Hydropower in the East European region
- challenges and opportunities

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Introduction

In course of the recent decade, the authors of this contribution had several opportunities to conduct analytical work on the hydropower sector status and development prospects in their countries and within the region or even worldwide. The HYDRO event - held this time in a country generally considered a part of the Eastern Europe - is a good opportunity for summarisation and presenting some results of the regional efforts at a global arena. The paper has no ambition of a comprehensive study. This would be a truly challenging task in view of numerous diversities within the region and the background of the authors, representing themselves only the Northern part of the region and Romania. Instead, our purpose is rather to present some general observations and conclusions following from our joint work and to give an insight to some trends that may provide a positive stimulus for further development of the sector or just pushing it out of the current stagnation or even recession in some parts of the region. Brief reports on local administrative regulations and practices as well as major projects will illustrate the main text. In view of the HYDRO 2018 venue, preference is given to situation in the host country.

The international initiatives, the authors were involved in, include among others:

- several EU projects co-ordinated in the years 2004-2014
  by the European Small Hydropower Association (ESHA[1]) [1÷3];
- the World Small Hydropower Report 2016 issued jointly by the UN Industrial Development Organisation (UNIDO, Vienna) and the International Center on Small Hydro Power (ICSHP, Hangzhou, China) [4];
- several RENEXPO events held recently in Warsaw [5]
  and the 1st East European Hydropower Forum held in 2017 in Salzburg.

Despite small hydro remaining in focus of the first two groups of projects, the scope of the analytic work generally covered also large hydro, which is the reason for using results of the above initiatives as a reference together with some other data sources. Most of the countries taken under consideration in this contribution are either EU members or candidates. Despite significant differences in their hydropower assets and potential, all of them are subject to the same EU policy and global trends which on the one side support the idea of developing the renewable energy sources and on the other try to prevent any local environmental effects. In some countries the rigorous implementation of relevant environmental directives and the pressure from the green NGOs have led to almost total blockade of any further hydropower sector development. The signs of recession can be noticed locally. The situation may change due to the rising understanding of the need to enhance the water and energy storage capacities in the context of the ever

[1] Due to falling in severe financial problems, ESHA ceased its activities shortly after the mentioned period. In view of the obvious need for the small hydro sector representation at the EU level, efforts are made by the Small Hydro Chapter of the European Renewable Energy Federation (EREF) to take over the previous ESHA responsibilities.

more severe climate change effects (extreme droughts and floods) and the increased impact of unstable renewables on the state grid. Another significant factor is the intention to ease the environmental load of land roads by enhancing or at least restoring the inland navigation routes. In particular joining the AGN convention on European waterways is perceived in Poland as the last chance to revive the 70-years old Lower Vistula cascade project and a stimulus for continued work on the Oder river. It may be also a chance for some other regional initiatives including the Danube/Elbe/Oder inland navigation node with some hydropower schemes incorporated.

The term "Eastern Europe" covers of course such countries like Belarus, Moldova, Ukraine and Russian Federation, which on the one hand may feel lower pressure from the green NGOs and on the other one have to cope with economic and political problems of even higher significance. The Russian Federation itself is a country with vast territory covering more than 2/3 of the Eastern Europe region under consideration and ca 40% of the total surface of Europe. Its immense potential and vast assets have a profound effect on the regional statistics. Due to this reason, it is also explicitly stated whenever Russian Federation data are or are not included in the consideration.

1. Background

According to the UN nomenclature, the term "Eastern Europe" covers 10 countries: Belarus, Czech Republic, Hungary, Moldova, Poland, Romania, Slovakia, Ukraine and Russian Federation (see Fig.1 and Table 1). The classification may be considered well justified geographically and has been recently adopted by the already mentioned WSHPDR 2016 document. However, on numerous occasions also the Baltic states in the North (Lithuania, Latvia and Estonia) as well as the Western Balkan states in the South (the former Yugoslavian republics) are considered a part of the region as well. Such an approach has been also adopted by the REECO GmbH company when organizing the 1st East European Hydropower Forum held in 2017 in Salzburg. Besides the purely geographical division, the political and economic experience of the XXth century as well as some ethnic ties are surely a significant reason for this classification. This very approach has been adopted also by the authors of the current study. The scope of our considerations does not cover Albania and the Caucasus republics of Georgia, Armenia and Azerbaijan, occasionally included into the region as well.

