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Sources of renewable energy from Romania

Ionelia Panea
Faculty of Geology and Geophysics, University of Bucharest

Abstract: This paper explores Romania's diverse renewable energy resources—geothermal, wind, solar, and hydroelectric—and their role in reducing CO_2 emissions compared to fossil fuel-based energy. Romania's geothermal potential, with extensive resources in the west and Bucharest-Otopeni region, supports both heating and medicinal applications, with historical use dating back to the 19th century. Wind and solar energy have seen steady growth, though both are subject to intermittency; wind farms are strategically located to optimize performance, and solar installations are concentrated in the south for higher efficiency. Hydroelectric power, primarily generated by facilities on the Danube and other rivers, provides a consistent energy source, with landmark projects like Iron Gates enhancing national capacity. Together, these renewable sources position Romania for a sustainable energy future and demonstrate the potential for integrating various renewable systems within a national energy strategy.

Keywords: *Romania, Renewable Energy, Geothermal Energy, Wind Energy, Solar Power, Hydroelectricity*

The renewable energy is produced from non-fossile sources that regenerate naturally. Geothermal, hydroelectric, solar, wind, etc., energy are included in this category. Renewable energy sources are non-polluting for the environment, their use having very low CO_2 emissions. Currently, fossil fuels (coal, wood, gas, oil) are used to generate electricity and heat. At the international level, their share is the highest (Fig. 1). The main disadvantage of using fossil fuels is represented by the significant CO_2 emissions resulting from burning the fuels.

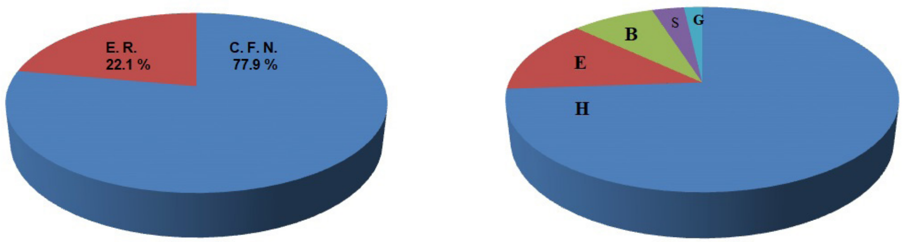

Fig. 1. *Percentages of renewable energies in the total of used energy (edited after Kannan and Vakeesan); E.R. – renewable energy, C.F.N – fossil and nuclear fuels, H – hydroelectrical (16,4%), E – wind (2,9%), B – biogas (1,8%), S – solar (0,7%), G – geothermal and oceanic (0,4%).*

Geothermal energy

This energy is obtained from the heat inside the Earth, heat originating from the formation of the Earth and from the slow radioactive decay of isotopes present in the crust and mantle at depths of km, tens and hundreds of km. The source of this energy is the thermal water, represented by warm water or hot water, in the form of steam. Waters with temperatures lower than 100°C are used for heating buildings (homes, offices), medicinal recovery in thermal baths, spas, heating of greenhouses. Waters with temperatures higher than 100°C are used to generate electricity.

Romania is part of the group of European countries with high geothermal potential. Italy is the first country in the world that used geothermal energy. The first geothermal generator which produces electricity was built in 1904 and is still active. The lifespan of geothermal plants varies between 80–100 years. In Romania, the thermal waters of the Herculaneum and Cozia-Calimanesti areas have been used since the time of the Roman Empire.[1] The first geothermal well was drilled in 1885 at Felix spa, near Oradea, and it is still in use.[2] Its depth is 51 m. The water temperature is 49°C. During 1893–1902, thermal wells were drilled at Caciulata, Oradea and Timisoara. The water temperatures are the well-head were 37°C, 29°C și 31°C.

Most of the geothermal structures were discovered during the drillings performed for hydrocarbon exploration. Important structures were identified along the western border of Romania (Satu Mare, Oradea, Beius, Arad, Timisoara) and in south (Oropeni-Bucuresti). The thermal waters are confined in sandy and/or calcareous formations, depending on the depth at which they

1 Rosca, 2011.

2 Roșca et al., 2016.

are intercepted and depending on the tectonic unit of which the geothermal structure is a part. These waters occur artesian at the soil surface (natural springs) or are extracted from the underground using different technologies.

Natural springs of thermal waters have been observed in different areas from Romania. A detailed description of these springs is presented in Slăvoacă et al. (1978).[3]

The Baia Mare area is known for the intense mining activity performed until the 90s. Waters with temperatures between 19°-45°C appeared naturally in drilling and mining works.

The Felix-1 Mai structure produces in artesian bicarbonated thermal waters with temperatures of 20°-35°C. Temperatures of 49°C were measured at depths of 40–100 m.

Waters with temperatures between 15°-25°C emerged naturally in the Beius and Zarand basins. These waters are contained in carbonate formations with Triassic, Jurassic or Cretaceous ages and in permeable Neogene (sedimentary and eruptive) formations.

In the area of the Gurghiu-Harghita massifs, there are three alignments where natural water springs with temperatures between 16°-29°C have been observed. The towns considered benchmarks for these alignments are Toplita, Praid and Tusnad.

