Each subsection describes the current domestic legislation and regulations affecting the relevant type of energy in Ukraine and the EU perspective on it, and provides recommendations for the reconstruction of the country's energy sector.

1.3.4 Energy Demand

The last section of the preliminary legal study looks at energy demand, covering energy efficiency as well as three particularly important sectors of the economy, namely industrial activity, buildings, and transport.

2. Cross-Cutting Sectoral Analysis

As the preliminary studies carried out during the initial part of the Ukraine Energy Roadmap project make clear, the energy transition is an intricate and multifaceted endeavor for an economy as large and complex as Ukraine. The country's Soviet past and resultant issues linked to democracy and the rule of law, as well as Russian aggression since at least 2014, further complicate the picture. Keeping all this in mind, this section attempts to provide a combined technical, financial, and legal summary of the analysis, conclusions, and recommendations of the preliminary studies across six major aspects of the energy transition in Ukraine: the general societal challenges, the necessary expansion of renewable-energy generation, the requirements for energy distribution and storage, and the particularities of industrial applications, transport, and buildings.

2.1. Challenges of the Energy Transition

One could be forgiven for thinking that Ukraine has more urgent priorities than an energy transition, however worthy a goal that is. This would be to underestimate both the direct and indirect benefits of such a transformation, however: direct because a well-executed energy transition would be a large net gain in itself both for Ukraine and the world (and the sooner it is planned and carried out the greater the benefit is likely to be) and indirect because the energy transition is a major strategy for the EU, which Ukraine aspires to join as quickly as possible. Moreover, the sheer scale of material destruction due to Russian aggression provides a chance to start fresh in many sectors instead of simply rebuilding yesterday's economic and energy systems. The war has also led to a great deal of innovation and flexibility among the country's administrations and institutions, which may help with the kind of forward thinking required for a green transformation.

2.1.1 The importance of early and comprehensive strategies

All of these factors mean that the time for reform is as early as practical, and in fact it will take some years to properly prepare the energy transition. The Ukrainian government recognizes this fact, as is demonstrated among other things by its commendable Energy Strategy until 2050. A green future for Ukraine based on the cleanest energy sources therefore depends on a major expansion of balancing capacities – not least battery storage and hydrogen generation. This paradigm shift can be achieved in the fastest and most efficient way by putting the necessary technical, legal, and financial structures in place early on. Prewar administrative systems or infrastructure which will not be fit for purpose in a decarbonized future should not be rebuilt in the same way. There are several cross-cutting priorities to think of when devising Ukraine's overarching strategy for the energy transition, and they are explored below.

2.1.2 Energy efficiency

Energy efficiency in industrial activities, transport systems, and the built environment is a crucial component of a successful energy transition. While Ukraine has greatly reduced its energy consumption and greenhouse-gas emissions in the past several decades, this has largely been due to deindustrialization, not improved efficiency, and the energy intensity of the Ukrainian economy remains several times above the EU average.

Remedying this and boosting productivity through energy-efficiency measures should be a crucial component of energy policy as well as public and private investment decisions. Energy efficiency in industry, transport systems and the built environment reduces dependence on fossil fuels and increases security of supply and the use of renewable energy. The potential of energy efficiency is often underestimated in existing planning and investment programs, however – a fact recognized by the EU's recast Energy Efficiency Directive, which highlights the "energy efficiency first" principle – a way of taking account of cost-efficient energy-efficiency measures in shaping energy policy and making relevant investment decisions. While taking full account of security of supply and market integration, the application of the principle in planning for Ukraine can ensure that only the energy really needed is produced, investments in stranded assets are avoided, and demand for energy is managed in a cost-effective way. The principle gives priority to demand-side solutions whenever they are a more cost-effective way to meet policy objectives than (potentially redundant) investments in energy infrastructure. In Ukraine, this should be a crucial guiding principle in the process of building a greener, more productive economy after the war. As such, it should be organically integrated into building codes, territorial plans, and transport-infrastructure strategies to ensure that energy-use lock-in is avoided and electricity prices in Ukraine remain low and competitive in the long term.

2.1.3 Dealing with intermittency

As the preliminary studies carried out under the auspices of the Ukraine Energy Roadmap project show, each of them has drawbacks in the ambition to achieve a truly renewable energy future. While hydropower is a very clean form of energy, it is simply insufficient to satisfy a major portion of Ukraine's energy needs today or in a highly electrified future, and cannot easily be expanded without potentially serious environmental damage. Even so, it is very useful as a balancing form of electricity, which is required in great amounts in an energy system based largely on the cleanest renewable energy sources – that is, solar and wind power.

Nuclear-power facilities do not produce greenhouse-gas emissions in operation and produce plentiful and economical baseload power. However, the output of nuclear plants cannot be quickly adapted to shifting needs, making it unsuited to balancing intermittent renewable-energy sources.

Natural-gas turbines are another imperfect transition technology – natural gas is a fossil fuel but the most modern types of turbines are efficient and produce less greenhouse-gas emissions in operation than other types of fossil energy. Most importantly, it is suitable for balancing intermittent renewable-energy production and can quickly replace coal in this role.

In the medium term, Ukraine will need to adapt its generation and transmission system to the needs of a large-scale expansion of intermittent renewable-electricity generation. This means ensuring that there is sufficient balancing capacity. The country should focus on retrofitting and leapfrogging through clean technology deployment.

Electrification and hydrogen investments will be key, as well as storage and delivery hubs which are flexible to help deliver the transition. Ukraine's natural gas pipeline system can be considered for use with hydrogen and optimized for the domestic market as well as trade with neighbors.

2.1.4 Direct intervention by the state

The production of clean electricity can be stimulated through market-based approaches, support to energy cooperatives and private households, and implementation of guarantee-of-origin mechanisms for electricity, as well as promoting renewable-energy sources. The government should make major investments in grid modernization and expansion, as well as smart-grid technologies to enable the integration of decentralized systems into the existing grid. Given likely budgetary constraints, financial support can be offset by reducing or removing subsidies for fossil fuels, and increasing taxes on emissions-intensive activities in alignment with other EU neighbors – which would have the added incentive value of making fossil fuels comparatively less attractive.

2.1.5 Indirect measures

Ukraine's Energy Strategy until 2050, was adopted in the spring of 2023 and this must continue to respond to the challenges and opportunities of a future decentralized energy system and be clearly reflected throughout all relevant primary and secondary legislation. Fostering political willingness at all levels to focus on the deployment of renewable energy sources even when this is complex and difficult will be needed. Secondary legislation can facilitate the development of lighthouse projects, and generally smaller initiatives that fit a decentralized energy system better and can more easily form part of project partnerships with EU companies.

Efficient communication is a priority, including through permanent regular meetings or platforms between government, energy companies, and civil society communities. There must be a systematic mechanism for the information management of collected experiences, allowing relevant stakeholders to learn from failures and to scale up positive experiences. The Ukrainian government should encourage incumbent utilities to diversify their portfolios and invest in decentralized systems, and develop financing mechanisms that are tailored to the specific needs of decentralized systems. Civil society should be involved as much as possible throughout these parallel processes.

2.1.6 Competitive and transparent markets

While free-market mechanisms have many drawbacks, well-executed and transparently governed markets will ensure a level playing field and enable high levels of innovation and dynamism. There is general consensus in EU institutions and most European governments that competitive, transparent markets are the best way to bring sustained development and prosperity. Governments have a crucial role to play in ensuring that the market playbook is respected, rules are predictable, and private-sector actors feel secure in their investments. This requires clearly formulated primary and secondary legislation as well as transparently enforced regulations. In the energy transition in Ukraine, a special role can be played by private and public investment from abroad.

2.1.7 Foreign investment and involvement

Donors, lenders, governments, and private companies from Ukraine's partner countries also have a crucial part to play in Ukraine's energy transition, through vital investments and knowledge transfer linked to green technology, practices and infrastructure, as well as technical advice and support for transparent, market-oriented regulations. Ukraine's government should work on creating an environment that attracts productive foreign investment and involvement from public and private stakeholders from allied countries. Special programs for renewable-energy projects could be established in municipalities for international donors.

2.1.8 Independent regulatory agencies

Ukraine's state agencies today have limited ability to effectively fulfill tasks related to promoting renewable energy and sustainability initiatives. They should be strengthened in their capacity to undertake tasks such as overseeing and administering new market-based schemes. They need the capacity to effectively monitor and regulate the implementation of sustainability initiatives, ensuring compliance with environmental standards and promoting a transparent and accountable energy sector. Additionally, they can provide a structured framework for rewarding producers of clean energy, thereby attracting investments, and facilitating the growth of sustainable-energy sources in Ukraine.

