Overview and Perspectives of Renewable Energy Sources in the Danube Region in Croatia

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Abstract: In this paper, potential of renewable energy sources for Danube region in Croatia will be presented. Croatian Danube region consists of two counties, Vukovar-Sriem County and Osijek-Baranya County. Potential of solar energy, wind energy, geothermal energy, hydro energy and biomass energy for Danube region in Croatia will be shown in detail. Overview of current state of renewable energy sources usage for electricity and heat production in Croatian Danube region will be presented. Usage of solar energy, wind energy, geothermal energy, hydro energy and biomass energy for electricity generation in Croatian Danube region will be shown in detail. Also, perspectives for further development in these two counties will be presented.

Key words: Danube region, renewable energy sources, potential, usage, perspectives.

1. Introduction

Renewable energy sources (RES) are very important part of energy balances in almost every country. They provide electric and thermal energy with reduced pollution and they exclude the use of fossil fuels. Also, unlike conventional technologies, RES use many dispersed sources of energy, and they are compatible with "smart grid" implementation in distribution system. Danube Region in Croatia consists of Vukovar-Sriem County and Osijek-Baranya County. Both Counties show interest in increasing the use of RES, which is visible in comparison of Figure 1. and Figure 2. Wind and waterpower energy potentials are insignificant in these two Counties, but biomass and solar energy potentials are clearly expressed, especially biomass, while geothermal energy mostly needs further researches. Current state of RES and perspectives with potentials are given in following chapters.

2. Overview of Renewable Energy installations in Danube Region in Croatia

Energy generated form renewable sources in Danube region in Croatia, like in the whole country, is paid by a tariff system given in following table. The prices of energy produced by any renewable source are determined with this system.s

It is important to note that the construction of solar power plants whose energy is paid by this tariff system is limited to 5 MW per year, and that every plant built beyond that limit is paid by regular prices for energy from conventional energy sources and not by this tariff system. Figure 1. shows built power plants in Danube Region in Croatia.

Table 1. Tariff system for renewable energy sources in Croatia

Group	Type of plant	Incentive price C (kn/kWh[4])
	The plant with installed capacity ≤ 5MW	
1.a.1	Solar power plants with installed capacity up to and including 10 kW.	1,91
1.a.2	Solar power plants with installed capacity exceeding 10 kW up to and including 30 kW.	1,70
1.a.3	Solar power plants with installed capacity exceeding 30 kW and up to and including 300 kW.	1,54
1.a.4	Ground – mounted solar power plants	RC
1. b. 1	Hydro power plants with installed capacity up to and including 300 kW.	1,07
1. b. 2	Hydro power plants with installed capacity exceeding 300 kW up to and including 2 MW.	0,93
1. b. 3	Hydro power plants with installed capacity exceeding 2 MW.	0,88
1. c.	Wind power plants.	RC
1. d. 1.	Solid biomass plants including biodegradable ind. and municipal waste with installed capacity up to and including 300 kW.	1,30
1. d. 2.	Solid biomass plants including biodegradable ind. and municipal waste with installed capacity exceeding 300 kW up to and including 2 MW.	1,25
1. d. 3.	Solid biomass plants including biodegradable ind. and municipal waste with installed capacity exceeding 2 MW.	1,20
1. e.	Geothermal power plants.	1,20

[4] 1 EUR = 7,578 kn

Group	Type of plant	Incentive price C (kn/kWh[4])
1. f. 1.	Biogas power plants from agricultural plants and organic remains and waste from agriculture and food processing industry, landfill gas power plants and power plants using gas from water treatment plants with installed capacity up to and including 300 kW.	1,34
1. f. 2.	Biogas power plants from agricultural plants and organic remains and waste from agriculture and food processing industry, landfill gas power plants and power plants using gas from water treatment plants with installed capacity exceeding 300 kW up to and including 2 MW.	1,26
1. f. 3.	Biogas power plants from agricultural plants and organic remains and waste from agriculture and food processing industry, landfill gas power plants and power plants using gas from water treatment plants with installed capacity exceeding 2 MW.	1,18
1. g.	Liquid biofuel power plants.	RC

