RENEWABLE ENERGY SOURCES IN SERBIA
- HYDRO ENERGY -

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RENEWABLE ENERGY SECTOR IN SERBIA
– HYDRO ENERGY –
Hydropower potential

• Taking into consideration geomorphological and hydrological characteristics of the terrain, Serbia's hydropower potential has been estimated at 31,000 GWh per year, 17,000 GWh of which are technically usable.

• The existing large hydropower plants use about 10,000 GWh. The remaining 7000 GWh could be used by constructing large (75%) and small (25%) hydropower plants.

• The potential of small watercourses suitable for installing mini hydropower plants reaches 0.4 million tonnes of oil equivalent or 3% of the total potential of renewable sources in Serbia.

• Most mountains in Serbia are relatively rich in water, with rivers running steeply downwards in short sections of the stream, which ensures favorable conditions for their exploitation for energy production.

• Although all preconditions in terms of the position of rivers, topographic and hydrological conditions are met, the attention paid to this problem is still insufficient and there is a lack of action in dealing with it.
Distribution of stations on regional stations and on the basins of major rivers

Regions:
- Novi Sad
- Valjevo
- Požarevac
- Kraljevo
- Niš
- Priština

Basins:
- Dunav
- Sava
- Kolubara
- Drina
- Velika Morava
- Južna Morava
- Zapadna Morava
- Timok
- Beli Drim
- Egej
An overview and characteristics of some active hydropower plants in Serbia

<table>
<thead>
<tr>
<th>Name</th>
<th>No. of generators</th>
<th>Active power (MW)</th>
<th>Type of hydropower plant</th>
<th>Annual production (GWh)</th>
<th>Lake volume (m³)</th>
<th>Total (MW)</th>
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<tbody>
<tr>
<td>Danube</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Đerdap I</td>
<td>6</td>
<td>176.3</td>
<td>Dam</td>
<td>5489</td>
<td>2800 mil</td>
<td>1026</td>
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<tr>
<td>Đerdap II</td>
<td>10</td>
<td>27</td>
<td>run-of-river</td>
<td>1504</td>
<td>716.5 mil</td>
<td>270</td>
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<td>Drina</td>
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<tr>
<td>Zvornik</td>
<td>4</td>
<td>24</td>
<td>pre-dam - run-of-river</td>
<td>550</td>
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<td>96</td>
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<tr>
<td>HE Bajina Bašta</td>
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<td>2</td>
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<td>Uvac</td>
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<td>36</td>
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<td>-</td>
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<td>Koka Brod</td>
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<td>Bistrica</td>
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<td>51</td>
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<td>-</td>
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<td>Potpeć</td>
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<td>17</td>
<td>pre-dam</td>
<td>-</td>
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<td>51</td>
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<tr>
<td>Zapadna Morava</td>
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<tr>
<td>Ovčar</td>
<td>1</td>
<td>2.2</td>
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<td>-</td>
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<td>5.5</td>
</tr>
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<td>1</td>
<td>3.3</td>
<td></td>
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<td>Međuvršje</td>
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<td>run-of-river</td>
<td>-</td>
<td>15 mil</td>
<td>7</td>
</tr>
<tr>
<td>1</td>
<td>4.5</td>
<td></td>
<td></td>
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<td></td>
</tr>
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<td>Vlasina</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pirot</td>
<td>2</td>
<td>40</td>
<td>accumulative</td>
<td>87</td>
<td>180 mil</td>
<td>80</td>
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<tr>
<td>Vrla 1</td>
<td>2</td>
<td>11.2</td>
<td>accumulative</td>
<td>165 mil</td>
<td>50</td>
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<tr>
<td>Vrla 2</td>
<td>1</td>
<td>10.7</td>
<td>accumulative</td>
<td>51</td>
<td>0.1 mil</td>
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</tr>
<tr>
<td>Vrla 3</td>
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<td>12.8</td>
<td>accumulative</td>
<td>73</td>
<td>-</td>
<td>29.4</td>
</tr>
<tr>
<td>Vrla 4</td>
<td>1</td>
<td>11.2</td>
<td>accumulative</td>
<td>63</td>
<td>0.1 mil</td>
<td>25.4</td>
</tr>
</tbody>
</table>

