ДИСКУСІЇ / DISCUSSIONS

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GEOTHERMAL OVERVIEW OF UKRAINE

This article is the summary of a report that was presented in March 2023 during the Ukrainian-Spanish cycle of conferences as of 'Global vision of Ukrainian Geology the 'Future of Geothermal Energy in Ukraine', organized by GEO3BCN-CSIC. The geothermal potential of Ukraine can play a key role in accelerating the transition to clean energy. Therefore, this article provides a detailed characteristics of the main types of geothermal sources in Ukraine, such as shallow geothermal, thermal waters and deep geothermal which can be apply for direct use, district heating as well as electricity generation. Analysis of the distribution of deep heat flux values on the territory of Ukraine, which varies from 40 to over 120 mW/m^2, allows to identify three main prospective zones, confined to the main oil and gas-bearing regions such as Transcarpathian (west), Steppe Crimea (south) and Dnipro-Donetsk basin (east). The total geothermal potential of Ukraine is estimated at 438*106 kWh p/ year. Annual technically achievable energy potential of geothermal energy in Ukraine is equivalent to 8,4 Mtoe, and its use can save around 10 bcm of natural gas. Currently, the development of geothermal energy is at an initial stage in Ukraine. Only low-temperature thermal waters are used mainly for recreational purposes in Transcarpathia and for heat supply in the Crimea. Therefore, it should be paid valuable attention to additional geothermal research and tools to stimulate the development of geothermal energy in Ukraine. The transition to clean and affordable energy sources will allow to build a new powerful economy, overcome socio-economic challenges, solve the problem of climate change, and also increase the safety and well-being of Ukrainians.

Key words: Geothermal energy, geothermal potential, geothermal resources, geothermal districts.

Introduction.

Geothermal energy in the world. Geothermal energy is the heat produced deep in the Earth's core. The geothermal energy is a renewable type of energy with the following advantages like baseload, domestic, small footprint and clean resources.

Wells, ranging from a few feet to several miles deep, can be drilled into underground reservoirs to tap steam and very hot water that can be brought to the

surface for use in a variety of applications, including direct use, heating and cooling, electricity generation.

Geothermal energy has been used on a large scale in more than 40 countries of the world for more than 50 years for direct use. Today, in more than 21 countries, heat energy is transformed into electricity.

Geothermal hot spots regions are in Asia Pacific, USA, North America, Europe, Latin America and middle and east Africa. Only 5% of geothermal potential is used world-wide from potential 318 GW [1].

a) California and Nevada in the United States;
b) El Salvador, Guatemala, Honduras and Nicaragua in Central America;
c) Chile and Peru on the westernmost extent of South America;
d) The Republic of the Democratic Republic of Congo (DRC), Eritrea, Ethiopia, and Kenya, on the East African Rift;
e) The Philippines in the western Pacific region in Southeast Asia; and
f) the Taupo Volcanic Zone of the North Island in New Zealand.

The total installed geothermal power generation capacity at year-end 2022 stood at 16,127 MW (Fig. 1).

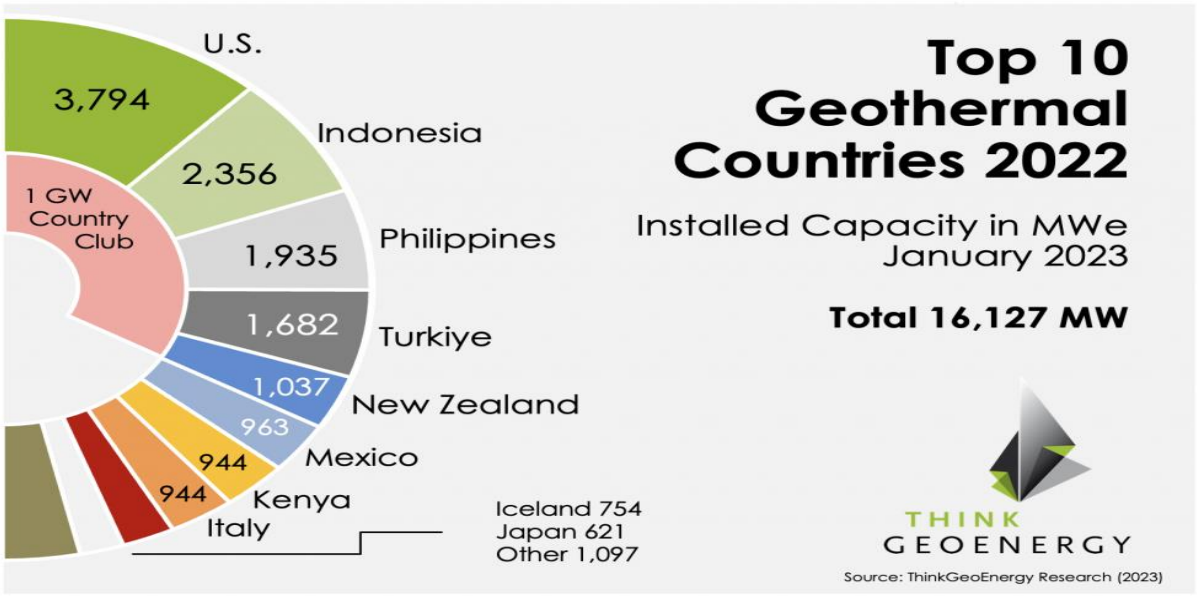


Fig. 1. Top 10 geothermal countries 2022 [1].

The 1 GW country Club united US, Indonesia, Philippines, Turkiy and New Zealand.

In this GEOTHERMAL POWER DATABASE [2] published by Iinternational Gepthermal Association, Ukraine is marked as geothermal energy can be direct use only (Fig. 2).

Fig. 2. Geothermal power database y in the world [2].

Geothermal resources in Ukraine. Geothermal energy in Ukraine have been studied since the mid-50s of the last century. Since then, numerous prospecting and exploration works for thermal waters have been carried out in certain regions of Ukraine, hundred geothermal wells were drilled, a lot of maps (maps of isotherms for depths from 500 to 12000 m, maps of promising territories for the use of geothermal resources) were created and geothermal resources were estimated.

The development of geothermal technologies for the exploitation of deep underground waters took place in the 80s and 90s. Since that and until now the geothermal development was not proceed due to lack of national support financing programs. Today it is necessary to resume the development of geothermal resources, as well as to provide more geothermal researches to ensure the energy security of Ukraine.