Capacity-building efforts in the energy sector on the national level would benefit from a single anchoring and coordinating institution embedded in the central government which could foster regulatory consistency and see that resources are used efficiently, by avoiding duplication of efforts and ensuring that the most pressing needs of the sector are being addressed. This institution could also launch a thinktank that researches the latest tendencies in the energy sector and translates them into concrete actions, and shares best practices and lessons learned.

Creating new institutions can be costly and time-consuming, and there are currently no homegrown thinktanks in Ukraine active in the relevant domains with a broad portfolio of projects. It may be more practical to build on existing institutions or to establish a network of institutions that can work together to implement capacity-building measures. International thinktanks and research centers already have expertise and experience in the fields of energy transition, energy tech, climate change and climate mitigation, and further related fields of expertise. They can also be well-connected in the international community and could help attract international funding and support for climate and energy-related projects in Ukraine.

2.1.9 Bolstering human resources

Human resources are another high priority. The deployment of modern power and heat-generation and transmission equipment requires new skills and regular training and education. Salaries must reflect market conditions and encourage the recruitment of the ambitious staff required to put in place the sector transformation. This requires that the finances of state-owned enterprises involved in activities such as power distribution and district heating be improved, which can partly be achieved by more targeted and less competition-distorting tariff structures, or individual metering, for instance.

Innovation and technology talents should be supported and promoted through direct government policy as well as encouraging and facilitating training efforts by the private sector. The government can promote knowledge transfer by partnering with organizations such as the International Renewable Energy Agency (IRENA) or making partnerships with countries that have experience in renewable-energy development. Government agencies and other stakeholders can benefit from technical assistance and capacity-building support to help them put in place regulatory reforms as well as monitor and evaluate their implementation. Finally, research and development involving the latest technological advances, such as smart grids, energy-storage systems, and energy-efficiency measures, should be a part of the postwar energy-sector reconstruction.

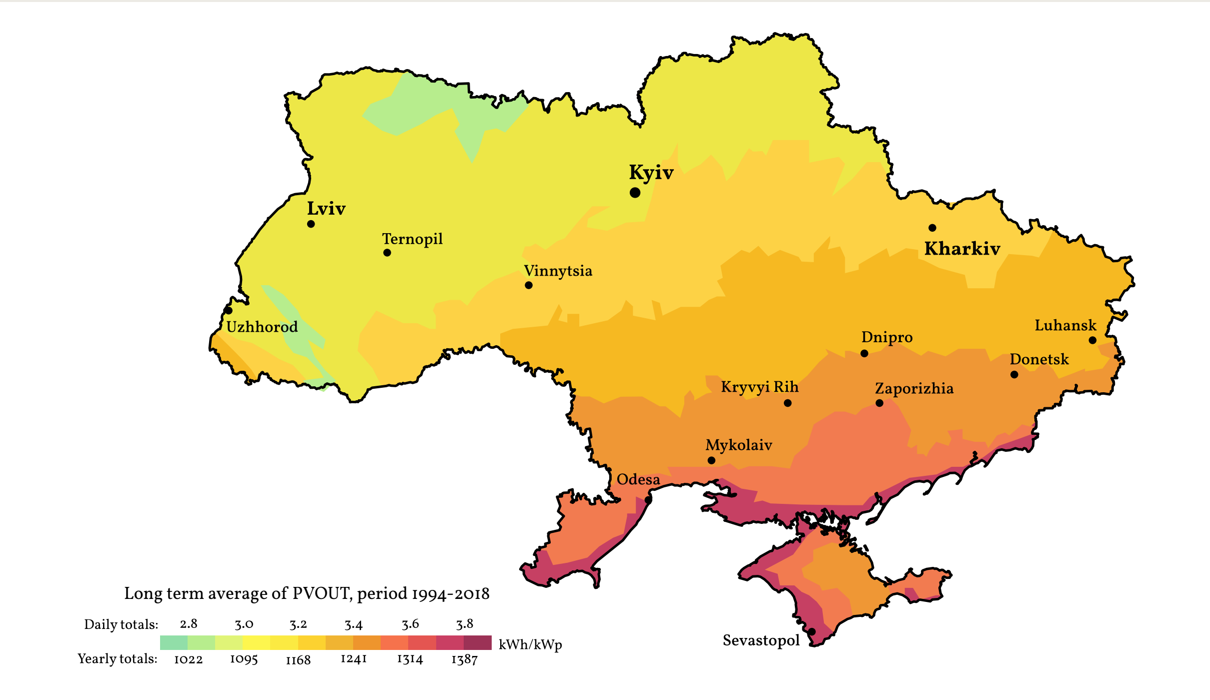
2.2. Renewable-Energy Generation

The production of renewable energy is the backbone of an energy transition. Clean forms of energy produce little to no net greenhouse-gas emissions in operation, but each have finite siting possibilities in terms of suitable rivers, resources and feedstock. Solar and wind are the lowest cost energy providers over their lives, but are intermittent and in the case of Ukraine will require balancing capacities (such as energy storage in the form of hydrogen – handled in the Energy Distribution and Storage section of this publication) and interconnections.

Pioneering countries such as Denmark and Spain have made the first steps towards the transformation this requires, and may provide inspiration on which path to take for other countries. Of course, the energy transition is incomplete, and there is no perfect model for Ukraine which will blaze its own trails based on its specific needs, resources, and particularities.

2.2.1 Solar power

At the beginning of 2022, Ukraine had total installed photovoltaic capacity of 7.6 GW, which equals 80% of the country's total renewable installed capacity; this excludes 0.4 GW located in the territories occupied by Russia before February 2022 and includes 45,000 prosumer installations with a total capacity of 1.2 GW. From a geographical perspective, Ukraine has substantial potential to produce solar electricity, with average annual amount of solar radiation ranging from 1070 kWh per square meter in the northern part of the country to 1400 kWh in the south. The overall potential of solar electricity production is estimated to be almost 83 GW with an annual potential of 100 TWh. The Energy Strategy of Ukraine until 2050 envisions an eventual increase in installed solar capacity to 17.5 GW.



Solar power potential in Ukraine
Source: Solargis, 'Photovoltaic Power Potential Ukraine'.

The Russian war of aggression has given solar energy an important role in terms of securing Ukraine's electricity supply. Solar electricity generation helps prevent power outages and protect critical infrastructures such as hospitals, improving resilience.

There are a number of solar panel manufacturers in Ukraine. In 2020 the product range covered everything from portable 10 W solar panels up to 390 W modules for solar power plants, as well as other materials, components, and equipment, like batteries, monocrystalline silicon ingots, silicon wafers, solar modules, and sapphire monocrystals. Some of the production is exported to other countries such as the United States, Japan, Germany or China.

Recommendations

During the immediate aftermath of the war, public authorities should set an example and increase renewable enhance generation by **supplying public buildings with solar panels** and stipulating that **reconstructed buildings should host solar panels.** Providing residents with small solar and storage systems to meet basic energy needs can also empower communities and **promote decentralized energy production.**

Moreover, it is advisable to **maintain the basic structure of the current market design** to continue promoting solar and residential solar plants. Simultaneously, **improving permitting procedures** and creating additional **regulatory incentives** will be essential to expediting solar project development. Early on, Ukraine should **explore innovative concepts** like floating solar on hydropower lakes and combining solar energy with agricultural land use, energy storage, or hydrogen generation. The development of a **handbook for greenfield solar projects** can serve as an additional resource for project developers, streamlining project implementation.

In parallel, Ukraine should conduct a comprehensive **assessment of financial and regulatory obstacles** hindering solar energy expansion. Subsequently, measures should be taken to address these challenges, ensuring a conducive environment for solar investments. Leveraging the existing solar industry is critical, and an assessment of local producers' needs can inform a **strategy to bolster local solar panel production**, fostering economic growth and energy self-sufficiency.

Eventually, Ukraine should build upon these foundations by **adapting regulations to facilitate the construction of medium and large-scale solar parks**, possibly in conjunction with other renewable energy generation sources. Additionally, regulatory and financial **support for local solar manufacturers**, in compliance with EU legislation, can bolster domestic production capabilities. Funding research to improve solar power technology can support the long-term advancement of Ukraine's solar industry. It is crucial also to develop a robust concept for an **optimal grid integration** of increased solar power capacity is crucial.