In the Streiului basin, the thermal springs in the Calan area have temperatures between 19°-23°C. Higher temperatures were measured on water samples from the Cerna graben area. The maximum value was 53°C. These waters are accummulated in Jurassic carbonate deposits and in the Cerna granite.

Geothermal structures contain waters that come from[4]:

- infiltrations in fractured carbonate formations from the subsurface – Mesozoic limestones that outcrop in the Padurea Craiului Mountains;
- infiltrations in Miocene saline deposits – areas of the Eastern Carpathians and the Getic Depression;
- mixture of infiltrations from the surface of the soil and from the basement – baile Herculane, Geoagiu, etc.

The temperature measurements carried out in the boreholes allowed the construction of a map at the scale of Romania showing the distribution of

3 Slăvoacă et al. 1978.

4 Preda and Țenu, 1981.

temperatures at a depth of 3 km (Fig. 2). On this map it is easy to identify the areas with high temperatures, areas that correspond to the locations of major geothermal structures known or in operation. (Fig. 3).

București-Otopeni geothermal structure

The thermal waters have been used since the 80s, when the Foradex company executed the first drillings. The first thermal bath was established within the company yard. The exploited structure has an area of approx. 300 km^2. The waters are extracted from fissured limestone and dolomites of Malm-Aptian ages.[5]

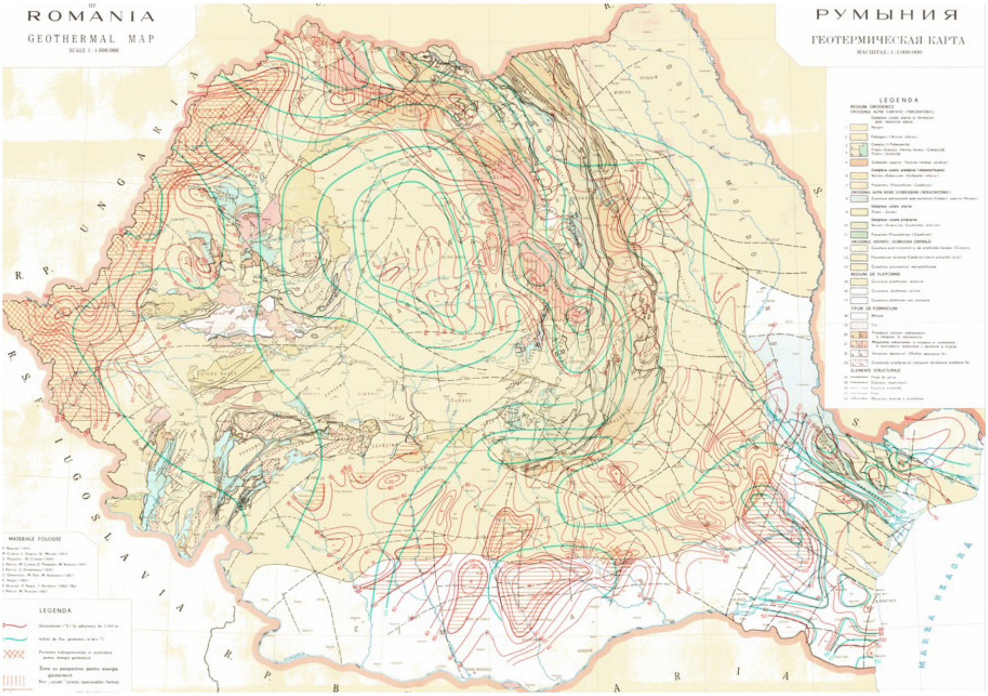

Fig. 2. *Map of Romania showing the distribution of temperatures at a depth of 3 km (red) and of heat flow (green). Black lines – fractures, double hatch – perimeters unders exploitation, hatch – perimeters with dry rocks, hot. Scale 1:1.000.000. Source of the map – IGR (Negoiță, 1970; Cristian et al., 1971; Paraschiv and Cristian, 1976; Veliciu et al., 1977; Veliciu and Demetrescu, 1979; Demetrescu et al., 1981a,b; Neguț, 1982;Veliciu and Visarion, 1984).*

5 Roșca et al., 2016.

Fig. 3. *The main geothermal structures from Romania (from Cohut and Bendea, 2000; Roşca et al., 2016).*

The temperatures of the used waters vary between 58°C (Băneasa) and 95°C (Gruiu). Over 20 wells have been drilled on this structure, of which only 18 produce geothermal water with flow rates between 22–35 liters/second. The first identified reservoir is developed in the depth range of 2000–3200 m.[6] Chemical analyzes carried out on water samples show a high concentration of sulfuric acid, for this reason their use requires a treatment in order to eliminate the corrosive nature of the thermal waters. The main use of these waters is for heating buildings and therapeutic recovery. The second geothermal reservoir was intercepted by drilling between the depths of 800–1000 m. The temperature of the water at the well head is 40°C.

Cozia-Căciulata-Călimăneşti geothermal structure

The structure has an area of approx. 10 km^2 and produces artesian waters stored in fissured sandstones of the Senonian age.[7] The reservoir was intercepted by 4 wells between the depths of 2700–3250 m. The water temperature at well head varies between 70–95°C. Thermal waters are used for space heating, spa and medical recovery.