Ukraine has the potential for the development of geothermal energy, which is determined by the thermogeological features and specificities of its geothermal resources.

Geothermal resources of Ukraine consist, first of all, of thermal waters and the heat dry rocks. And they could be represented by the following types of sources:

- Shallow geothermal – the heat of the upper layers of the Earth up to a depth of 500 m, which is used with the help of heat pump installations;

- Thermal waters – the heat of deep underground thermal waters, which is used with the help of heat and electricity generating units;
- Deep geothermal – the heat of superheated "dry" rocks, which is used with the help of borehole heat exchangers or by creating artificial underground permeable collectors.

Geothermal resources include heated water resources from operating wells of oil and gas fields that are promising for industrial use. The reserves of thermal and superheated waters are formed and circulate at depths exceeding 1 km.

Ukraine has significant resources of geothermal energy. The total potential is estimated at $438*10^6$ kWhp/year, which was aprooved in the Program of state support for the development of non-traditional and renewable energy sources.

Annual technically achievable energy potential of geothermal energy in Ukraine is equivalent to 8,4 Mtoe, and its use can save around 10 bcm of natural gas.

The distribution of geothermal resources in Ukraine is primarily determined by the values of heat flow (Fig.3), formation which depends on geological age of the area and the activity of tectonic and magmatic processes.

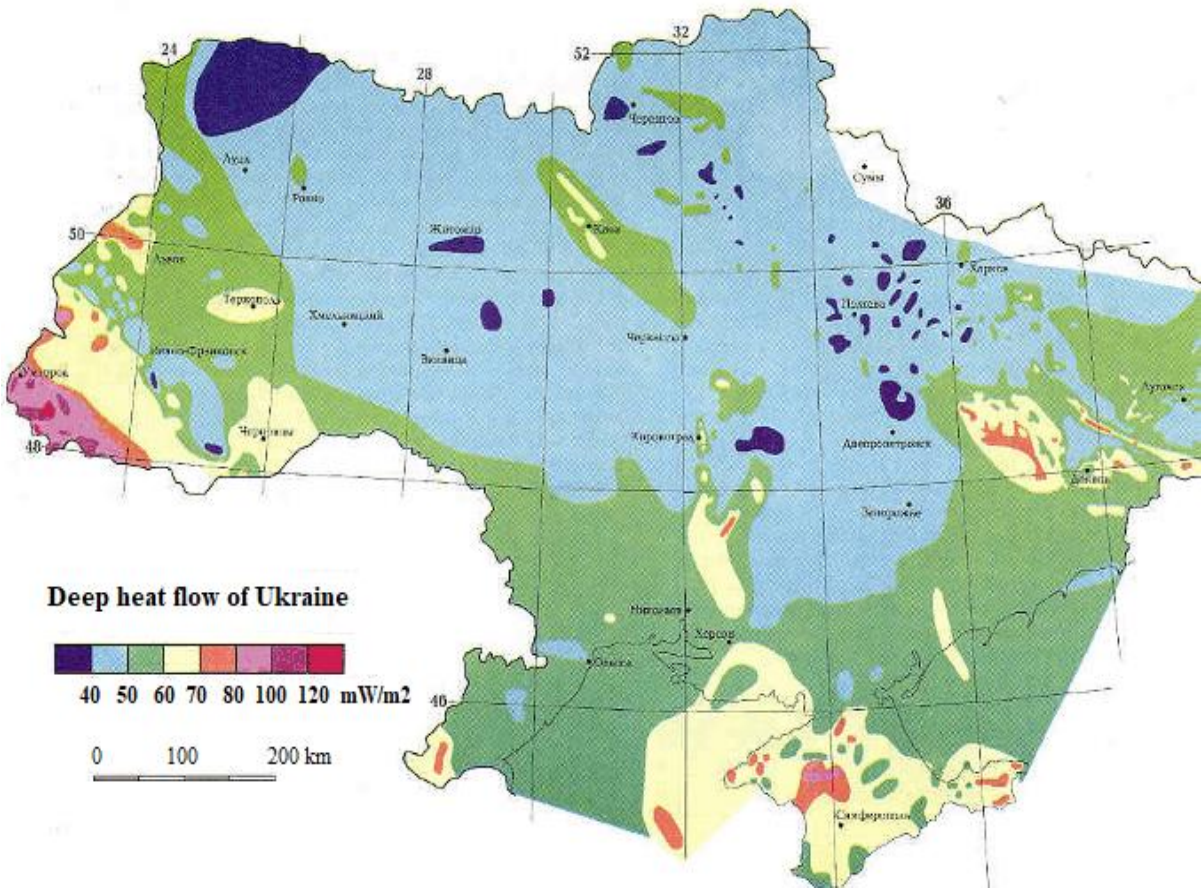


Fig. 3. Distribution of deep heat flux values on the territory of Ukraine, mW/m^2 [3, 10].