Legend: = 500 MW
Hydro power plants (HPP)

• The first hydro power plants were put in operation in 1955 – HPP Vlasina, followed by HPP Morava (1954-1957).
• However, HPP Djeerdap is deemed to be the “queen” of all hydro power plants.
• Total installed capacity of Djeerdap 1 is 1026 MW and Djeerdap 2 is 270 MW. Their joint annual generation is 5489 GWh, which makes 18% of electricity generation in EPS.
• Main structures of the HHPs are built at km 943 and km 862.8 of the Danube River to its mouth on the Black Sea, each including 2 navigation locks, an earthen non-overflow dam, 2 hydroelectric power plants, an overflow concrete gravity dam, and other facilities. The HPPs operate as run-of-river, and reservoirs provide daily and sometimes weekly flow regulation.
HPP Djeđdap 1

- HPP Djeđdap 1 construction began as early as 1964, through joint investment of Serbia and Romania. The entire facility was put in operation in 1972.

- The dam is 1.280 m long. It consists of two symmetrical parts (Serbian and Romanian portion), which allows both countries to have an equal exploitation of the water resource for electricity production and for navigation purposes. Each part comprise a 34 m wide and 310 m long double step navigation lock, earthen non-overflow dam, hydro-electric power plant (with 6 Caplan turbines 170 MW) and a part of overflow dam.

- The overflow concrete gravity dam in the middle of cross-section has 14 spillway bays (each 25 m wide, with double table-gates), enabling the evacuation of the flood with return period once in 10,000 years. Two 2.050 MW electric power-plants (with 21-35 m head, 8700 m³/s installed discharge) generate an annual average of 11.5 billion kWh.

- The reservoir upstream of the dam has 3.500 million m³ volume under average hydrologic conditions.

- Major characteristic of the reservoir is variable length, backwater magnitude, and volume, which are a function of discharge and the hydro-power plant's operating mode. At low flows the backwater stretches along a length of the Danube of about 310 km (up to km 1.255), along about 100 km of the Sava, and along about 60 km of the Tisza River.
Schematic representation of Iron Gate (Djerdap 1 and 2) location on the Danube River
Operation regime of HPP Djerdap 1

All operating modes were defined by water level elevations for characteristic discharges, or discharge curves over a low flow to an extremely high flow range at control cross-sections near the mouth of the Nera (km 1075) and at the dam (km 943+000).

- The 69.5/63 mode (a): The hydro-power plant operated in this mode from 1972 to 1976. When discharges of the Danube were less than 7350 m$^3$/s, the headwater levels at the dam had to be maintained such that the water level at the mouth of the Nera remained at 68.00 m above sea level; at higher discharges, the headwater level at the dam was maintained at 63.00 m above sea level and the water level at the mouth of the Nera established its natural water level regime.

- The 69.6/63 mode (b): The hydro-power plant operated in this mode from 1977 to 1985. When discharges of the Danube were less than 9,750 m$^3$/s, the headwater levels at the dam were maintained such that the water level at the mouth of the Nera remained at 69.50 m above sea level; at higher discharges, the headwater level at the dam was maintained at 63.00 m above sea level and the water level at the mouth of the Nera established its natural water level regime.

- The 69.5+ mode (c – up to 70.3): Operation in this mode began in 1985. Headwater levels at the dam were maintained such that design water levels were established at the mouth of the Nera. This operating mode was precisely defined in the 1998 Convention.
The construction officially started in 1977, and the first generating units were put in operation in 1985.

The dam is located on the main course of the Danube River, and has a total width of 1.009 m.

A 330 m wide HPP equipped with 16 Kaplan turbines (27 MW) are located on the left bank, divided between Romania (8 units) and Serbia (8 units), followed by a spillway (all within Serbia territory) of 196 m and 14 gates (21 m wide, regulated by radial sluice gates), an earthfill dam and a navigation lock 34 m wide.