Oradea geothermal structure

Its area is about 75 km^2. The reservoir is developed in the depth range of 2200–3200 m. The thermal waters are extracted from the fractured limestone and dolomites of Triassic age using 14 wells.[8] The water temperatures at well

6 Roşca et al., 2016.
7 Roşca et al., 2016.
8 Roşca et al., 2016.

head vary between 70°–105°C. Hydrogeological studies have shown that the reservoir is connected to the one intercepted by the Felix Spa well. The age of waters is about 20000 de ani. The sources of these waters are located in the northern part of the Pădurea Craiului mountains and in the Borod basin. Reinjection of water into the subsurface is a procedure used since the 90s in order to avoid lowering the water pressure in the reservoir.

Located near Oradea, the reservoir in the Bors area has a surface of about 12 km². The temperature of the water in the reservoir exceeds 130°C at a depth of 2500 m. The reinjection of cold water in the subsurface ensured the artesian production of the wells for years. The waters are used for heating (greenhouses, buildings).

Beiuș geothermal structure

The city of Beiuș uses the thermal waters extracted from this structure for the heating system; it is the only city from Romania fully heated with thermal water. The surface of the structure is 47 km². The reservoir is developed between depths of 1870–2370 m, in fractured Triassic limestons and dolomites.[9] The first well was drilled in 1996 at a depth of 2576 m. The water temperature at well head is 83°C. Similar temperatures were measured for waters drawn from other wells dug later. Reinjection is used to ensure the required pressure in the reservoir.

Ciumeghiu geothermal structure

This structure is located 50 km south of Oradea. The waters are confined in the Pannonian sandstones. The temperatures of these waters at the well head exceed 100°C. The water is used for heating homes and greenhouses.

Arad-Timișoara geothermal structure

The thermal waters are concentrated in Pannonian sandstone formations. The measured temperatures show values of 85°–90°C at depths of approx. 1800 m and at the well head, values of 40°–80°C. These waters are used to heat homes in the cities of Lovrin, Timișoara, Tomnatec, Sânnicolaul Mare and Saravale.[10]

Satu Mare geothermal structure

The reservoirs are developed at depths greater than 1000 m in Pannonian formations. The water temperature exceeds 50°C. Thermal waters are mainly used for spa and medical recovery.

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9 Roșca et al., 2016.

10 Antal, 2008.

Evaluation of geothermal potential

Most of the reservoirs with thermal water known or under exploitation were accidentally intercepted during exploratory drilling for hydrocarbons. Drilling to assess the geothermal potential of an area requires significant funds. In addition, lithology and fluid content information is obtained onl along the well with extrapolation of data in its immediate vicinity.

Geophysical measurements performed using seismic and magnetotelluric methods allow obtaining accurate information about the geological structure and fluid content of the subsurface over a much larger area. The integrated interpretation of geophysical, geological and hydrogeological data helps to build structural and tectonic models, distribution models of geophysical parameters useful in the identification of thermal water-bearing strata.

The first multidisciplinary research project for the evaluation of the geothermal potential in the northwestern part of Romania, the Baia Mare area, was carried out in the period 2020–2024; the Geysir Baia Mare project was realized with funds from Norway grants. The objectives of the project were to obtain information about the architecture of the Neogene sedimentary deposits, the presence of fluids, to map the possible fractures and/or open fracture systems that represent pathways for the movement of thermal water to the surface.

The activities proposed to achieve the objectives and to be performed during the project were the following:

a) collection of geological information and recording of geophysical data: surface geological and hydrogeological mapping, recording of active and passive seismic data, magnetic and magnetotelluric data;
b) geophysical data processing;
c) structural, hydrogeological and geothermal modeling (2D and 3D);
d) integrated interpretation of geological, hydrogeological and geophysical data.

Seismic measurements using the active method provided the most important information needed to achieve the project's objectives. These measurements were performed along two lines with a total length of 32 km (L1 and L2 in Fig. 4).

The generation of seismic waves was performed using explosives detonated in boreholes drilled at distances of approx. 100 m; 2 kg of dynamite was used for an individual well of 8 m depth and 1 kg/well of 5 m depth for groups of two wells. The seismic energy was generated in 133 points along the line L1 and 188 points along the line L2; the spacing between shot points was approx. 100 m. The recording of seismic waves was performed using fixed spread of receivers spaced at approx. 12.5 m; 1045 receivers were used for the line L1 and 1411 for the line L2.

Examples of raw seimograms are displayed in Fig. 5. The signal useful for data processing is represented by the reflected waves (UR in Fig. 5). These waves are reflected toward soil surface from limits between layers with different acoustic impedances. The amplitude of reflected waves is high if the contrast in acoustic impedance is great.