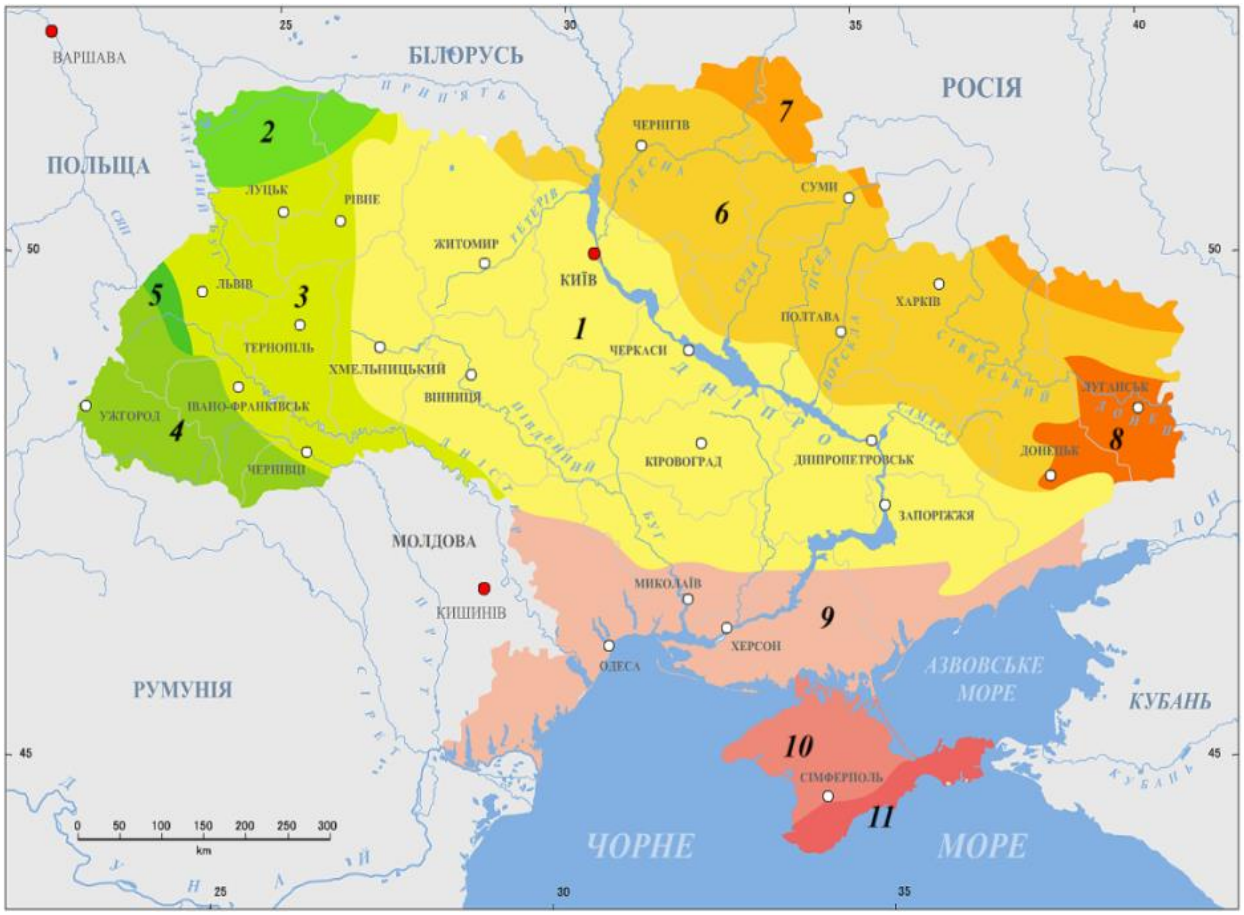


Fig. 4. Main tectonic structures of Ukraine [4].

1 – Ukrainian Crystalline Shield; 2 – Kovel's speech; 3 – Volyno-Podilsky plate; 4 – Carpathian fold and thrust belt (Transcarpathian, Carpathians Mountains and Precarpathian depression); 5 – Western European platform; 6 – Dnipro-Donets depression; 7 – Voronezh massif; 8 – Donets fold belt; 9 – Black Sea depression; 10 – Scythian plate (Steppe Crimea); 11 – Crimean fold and thrust belt (Crimean Mountains).

The most prospective geothermal regions are in the west, east and south Ukraine.

All these regions are confined to the following tectonic structures:

- Carpathian fold and thrust belt region in the west that consist of Transcarpathian, Carpathians Mountains and Precarpathian depression
- Dnipro-Donets depression and Donetsk folded region in the east
- Black Sea basin and Scythian plate in the south

According to the values of heat flow the Ukrainian territory is divided into three zones (Table 1).

Table 1.

The main characteristics of thermal flows

Zones	Heat flow	Geothermal gradient	Tectonic structures
Low thermal flow	22-60 mW/m^2	2°C/100m	Crimean and Carpathians Mountains
Intermediate values of heat flow	50-70 mW/m^2	do not exceed 3-3,5°C/100m	Steppe Crimea, Donets fold belt, Precarpathian region
Highest heat flows	Above 80 mW/m^2	7-8,4°C/100m	Transcarpathian depression, in the central part of the Crimean - Scythian plate (Steppe Crimea) and the Black Sea Coast

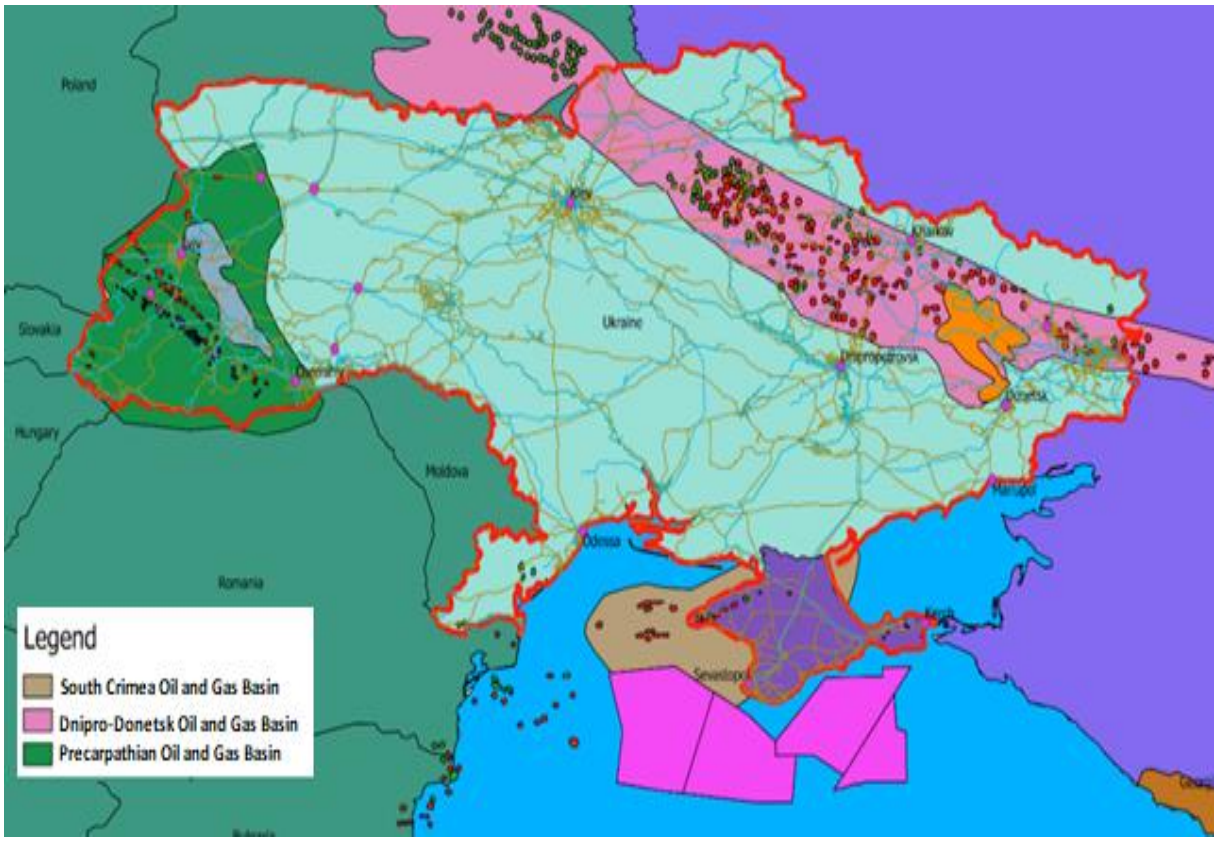


Fig. 5. Oil and gas-bearing regions in Ukraine.