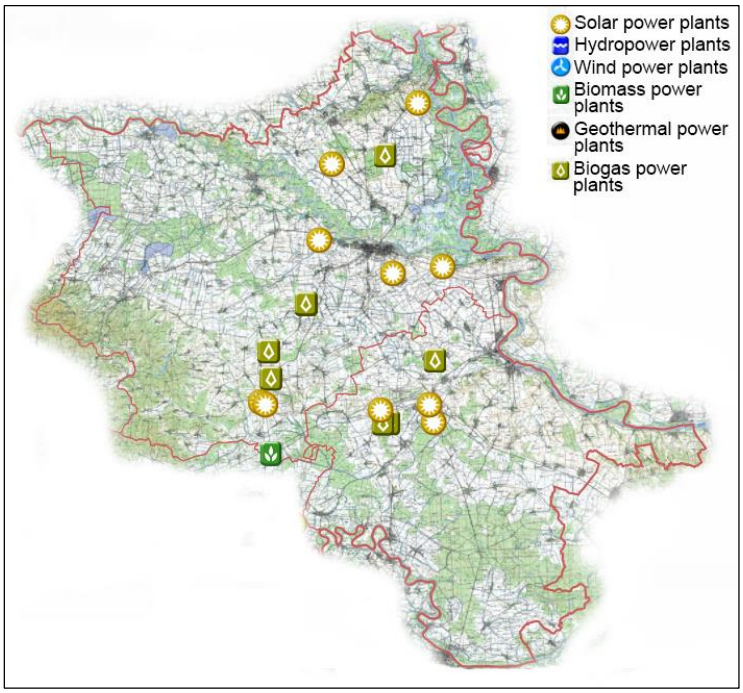

Figure 1. Built power plants on renewable energy sources (Ministry of Economics)

2.1. Photovoltaics

Overview of operating photovoltaic power plants in Danube region in Croatia is given in Table 2. for Osijek-Baranya County and in Table 3. for Vukovar-Sriem County.

Table 2. Overview of photovoltaic power plants in Osijek-Baranya County (HROTE)

Project	Plant type*	Location	Electrical capacity (kW)
ZMAJEVAC-1	1.a.1	Kneževi vinogradi	10.0
SEG1	1.a.2	Osijek	30.0
SEG3	1.a.1	Jagodnjak	9.8
SEG5	1.a.1	Osijek	10.0
TENJA1	1.a.1	Osijek	10.0
Mijakić – 1	1.a.1	Đakovo	10.0
Knežević – 1	1.a.1	Đakovo	10.0
Hrastović – 1	1.a.1	Đakovo	10.0
Total			99.8

*According to tariff system by HROTE: 1.a.1 – solar power plants <10 kW;
1.a.2 – solar power plants from 10 kW to 30 kW.

Table 3. Overview of photovoltaic power plants in Vukovar-Sriem County (HROTE)

Project	Plant type*	Location	Electrical capacity (kW)
Suhomont	1.a.2	Vinkovci	29.0
Krmek	1.a.1	Vinkovci	4.1
Patričar 2	1.a.2	Ivankovo	30.0
Total			63,1

*According to tariff system by HROTE: 1.a.1 – solar power plants <10 kW,
1.a.2 – solar power plants from 10 kW to 30 kW.

2.2. Biomass Power Plants

Overview of operating biomass power plants in Danube region in Croatia is given in Table 4.

Table 4. Overview of biomass power plants in Osijek-Baranya County (HROTE)

Project	Plant type*	Location	Electrical capacity (kW)	Thermal capacity (MW/h)
Hrast	1.d.3	Strizivojna	3	3,5

*According to tariff system by HROTE: 1.d.3 – biomass power plant on solid biomass > 2 MW.

2.3. Biogas Power Plants

Overview of operating biogas power plants in Osijek-Baranya County is given in Table 5. and Table 6. for Vukovar-Sriem County.