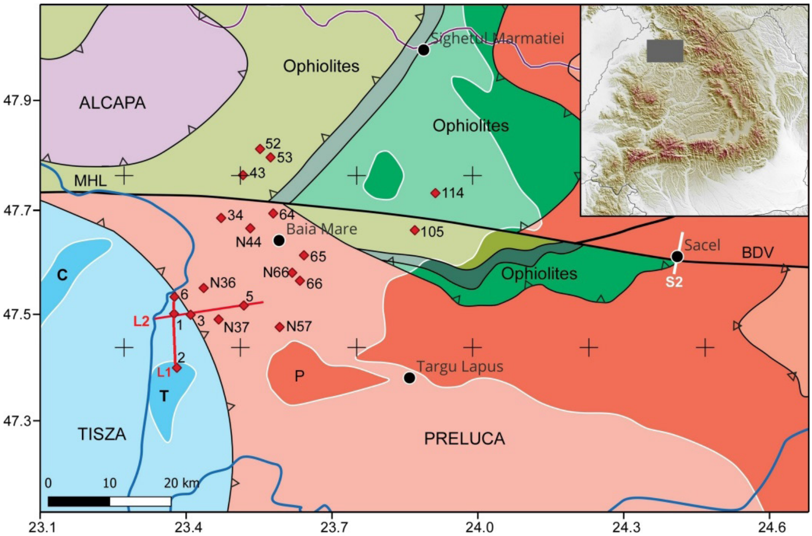

Fig. 4. *Tectonic map of the study area with indication of seismic lines (L1, L2) and magnetotelluric measurements points (red dots); C, P and T – Codru, Preluca and Ticau crystaline islands, BDV – fault Bogdan-Dragoș-Vodă, MHL – Mid-Hungarian Line. Source of the map – Schmid et al. (2020). Inset – topographic map of Romania with indication of the study area (grey rectangle). Source of the topographic map – https://www.gebco.net/data_and_products/gridded_bathymetry_data/gebco_2020.*

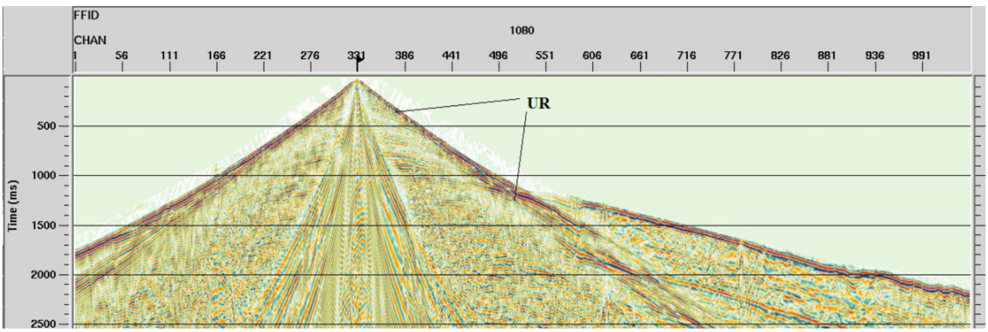

Fig. 5a. *Raw seismogram recorded along the line L1; UR – reflected wave.*

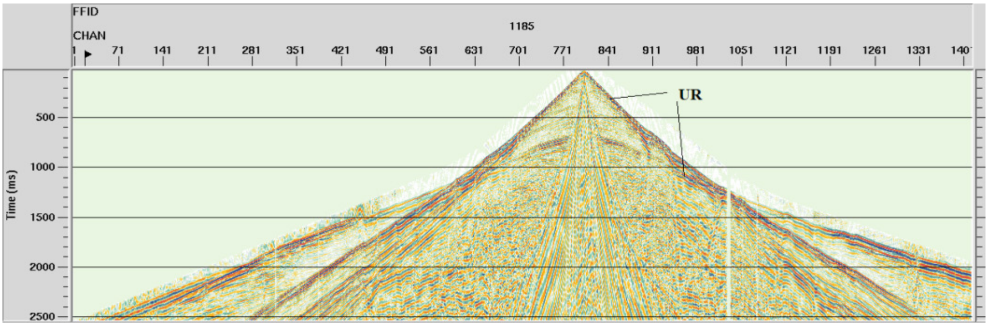

Fig. 5b. *Raw seismogram recorded along the line L2; UR – reflected wave.*

The results of data processing are represented by the time and depth-converted seismic sections from Fig. 6. The orizontal and dipping events (reflections) image the limits between sedimentary layers. Such events are observed on the seismic section from Fig. 6a until distances of approx. 10 km and two-way traveltimes of 1.5–0.25 s. Their shape indicate the presence of sedimentary deposits with decreasing thickness from north to south (Fig. 7a). Their ages were assigned using information from existing publications.[11]

Taking into account that the geothermal gradient varies between 4.5°–5°C / 100 m, it is possible to find thermal waters into subsurface toward the northern end of the line L1. These waters can come from underground acquifers or cold water injections through boreholes.

The reflections seen on the seismic section along the line L2 have much less continuity compared to those on the L1 seismic section (Fig. 6b).

The presence of a fault system between the distances of 6–9 km from the line L2 is indicated by the significant decrease in the amplitude of the reflections up to times of 1 s and the strong deformation of the high-amplitude reflections interpreted at times of 0.9–1.25 s (Fig. 7b).