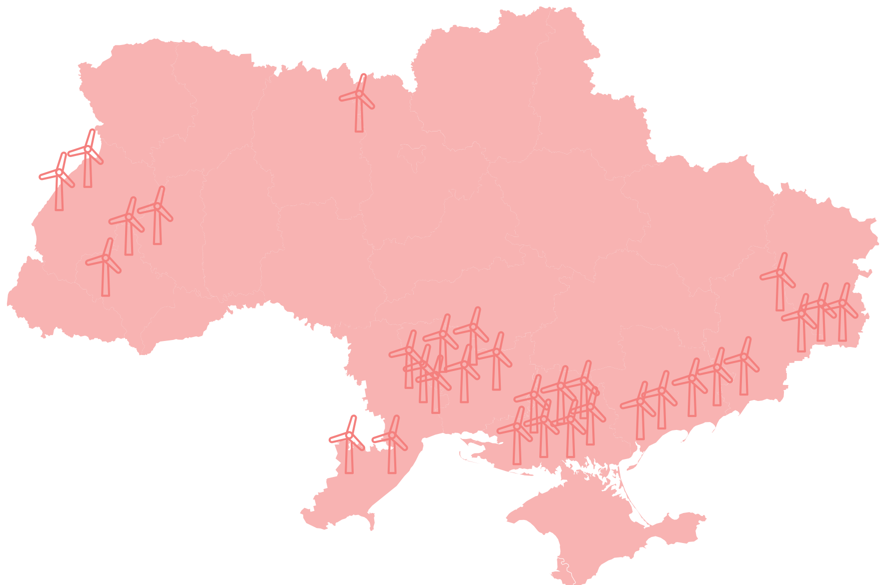
2.2.2 Wind power

In 2021, wind power in Ukraine had a capacity of 358.8 MWp and produced 30.6% of total green electricity, making it the second biggest source of renewable energy after solar. Before the full-scale Russian invasion, the country counted 34 wind farms, mainly in the south and southeast, with around 85% situated on the Black and Azov Sea coasts. Ukraine's total installed capacity of wind power plants, mostly located in the Kherson and Zaporizhzhia regions, was 1.6 GW; this excludes the 0.2 GW located in territories already occupied by Russia at that time. Wind power produced 3,866 GWh of green electricity, which is enough to meet the annual electricity consumption of around 650,000 households with a monthly consumption of about 500 kWh.

Russia's attack has had a disastrous impact on Ukraine's wind energy sector, with most capacity being in occupied territories. The Ukrainian Wind Energy Association reports that 75% of the total installed wind capacity was offline and at least 10 wind turbines are damaged. The war also negatively affected the development and construction of wind projects which would otherwise have added a capacity of around 300 MW.

According to a study by the Centre for European Policy Studies, Ukraine has overall capacity for as much as 320 GW of onshore wind energy. Steppe zones are best suited because of strong winds in both cold and warm seasons, and compensating local winds in-between. Furthermore, these areas in Ukraine already have good logistics infrastructure.

There are currently no offshore wind farms in Ukraine, but the country has great offshore wind power potential, thanks to the shallow waters of the Azov and Black Seas, the Dnipro cascade, the Dnister reservoir, and Sivash Bay, among others. According to the World Bank, Ukraine may have some 251 GW of potential capacity in offshore wind, of which 183 GW fixed and 68 GW floating. The Ukrainian Wind Energy Association envisions a significant boost in wind power capacity by 2030, including a contribution of 1 TWh in electricity production through offshore wind farms, which are meant to have an installed capacity of 300 MW in that year.



Wind turbines and wind parks located in Ukraine in 2021
Source: Razumkov Centre, 'Сектор Відновлюваної Енергетики України До, Під Час Та Після Війни'.)

Recommendations

Ukraine can foster the development of onshore and offshore wind power through a series of strategic measures. An essential step in the early post-war period will be to conduct a **comprehensive assessment of onshore wind energy potential** across every oblast to pinpoint areas with optimal conditions for rapid onshore wind energy deployment, often referred to as "**go-to areas.**" To further bolster onshore wind energy generation, Ukraine should also consider the development of instruments that **facilitate project development**. These may include the creation of a publicly accessible detailed wind atlas – a comprehensive handbook offering information on suitable areas, wind conditions, and power-generation potential.

Another critical factor will be the **simplification of permitting procedures and administrative workflows** to expedite project development and reduce project lead times, thus attracting more investments into the wind industry. Moreover, Ukraine can expedite wind energy growth by **initiating onshore wind projects on state-owned land**.

In parallel, it is essential to consider measures that **enhance local acceptance** of onshore wind projects. Drawing inspiration from successful practices in EU countries, Ukraine could explore the creation of schemes for **local buy-in**, such as energy cooperatives. Additionally, the implementation of local taxes or other **benefits for municipalities involved**, such as reduced energy costs, can help align community interests with the expansion of onshore wind power.

In the longer term, after the reconstruction phase, Ukraine should conduct a **strategic assessment** of the existing **know-how and infrastructure**, and the **needs of manufacturers** and other stakeholders. The country should also **facilitate joint ventures** with companies from EU countries, where appropriate. Moreover, it will be crucial to conduct a thorough assessment of the effects of increased renewable-energy generation on the **transmission system** at an early stage. This assessment should serve as a basis for creating a **national grid-development plan**, outlining the needs of the transmission system.

In parallel, it is imperative to establish clear and **effective guidelines for environmental-protection measures linked** to the installation of new wind turbines. Adhering to EU standards while maintaining speed in permitting procedures is crucial. Learning from successful models can provide valuable insights for the development and adoption of these guidelines.

Moreover, Ukraine should assess the supply chain for wind turbine production to find out which components can be produced within the country and which will have to be imported. Based on these findings, a comprehensive strategy should be formulated to establish a **Ukraine-based industry for renewable power plants and related services.** This strategic move can contribute to the growth of the local economy and the creation of a self-sufficient renewable energy sector.

Ukraine's existing expertise in maritime operations, particularly in offshore oil and gas, offers a strong foundation upon which Ukraine can **build an offshore wind industry**. Considering the unique challenges posed by the marine environment, environmental-protection measures must be robust. Exploring the possibility of implementing a **maritime planning procedure** specific to wind energy can help align environmental considerations with rapid project development.

In addition to domestic efforts, Ukraine should actively assess opportunities for offshore wind generation in **collaboration with neighboring EU countries** Romania and Bulgaria, as well as Turkey. Developing a long-term strategy for a meshed-grid approach for the Black Sea, mirroring successful concepts in the North and Baltic Seas, could enhance regional energy security and cooperation.

Lastly, Ukraine should explore the potential for **offshore hydrogen production**, taking inspiration from similar plans from EU countries. Engaging in cooperative ventures with these countries can facilitate knowledge exchange and joint projects, ultimately advancing Ukraine's offshore wind and renewable energy objectives.

2.2.3 Bioenergy

Energy carriers derived from biomass come in many forms. Practically any of the most common physical energy carriers today can be produced with biomass – this applies both to carbon-based fuels, such as biomethane, bioethanol, or biodiesel, and to carbon-free fuels such as biohydrogen or bio-ammonia. They are produced through a variety of processes which require different feedstocks, levels of energy input, equipment, and expertise.

As a country with one of the largest agricultural sectors in the world, Ukraine has no shortage of biomass. Biomass can be both combusted for heat production or turned into biogas – a mixture of methane and carbon dioxide – for electricity production or indirect heat production. In 2022, there were 73 biogas plants in Ukraine producing some 260 million cubic meters of biogas per year. The biomass currently used for heat production in Ukraine mainly comes from wood chips produced in lumber operations. Agricultural waste is not yet used on a large scale, despite great potential, especially from the country's abundant sunflower and wheat production.

In 2021, biomass accounted for 9% of Ukraine's total heat production (almost all of it in industrial processes), substituting imports of around 4 billion cubic meters of natural gas a year. Biogas is also used to produce electricity, with capacity in Ukraine increasing from less than 5 MW to 60 MW between 2017 and early 2020.

Biogas can be refined into biomethane, which is chemically almost identical to natural gas. In 2021, Ukraine consumed some 30 billion cubic meters of natural gas, of which one third was imported indirectly from Russia for billions of dollars a year – in other words, sustainable biomethane, which can replace natural gas in most applications, could contribute greatly to the country's energy security as well as its national accounts, economic activity and employment. Among the benefits of biomethane is the fact that a great deal of infrastructure already exists in Ukraine in the form of well-developed gas grids. According to the European Bank of Reconstruction and Development's (EBRD's) bioenergy program in Ukraine, with a high enough level of investment (some USD 2 billion), the country could realistically develop an annual production capacity of five to six billion cubic meters of biomethane.

Municipal district heating companies in Ukraine typically use gas-fired boilers or combined heat and power plants, consuming around 6 billion cubic meters per year. They are well-placed to use biogas instead. If 50% of the natural gas used by district heating companies (a realistic medium-term goal) could be substituted by biomass, Ukraine could reduce its consumption of natural gas by 3 billion cubic meters a year, or a third of its imports.

There are a number of issues standing in the way of an expansion in bioenergy production and deployment, however, including lack of connections from producers to district heating, low conversion efficiency (and therefore higher prices), lack of appropriate legislation or other state support such as certification programs and insufficient supplier guarantees. Moreover, natural gas is sold by the government to district heating companies at a steep discount, creating little incentive to invest in alternative sources (or increase efficiency).