Table 5. Overview of biogas power plants in Osijek-Baranya County (HROTE, Osatina group)

Project	Plant type*	Location	Electrical capacity (kW)	Thermal capacity (MW/h)
Mitrovac	1.f.2	Čeminac	2	–
Slašćak	1.f.2	Viškovci	1	–
Mala branjevina – 1	1.f.2	Vuka	1	–
Mala branjevina – 2	1.f.2	Vuka	1	–
Tomašanci	1.f.2	Gorjani	1	1,3
Tomašanci – 2	1.f.2	Gorjani	1	1,3
Total			7	2,6

*According to tariff system by HROTE: 1.f.2 – biogas power plants from 300 kW to 2 MW.

Table 6. Overview of biogas power plants in Vukovar-Sriem County (HROTE, Osatina group, Novko et al. 2014)

Project	Plant type*	Location	Electrical capacity (kW)	Thermal capacity (MW/h)
Ivankovo	1.f.2	Ivankovo	1	1.30
Ivankovo 2	1.f.2	Ivankovo	1	1.30
Landia	1.f.2	Tordinci	1	1.07
Total				3,67

*According to tariff system by HROTE: 1.f.2 – biogas power plants from 300 kW to 2 MW.

3. Perspectives of Renewable Energy Sources in Danube Region in Croatia

Danube Region in Croatia has very good potentials for solar and biomass energy exploitation. Both Counties are rich with forests, fields, livestock and sun. Figure 2. shows planned power plants on renewable energy sources in this region and it is obvious how much biomass and sun come to expression.

In this chapter terms theoretical and technical potential will be used very often. Theoretical potential is potential of area in case of complete utilization of resources (without losses) and technical potential is potential of area which takes in consideration inability of complete utilization in some areas, energy and raw material losses, exploitation efficiency and similar impacts. Distribution of projects and their power output in Osijek-Baranya County by type of renewable energy sources is shown in Figure 3. and Figure 4. shows same for Vukovar-Sriem County (Ministry of Economics n.d.).

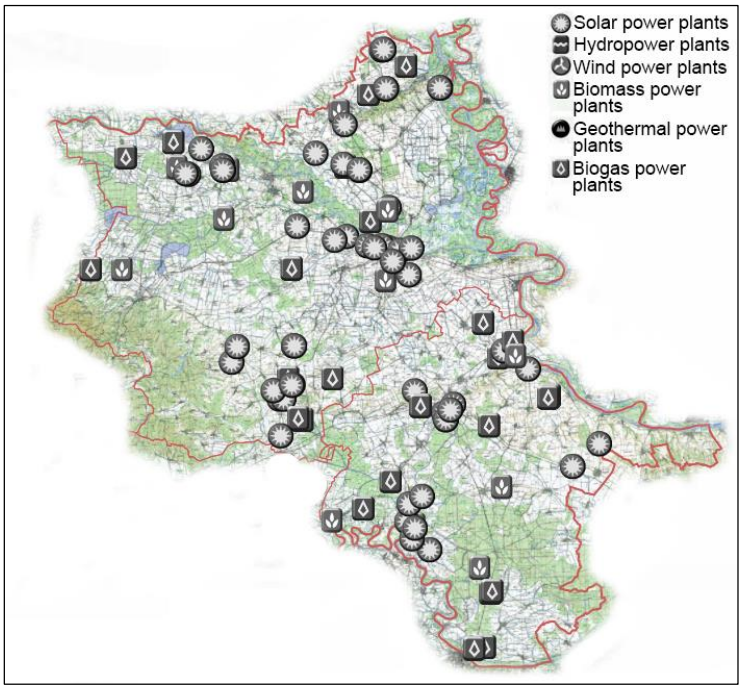

Figure 2. Planned power plants on renewable energy sources [mingo]