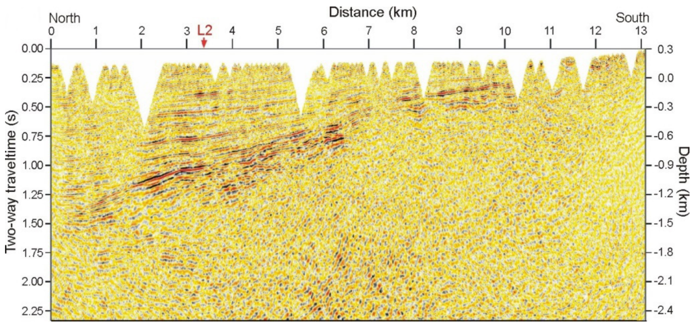

Fig. 6a. *Seismic section along the line L1 (Panea et al., 2023).*

11 Rusu et al., 1983; Săndulescu, 1984; Săndulescu et al., 1993; Tischler et al., 2007.

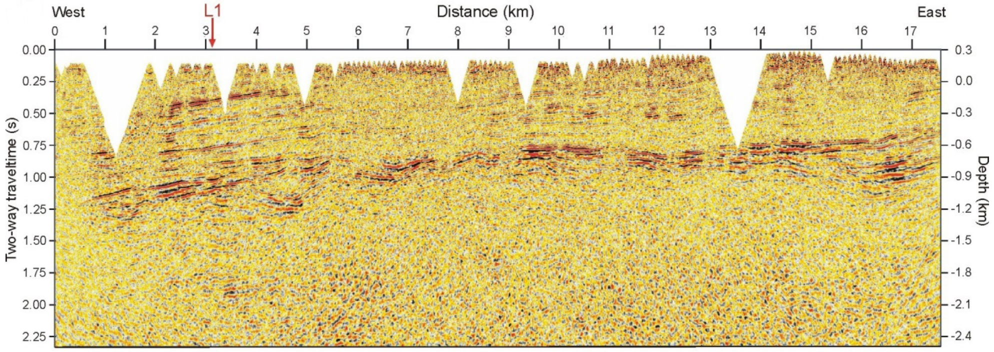

Fig. 6b. *Seismic section along the line L2 (Panea et al., 2023).*

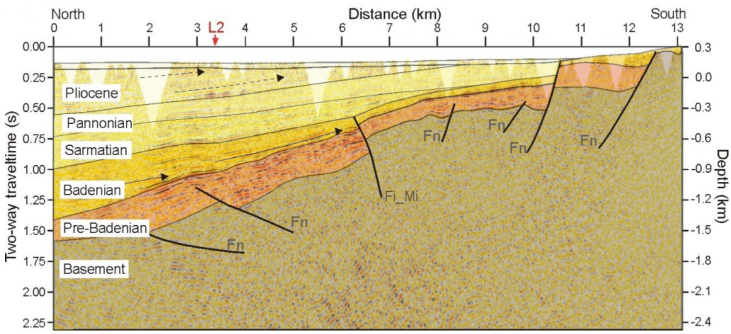

Fig. 7a. *Interpreted seismic section along the line L1 (Panea et al., 2023).*

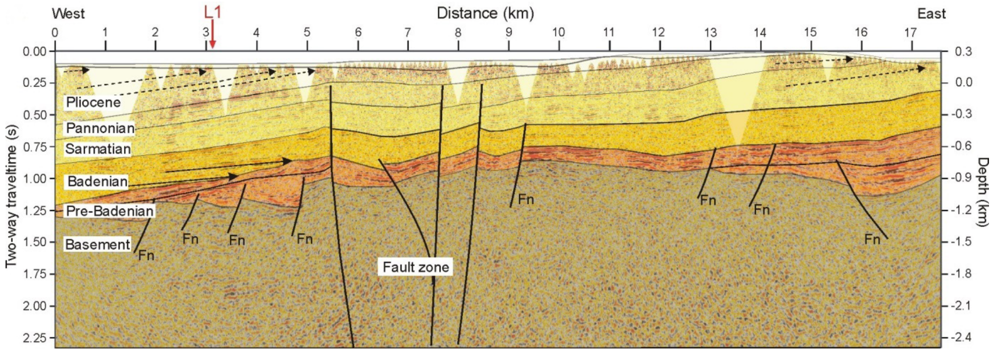

Fig. 7b. *Interpreted seismic section along the line L2 (Panea et al., 2023).*

Wind energy

Man has been using this type of energy for thousands of years. In the past, windmills were built for grinding grain and pumping water from underground. The Netherlands is the country known as the "land of windmills". The use of wind energy depends on the climatic conditions. The power drawn from the wind is directly controlled by wind speed and air density; the wind speed must not drop below 4 m/s. For this reason, wind turbines are considered intermittent sources of energy. They do not produce electricity if the wind speed falls below 4 m/s.

Classification of wind turbines according to Viișoreanu, 2022:

a) blade diameter: low power (12 m), medium power (12–45 m), high power (46 m).
b) electric power supplied: low power (< 100 kW), high power (> 100 kW).

The largest wind farms are built in Dobrogea (Fig. 8).