Recommendations

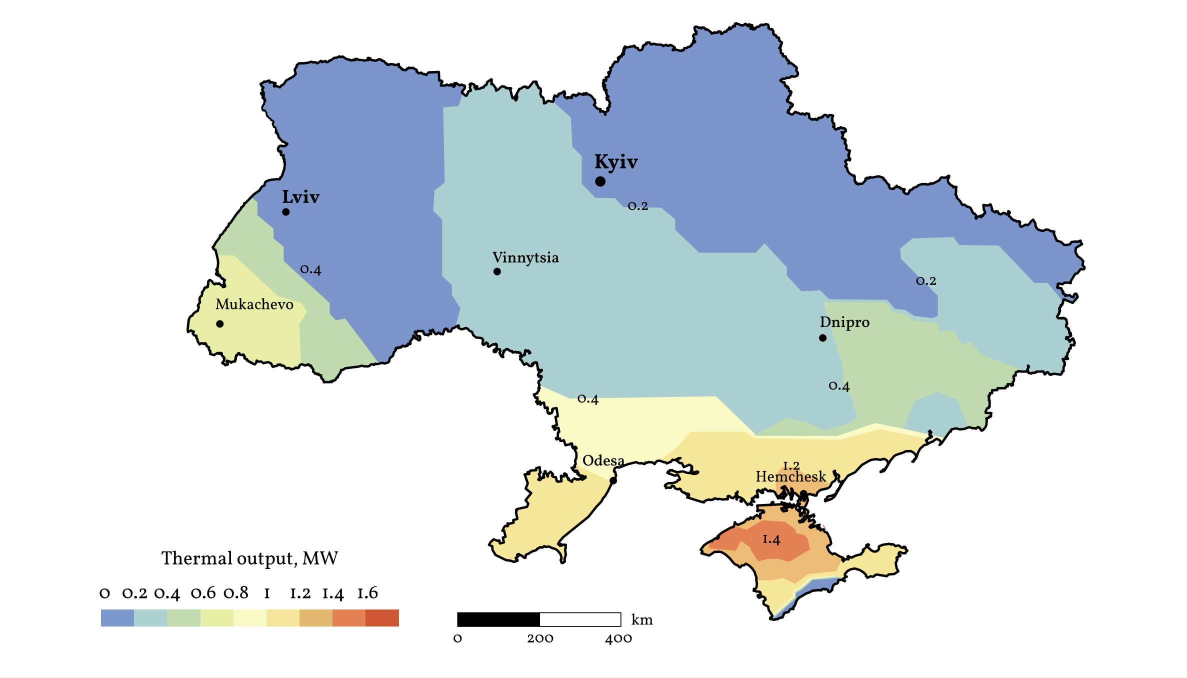
Once the war ends, Ukraine's priority should be to reintegrate the bioenergy production in previously occupied territories into its supply chains and distribution grids. The country should also start to lay the groundwork for a multifaceted expansion and deployment of bioenergy by assessing the overall biomass potential and infrastructure requirements for every region.

Based on this assessment, Ukraine should develop and implement a **medium to long-term strategy to expand the production and use of bioenergy**. This strategy should include measures increasing production of all energy carriers based on biomass for domestic use as well as export, and creating the **regulatory and physical infrastructure** needed to deploy more bioenergy across all sectors.

Many farming and forestry enterprises in Ukraine may lack the scale necessary to profitably market heat and/or electricity produced through biomass. Ukraine could **incentivize smaller operations** by providing financial support schemes and information for navigating the relevant regulatory, economic, and technical environments, for instance by **dedicated government agencies** or private development companies.

2.2.4 Geothermal energy

Geothermal energy is generally sustainable and renewable, with some manageable environmental concerns. Ukraine has substantial untapped potential in this field, with the Institute of Renewable Energy of the National Academy of Sciences of Ukraine calculating the total geothermal potential for the whole country to be some 10.81 GW, or 80.5 TWh per year – substantial opportunities can be found especially in the regions Crimea and Kherson in the south, Chernihiv in the north, Zakarpattia and Lviv in the west, and Poltava and Kharkiv in the center-east. In theory, 80 TWh of geothermal energy could replace almost 9 billion cubic meters of gas, or about the equivalent of Ukraine's current indirect gas imports from Russia.



Distribution of expected thermal output across Ukraine
Source: Shogenov, 'Geothermal Prospects in Ukraine'.

Very little of this potential is currently harnessed in Ukraine (or elsewhere), due to high upfront-investment costs, environmental issues, and the need for advanced technological knowhow. The Ukrainian government should support an expansion of geothermal energy by facilitating investment and distribution through instruments such as loan guarantees, incentives attracting investment and the accompanying expertise from allied countries, and openness to new, non-centralized and bottom-up methods and ideas.

Initially, geothermal energy can be used for direct heating of buildings and low-intensity industrial heat applications in places where it is easiest to harness. Eventually, once large-scale investments are safe and realistic, deeper wells may be used for higher-intensity industrial processes or the production of electricity or other green energy carriers such as hydrogen or ammonia. Particularly in the east of the country, geothermal energy may eventually help fire the industry which is currently powered by coal. Such large-scale projects could initially be pioneered by a few international consortia of large companies.

Recommendations

The Ukrainian government should establish an **overarching strategy for the expansion of geothermal energy which takes into account the relative maturity level of the available technology.** Initially, geothermal energy can be used for **direct heating** of buildings and **low-intensity industrial-heat applications** in places where it is easiest to harness. Eventually, once large-scale investments are safe and realistic, deeper wells may be used for **higher-intensity industrial processes** or the production of **electricity or other green-energy carriers** such as hydrogen or ammonia. Particularly in the east of the country, geothermal energy may partly **fire the industry** which is currently powered by coal.

2.2.5 Hydroelectric energy

Ukraine has a total installed hydro capacity of some 6,306 MW (this takes into account the unit added to the Dnister pumped-storage plant in 2021 and the destruction of the Kakhovka Dam in 2023). The World Bank is financing a project to expand this capacity by another 215 MW or so. Since 1985, the proportion of electricity produced with hydropower plants in Ukraine has fluctuated between 3 and 10%. More than half of the installed hydropower base is over 50 years old and requires renovation and rehabilitation. In theory, the country's total hydropower capacity could be expanded by more than 4 GW and there are in fact a number of projects in the planning or feasibility study phases, such as a plan to expand the capacity of the Dnister hydropower complex by almost 1 GW, for instance.

Hydropower plants play a major part in keeping power supply stably matched to demand with frequency-response ancillary services. Hydropower is reliable, dispatchable and produces no emissions during generation. At the same time, dams are not always as green as they may seem – hydropower can lead to serious environmental degradation and biotope disruption. As far back as 2010, a study estimated that 472 million people downstream from large dams suffer from regular flooding, reduced food security and/or issues with their livelihood.

Recommendations

After the end of hostilities, Ukraine's primary focus should be to thoroughly evaluate, stabilize, and, whenever feasible, undertake **renovation or reconstruction efforts** for its existing hydroelectric plants. The government should also explore potentials for symbiosis with other modes of renewable power generation, e.g., floating solar or the integration of hydrogen generation. To ensure any new hydro projects' compliance with EU regulations, careful **environmental impact assessments** considering the effects of dams on ecosystems and livelihoods should begin in the immediate afterwar period. These assessments should inform a comprehensive **cost-benefit analysis** for these projects. Overall, Ukraine's priority for additional renewable energy should be on more sustainable sources such as solar, wind, and biomass, with hydropower plants considered only on a smaller scale.

2.2.6 Funding possibilities

Financing renewable-energy generation in Ukraine typically involves a mix of financial instruments to attract investors and secure the necessary capital. The choice of financial instruments depends on a range of factors, including project size, risk profile, market conditions, and the preferences of investors and lenders. The most promising instruments to foster the expansion of renewable-energy generation include:

- Government incentives, such as feed-in tariffs, tax credits, or grants, which reduce the overall project costs and encourage investment in renewable energy.
- Green bonds: debt securities earmarked specifically for environmentally friendly projects, which can attract environmentally conscious investors.
- Power-purchase agreements, which involve selling the electricity generated by renewable producers to buyers (often utilities or corporate entities) at a predetermined price over a fixed term. Such long-term contracts can provide a stable revenue stream, making projects more attractive to lenders and investors.
- International climate funds and multilateral development banks like the World Bank or the European Investment Bank often provide financing in emerging markets like Ukraine.
- Crowdfunding and community investment – especially interesting considering Ukraine's experiences with contributions from large numbers of individuals or communities so far – can help raise capital for local projects.

The choice of financial instruments should be carefully tailored to the specific needs and circumstances of each concrete project in Ukraine, as well as the regulatory and market conditions in the country.