The main prospective geothermal regions are confined to three oil and gas bearing basins of Ukraine (Fig.5):

1. In the west — Western Ukrainian region (consist of Volyn-Podilska, Precarpathian, Carpathian, Transcarpathian oil and gas provinces),

2. In the east — Dnipro-Donetsk oil and gas basin
3. in the south - South Crimea oil and gas basin.

The first estimation of geothermal resources in Ukraine was implemented in 1979. At the present time results of these calculations are officially accepted and approved by the State Commission of Ukraine on Mineral Resources reserves. Approved the cogeneration potential of geothermal water resources is **27,3 million m^3/day**, and their thermal power capacity at **351 million GJ/year**

According to geological-structural features the most promising for the development of geothermal energy in Ukraine regions are (Fig.6):

- **Transcarpathian and** Precarpathian depression **in the west**
- **Steppe Crimea and Black Sea Coast in the south**
  where, according to geological and geophysical data, rock temperatures at depths of up to 6 km reach 230-275C.
- **Dnipro-Donets depression** in the east.

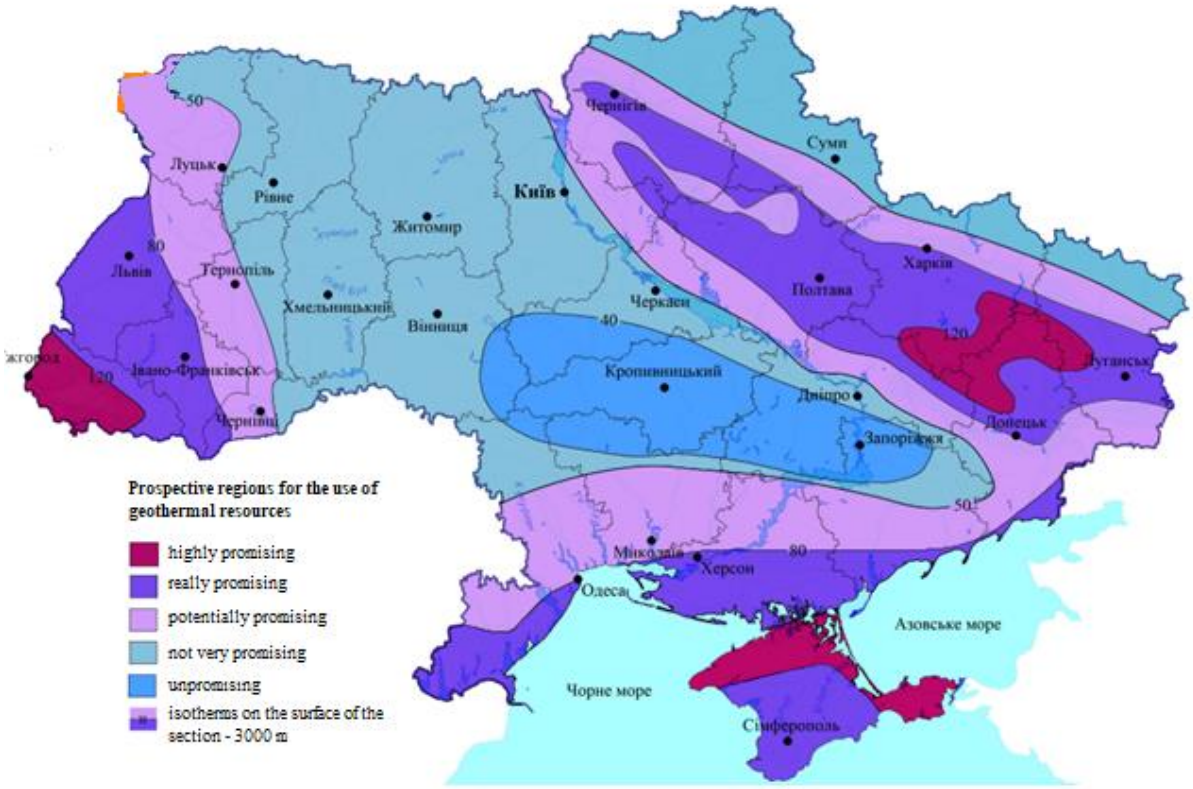


Fig.6. Prospective regions for the use of geothermal resources [9]
(Source – Institute of Renewable Energy at NAS, «Atlas of energy potential of renewable energy in Ukraine»)

The most promising and currently suitable for technical use source of geothermal energy in Ukraine is thermal water, the projected energy potential of which is presented in the Table 2 and, accordingly, on the Figure 7.

Table 2.

Geothermal resources of Ukraine [8].

	Region	**The amount of heat carrier extracted during operation with reservoir pressure support, thousand m^3/day**	**Heat potential of thermal waters, MW**
1	Transcarpathian	239.4	490
2	Mykolaiv	1620	2820
3	Odesa	1350	2350
4	Poltava	5.9	9.2
5	Sumy	4.2	15.8
6	Kharkiv	0.4	1.3
7	Kherson	2430	4230
8	Chernihiv	37.2	58.3
9	Crimea	21600	37600
	Total	**585.4**	**47574.6**