The downstream reservoir is small (only 80 km long) and does not extend beyond the channel of the Danube.

The intends is to increase the capacity of each of the power units of Djerdap 2 to 32 MW from 27 MW, overhauling one unit per year.
Small hydropower plants in Serbia

• According to Serbian regulations, until December 2012, the term “mini hydropower plants” covered all hydropower plants with the installed power up to 10 MW regardless of their type (i.e. it included both plants using reservoirs and run-of-river hydropower plants).

• Since the adoption of the Decree on Incentive Measures for Privileged Electric Power Producers in January 2013, this term has been extended to include hydropower plants with the installed power up to 30 MW.

• The hydropower plants with the installed power up to 100 kW are called microenergy plants.

• So far, 69 SHPs have been built on the rivers in Serbia, but the majority of them is in poor condition. Out of that number, 31 with a total power of 31.3 MW and an annual electricity production of 150 GWh are in use. Thirty-eight facilities with a total power of 8.7 MW are out of use.
Hydro power

- HP is very important RES potential in Serbia – 1.68 Mtoe (total)
- About 1000 locations suitable for SHPP (100kW < P < 10MW), used < 5%
- Used potential – 0.9 Mtoe  Unused potential – 0.77 Mtoe

<table>
<thead>
<tr>
<th>P &gt; 30MW</th>
<th>10MW &lt; P &lt; 30MW</th>
<th>P &lt; 10MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unused</td>
<td>517</td>
<td>102</td>
</tr>
<tr>
<td>Used</td>
<td>885</td>
<td>20</td>
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</table>

Total power of SHPP in Serbia
## Small hydropower plants in Serbia

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>River</th>
<th>Municipality</th>
<th>Owner</th>
<th>Power (MW)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Radaljska banja</td>
<td>Radaj</td>
<td>Mali Zvornik</td>
<td>EPS**</td>
<td>0.27</td>
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<tr>
<td>2</td>
<td>Đordić</td>
<td>Ljubovida</td>
<td>Ljubovija</td>
<td>Private</td>
<td>0.01</td>
</tr>
<tr>
<td>3</td>
<td>Vrelj</td>
<td>Perućačko vrelj</td>
<td>Bajina Bašta</td>
<td>EPS</td>
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<tr>
<td>4</td>
<td>Vrutci</td>
<td>Detinja</td>
<td>Ulince</td>
<td>Private</td>
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</tr>
<tr>
<td>5</td>
<td>Turča</td>
<td>Detinja</td>
<td>Ulince</td>
<td>EPS</td>
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<tr>
<td>6</td>
<td>Pod gradom</td>
<td>Detinja</td>
<td>Ulince</td>
<td>EPS</td>
<td>0.36</td>
</tr>
<tr>
<td>7</td>
<td>Ovač banja</td>
<td>Zapadna Morava</td>
<td>Čačak</td>
<td>EPS**</td>
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<td>8</td>
<td>Međutvršje</td>
<td>Zapadna Morava</td>
<td>Čačak</td>
<td>EPS</td>
<td>7.00</td>
</tr>
<tr>
<td>9</td>
<td>Kratovska reka</td>
<td>Kratovska reka</td>
<td>Prijepolje</td>
<td>EPS</td>
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<tr>
<td>10</td>
<td>Seljašnica</td>
<td>Seljašnica</td>
<td>Prištopje</td>
<td>EPS</td>
<td>1.26</td>
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<tr>
<td>11</td>
<td>Moravica</td>
<td>Goljaškog Moravica</td>
<td>Kranj</td>
<td>EPS**</td>
<td>0.16</td>
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<tr>
<td>12</td>
<td>Studenica</td>
<td>Studenica</td>
<td>Krškojevo</td>
<td>SOC***</td>
<td>0.09</td>
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<tr>
<td>13</td>
<td>Radošiška reka</td>
<td>Radošiška reka</td>
<td>Raška</td>
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<td>0.04</td>
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<td>14</td>
<td>Raška</td>
<td>Novi Pazar</td>
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<tr>
<td>15</td>
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<td>Toplica</td>
<td>Kuršumija</td>
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<td>16</td>
<td>Grčki mlini</td>
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<td>Prokuplje</td>
<td>Private</td>
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<td>Zajecar</td>
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<td>Crni Timok</td>
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<td>Niš</td>
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<td>0.40</td>
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<td>Prvomec</td>
<td>Banjska</td>
<td>Vranje</td>
<td>EPS</td>
<td>0.91</td>
</tr>
</tbody>
</table>