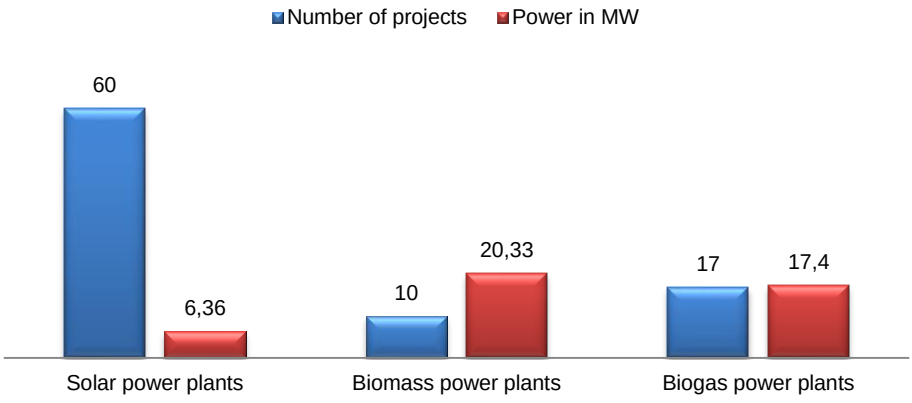

Figure 3. Distribution of projects and their power output by type of renewable energy sources in Osijek-Baranya County

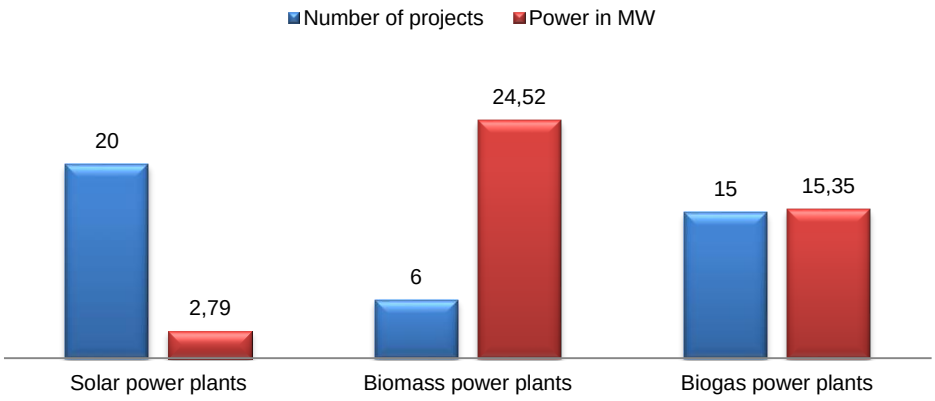

Figure 4. Distribution of projects and their power output by type of renewable energy sources in Vukovar-Sriem County

4. Wind Energy

Characteristic winds for Osijek-Baranya County are northwest wind in warmer months and southeast wind during colder months with quiet times mostly during summer and autumn. The intensity of wind is stronger in winter, but there are no outstandingly strong winds on the annual level which could be used for production of energy. Average annual speed of wind in this County doesn't exceed 5.6 m/s on altitude of 80m. Preliminary available technical wind potential in Osijek-Baranya County is estimated at about 20 MW, while satisfying the necessary technical conditions. In Osijek-Baranya County on the exposed mountain tops of Diljska gora and Krndija, the loess plains in Baranya and some clearings are probably some locations that would have justified use wind energy from the standpoint of available resources. However, identifying potential locations would require a closer investigation, which in this time is not done (Bačan et al. 2012).

Northwest wind in warmer months and southeast wind during colder months are characteristic for Vukovar-Sriem County. The intensity of wind is stronger in winter; however, on annual level there are no particularly prominent winds which could be used for production of energy. Average annual speed of wind in this County doesn't exceed 5.6 m/s on altitude of 80m. Preliminary available technical potential in Vukovar-Sriem County is estimated at about 30 MW, while satisfying the necessary technical conditions. North and more eastern parts of County have best wind energy potential. Determining the potential sites would require a thoroughly research, which at this time hasn't been done (Bačan et al. 2012).

5. Solar Energy

Natural potential of solar energy is estimated by the annual irradiance on horizontal plane (Bačan et al. 2012). Annual solar irradiation and potential power production by photovoltaic installations for Osijek-Baranya and Vukovar-Sriem County with three angles (horizontal, vertical and optimal – 33°) are presented in following tables.