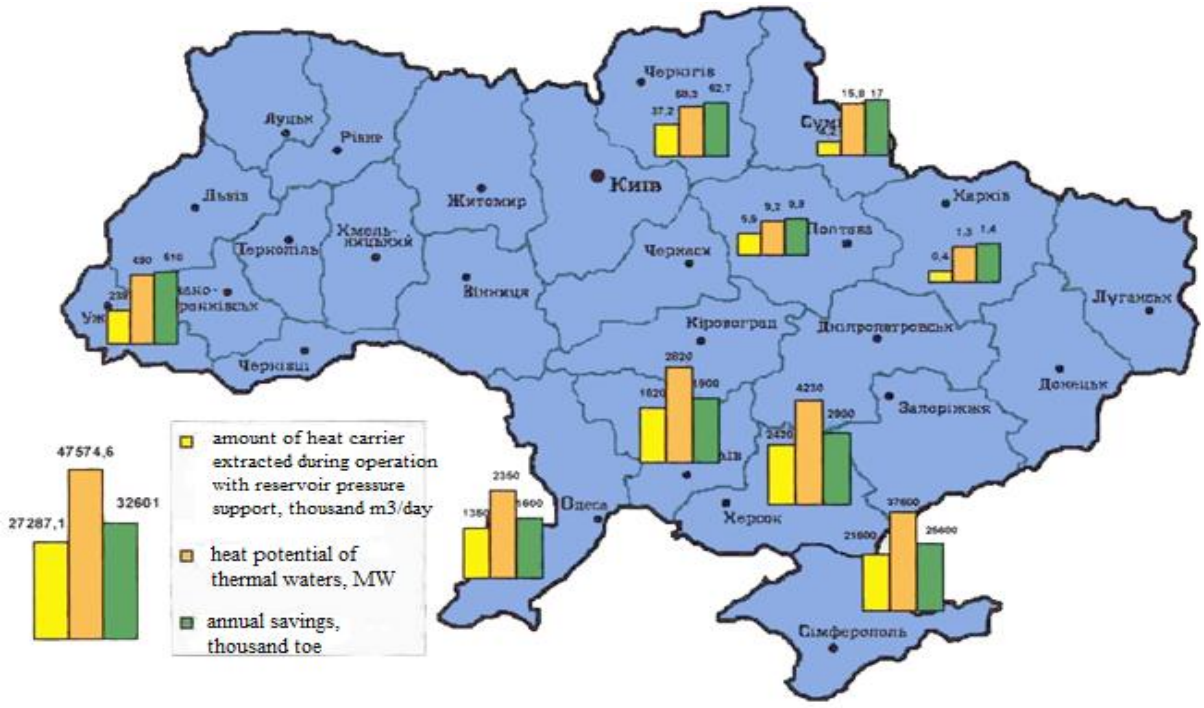


Fig. 7. The projected energy potential of thermal water [9].

Prospective regions for the use of geothermal resources. The first of the promising regions is the West Carpathian geothermal region, which is confined to the two tectonics zones – Transcarpathian and Precarpathian depressions (Fig.8).

The rock temperature of wells drilled in the Carpathians at a depth of 4 km reaches 210°C, and the temperatures of underground water (>150°C)

Its necessary for the effective functioning of geothermal power plants require much lower depths (from 1 to 1.5 km) than in other favorable for these places. The thermal waters of the Transcarpathian deposits are highly mineralized.

Transcarpathian depressions – geological structure was formed because of Neogene tectono-magmatic activation of the Internal Carpathians and is characterized by wide distribution of volcano-tectonic structures resulted from volcanic centres of that time.

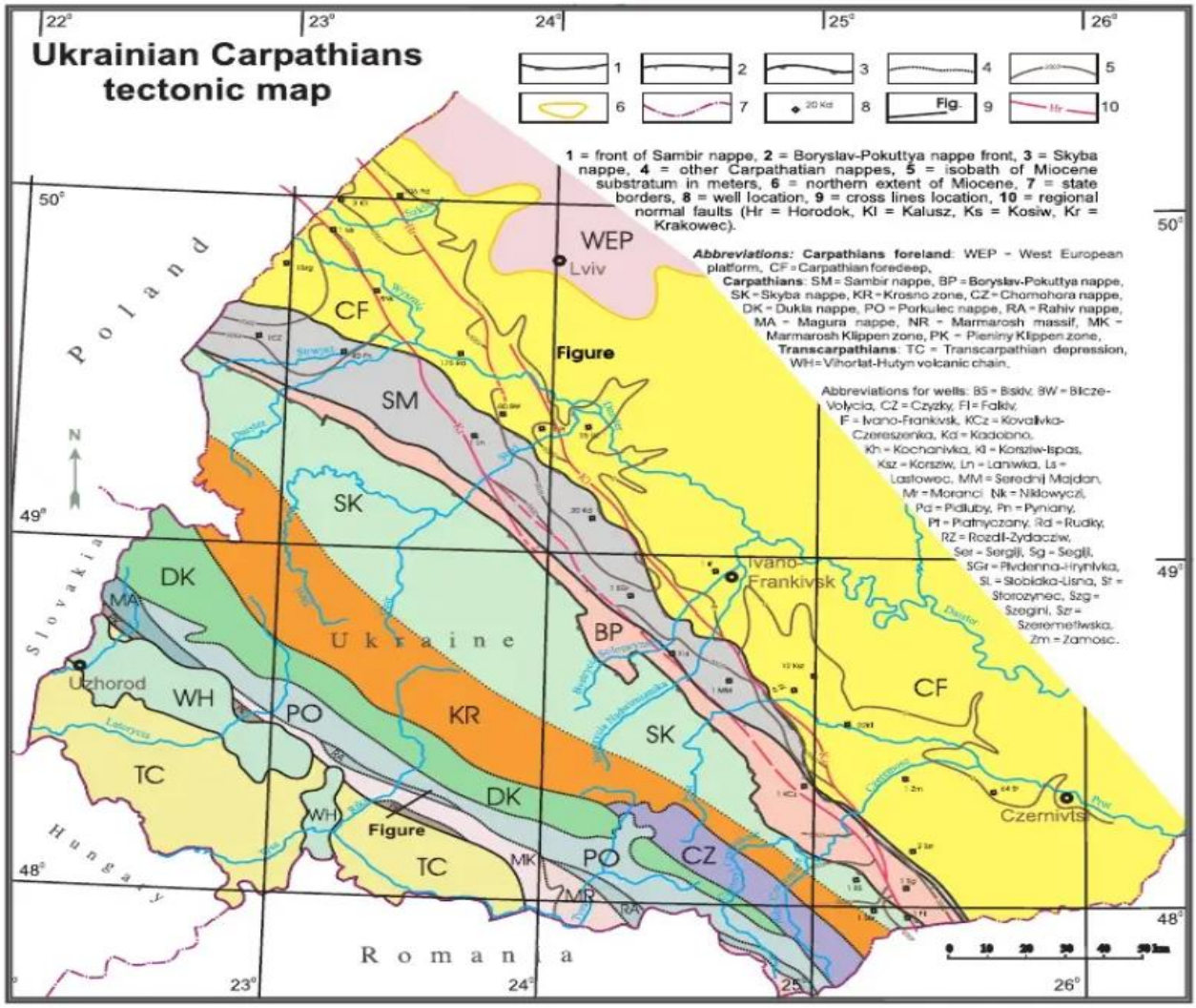


Fig. 8. Ukrainian Carpathian tectonic map [14].