** EPS—Electric Power Industry of Serbia.
*** SOC—Serbian Orthodox Church.
Possibilities for future SHP development in Serbia

- Conducted research shows that the greatest hydropower potential usable for sHPP is located in western, eastern and south eastern provinces of Serbia.
- In the northern, flatland area of Serbia (Podunavlje, Vojvodina, the Belgrade area), hydropower potential is lower.
- There are substantial uncertainties related to the estimation of the sHPP potential in Serbia.
- Since 1987, but officially since 2014 locations for small HPS with all relevant data publicly available on web site of the Ministry for Energy (Cadastre of small HPPs).
- The Cadastre provides a precise description of 853 potential sites. A separate Cadastre, containing 13 potential sites, exists for the northern Serbian region of Vojvodina.
Possibilities for future SHP development in Serbia

- Based on the data from the Cadastre the following figure depict the size distribution of the potential in sHPP - the most sites are relatively small (between 100-200 kW).

- The data derived from the Cadastre are no longer reliable without prior additional investigation, since there were significant migrations and developments in certain areas and it is expected that registered sites may no longer be available, or their capacities may have changed. Accordingly, the total capacity for electricity generation from sHPPs may differ from the values presented above.
Feed-In-Tariffs

- Since the approval of Feed-In-Tariffs in 2009, there has been increased activity in the area of sHPP.
- One indication for the uptake of the larger sHPP opportunities is the list of the energy permits issued or the status of privileged producers being obtained.
- This sort of incentive is provided for by the Energy Law of the Republic of Serbia and it implies a privileged position in the market compared to other energy producers who sell energy under equal conditions; it also implies a right to subsidies (tax, tariff and other subsidies provided for by law), as well as the incentive feed-in tariffs (for small hydropower plants in the Republic of Serbia).

<table>
<thead>
<tr>
<th>Categories of SHPs</th>
<th>Installed power P (MW)</th>
<th>Incentive purchase price (€/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newly built facilities</td>
<td>&lt; 0.2</td>
<td>12.40</td>
</tr>
<tr>
<td>Newly built facilities</td>
<td>0.2–0.5</td>
<td>13.727–6.633×P</td>
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<tr>
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<td>0.5–1</td>
<td>10.41</td>
</tr>
<tr>
<td>Newly built facilities</td>
<td>1–10</td>
<td>10.74–0.337×P</td>
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<tr>
<td>Newly built facilities</td>
<td>10–30</td>
<td>7.38</td>
</tr>
<tr>
<td>At the existing infrastructure</td>
<td>&lt; 30</td>
<td>5.90</td>
</tr>
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</table>

- Today 44 sHPPs have received the privileged producer status, with total installed capacity of 33,26 MW.
Case study: SHP Tartići

• The SHP Tartići is located on the Sokolska River and the Zakućanski Potok stream, in the Ljubovija municipality, in the western part of Serbia.

• The SHP is designed as a derivation facility, highly automated, with supply water pipes, pressure piping systems and Kaplan turbine.

• With net head of 40.5 m and the installed discharge of 0.55 m³/s, the installed capacity of the hydropower plant is 185 kW and the average annual energy production is 0.75 GWh.

• The total investment for this small hydropower plant is 459,750 €, 80% of which is funded by a ten-year bank loan with an interest rate of 5.70% per year and a 2-year grace period; the remaining 20% are investors' equity.