According to data from register of renewable energy sources by Croatian Ministry of Economy, 60 solar power plants are planned to be built in this County with installed power capacity of 6.36 MW (Ministry of Economics). In comparison with current state of installed solar power (99.8 kW) that is tremendous growth.

According to data from register of renewable energy sources by Croatian Ministry of Economy, 17 solar power plants are planned to be built in this County with installed power capacity of 2.72 MW (Ministry of Economics). In comparison with current state of installed solar power (64 kW) that is tremendous growth. Thermal energy is second type of energy obtained from solar irradiance. Solar thermal system can satisfy up to 75% of energy needs for heating domestic hot water in case of a household of four members (solar collectors ~4 m^2 and DHW cylinder volume ~300 l). Both Counties have big potential for solar thermal energy but it requires more researches to obtain concrete numbers.

Table 7. Annual solar irradiation and potential power production by photovoltaic (PV) installations for Osijek-Baranya County (Huld–Suri, n.d.)

	Yearly global irradiation (kWh/m^2)			Yearly PV power (kWh/1kWp)		
	Horizontal	Vertical	Optimal	Horizontal	Vertical	Optimal
Minimum	1,192	888	1,342	890	669	998
Average	1,219	909	1,374	909	684	1,020
Maximum	1,236	925	1,395	921	696	1,035

Table 8. Annual solar irradiation and potential power production by photovoltaic (PV) installations for Vukovar-Sriem County (Huld–Suri, n.d.)

	Yearly global irradiation (kWh/m^2)			Yearly PV power (kWh/1kWp)		
	Horizontal	Vertical	Optimal	Horizontal	Vertical	Optimal
Minimum	1,236	923	1,394	921	694	1,034
Average	1,254	940	1,417	934	706	1,050
Maximum	1,280	966	1,451	954	726	1,075

6. Biomass Energy

According to the Spatial plan of Osijek-Baranya County, agricultural land covers 266,245 ha or 64% of total area and about 114,257 ha is covered by forest (Grigić et al. 2002).

Biogas is a product of anaerobic decomposition of organic matter; it was assumed utilization of the total amount of manure generated on farms in the County for calculation of biogas production. The amount of waste from animal husbandry is calculated on the basis of data on the number of livestock units of cattle, pigs and poultry. The theoretical energy potential of biogas production in Osijek-Baranya County on an annual basis is presented in following table (Bačan et al. 2012).

Table 9. Energy potential of biogas production in Osijek-Baranya County on an annual basis

Raw material	Availability of manure	Theoretical energy potential (MWh/year)	Theoretical energy potential (TJ/year)
Biogas production in monodigestion			
Cattle manure	344 764	189 620	683
Pig manure	251 901	41 967	151
Poultry manure	16 972	16 758	60
Raw material	Area required for growing maize silage (ha)	Theoretical energy potential (MWh/year)	Theoretical energy potential (TJ/year)
Biogas production in digestion with maize silage (silage mass portion ~30%)			
Cattle manure + silage	4 395	342 814	1 234
Pig manure + silage	3 211	153 897	553
Poultry manure + silage	216	24 279	87

According to the Spatial plan of Vukovar-Sriem County, agricultural land covers 150,856 ha or 62% of total area and about 72,000 ha is covered by forest Premuž – Štajcer et al. 2002). Approximately 40,000 ha of cultivable land is currently used by agricultural companies and livestock farms so there is a lot of potential for growth of biomass energy business, along with Osijek-Baranya County, this County has highest biomass potential in Croatia (Šljivac et al. 2008).

The theoretical energy potential of biogas production in Vukovar-Sriem County on an annual basis is presented in following table (Bačan et al. 2012).

Taking into consideration the existing practice in agriculture, assuming consolidation of livestock production and in accordance with the Energy Development Strategy of the Republic of Croatia can be estimated that about 20% of the theoretical potential could be used to produce renewable energy.