In Transcarpathia near 30 deposits and manifestations of thermal waters and brines of various chemical compositions are known (Berehove, Kosyno, Zaluzzia, Tereblya, Velyatyn, Poladske etc.)

Currently, the use of only low-temperature thermal waters for recreational purposes is actively developing in Transcarpathia, and in the future it is advisable to use the available medium- and high-temperature thermal waters for energy.

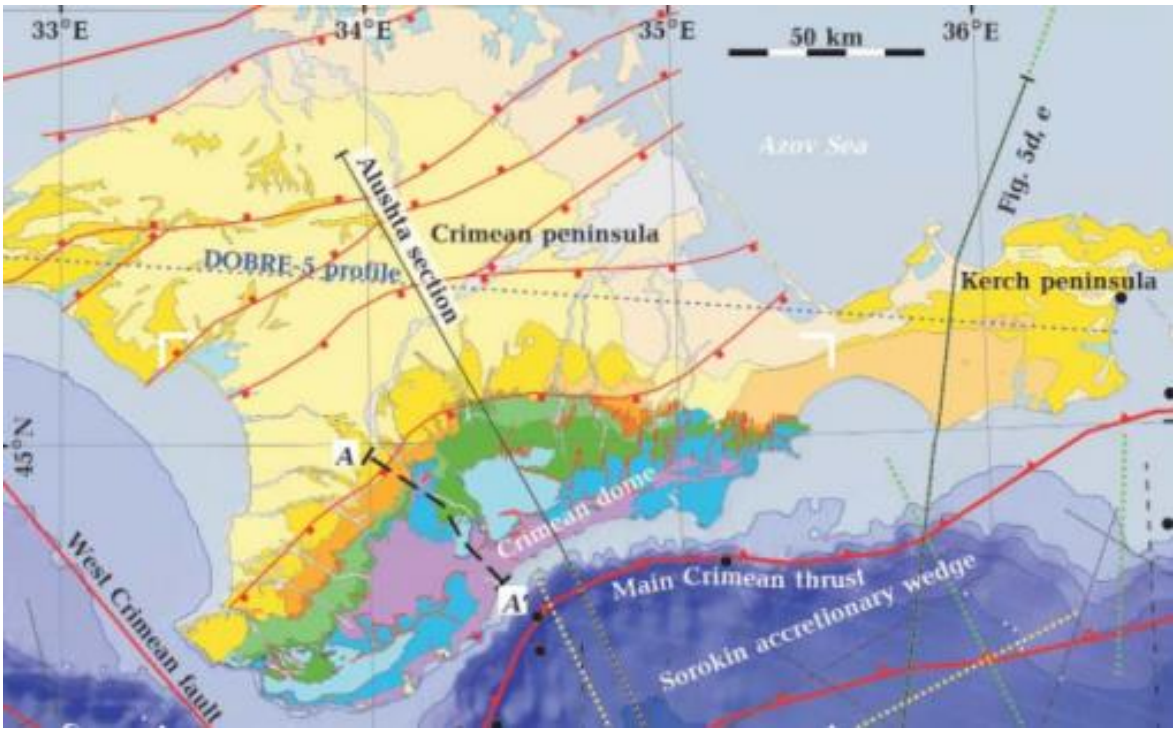
In Transcarpathia there is a unique place with an area of 30 km^2 in the area of the village Zaluzzia (Mukachevo region) with a dry rock isotherm of 200 °C at a depth of 4 km. These reserves are sufficient for the operation of several small geothermal power plants and greenhouse agro-industrial complexes.

The second tectonic zone within Carpathian region is **Precarpathian depressions –** is a young alpine region of crustal subsidence, which is located between the dislocated Carpathian folded structure and the Volyn-Podilsky plate.

The second promising region for the development of geothermal energy is the territory of the **Black Sea artesian basin whick coclude Steppe Crimea and Black Sea Coast** (Odessa and Kherson region)

The depths of the drilled wells in Crimea are small (up to 2 km), the temperature of the thermal waters at the mouth is 50-70°C, and their mineralization is 20-70 g/l.

Steppe Crimea is a flat plain connected to the Epihercynian Scythian platform. The surface is formed by marine Neogene and continental Quaternary sediments. The resources of the Kerch Peninsula are the most promising for the development of geothermal energy (Fig. 9).



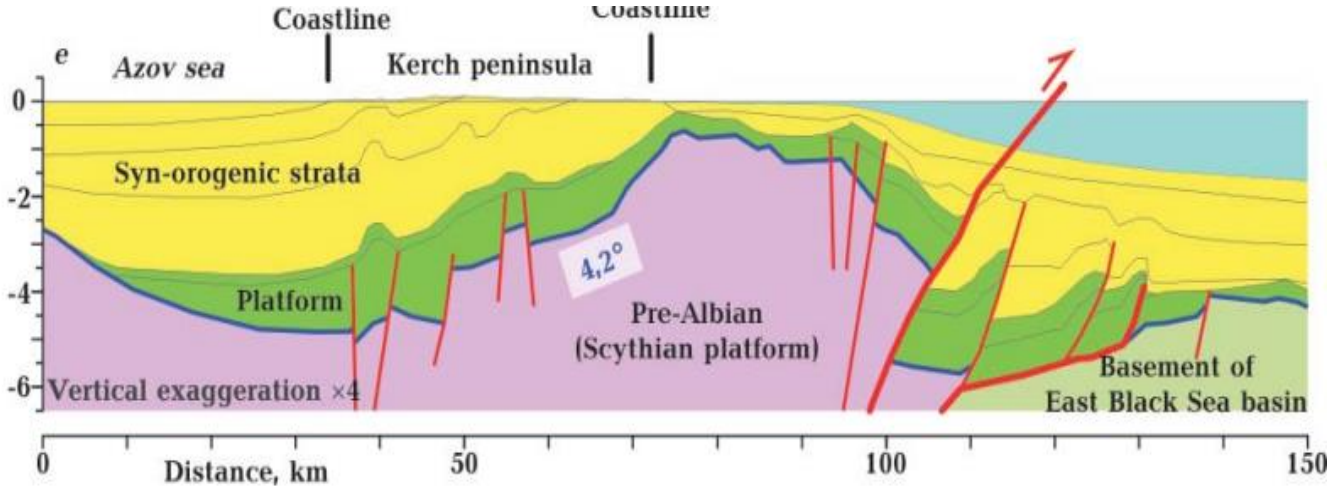


Fig. 9. Structural map of the Crimea and Cross-section through Kerch peninsula.