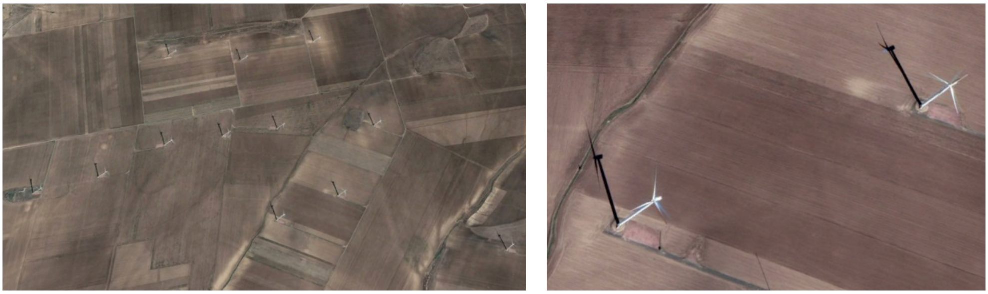

Fig. 8. *(left) Windmill park in Dobrogea. (right) detailed image of windmill park; (sursa imaginii: https://earth.google.com).*

Wind turbines are placed at distances chosen so that they do not influence the flow fields of the winds. Their design requires geotechnical studies to investigate foundation conditions.[12] Informations about the subsurface geological structure and the fluid content are obtained using geophysical measurements and boreholes.

Research geophysical program for the designing of windmill parks

The main geophysical measurements included in this program are based on the seismic and electrical methods. *Seismic measurements* provide information about the architecture of the underground deposits (sedimentary, metamorphic), the presence of faults or system of faults and the fluid content. The seismic energy is generated using a hammer of 10 kg. Next, the seismic waves are recorded using receivers connected or not by cables. The seismograms obtained after the data acquisition campaign are processed in order to obtain depth-converted seismic sections, velocity distributions for longitudinal and shear waves. Integrated interpretation of the processing results helps to build

12 Tomlinson, 1995; Day, 2005.

a structural model for the first tens of meters below the ground surface and to identify acquifers.

This type of seismic measurements were performed in 2017 in the Sacel area, Maramures county, in a research project with funds from the Society of Exploration Geophysicists (SEG-USA). Students from the Faculty of Geology and Geophysics from the University of Bucharest participated in the recording and processing of seismic data. Examples of raw seismograms are displayed in Fig. 9. The seismic dataset was processed to obtain a depth-converted seismic section that provides information on the geological structure in the subsurface (Fig. 10). Velocity distributions for the longitudinal and shear waves were obtained after the processing of the head and surface waves (Fig. 11).

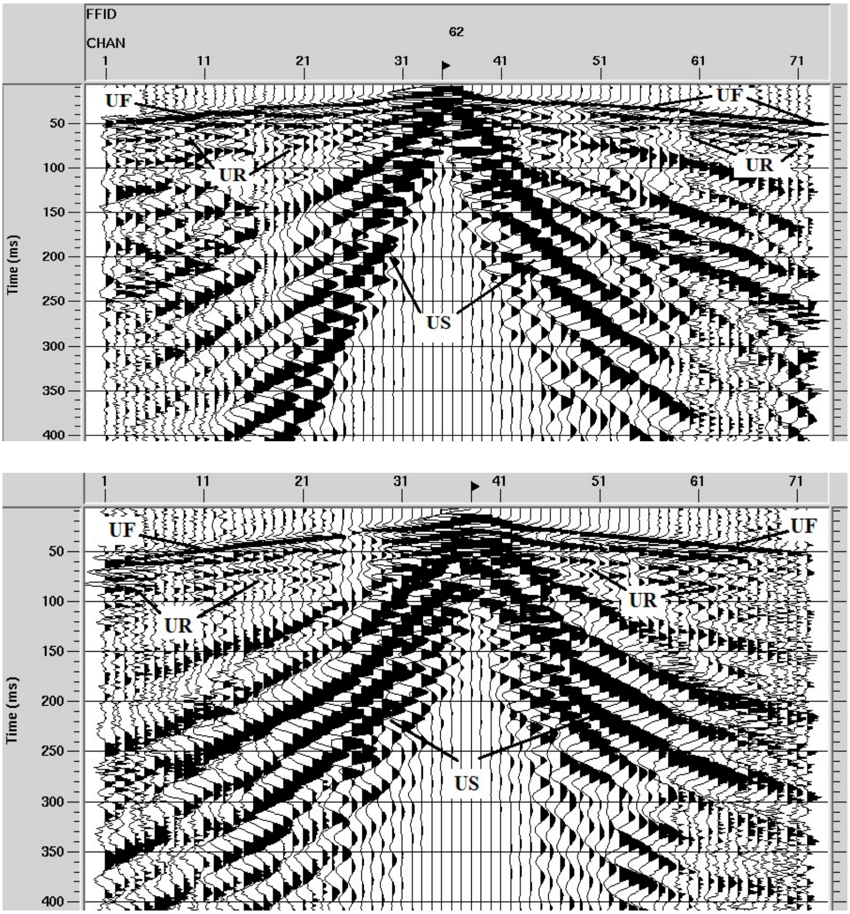

Fig. 9. *Raw seismograms with reflected waves (UR), head waves (UF) and surface waves (US).*