Hydraulic scheme of the SHP Tartići
Case study: SHP Tartići

- Initial costs of the facility, presented in table, show the distribution and share of various group of costs. The average unit cost of the facility is 2485 €/kW. Simple payback time is 4 years and 9 months.

<table>
<thead>
<tr>
<th>Cost Component</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designing, planning and project management</td>
<td>23,180</td>
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<tr>
<td>Construction costs</td>
<td>150,030</td>
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<tr>
<td>Mechanical equipment</td>
<td>151,300</td>
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<td>Electrical equipment</td>
<td>81,600</td>
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<tr>
<td>Transport and setup</td>
<td>18,970</td>
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<tr>
<td>Contingencies</td>
<td>34,670</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>459,750</strong></td>
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</tbody>
</table>

- Other costs related to SHP operation include employees’ salaries and remunerations; calculated for three necessary employees, they reach the amount of 6150 € per year; the machinery break down insurance and fire insurance amount to 1380 € per year; the amortization costs, which are directly related to the technological life of the facility and equipment, amount to 10,020 €.

- The average unit cost of the electric power produced at this SHP is 4.19 c€/kWh; excluding profit and interest, it is reduced to 3.08 c€/kWh.

- In accordance with the recently adopted Decree on Incentive Measures for Privileged Electric Power Producers, the electric power purchase price for this SHP is 12.4 c€/kWh.
Conclusion

• Although the idea of installing SHPs in Serbia emerged already in the early 20th century, which was followed by the construction of several dozen such facilities, more recent political and economical changes caused a significant delay in their development compared to other countries.

• Although relevant legislation and planning documents seek to promote a more intensive exploitation of the mentioned energy source due to its numerous advantages there are numerous limiting factors which hinder and impede it.

• The greatest disadvantages of SHPs are related with great costs accompanying the exploration of potential sites for their construction. The application of methods based on GIS, which allows to survey precisely large areas in a short period of time, could reduce the cost of location analyses.

• Taking into account global climate changes, significant reductions in hydropower yields need to be considered in future water management plans in Serbia.

• Having in mind the advantages and limits for the construction of SHPs, some of the possible solutions would include drafting of the new Survey of SHPs in Serbia; a long-term Energy Strategy; strict application of ecological measures when planning and devising projects for SHPs in compliance with EU directives; defining criteria and rules for the utilization of watercourses for SHPs and strict control of development activities and resource exploitation.
RENEWABLE ENERGY SOURCES IN SERBIA
- GEOTHERMAL ENERGY -

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GEOTHERMAL ENERGY

• Geothermal energy is the natural energy accumulated in fluids (water and magma) and the rocky masses of the earth's crust.

• This kind of energy somewhere finds its way to the surface in the form of hot water and steam, and somewhere remains trapped at great depth.

• Apart from heat transfer of the earth's core by conduction and convection, the earth's crust has its own independent source of heat created by the disintegration of uranium, thorium, and other radioactive elements.

• In 2013 Serbia adopted the National Action Plan for renewable energy that defines national goals, as well as measures to achieve them. According to the “Energy Development Strategy of the Republic of Serbia to 2025 with projections to 2030” the total potential for renewable energy sources is 5.65 Mtoe per year, where the geothermal potential is estimated at about 0.18 Mtoe per year, or 3.2% of the total available potential of renewable energy sources.
The manner of application of geothermal energy depends on the temperature of the working fluid and the rock massif, so in this sense we can have: direct and indirect application.

Direct application (up to 100 °C) means that geothermal water heat is used directly (without transformation into some other type of energy) for various purposes.

In such systems the hot water from the boring hole is transferred by pumps directly into heating systems or into a heat distributor.

Heating pumps represent yet another way of direct application of geothermal energy. Such devices absorb heat energy from one of the three possible sources: open air, soil or aquatoriums (rivers, lakes or sea) which they transfer to another locality where it is used for heating of buildings or to create hot water, while in vice versa process it can be used for cooling.
Geothermal energy application

• **Indirect application (over 100 °C)** means that geothermal energy is used to obtain electric energy.