The geology of the Crimean peninsula records the interaction between the Eastern Black-Sea basin and the Scythian platform as the result of the Arabia-Eurasia collision.

Onshore, new biostratigraphic studies indicate the existence of at least two lithostratigraphical units comprising turbidites ("flysch"), formed in the Upper Triassic—Lower/Middle(?) Jurassic and the Upper Jurassic—Lower Cretaceous during continental margin and backarc rift formation, respectively.

Currently, low geothermal resources of Crimea are used mainly for **heat supply purposes**. Crimean thermal waters are used in the resorts of Saki and Yevpatoria, as well as in some settlements for baths and heating. The flow rates of individual wells here reach 2-4 thousand m3/day.

There are more than 50 thermal springs.

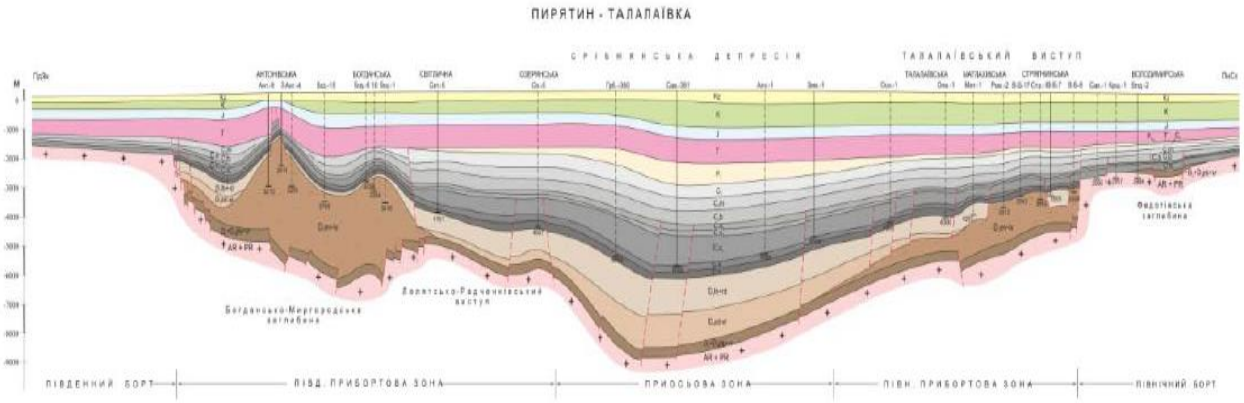


Fig. 10. Cross-section of the Dnipro-Donets depression [15].

Regarding to prospect use: Hundreds of wells were drilled that reached thermal waters and hot dry rocks and could be used to build power plants.

However, the temporary occupation of Crimea and the war in Ukraine brought stopped these activities.

The last Promising areas as concerns the central part of the Dnipro-Donets depression. Heat flows in this area vary from 70 to 90 mW/m^2, and geothermal gradients do not exceed 3- 3.5 °C/100 m.

Dnipro-Donets depression is a graben with a depth of 12 to 20 km and divided into 2 sourth and north sides.

In terms of lithology, the basin is mainly represented by terrigenous sediments. In addition, three salt-bearing strata are developed here. Its one of the most popular oil and gas basin in Ukraine.

In Dnipro-Donets depression prospect use of geothermal resources is related with deep geothermal, development and geothermal power plants building. A lot of assessment shows that on the basis of oil and gas wells it is possible to build geothermal power plants with a depth of drilling or opening of wells up to 3 – 4.5 km.

So, the main target of use of geothermal resources is the production of electricity.

Table 3.

Forecast resources of geothermal energy in the territory of Ukraine for the electric power industry

Deposits of regions	Drilling depth, km	Water temperature, °C	Deposit area, km2	Efficiency, %	Power of Geothermal power, thousands of MW
Transcarpathia	**3-6**	**210-250**	**50-130**	**1.7**	**5.8**
Precarpathia	**4-7**	**200**	**600**	**1.3**	**4.6**
Crimea	**4-7**	**200-220**	**300-500**	**3.1**	**10.5**
Eastern Ukrainian region	**5-7**	**185-217**	**660-2800**	**14.0**	**48.0**
Total					**70**

The most promising region for electricity supply is the eastern part of Ukraine, as there are thousands of abandoned oil and gas wells that can be repurposed for geothermal.

Key geothermal stakeholders in Ukraine.

There are a lot of Intitutes under the National Academy of Science of Ukraine working on the researches. In terms of decarbonizarion some state and private drilling companies try to change their policy and develop geothermal and of cause a big part in transition to clean and affordable renewable energy sources play public organization as well as Geothermal Ukraine to increase the safety and well-being of its citizens.

List of key geothermal stakeholders in Ukraine:

- Institute of Renewable Energy of NAS of Ukraine
- Institute of Geophysics NAS of Ukraine
- Institute of Geology and Geochemistry of Combustible Minerals of NAS of Ukraine
- Institute of Geological Sciences (IGS) of NAS of Ukraine
- Institute of Engineering Thermophysics of NAS of Ukraine
- State Agency on Energy Efficiency and Energy Saving of Ukraine
- NGO “Geothermal Ukraine” – R&D organization
- JSC Institute of Geology
- Subsidiary Enterprise of PRJSC NJSC Nadra Ukrainy Zahidukrgeologiya
- Naftogaz Group
- Drilling companies

All stakeholders need to combine their efforts with one aim – to contribute in geothermal energy development in Ukraine, establish cooperation with leading international geothermal organizations.

Legislative base of Geothermal Energy in Ukraine. In recent years, in legislative basis of Ukraine a lot has been done to regulate legal relations in the field of conservation, scientifically proven natural resource management, environmental protection, development of alternative and renewable energy sources, including, geothermal waters. There have been accepted Codex "On Subsoil" (from 27.07.94, № 132/94-VR), "Water Codex" (from 06.06.95, № 213/95-VR), the law "Of alternative energy sources" (from 20.02.03, № 555-IV) and others.