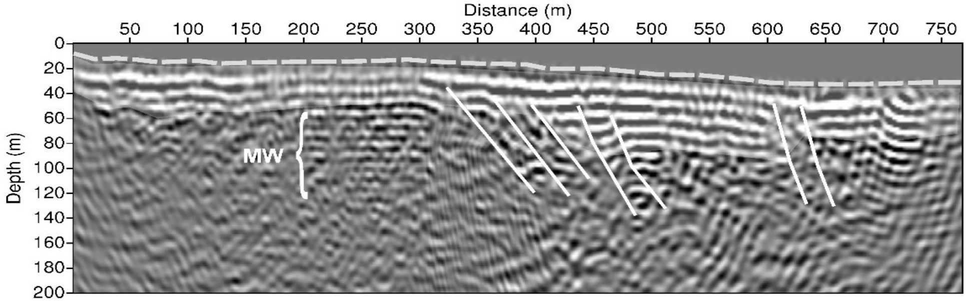

Fig. 10. *Interpreted seismic section; white area – sedimentary formations, white lines – fractures, MW – multiples (Panea, 2019).*

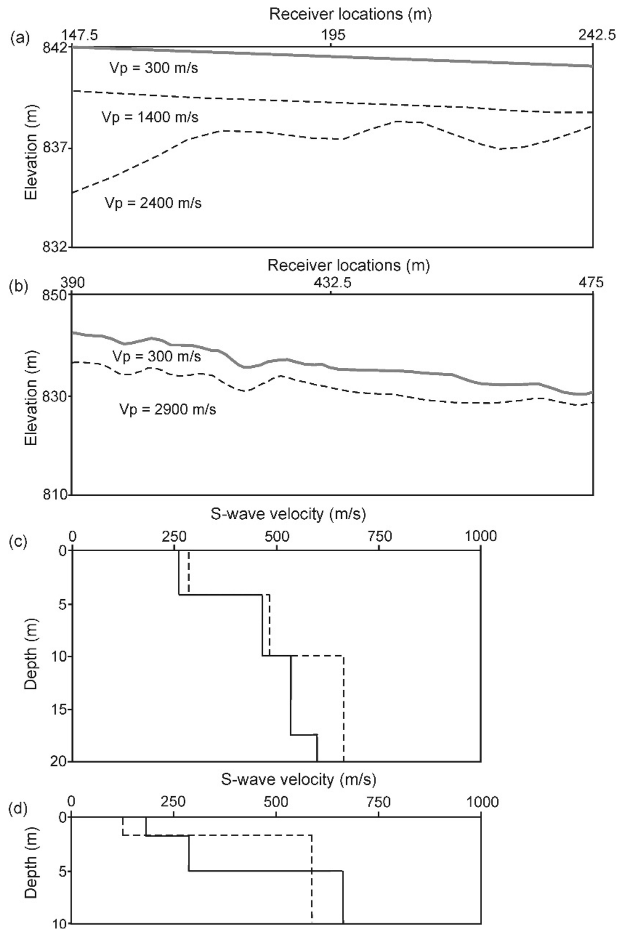

Fig. 11. *Velocity distributions for the longitudinal waves (a,b) and the shear waves (c,d) obtained after the processing of head and surface waves (Panea, 2019).*

Solar energy

The energy is emitted by the Sun, it is a renewable and inexhaustible energy. Electricity is generated with the photovoltaic cells and solar thermal plants. Photovoltaic cells produce electricity directly through silicon cells. The amount of electricity generated is influenced by the time of day and the climate. For this reason, solar energy is considered an intermittent energy source. The largest photovoltaic park in Romania that produces electricity was built in the southern part of the country (Fig. 12). Built on a smaller scale, solar panels can be mounted on buildings to provide hot water and/or electricity.

Fig. 12. *Photovoltaic park from the southern part of Romania (source: https://earth.google.com).*

Hydroelectric power

This type of renewable energy is produced by the controlled movement of water that drives a turbine located inside a hydroelectric plant. In Romania, hydroelectric plants were built on rivers that have a relatively constant flow and on the Danube.

The power plants at the Iron Gates I and II were built on the Danube (Fig. 13). They were designed and built in collaboration with the former Yugoslavia, Iron Gates I in 1964 and II in 1977. Large and small power plants were built on the rivers (Jiu, Arges, Olt). The Vidraru power plant on the Arges river is schematicall constituted by a concrete arch dam and a reservoir (Fig. 13). The dam has a hight of 166.6 m and a crown length of 307 m. it was inaugurated in 1966, being at that time the 5th in Europe and the 9th in the world.

Fig. 13. *(left) Iron Gate I and (right) Vidraru dam; source – personal archive.*

References

Antal, C., 2008. *Potențialul geotermal din România*, Universitatea Oradea.

Cohut, I., Bendea, C., 2000. "Romania update report for 1995–1999," in *Proceedings of the World Geothermal Congres 2000, Kyushu-Tohoku*, Japan.