Recommendations

Fostering renewable energy during the postwar reconstruction should be carefully reflected in a comprehensive and detailed regulatory framework. The adoption of the Green Transformation Law addressed a range of challenges which hinder the development and optimal operation of renewable energy in Ukraine. However, a significant amount of legislative work still needs to be completed. This should include at least:

1. conducting a **thorough analysis of secondary legislation to identify obstacles or bottlenecks** in the implementation of the Green Transformation Law (with special attention to tax regulation) to grant renewable-electricity producers the right to sell electricity;
2. speeding up the development of secondary legislation to:
   - implement a mechanism for **suspending and renewing contracts with the guaranteed buyer** and
   - develop standard additional agreements to the contract for the purchase and sale of electricity **at the feed-in tariff** and the contract on participation in the **balancing group of the guaranteed buyer**;
3. adopting secondary legislation to implement a **market-premium mechanism** and design a model contract for the provision of and payment for services under the market-premium mechanism;
4. approval by the Cabinet of Ministers of Ukraine of a **dedicated procedure** for issuing, circulating, and redeeming **guarantees of origin**;

5. granting authority to the National Energy and Utilities Regulatory Commission (NEURC) for **issuing guarantees of origin**;
6. creating a separate **register of guarantees of origin**, which should be integrated into the regional register of the Energy Community; and
7. Defining and adopting annual support quotas and auction schedules by the Cabinet of Ministers to ensure full operation of green auctions in Ukraine.

Ukraine should encourage private-sector investments in bioenergy by establishing a **clear and stable regulatory framework** that provides **long-term predictability** for investors. A major building block could be the reintroduction of a **feed-in tariff** both for electricity generation and gas production. Another effective incentive could be to continue to offer **loan guarantees**, such as those currently provided in Ukraine by the German state investment and development bank KfW.

2.3. Energy Distribution and Storage

The energy transition is making it more complex to bring energy to final consumers in three ways. Firstly, many processes that are currently powered by fossil fuels will become electrified, and electricity is comparatively more difficult to stockpile, transport, and transform into thermal energy than fossil fuels. Secondly, most electricity will be generated from renewable sources, which are largely intermittent & decentralized and have to be balanced by steady but flexible dispatchable power – and this balancing in turn may require moving larger amounts of electricity across greater distances, or using small-scale local batteries. Finally, a substantial amount of electricity will be produced by small-scale, usually also intermittent, facilities like rooftop solar panels, and will need to be fed into the grid without leading to disruptions.
The main ways to manage this complexity will be grid enlargement, smart grid management and a big expansion of storage capacity in a wide range of formats, from grid scale to small local systems. The state of technology for many of these fields is not yet sufficiently advanced for large-scale adoption in the near term, but can already be prepared to some extent. This set of conclusions and recommendations focuses on transmission & distribution, smart grids, and energy-storage systems. While hydrogen and its derivatives can be and are likely to be used for energy storage, they are described at more length in section 0 Industrial Applications.

2.3.1 Transmission and distribution

The production of renewable energy being more erratic than that of conventional plants places particular demands on electricity grids. Ukraine's future energy transition will be further complicated by the strain imposed on the country's grid since the full-scale Russian invasion began in early 2022, and especially during Russia's deliberate attempts to destroy power infrastructure during the winter of 2022/2023. From October 2022 to February 2023, Russia launched almost 200 missiles and 46 drones at Ukraine's electricity grid, knocking out 10 GW of generation capacity and 43% of the high-voltage transmission grid. Ukrenergo had to impose rolling blackouts, with up to 12 million people without power at any given moment.

The transmission-system operator (TSO) Ukrenergo connected Ukraine to the synchronous grid of continental Europe within days of the full-scale Russian invasion in March 2022. By the summer of 2022, it had established interconnector capacity of around 2,300 MW per hour and was exporting some 500 MW of power per hour to European Union countries. Ukraine managed to keep its grid functional and was back to exporting electricity again by April 2023. This appears partly to have been achieved through specialist techniques to preserve system balance despite local failures, including procedures that allowed the grid to function as a number of independent islands, preventing collapse if one island is knocked out.

Before the full-scale Russian attack, Ukraine had 17.7 million consumers of electricity, of which 500,000 were commercial customers. By early 2023, electricity production had decreased by a quarter while demand had dropped by 30-35% and shifted massively due to the displacement of people from the east of the country to the west, as well as the disappearance or shutdown of economic activity. In early 2023, hundreds of settlements and more than half a million people remained without electricity, and millions more had only partial access or were on capacity-limiting schedules.

Ukrenergo is fully owned by the Ukrainian government through the Ministry of Energy. It plays a vital role among other things in implementing EU regulations on fundamental data transparency in the electricity market and has observer status in ENTSO-E since April 2022. Ukrenergo owns and operates Ukraine's high-voltage transmission grid and works closely with Energorynok, the market operator, though these two entities are separate and have independent budgets. Ukrenergo is also independent from the generation and distribution companies.

Access to transmission and distribution systems in Ukraine is ensured through publicly available tariffs, which also apply to generators. Distribution system operators (DSOs) are legally and functionally unbundled in compliance with EU legislation. Since March 2023, DSOs are required to develop and submit development plans and investment programs. These plans aim to ensure efficient, transparent, and renewable energy-friendly grid planning, enhancing grid stability, regulatory oversight, and consumer protection while aligning with national energy goals.

Recommendations

Once the hostilities cease, Ukraine will need to immediately shore up and reinforce the **basic physical power transmission and distribution infrastructure**. No major refurbishments or investments should be made until it is clear which parts of the grid will no longer be needed as the power system evolves toward a greater share of renewable energy in the medium term. This assessment should also include an analysis of infrastructure upgrades that can **reduce transmission losses** and the **potential of smart and decentralized grids** (e.g., to boost resilience) – both of which are crucial to **improved energy efficiency** – and lead to an overarching strategy towards future-proof transmission infrastructure.

There are several priority reforms in the legal framework related to Ukraine's transmission system that should be carried out within the period immediately after the end of the war. Domestic law should be **harmonized with Energy-Community legislation** and the energy acquis to maintain consistency with regional energy standards and give **special consideration to renewable-energy sources**. Tariffs should be adapted following an assessment of which structure would best suit the country's needs. Ukrenergo should be included in the EU's inter-TSO compensation mechanism.

Ukraine should also adopt Connection Network Codes within regulatory acts so as to **align its energy infrastructure with European standards** and facilitate seamless integration into the broader European energy market. The connection process of renewable energy into the grid should be streamlined, minimizing bottlenecks, enhancing transparency, and improving efficiency. And a comprehensive grid master plan for the coming decade should be set up, with data on grid development that allows renewable-energy projects to identify areas with optimal grid access.

In the medium term, Ukraine should start to plan and build its **future transmission infrastructure**. These plans should be developed in parallel with the broader strategies for the coming expansion of – mostly intermittent – renewables. Measures including ramping up digitization and **advanced grid management**, creating **demand-side flexibility**, integrating **energy storage** as well as taking steps towards more **interconnectivity** and regional grid integration will be essential to ensure grid reliability, maximize energy utilization and efficiency, and support the integration of renewable energy sources into the energy mix.

Funding for future-proof grid infrastructure can be secured from a number of sources, not least multilateral development banks like the World Bank, the European Investment Bank or the European Bank for Reconstruction and Development. Government support can be provided through subsidies to private initiatives, or public-private partnerships, mitigating risk and leveraging public resources. **Private-sector funding** can be brought in via green bonds, energy performance contracts, or energy savings agreement, as well as crowdfunding or impact investing platforms.

2.3.2 Smart grids

Smart grids are a constructive part of a future energy system based largely on intermittent renewable energy. These electricity networks deploy digital technologies, sensors, and software to match the supply and demand of electricity in real time. This maintains the stability and reliability of the grid while minimizing costs. They are particularly helpful in functions such as balancing electricity supply and demand, ensuring the long-term ability of the grid to meet the needs of domestic and cross-border trade, and actively boosting the efficiency, reliability, resilience, stability, and flexibility of power grids. Smart-grid technology is largely mature, but they are complex to deploy on a large scale.

Recommendations

The development of smart grids in Ukraine could be fostered by eliminating legislative and institutional barriers to their deployment and bolstering the conditions, incentives, motivations, and methods appropriate for their use by electricity companies, businesses, and citizens. This can, for instance, include establishing regulations that mandate that both the transmission system operator and distribution system operators actively **develop comprehensive plans for smart-grid deployment and expansion**. **Approval processes** for smart-grid projects should be simplified, and **tariff structures** should be reformulated to reward electricity companies for enhancing grid efficiency through smart-grid technologies.

2.3.3 Storage systems

Energy storage plays a major role in the system integration and decentralization of the energy market. This include grid-scale energy storage feeding into the electrical grid, storage of electricity for direct use, electrification of the transport sector through the deployment of batteries, and heat storage. By helping manage energy flows and match demand to supply, storage facilities can help improve the efficiency of infrastructure, markets, and consumption patterns.