• There are several types of geothermal power plants and their characteristics depend on the type of geothermal layer and the temperature of working fluid:

1. Power plants that use **dry steam** of high temperature, usually over 235 °C, which after passing through the separator of large particles is directly used to operate the turbine generator for the production of electric energy;

2. Power plants based on the **flash steam principle** use hot water (over 189 °C) from the geothermal reservoir which is under high pressure. Hot water while entering the power plant is released from the pressure and instantly turns into the steam, which is then used to start the generator's turbine;

3. A power plant with **binary cycle** uses water of lower temperature (100–150 °C) by which the fluids with lower boiling point (isopentan, isobutane, liquid carbon dioxide) are heated. By transfer of the heat via exchangers, working fluid turns into the steam which serves to start the turbines;

4. Power plants that use the heat of **hot dry rocks**. The cold water is under pressure injected into the created reservoir by the deeper hole where it is being heated by contact with hot rock mass and after that is led through a shallower hole to the installations for turning heat energy into the electric.
The development of hydrogeology in Serbia

- Serbia is centrally situated in the Balkan peninsula and covers a relatively small surface area but its geology is quite complex.

- The first descriptions of geothermal resources in Serbia were given at the end of 19th century by Radovanovic (1897) in the book "Ground Water," which was the first synthetic hydrogeological work not only in Serbia, but also in South East Europe and the Balkans.

- Radovanovic was one of the first Serbian hydrogeologists, and "the father" of Serbian Hydrogeology and Geothermology.

- Later, geothermal explorations in Serbia were initiated by hydrogeologists in 1974 and were carried out only for hydrothermal resources.

Svetolik Radovanović (1863-1928)
Serbian paleontologist and geologist
Since then till nowadays numerous studies and projects of deep geothermal drill holes were made.

A first geothermal Atlas was completed in 2010 for the northern part of Serbia, Vojvodina and later in 2013 for Central Serbia.

Geothermal energy in Serbia has been used in amount of 170.4 MWth although its geothermal potential is much greater.

The greatest number of objects is used in balneology, then for indoors and outdoors swimming pools, wellness and spa centres, fewer are used for spa premises and greenhouses heating, then for industrial and agricultural processes.
Geological overview

- Serbia is a country with traditionally known, but underused geothermal resources.
- From a geological point of view the territory of Serbia encompasses four large geotectonic units.
- The first geotectonic unit (Pannonian Basin) covers essentially Northern Serbia (Vojvodina Province) while the other three geotectonic units (Dinarides and Vardar Zone, Serbian-Macedonian Massif and Carpatho-Balkanides) split Central Serbia from west to east.
- The Pannonian Basin consists of sediments with a total maximum thickness of about 4000 m.
- The Dinarides occupies a large part of Serbia and they are made of Mesozoic rocks, mainly limestones and dolomite.
- Serbian-Macedonian Massif is composed of very thick Proterozoic metamorphic rocks.
- The Carpatho-Balkanides were formed in the Mesozoic as a carbonate platform dominantly composed of limestones.
Geological map of Serbia
Geothermal background

• In Serbia, the Earth's crust varies in thickness, increasing to the south.
  • In the Pannonian Basin area this thickness is uniform, about 25-29 km.
  • South of it, in the Dinarides, the thickness increases to about 40 km in extreme southwest Serbia.
  • In the Serbian-Macedonian Massif, the crustal thickness is about 32 km, and in the Carpatho-Balkanides from 33 to 38 km.

• Values of the terrestrial heat flow density under most of Serbia are higher than the average for continental Europe.
  • The highest values (>100 mW/m²) are in the Pannonian Basin, Serbian-Macedonian Massif, and in the border zone of the Dinarides and the Serbian-Macedonian Massif.

• The thickness of the lithosphere is thinnest in the Pannonian Basin, Serbian-Macedonian Massif, and its border zone on the Dinarides, only 40 km.