Table 10. Energy potential of biogas production in Vukovar-Sriem County on an annual basis

Raw material	Availability of manure	Theoretical energy potential (MWh/year)	Theoretical energy potential (TJ/year)
Biogas production in monodigestion			
Cattle manure	252 050	138 628	499
Pig manure	100 319	16 713	60
Poultry manure	9 535	9 440	34
Raw material	Area required for growing maize silage (ha)	Theoretical energy potential (MWh/year)	Theoretical energy potential (TJ/year)
Biogas production in digestion with maize silage (silage mass portion ~30%)			
Cattle manure + silage	3 213	250 624	902
Pig manure + silage	1 279	61 289	221
Poultry manure + silage	122	13 676	49

6.1. Biomass from forestry

The most common forms of forest biomass used for energy purposes are firewood, chips, bark, sawdust, shavings, briquettes and pellets. Wood biomass can be converted into heat and electricity as well as in liquid and gaseous fuels using various thermochemical and biochemical technologies. Table 11. presents theoretical energy potential from forest biomass, and Figure 5. shows distribution of total wood stock in Osijek-Baranya County.

Distribution of total wood stock in Vukovar-Sriem County is shown in following figure and theoretical energy potential of forest biomass is shown in Table 12.

Table 11. Theoretical energy potential from forest biomass in Osijek-Baranya County (Bačan et al. 2012)

Total timber stock (m^3)	Total annual growth (m^3)	Annual allowable cut of the stacked wood (including conifers) (m^3)		Theoretical energy potential of annual cut of stacked wood (including conifers)			
				Planned logging		Realized logging	
		Planned logging	Realized logging	GWh	TJ	GWh	TJ
22 291 528	758 689	274 143	186 370	479	1 724	344	1 239

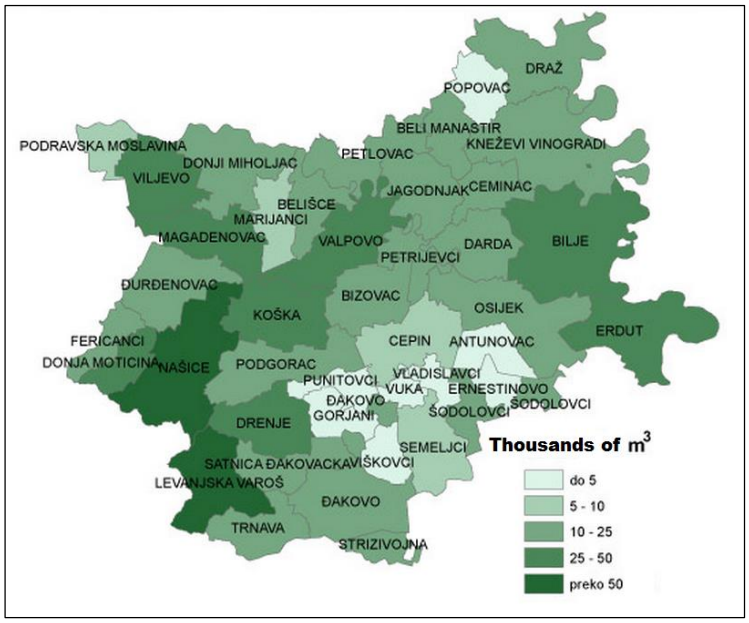

Figure 5. Total wood stock of economic forests in Osijek-Baranya County (Šumska biomasa)