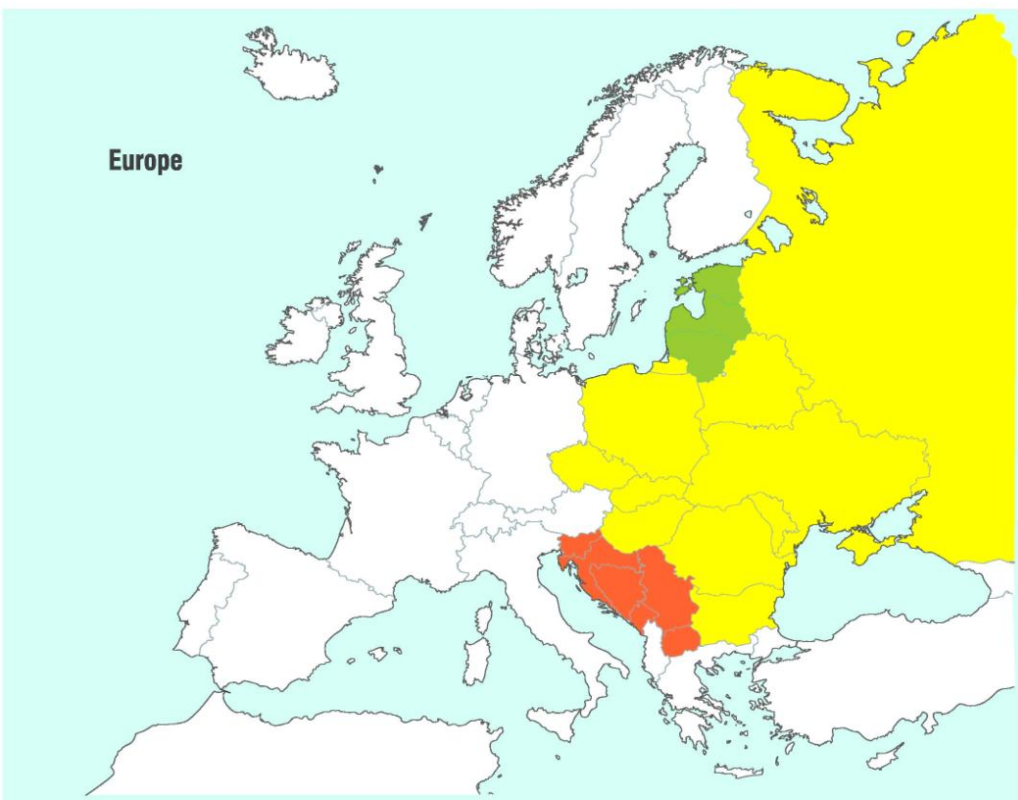

Fig.1 The East European region under consideration

The region under consideration is crossed by major European rivers, including Danube, Dnieper, and Volga - all of them of great significance both for the inland navigation and the hydropower use. The technical potential of Danube (ca. 43 TWh/a) and the economic potential of Volga (ca. 42 TWh/a) are higher than the technical potential of any single country within the region – excluding the Russian Federation. The above list of powerful rivers may be supplemented by a number of other ones, including Pechora, Northern Daugava, Kama, Terek and Sulak at the territory of Russian Federation and (Western) Daugava, Nemunas, Vistula, Vah, Sava, Prut or Dniester in the rest of the region. Oder and Elbe rivers at the western outskirts of the region are worthwhile to be mentioned due to their essential importance for the European inland navigation systems.

The hydropower potential of Danube, Dnieper and Volga has been already substantially exploited which does not imply there is no place for any further projects here - just to mention the disputed schemes of Pečensky Les (Wolfsthal) and Visegrád/Nagymaros at the Slovak/Austrian and the Hungarian segments of Danube. Following the Blue Heart report [6] new installations are under consideration also at the Bulgarian/Romanian segment of the river.