Grid-scale storage technologies can provide significant system services in a decentralized and decarbonized energy system, including short-term balancing and operating reserves, ancillary services for grid stability and deferment of investment in new transmission and distribution lines, to long-term energy storage and restoring grid operations following a blackout. The Energy Strategy of Ukraine until 2050 aims to increase the capacity of energy storage facilities, including long-term (seasonal) storage devices that use power-to-X technologies, to help balance the power grid.

There are a number of technologies that allow the storage of energy in various forms. According to the International Energy Agency, pumped-storage hydropower accounts for over 90% of total global electricity storage. Before the full-scale Russian invasion, Ukraine had a total installed pumped-storage hydro capacity of 6,317 MW. Lithium-ion batteries are another common form of electricity storage. They can be used as portable energy storage systems (such as batteries in cars) as well as for grid-scale storage. They require a large amount of resources, however; most of these can be found in Ukraine in some quantities, but are not yet mined on an industrial scale. Lithium-ion batteries also suffer from problems linked to environmental impact, the supply chain, and waste recovery & recycling – the latter is a particular problem for Ukraine, which has accumulated thousands of tons of used batteries over the past decades and lacks industrial facilities to recycle them.

Other promising types of storage include redox flow batteries, as well as mechanical solutions such as compressed-air energy storage systems (no such systems exist in Ukraine yet). Hydrogen and ammonia can be used as chemical energy storage (see also section 0 Hydrogen), and other systems may be considered in the future, such as sensible heat, liquid air, gravitational storage, metal air, latent heat, thermochemical heat and flywheel energy storage.

There are many battery manufacturers in Ukraine, producing a wide range of electrochemical battery systems, including lithium-ion batteries, lead-acid batteries, and alkaline accumulator batteries. Given the breadth of applications required, stakeholders in the Ukrainian energy system should assess all options, pursuing a technology-open approach.

Recommendations

In the first years after the war, Ukraine should facilitate the access of residents to **small-scale storage systems connected with solar-power generation**, and carry out an evaluation of the best locations for grid-scale storage capacity, as well as a plan to expand grids to accommodate it. A **range of different storage technologies** should be explored, and **regulations and monitoring** based on EU law should be introduced to ensure environmentally sound mining and recycling. Regulations supporting **recycling and second-life use** for batteries should also be developed.

In the longer term, Ukraine's recovery will involve large-scale increases in renewable energy, requiring **much more storage capacity**. This will help make energy systems – infrastructure, generation, consumption – **more efficient, resilient and cost-effective.** It should be accompanied by more system integration, for instance by connecting car batteries to the grid. **Battery recycling** should be improved and the **mining of raw materials** critical to battery production should be safeguarded and expanded where possible. Battery-storage systems should be granted **exemptions from certain tariffs and given benefits when they store only renewable electricity to encourage their widespread adoption and integration into the energy grid.**

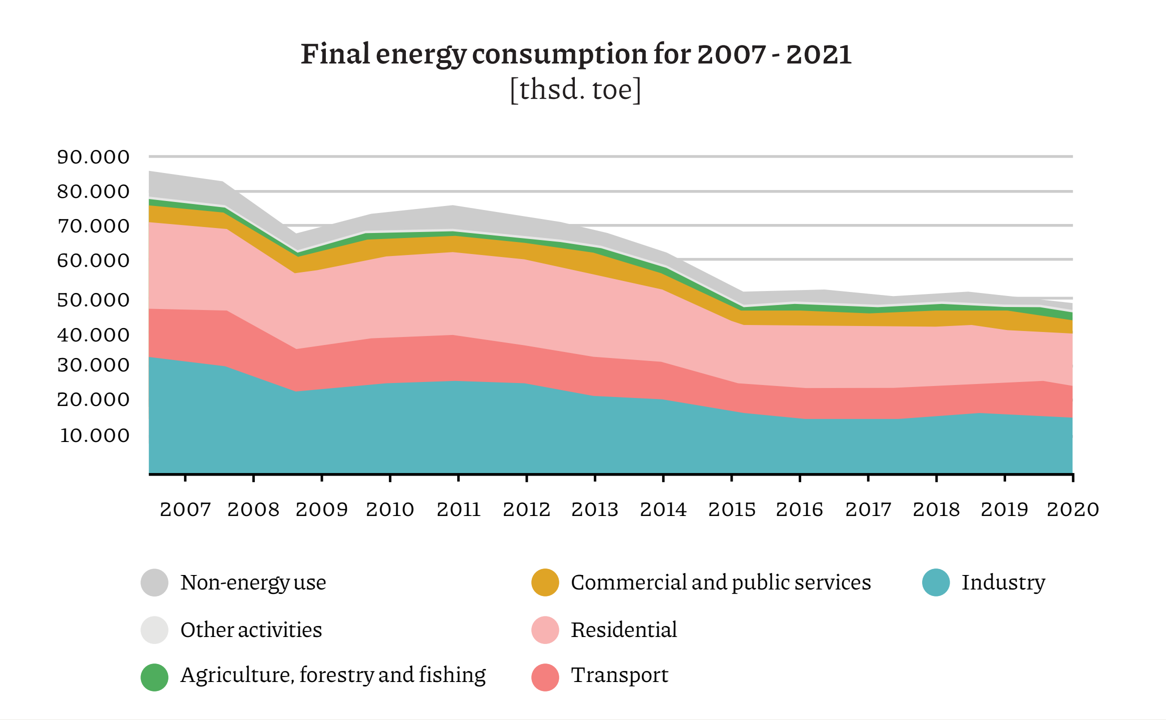
Other actions to bolster the use of batteries through a streamlined regulatory framework should include **support to domestic suppliers involved in battery manufacturing and improving access to grid services. Ukraine should** implement the recently introduced EU Batteries Regulation, adopt a dedicated law to ensure a **stable and sustainable supply of raw materials** needed for battery manufacturing and other energy storage technologies, adopt a **circular-economy law** that acknowledges battery materials as valuable raw materials, and develop regulations that facilitate **synergy between renewable energy and battery technologies**. Maintaining a **technology-open approach** throughout these processes will be of paramount importance.

2.4. Industrial Applications

The industrial sector is the largest energy consumer in Ukraine. Products include ferrous metals, a wide range of heavy machinery, and many different chemicals, foods, and other products. The ultimate effects of the ongoing war, not least in the industrial heartland of the Donetsk Basin, are difficult to predict, and it is not clear to what extent and under which circumstances the manufacturing sector can be rebuilt or established again in a shape that is efficient and competitive in the global markets. As in other sectors, however, the destruction caused by the war offers a chance to start fresh by applying innovative methods and procedures and boosting productivity and prosperity while reducing environmental and climate effects. This section looks at manufacturing and hydrogen applications separately.

2.4.1 Manufacturing

As shown below, the energy consumption of the industrial sector in Ukraine has been steadily decreasing over the years due to deindustrialization and economic decline. According to the State Statistic Service of Ukraine, the industrial sector consumed almost 16 million tons of oil equivalent (mtoe) in 2020, of which iron and steel production accounted for over 8 mtoe. The most common energy sources are coal, peat, and natural gas, while biofuels, waste, and direct electricity (which is partly renewable) account for only a small part of the energy consumed.



Development of final energy consumption by sector in Ukraine (excluding occupied areas) in million tons of oil equivalent from 2007 to 2021
Source: State Statistics Service of Ukraine.

Manufacturing plays a pivotal role in the Ukrainian economy, contributing significantly to both productivity and revenue generation. The production of cast iron, rolled steel, and steel pipes takes place primarily in the Donetsk Basin, the country's industrial heartland (which has been occupied by Russia for almost a decade). There is also a great deal of heavy industries manufacturing vehicles, generators, turbines, and other equipment and machinery. The country's strong agricultural sector is supported by numerous processing plants.
Manufacturing applications are characterized by wide variation in the type and quantity of energy required. Industrial processes can require low-grade heat, high-grade heat, cooling, kinetic energy for motors and similar processes, energy for chemical processes, or electricity for applications such as computers or lighting. Leveraging innovation in energy to achieve a more vibrant, dynamic, and competitive industrial sector is therefore associated with a range of challenges.

The sector comprises a number of state-owned enterprises, many of which are inoperative (being in territories occupied during the Russian aggression) or inefficient and unprofitable. The Ukrainian government plans to privatize or wind down most of these. Realistically, reconstruction will depend largely on decisions and transitions undertaken by private-sector operators in an uncertain timeframe. The Ukrainian government and its partners will therefore foster the decarbonization of manufacturing through regulation and supportive measures rather than direct operational decisions.