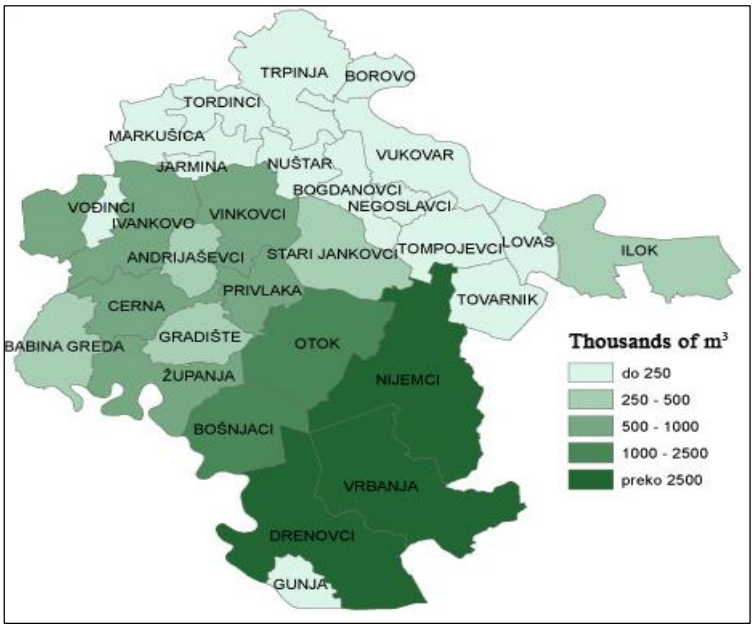

Figure 6. Total wood stock of economic forests in Vukovar-Sriem County (Šumska biomasa)

Table 12. Theoretical energy potential from forest biomass in Vukovar-Sriem County (Bačan et al. 2012)

Total timber stock (m^3)	Total annual growth (m^3)	Annual allowable cut of the stacked wood (including conifers) (m^3)		Theoretical energy potential of annual cut of stacked wood (including conifers)			
				Planned logging		Realized logging	
		Planned logging	Realized logging	GWh	TJ	GWh	TJ
19 602 016	533 733	164 037	163 571	389	1 399	387	1392

It should be noted that the energy potentials shown in tables represent the theoretical potentials. The technical potentials will depend on the efficiency of facilities for production of useful energy (stoves, heating plants, power plants, or cogeneration plants) (Bačan et al. 2012).

6.2. Geothermal Energy

In Osijek-Baranya County the value of geothermal gradients ranges from 40 to 50 °C/km. Thermal water is already found in several deep research wells like:

- Slavonka-1 – 75 °C (1667 m), water is used for spa therapy and for energy purposes (heating);
- Mandarinci-1 – 96 °C (1970–2630 m);
- Bokšić-3 and Obradovci-2 – 41°C (300–850 m);
- Ernestinovo-1 – 74 °C (1600–2100 m).

In Vukovar-Sriem County the value of geothermal gradients are little larger and ranges from 50 to 65 °C/km. Thermal water is already found in several deep research wells like:

- Babina Greda – 110 °C (1571–1585 m) and 121°C (1767–2266 m), geothermal power plant is planned to be built on this location;
- Domaljevac – 70–80 °C (1212 m), water is used for heating of greenhouses;
- Sikirevci – water of technological quality (655–665 m);
- Otok – 130 °C (2635 m) – water flow and quality still not tested;
- Ranisavlje – 130 °C (3000 and 3063–3078 m) – water flow and quality still not tested;
- Lešić – 70 °C (1063–1275 m) – water flow and quality still not tested.

With deep sources of geothermal energy in this region there is also a possibility of using geothermal energy via heat pumps that are suitable for low – temperature heating and / or cooling, and domestic hot water. Mostly their application is for small

and large objects. Heat pumps use the constant temperature of the soil at a depth of about 2 m or ground water and use it for reheating during winter and cooling during summer and / or for domestic hot water (Bačan et al. 2012).

6.3. Hydropower Energy

Hydropower potential is not recognized in this area. There is no hydropower plant under 10 MW of nominal power, and there are no plans for the construction of the same (Bačan et al. 2012).

7. Conclusions

Danube Region of Croatia, Osijek-Baranya County and Vukovar-Sriem County, has significant interest in the increasing of use of RES which is shown in this paper. Most of installed capacities of biomass and biogas power are in these two Counties and it will grow even more which is shown in chapter 3. Geothermal energy is still in process of research for whole Croatia not only for this region, but several locations have good potential for energy exploitation, it is used for spa treatments and heat. Waterpower in terms of RES is insignificant in this region, because there are no small and fast rivers. Wind power is also still unexplored area, but few locations show potential for small wind parks.

Conflict of Interest

The authors declare no conflict of interest.

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