• In the Carpatho-Balkanides and the rest of the Dinarides, this thickness is up to 150 km. The lithosphere is the thickest in the Mesian Platform - from 160 to 180 km.
Geothermal potential

- The reported geothermal potential has a wide range, ranging from 86 to 216 MW\textsubscript{th}.
- Two approaches were applied to estimate the geothermal potential:

1. The first included a volumetric method:

\[
P = \Delta T \cdot [V_t \cdot (1-\Theta) \cdot \rho_r \cdot C_r + V_t \cdot \Theta \cdot \rho_w \cdot C_w] \cdot r / (10^3 \cdot t)
\]

- P = Potential [MW] over 50 years;
- \(\Delta T\) = The difference between the inlet and outlet temperature [°C];
- \(V_t\) = Total Volume of rock hosting the geothermal reservoir [km\(^3\)];
- \(\Theta\) = Porosity factor;
- \(\rho\) = Density [kg/km\(^3\)]; \(r = \) rock, \(w = \) water;
- \(C\) = Heat capacity [kJ/kg°C]; \(r = \) rock, \(w = \) water;
- \(t\) = time [s] (7000 hr/yr for 50 years);
- \(r\) = recovery factor telling how much of the stored energy is possible to use;

There are big uncertainties in all the parameters.
2. The second approach was based only upon information from existing wells:

\[
Q = \dot{v} \cdot \rho \cdot c_p \cdot [t_1-t_2] /10^6
\]

- Q – Thermal capacity of the geothermal fluid [MWth]
- \( \dot{v} \) - fluid flow [l/s]
- \( \rho \) - water density [kg/km³]
- \( c_p \) – specific heat [kJ/kg°C]
- \( t_1 \) – inlet temperature [°C]
- \( t_2 \) – outlet temperature [°C]

The outlet temperature was not known for all cases and thus estimated as 15-25°C dependent on inlet temperature and application.
Geothermal potential

- Neither approach gives an exact account of the actual geothermal potential in Serbia.
- Nevertheless by comparing the two approaches and presenting the available research on the geothermal resource of Serbia as a whole and in detail by areas of interest, the results came up with the best possible estimate of the theoretic geothermal potential based upon available data.
- The theoretic geothermal potential of Serbia was estimated to be about $180,000 \text{ MW}_{\text{th}}$ by the volumetric method and $330 \text{ MW}_{\text{th}}$ based on the theoretical potential of available information on existing wells if the geothermal fluid was used by cascading solutions down to the average ambient temperature of Serbia ($10.5^\circ\text{C}$).
- The difference between these two approaches gives an indication of how much untapped thermal potential lies in the unexplored basins of Serbia.
- In the existing well approach, the potentials represent already located geothermal resources whereas in the volumetric method approach consideration is taken to future research of the total geothermal potential in Serbia.
Geothermal potential

- Within the territory of Serbia excluding the Pannonian Basin, i.e. the terrain comprising solid rocks, there are 159 natural thermal springs with temperatures over 15°C.
- The warmest springs (96°C) are in Vranjska Banja, followed by Josanicka Banja (78°C), Sijarinska Banja (72°C) Kursumlijska Banja (68°C), Novopazarska Banja (54°C).
- The total flow of all natural springs is about 4000 l/s.
- The greatest number of thermal springs are in the Dinarides, then the Carpatho-Balkanides, the Serbian-Macedonian Massif, and the lowest, only one in each, the Pannonian Basin and the Mesian Platform.
- As to the elevation, the greatest number of thermal springs is within the range 200-300 m. More than 90% of all thermal springs are at elevations below +600 m.
Map of geothermal resources