One example of a constructive initiative is the Coalition for the Green Recovery of the iron and steel sector, a program by the Government of Ukraine that Breakthrough Energy is helping set up and operate. The coalition aims to develop a pipeline of investment projects, address financial and policy issues, and facilitate coordination among stakeholders and with other recovery initiatives in the country. This will help Ukraine make the most of its existing assets in terms of infrastructure, expertise, and raw materials, and establish dynamic green steel industries by leveraging smart investment choices.

Ukraine can become a global leader in green iron and steel, and build a revitalized industrial sector that provides plenty of quality employment while supporting Europe's industrial and climate goals.

Recommendations

Ukraine's progress towards a vibrant and dynamic industrial sector based on innovative technologies and methods hinges on wise choices during its reconstruction. From an energy perspective, the country needs to establish **renewable-energy sources as the backbone of the energy supply** and ensure a **streamlined legal environment** that facilitates a dynamic and resourceful industrial renaissance, not least by implementing a **robust greenhouse-gas emissions certification scheme** to guide and accelerate the path towards achieving net-zero emissions in a way that is **cost-effective** and **technology-oriented** and conforms with **market principles**. It would also help **allocate scarce resources** transparently and proficiently, **strengthen energy-efficiency measures**, and **safeguard against waste**.

In the near term, Ukraine must prioritize the rebuilding and reconstruction of destroyed energy infrastructure using the best available technologies that minimize greenhouse-gas emissions. The Ukrainian authorities should, wherever possible, also include **climate and sustainability considerations** in their privatization plans (the exact definitions depending on the given industry sectors). Special care should be given to **iron and steel production**, which are particularly important to Ukraine's economy but have high energy consumption.

Combined heat and power (CHP) plants should be explicitly included in medium and long-term strategies and considered in the relevant cost-benefit analyses as an efficient measure to balance the grid system or during capacity shortages. The government should see to it that **no lock-in effects** occur with CHP plants that initially operate with fossil energy carriers – CHP plants should be planned to eventually use **hydrogen or similar** energy carriers. Regulations should be implemented to support the use of sustainable bioenergy originating in residual materials and waste, improving economic circularity. Eventually, CHP plants can be retrofitted for use with more renewable-energy carriers.

Given its EU candidacy, Ukraine must join **the EU's emissions trading scheme (ETS)** or develop **its own carbon-pricing system**. Both options have economic implications that need careful evaluation. Joining the ETS is a shortcut to high standards but requires adjusting to demanding EU policies. Establishing a national scheme would offer more flexibility but less access to European markets. Strengthening the efficiency of the sector is vital for both options. Considering circumstances post-war, it may be prudent to introduce a **gradual and phased approach** to avoid overburdening the industrial sector.

Transition bonds can be used as a debt instrument for projects that enhance energy efficiency, reduce emissions, or support renewable-energy adoption in their operations. Leveraging **government grants and incentives** can help reduce the financial burden of deploying inventive new methods and technologies, as well as energy-transition initiatives.

A legal basis should be established for an **energy exchange**, giving energy-market participants access to transparent liquidity, standardized contracts, and centralized clearing, There should also be a legal framework that makes it easier for industrial enterprises to run **small-scale renewable-power plants** to meet their own demand. A circular-economy law should also be adopted to promote sustainable **resource management and supply chains**, not least when it comes to batteries. This would help promote **greater investment, transparency, and sustainability** in **critical industries**.

2.4.2 Hydrogen

Hydrogen and its derivatives will be essential in the future energy mix required to achieve a prosperous, technologically advanced future and energy independence for Ukraine. Europe's energy transition, for instance, foresees large-scale production and use of hydrogen – and given European climate goals, this may eventually largely have to be renewable or climate-neutral hydrogen, that is, hydrogen produced through electrolysis powered by renewable solar, wind or hydro energy. Pink (made through nuclear-powered electrolysis) and blue (made with fossil-powered electrolysis with carbon capture) hydrogen are, however, also admissible under EU rules, and likely to remain so indefinitely.

The production of hydrogen requires great amounts of energy. Ukraine has plenty of renewable-energy resources compared to its European peers. The country may also have spare nuclear-power capacity which can be used to keep electrolyzers running when general demand for electricity is low.

The choice of financial instruments for hydrogen projects depends on the specific technology, scale, and market conditions. The following instruments show promise in the financing of hydrogen projects in a Ukrainian context:

- governmental subsidies and incentives, e. g. grants or tax incentives to promote hydrogen projects, especially those focusing on green hydrogen production from renewable sources;
- public-private partnerships, which help mitigate risks and provide access to government resources;
- green bonds, which are especially favorable for investors looking to support sustainable-energy projects; and
- hydrogen-investment funds specifically focusing on hydrogen-related projects to provide financing and expertise in the hydrogen sector.

No large-scale hydrogen production projects will come on stream within the first few years after the war in Ukraine ends. However – as with the energy transition in general – it is important that no path dependencies be created during this time that might prevent the later deployment of innovative solutions and technologies. To give just an example from the steel industry, the lifetime of a blast furnace – that is, the period until its refractory lining needs to be completely renewed – is around 15-20 years. Other plant components can have even longer lifetimes.

Recommendations

It is important for Ukraine to design projects and establish partnerships between domestic hydrogen producers and buyers as well as between domestic hydrogen producers and international buyers – a global market for hydrogen does not yet exist, but is emerging. This applies to **political agreements as well as concrete partnerships** and projects at company level. Declarations of intent should gradually be backed up with concrete project approaches so as to **build a project pipeline** during the period right after the end of the war.

In addition, renewable-energy generation must be expanded, as this is the main bottleneck of hydrogen production. The first pilot projects involving the production and deployment of hydrogen should be carried out soon after the end of the war to build up expertise. Above all, Ukraine's long-standing expertise in European **gas transport should be harnessed** for possible export ambitions. It is crucial that the country be continuously guided by **European requirements**, ensuring that products are **qualified for export** to the EU. Specific measures for the near term include:

- adapting regulations and incentives to foster innovation and investments into **hydrogen infrastructure**;
- preparing **licensing authorities for new technologies, allowing them to implement appropriate processes and train employees in a timely manner;**
- connecting with European transmission-system operators and fostering knowledge transfer; and
- carrying out cost-benefit analyses and plans for **making gas infrastructure hydrogen ready**.

In the medium and longer term, the first **blast furnaces** should be converted to **direct reduction** with hydrogen, creating know-how that can be transferred to other plants. Partnerships between hydrogen producers and the steel industry should be intensified and binding contracts concluded.

In **road transport**, too, the use of hydrogen or its derivatives should be ramped up where there is no alternative. And the **ammonia industry** – for which hydrogen is a major feedstock – should be gradually decarbonized, making it ready for export to the rest of Europe.

2.5. Transport

The transport of people and goods is a mainstay of any society and economy. The faster and more efficiently it can be carried out, the more it facilitates a wide range of valuable activities. Transport infrastructure can also have a strategic value, as has been amply demonstrated by the heroic performance of Ukrainian railways in conveying people and goods – not least refugees, soldiers, and army equipment – around the country during wartime, especially after Ukraine's airspace was closed by the Russian invasion.

A country's economy cannot reach its full potential in terms of progress and prosperity without efficient transport infrastructure. For individual needs, this in most cases means passenger vehicles and ample roads within and between cities. However, everyone having their own personal vehicle which is used for most purposes can come at great cost in terms of efficiency, space, human health, climate, and building & maintenance expense. Where it can practically be built and maintained, comfortable and efficient public transport for individuals and rail for cargo can free up streets and freeways for situations where road transport is preferable, saving time and cost for individuals and society at large.

In situations where transport takes place via road, it should be decarbonized when possible to minimize effects on human health and the climate. There are essentially four options for decarbonizing road transport: battery-electric vehicles (BEVs), fuel-cell vehicles (FCEVs), vehicles with hydrogen-combustion engines and conventional combustion engines that use synthetic fuels – so-called e-fuels. There are major differences between these applications in terms of efficiency.

	$[kWh_{el}]$	Drive Technology [%: Utilisation rate]			Drive energy [kWh]
Battery electric vehicle (BEV)	1	Battery charge 95%	Battery discharge 90%	E-motor 90%	0.75
Fuel cell electric vehicle (FCEV)	1	Electrolysis 65%	Fuel cell 55% el.	E-motor 90%	0.3
Vehicle with H_2 combustion engine	1	Electrolysis 65%	Internal combustion engine 30%		0.2
Diesel vehicle with eFuels	1	Electrolysis 65%	Fischer-Tropsch synthesis 56%	Internal combustion engine 40%	0.15

● Power ● Hydrogen ● eFuel

Comparison of average utilization rates of propulsion technologies (transport losses are not taken into account)

The use of BEVs is usually recommended for passenger cars, but they are impractical for long-distance truck traffic, which carries heavy payloads across long distances, requiring batteries to be very large and heavy, or recharging stops to be very many. Ukraine has a relatively low density of population and high distance between economic centers, which would make this impractical. For instance, Kyiv is almost 500 kilometers or 300 miles from the second and third largest cities in Ukraine (Kharkiv and Odesa). This cannot be covered with today's BEV trucks without a charging stop, and exports, for instance, would have correspondingly larger distances to go. Charging processes for FCEVs are roughly the same as for conventional vehicles, but significantly quicker (depending on the available charging infrastructure).