Cristian, M., Dogaru, L., Mocuța, Șt., 1971. "Considerațiuni asupra regimului termic al sondelor de mare adâncime din R.S.R.," *Revista Petrol și Gaze*, vol. 9, pp. 522–527.

Day, R.W., 2005. *Foundation Engineering Handbook*, The McGraw-Hill Professional Publishing, p. 995.

Demetrescu, C., Ene, M., Andreescu, M., 1981a. "Geothermal profile in the Central Moesian Platform," *Studii și Cercetări de Fiziologie*, vol. 33, pp. 1015–1021.

Demetrescu, C., Ene, M., Andreescu, M., 1981b. "On the geothermal regime of Transylvanian Depression," *St. Cerc. Geol., Geofiz., Geogr.*, Geofizica, vol. 19, pp. 61–71.

Kannan, N., Vakeesan, D., 2016. "Solar energy for future world: – A review," *Renewable and Sustainable Energy Reviews*, vol. 62, pp. 1092–1105.

Negoiță, V., 1970. *Component parts of the World Heat Flow Data Collection (dataset).* PANGAEA, https://doi.org/10.1594/PANGAEA.808071.

Neguț, A., 1982. "Implications of thermal field structure in Muntenia and Oltenia," *Studii și cercetări de geofizică*, Universitatea din București.

Panea, I., 2019. "Physical properties and structure of the near subsurface in the Săcel area, Romania, from shallow seismic measurements," *Journal of Environmental and Engineering Geophysics*, vol. 24(1), pp. 151–158.

Panea, I., Munteanu, I., Găină, C., Mocanu, V., Roban, R.D., Bouaru, C.F., and

Geysir-Baia Mare working group, 2023. "Miocene tectonic activity at the boundary between NE Pannonian and NW Transylvanian basins (Romania): Insight from new seismic data," *Terra Nova*, vol. 35, pp. 542–551.

Paraschiv, D., Cristian, M., 1976. "Cu privire la regimul geotermic al unităților structurale de interes pentru hidrocarburi din România," *Stud. Cerc. Geol. Geof. Geogr*., Geofizica, vol. 1, pp. 65–73.

Preda, I., Țenu, A., 1981. *Resurse de ape minerale și termale*, Note de curs și lucrări practice, Ed. Univ. din București.

Roșca, M.G., 2011. *Geothermal resources of Romania*, GEOELEC, workshop Athens.

Roșca, M., Bendea, C., and Vîjdea, A.M., 2016. "Mineral and thermal waters of Romania," in Petar Papić (ed.), *Mineral and Thermal Waters of Southeastern Europe, Environmental Earth Sciences*, pp. 97–114, doi 10.1007/978–3-319–25379-4_6.

Rusu, A., Balintoni, I., Bombita, G., Popescu, G., 1983. *Geological map of Romania, Preluca map*, Geological Institute of Romania, scale 1:50.000.

Săndulescu, M., 1984. *Geotectonica României*. Ed. Tehnică, Bucureşti, pp. 336.

Săndulescu, M., Visarion, M., Stănică, D., Stănică, M., Atanasiu, L., 1993. "Deep structure of the Inner Carpathians in the Maramures-Tisa zone (East Carpathians)," în *Romanian Journal of Geophysics*, vol. 16, pp. 67–76.

Schmid, S.M., Fügenschuh, B., Kounov, A., Matenco, L., Nievergelt, P., Oberhänsli, R., Pleuger, J., Schefer, S., Schuster, R., Tomljenović, B., Ustaszewski, K., van Hinsbergen, D.J.J., 2020. "Tectonic units of the Alpine collision zone between Eastern Alps and western Turkey," *Gondwana Research*, vol. 78, pp. 308–374.

Slăvoacă, D., Feru, M., Geamănu, V., Simion, G., Goliță, N., Lungu, P., 1978. "Considérations hydrogéologiques sur les émergences naturelles dțeaux thermales de Roumanie," *Studii tehnice și economice, Studii de hidrogeologie*, Institutul Geologic al României, București, pp. 14–38.

Tischler, M., Gröger, H.R., Fügenschuh, B., Schmid, S.M., 2007. "Miocene tectonics of the Maramures area (Northern Romania): implications for the Mid-Hungarian fault zone," *International Journal of Earth Sciences*, vol. 96, pp. 473–496.

Tomlinson, M.J., 1995. *Foundation design and construction*, ed. John Willey & Sons, Inc., New York.

Veliciu, S., Cristian, M., Paraschiv, D., Visarion, M., 1977. "Preliminary data of heat flow distribution in Romania," *Geothermics*, vol. 6, pp. 95–98.

Veliciu, S., Demetrescu, C., 1979. "Heat flow in Romania and some relations to geological and geophysical features," in Cermak, V., Rybach, L. (eds.), *Terrestrial Heat Flow in Europe*, Springer Verlag, Heidelberg-Berlin-New York, pp. 253–260.

Veliciu, S., Visarion, M., 1984. "Geothermal models for the East Carpathians," *Tectonophysics*, vol. 103, pp. 157–165.

Viișoreanu, A.M., 2022. *Cercetări privind echipamentele și mașinile electrice pentru sistemele eoliene de producere a energiei*, PhD, Universitatea Politehnică din București.