- Considering the present state of our knowledge of the geologic composition and hydrogeothermal properties of rocks to a depth of 3000 m, there are 60 convective hydrogeothermal systems in Serbia.
- Of this number, 25 are in the Dinarides, 20 in the Carpatho-Balkanides, 5 in the Serbian-Macedonian Massif, and 5 in the Pannonian Basin under Tertiary sediments.
- Conductive hydrogeothermal systems are developed in basins filled with Paleogene and Neogene sedimentary rocks. The majority of these are in the Pannonian Basin in Vojvodina, northern Serbia. The other 14 systems are less interrelated and less important.
Some Serbian researches have sorted all mineral and thermal waters of Serbia into four groups according to the type of hydrogeological structure in which a certain type of aquifer prevails:

1. Mineral and thermal waters of volcanic massif
2. Mineral and thermal waters of karst areas
3. Mineral and thermal waters of metamorphic zone
Distribution of geothermal resources
Utilization of geothermal energy

- At the present time the main utilisation is at thermal spas for balneology and recreation.
- The 160.5 MW<sub>th</sub> installed capacity is used for bathing and swimming, space heating, greenhouses, fish and other animal farming, industrial process heat and agricultural drying.
- In addition, about 9.9 MW<sub>th</sub> of thermal water heat pumps are in use.
- Today there are 59 thermal water spas in the country used for balneology, sports and recreation and as tourist centers.
- Thermal waters are also bottled by nine mineral water bottling companies.
- Space heating and electric power generation from geothermal energy is in the exploration stages.

<table>
<thead>
<tr>
<th>Utilization reviewed from collected data</th>
<th>Installed Thermal Power (MW&lt;sub&gt;th&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Heating</td>
<td>33.4</td>
</tr>
<tr>
<td>Bathing and Swimming</td>
<td>83.6</td>
</tr>
<tr>
<td>Agricultural Drying</td>
<td>0.6</td>
</tr>
<tr>
<td>Greenhouses</td>
<td>34</td>
</tr>
<tr>
<td>Fish and other Animal Farming</td>
<td>8</td>
</tr>
<tr>
<td>Industrial Process Heat</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>160.5</strong></td>
</tr>
<tr>
<td>Heat Pumps</td>
<td>9.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>170.4</strong></td>
</tr>
</tbody>
</table>
Utilization of geothermal energy

• There are presently 25 wells in use within the Pannonian Basin, and with uses for heating greenhouses (4 wells), heating pig farms (3 wells), industrial process such as in leather and textile factories (2 wells), space heating (3 wells) and 13 wells for various uses in spas and for sport and recreation facilities.

• Outside the basin, geothermal water is used for space heating, greenhouse heating (raising flowers), a poultry farm, a textile workshop, a spa rehabilitation center and a hotel.

• Three other spas and rehabilitation centers also use geothermal heat, including heat pumps 6 MW$_{th}$, which uses water at 25°C, and in the carpet industry.

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NEW APPROACHES IN UTILIZATION OF GEOTHERMAL ENERGY

• Before the year 2000, all natural resources in Serbia were state owned, and only governmental companies could utilize natural resources such as geothermal energy.

• After year 2000 and a period of transitions, all companies, private or governmental, could utilize geothermal energy according to the new regulations.

• For the last 20 years, state investments in all geological exploration have decreased from 40 million euros (year 1988) to less than 1 million euros (year 2007) per year.

• After the year 2000, private companies started to invest in geological exploration, especially in investigations of groundwater resources and geothermal energy.

• For the last ten years, private companies have built approximately 25 ha of greenhouses heated by geothermal energy and invested about 50 million euros in realization of geothermal projects.
FUTURE PROSPECTS

• Exploration to date has shown that geothermal energy use in Serbia for power generation can provide a significant component of the national energy balance.

• The prospects for use of heat pumps on pumped ground water from alluvial deposits along major rivers are very good.

• For intensive use of thermal waters in agro- and aqua-cultures and in district heating systems, the most promising areas are west of Belgrade westward to the Drina, i.e. Posavina, Srem, and Macva.

• The priority region is Macva, where reservoir depths are 400-600 m, and water temperatures are 80°C. The completed studies indicate that thermal water exploitation in Macva can provide district heating system for Bogatic, Sabac, Sremska Mitrovica, and Loznica, with a population of 150,000.