The extent to which future advances in battery technology will make up for these disadvantages is difficult to foresee. It is equally hard to predict whether fuel-cell vehicles or conventional trucks with synthetic-fuel drives will prevail in the future. The benefits of FCEVs are that they produce no local emissions of polluting nitrogen oxides or carbon dioxide, and are less noisy, while enjoying lower fuel costs and less maintenance, as electric motors have fewer moving parts than internal combustion engines. The advantages of conventional trucks are the broad availability of refueling and maintenance infrastructure, and lower upfront purchase costs. The future cost and availability of synthetic fuels are as yet uncertain, however. Hydrogen can also be expected to have some role in the decarbonization of road transport, but the precise extent cannot be predicted right now.

Recommendations

The streamlining, expansion and decarbonization of different types of transport will be crucial to Ukraine's postwar recovery and future prosperity. This should be bolstered by the deployment of innovative regulatory and financial instruments. Immediately after the war ends, the country should **repair its existing railroad network**, and ensure that its long-term strategies (such as the Energy Strategy of Ukraine until 2050 or the National Transport Strategy of Ukraine 2030) **foster public-transport** coverage and usage. It should also interlink **city planning** with sustainable transportation and put in place measures which support the **electrification** of individual transport and logistics. In the medium and long term, Ukraine should advance the **electrification of the railway** system and promote **green fuels** for non-electrifiable activities, as well as facilitate the use of vehicles which do not have combustion engines by, for instance, increasing the **availability of charging stations**.

The financial tools that can be deployed to bolster the use of modern and sustainable transport include:

- **municipal bonds** issued by local governments to fund local transportation infrastructure projects, such as public-transit systems and local infrastructure improvements;
- multilateral and bilateral financing through collaboration with **multilateral development banks** (World Bank, EBRD, EIB) and national development banks and agencies, e. g. KfW and USAID, which can provide access to loans and grants for transport projects;
- **public-private partnerships**, which can help mobilize private sector capital and expertise for transport infrastructure projects – private partners can invest in the construction, operation, and maintenance of transport facilities, such as toll roads or public transit systems, in exchange for revenue-sharing agreements;
- **green bonds**, which are an effective way to finance sustainable transport projects that prioritize reducing emissions and enhancing environmental sustainability; and
- **microfinance and crowdfunding**, which are suitable for smaller-scale transport transition projects, or initiatives focused on community-based solutions, microfinance and crowdfunding platforms.

2.6. Buildings

As the sites of most of the components of any economy, buildings are not merely a neutral backdrop. The way they are built, inhabited, and operated can facilitate or obstruct economic activity and innovation, and has a major influence on sustainability. The results of the analysis carried out under the auspices of the Ukraine Energy Roadmap project are here presented for construction methods and heating solutions separately.

2.6.1 Construction

In 2021 there were more than 17 million residential units in Ukraine. According to the Kyiv School of Economics, by the end of 2022, war damage in the housing sector was USD 54 billion (of a total of $138 billion). This included 149,300 damaged or destroyed housing units. Given the degree of damage Ukraine has suffered, the country has major choices to make during its rebuilding. Here, as in other aspects of the postwar economic recovery, there is a possibility to catch up with current and future EU standards – with which the country will eventually have to comply on its road to European integration – and even leapfrog them, as opposed to simply building everything back the way it used to be, including in terms of inefficiencies and high carbon footprint.

Recommendations

One general way to rebuild or build more modern buildings would be to embrace a **more circular economy** model, attempting to **minimize waste** and **maximize resource efficiency** throughout the entire lifecycle of buildings. This includes promoting the **reuse and recycling** of materials, as well as designing structures that can be easily disassembled and repurposed – for instance, sustainable building standards that prioritize the use of **environmentally friendly** materials such as wood, straw, lime, or carbon-concrete composite instead of steel alternatives (at least until such a time as sustainably produced steel is widely available).

Specific measures that can be undertaken include developing **energy-efficiency programs** for the public sector and equipping government buildings with more solar facilities and storage systems, and **reconstructing** buildings with **improved energy-efficiency measures.** Eventually, **renewable heating** systems and measures to increase energy efficiency in **existing buildings** should also be undertaken. A report by the consultancy Ukrainian Industry Expertise calculated in November 2022 that Ukrainian manufacturers could eventually provide 90% of the construction materials needed for reconstruction.

2.6.2 Heating

Space heating is an integral aspect of how buildings are used and inhabited. For instance, in 2021, the largest share (50%) of final residential energy consumption was taken up by space heating. This is often quite energy-intensive and includes room for improvement in terms of efficiency or carbon footprint. One particularity of Ukraine’s built environment is the prevalence of district heating – a centralized network of pipes that distributes heat to homes, businesses, and public services, on which 53% of urban households relied in 2021.

The size, age and dispatchability requirements of these systems mean that they were built for, and are currently almost exclusively powered by, fossil fuels. However, being large-scale centralized heating systems, they can be adapted for use with more sustainable fuels more easily than the small-scale distributed heating systems that are more common in Western European residential buildings. They could be fueled by biomass or waste heat from sewage systems, industrial processes or even data centers, and could be combined with electric-power generation in combined heat and power plants. The heat-generation efficiency of boiler houses in Ukraine is 89% on average, but many of the boilers as well as auxiliary equipment such as pumps need to be modernized or replaced. Most pipelines are old and poorly insulated. Companies' operational expenses are therefore quite high, while income is limited due to tariffs being capped by politicians. The level of investment in modernization has therefore been insufficient for many years.

Heat metering nowadays is carried out at the level of individual buildings, making it difficult for end users to control their consumption and reducing the impetus for energy-efficiency improvements. Instead, investors and inhabitants have installed many individual heating units (mostly electrical) to top up the heat supply in a way that consumers can fine-tune. Between 1995 and 2018, the share of urban households in Ukraine benefiting from district heating decreased from 89% to 55%. The solutions which have replaced it have led to reduced efficiency and increased pollution, while creating a burden on other infrastructure, including electricity and gas supply. This contributes to overcapacity and operational inefficiency in district-heating systems, which now have too much capacity (although this is partly also due to the fact that they were built in an era when there was more demand from industry, and energy efficiency was lower).

Recommendations

Any economy looking to bolster its efficiency and sustainability must look for solutions to replace fossil fuel-based heat generation with renewable energy sources, and to **prioritize energy efficiency in buildings. To achieve this,** Ukraine should establish **regulatory frameworks** that support the adoption of energy-efficient heating technologies, such as **building codes and energy-efficiency standards**. Such standards could include best-in-class building codes (net-zero-energy buildings). This can also help to create a level playing field and promote investment in state-of-the-art heating technologies.

Ukraine will require a **comprehensive heating strategy**, supported by **action plans** at the state and local levels, including a long-term **building-renovation strategy**. The planning of heat-supply systems in settlements could be improved through further development of the national energy and climate plan with clear targets and roadmap for the deployment of heat technologies.

Non-fossil alternatives should be found for all heat sources, and **efficiency should always come first** in planning and rebuilding. Private households and small & medium enterprises should be given more access to **support schemes**, and governments should provide incentives to **encourage investment** in new heating technologies, thus offsetting the high upfront costs and promoting adoption.

There should be an analysis of the state of existing large-scale centralized district-heating systems throughout Ukraine and a thorough **cost-benefit review for a range of future options**, such as refurbishing of existing systems, decentralization to smaller units, or installation of individual heating systems in residences and offices. Where possible, competition should be encouraged in the district-heating sector.

The use of **biomethane and waste heat** for heating should be boosted where possible. Large heat pumps can be used to provide district heat to buildings, commercial premises, and industrial facilities, and can **recover heat** from wastewater, data centers, metro tunnels, industrial facilities, or electrolyzers. Cogeneration can also be considered. Moreover, **individual metering** should be expanded, creating incentives for households to improve energy efficiency and avail themselves of cleaner technologies.

Innovative financing instruments such as **green bonds** can be used to finance certain actions, such as the construction of green office buildings, residential complexes, and industrial facilities, or retrofits of existing buildings. This should rest on a **comprehensive analysis that takes into account t**he complexity of the required investments, the availability of equipment as well as the time & cost required for installation and maintenance, and the net-value added for consumers, municipalities, suppliers, and investors. Before a comprehensive approach is defined, individuals and institutions should be **discouraged from installing multiple smaller systems**, which are likely to run on fossil fuels and may end up being comparatively harder to convert to sustainable operation given that they will be more recent and decentralized.