The classification of geothermal waters reserves, approved provisions for preparedness of geothermal deposits to commercial operation, defined procedure for conducting geological exploration works at geothermal deposits, set technical requirements for safe, reliable and economic operation of heat sources were brought up into accord to the international standards. The procedure for development of geothermal deposits, requirements for provision of special permits (licenses) is based on the Cabinet of Ministers of Ukraine № 615 of May 30, 2011 "On approval procedure for giving special permits for subsoil use".

Requirements forresearch on geothermal deposits, that are used to calculate their reserves and government calculation, are set on the basis of "Instructions of reserves classification and mineral resources of subsoil state fund to thermal power underground water deposits", which was approved by the Cabinet of Ministers of Ukraine from 21.06.07, №707/13971). In the field of standardization adopted state national standards of Ukraine: "Geothermal energy. Terms and definitions", "Geothermal energy. Geothermal heat stations" and "Geothermal energy. Geothermal power stations". Developer of standards – Institute of Renewable Energy, NASU [15].

But, despite all the achievements, Ukraine has to go through a difficult path to the adaptation of Ukrainian legislation to the EU.

CONCLUSIONS.

1. Ukraine is abundant in geothermal energy resources, but this type of renewable energy is grossly underestimated. According to estimates, about 90 billion kWh of geothermal energy can be extracted annually in Ukraine and replace 10 billion cubic meters of gas.
2. Ukraine is among the countries with medium-level geothermal gradients. Although, Ukraine has three promising regions in Transcarpathian, Crimea (south), and the Dnipro-Donetsk basin, exactly West Ukraine is the most promising region for the near future.
3. The most favorable conditions for the formation of geothermal resources are characterized by gas, gas condensate, and some oil fields. This applies particularly to depleted gas fields that are filled up with water during operation.
4. Hot underground water can be used for heating and for the production of electricity, depending on the temperature regime of underground sources. The widespread using of geothermal energy in western Ukraine is for balneological purposes. This will be extremely relevant for the physical rehabilitation of military and civilian residents of Ukraine who were wounded and maimed during the war.
5. It is possible that geothermal sources can be a potential environment for the extraction of critical raw materials (rare elements). Ukraine has more than 20 types of CRM.
6. Geothermal resources are important and promising in national energy production of Ukraine, and geothermal energy should become one of the leading branches of the country's heat and power industry in the near future.

REFERENCES

1. https://www.thinkgeoenergy.com/thinkgeoenergys-top-10-geothermal-countries-2022-power-generation-capacity-mw/
2. https://www.lovegeothermal.org/explore/our-databases/geothermal-power-database/#direct-uses-by-country
3. https://askjaenergydotcom.files.wordpress.com/2014/08/ukraine-geothermal-map-2004.gif
4. https://uk.wikipedia.org/wiki/%D0%A3%D0%BA%D1%80%D0%B0%D1%97%D0%BD%D1%81%D1%8C%D0%BA%D0%B8%D0%B9_%D0%BA%D1%80%D0%B8%D1%81%D1%82%D0%B0%D0%BB%D1%96%D1%87%D0%BD%D0%B8%D0%B9_%D1%89%D0%B8%D1%82
5. https://www.researchgate.net/publication/330933236_GEOTERMICESKIJ_ATLAS_UKRAINY
6. https://europeangeothermalcongress.eu/wp-content/uploads/2019/07/CUR-32-Ukraine.pdf
7. https://science.lpnu.ua/sites/default/files/journal-paper/2017/may/1987/geodynamika13201214.pdf
8. http://dspace.nbuv.gov.ua/bitstream/handle/123456789/109877/10-Dolinskiy.pdf?sequence=1
9. https://www.ive.org.ua/wp-content/uploads/atlas.pdf
10. https://askjaenergy.com/2014/08/26/iceland-and-ukraine-to-cooperate-on-energy-efficiency/
11. http://dspace.nbuv.gov.ua/bitstream/handle/123456789/59536/41-Lozyniak.pdf?sequence=1
12. http://dspace.nbuv.gov.ua/bitstream/handle/123456789/145415/02-Nakapelyukh.pdf?sequence=1
13. http://dspace.nbuv.gov.ua/bitstream/handle/123456789/59536/41-Lozyniak.pdf?sequence=1
14. https://www.researchgate.net/figure/Tectonic-map-of-the-Ukrainian-Carpathians-after-Andreyeva-Grigorovich-et-al-2008_fig1_307652655
15. https://orkustofnun.is/media/jardhiti/OS-2016-01.pdf

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ПОТЕНЦІАЛ РОЗВИТКУ ГЕОТЕРМАЛЬНИХ ДЖЕРЕЛ ЕНЕРГІЇ В УКРАЇНІ

Ця стаття є підсумком доповіді, яка була представлена в березні 2023 року під час українсько-іспанського циклу конференцій «Глобальне бачення української геології «Майбутнє геотермальної енергетики в Україні», організованого GEO3BCN-CSIC. Геотермальний потенціал України може відіграти ключову роль у прискоренні переходу до чистої енергії. Таким чином, у цій статті наведено детальну характеристику основних типів

геотермальних джерел в Україні, таких як мілководні геотермальні джерела, термальні води та глибоководні геотермальні джерела, які можна використовувати для прямого використання, централізованого опалення, а також виробництва електроенергії. Аналіз розподілу величин глибинного теплового потоку по території України, який коливається від 40 до понад 120 мВт/м^2, дає можливість виділити три головні перспективні зони, приурочені до основних нафтогазоносних регіонів, зокрема, Закарпатська (західна), Степовий Крим (південь) і Дніпровсько-Донецький басейн (схід). Загальний геотермальний потенціал України оцінюється в 438*106 кВт/год на рік. Річний технічно досяжний енергетичний потенціал геотермальної енергії в Україні еквівалентний 8,4 Mtoe, а його використання може заощадити близько 10 млрд кубометрів природного газу. В даний час розвиток геотермальної енергетики знаходиться на початковій стадії в Україні. Використовуються в основному лише низькотемпературні термальні води для рекреаційних цілей на Закарпатті та для теплопостачання в Криму. Тому слід приділити велику увагу додатковим дослідженням геотермальних джерел та засобів стимулювання розвитку геотермальної енергетики в Україні. Перехід на чисті та доступні джерела енергії дасть можливість побудувати нову потужну економіку, подолати соціально-економічні виклики, сприяти вирішенню проблеми зміни клімату, а також підвищить безпеку та добробут українців.

***Ключові слова*:** геотермальна енергія, геотермальний потенціал, геотермальні ресурси, геотермальні райони.

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