As shown in Table 1, the region is highly differentiated in respect to its economic capacities and demography as well as the hydropower potential and its use. Hydropower is a significant source of energy for all the Balkan states (except Kosovo) as well as Russian Federation, Romania, Czech Republic, Slovakia and Latvia. In all these countries the hydropower contribution to the mix of generated electricity exceeds 15 %, surpassing the threshold of 50 % in Montenegro and Croatia. On the other end are countries with hydropower input below 2 % - Estonia (0.3 %), Belarus (0.4 %), Hungary (0.8 %) and Poland (1.4 %).

Apart from the Russian Federation, the highest hydropower potential exists in Romania and Ukraine where it is used in 47 and 52 %, respectively. The leader in the use of the hydropower potential is Latvia (73 %). High use of hydropower resources may be stated also in the Czech Republic (57 %), Slovakia (65 %), Croatia (58 %), Serbia (54 %) and Slovenia (47 %). The smallest use of the potential is to be observed in Hungary (2.8 %), Belarus (4.6 %) and Estonia (6.5 %). It is worthwhile to mention that Belarus and Estonia are lowland countries showing also the lowest hydropower potential concentration - 12 and 9 MWh/(a·km^2), respectively. At the same time, Belarus makes significant efforts to increase its own hydropower capacities in order to ease heavy dependence of its economy on the imported natural gas. With commissioning of the Vitebskaya HPP (40 MW) at Daugava river it has already increased the use of Belorussian potential to over 7 % last year. The highest concentration of the potential – between 200 and 600 MWh/(a·km^2) - is to be stated in the former Yugoslavia. Romania, Slovakia and Bulgaria follow the former Yugoslavian republics with the average potential density between 130 and 150 MWh/(a·km^2).

The total technical potential of Russian Federation is estimated at the 1 670 TWh/a level of which merely 229 TWh/a is considered to be located in Europe [7]. Hydropower installed capacity and the normalised generation values[1] at the European territory (including the Ural region) - as estimated by adding contributions from 5 regional divisions of the Russian United Power System (UPS) operator - are close to 19,5 GW and 65,3 TWh/a, representing thus 35 and 46 % of the total East European regional values, respectively. The differences in relative capacity and generation contributions result most probably from higher proportion of the pumped storage and more frequent peak-load operation at the territories outside Russia. Some of the 2 GW differences in the all-Russian data of the UPS [8] and IHA [9] and those of international energy agencies (e.g. EIA [10], WEC [11], IRENA [12]) may result from the capacities in the North-Eastern Siberia which are run by local autonomous operators and from some inaccuracies in data processing.

A significant portion of the unharnessed East European hydropower potential is linked with the abovementioned large rivers and their catchment basins. With 6 TWh/a the Vistula river alone (without the rest of the catchment basin) represents a half of the Polish technical hydropower potential. Due to various reasons this is used in less than 15 % - mainly by a single hydropower plant in Wloclawek – bringing over 1/3 of the total renewable hydropower generation of Poland. Unharnessed river potential is known also to exists at the above mentioned rivers in the South and North of Russia as well as at Nemunas, Prut and Dniester.

[1] According to Annex II to the EU directive 2009/28/EC on the promotion of the use of energy from renewable sources this is calculated by multiplying the multiyear average duration of annual installed capacity use (in hours) by the installed capacity value (in power units) in the last year of the averaging period. The directive recommends using the periods of 15 years duration, but in case of lacking statistics averaging over shorter periods has been applied by the authors of this contribution.

Table 1 Main statistical data of the countries under consideration. Most data valid for 2016. Reproduced from or calculated basing on [7÷18]

Country/region	General data				Hydropower sector					
	Area	Population	GDP	Electricity generation	Technical potential	Techn. potential density	Normalised generation	Total capacity	Technical potential use	Contribution to energy mix
	10^3 km^2	thousand	M€	TWh	TWh/a	MWh/(a·km^2)	GWh/a	MW	%	%
1. Belarus	207,6	9 499	42 863	33,6	2,5	12,0	114	50	4,6	0,4
2. Bulgaria	111,0	7 102	48 129	45,3	15,1	135,6	3 718	3 223	24,7	8,4
3. Czech Republic	78,9	10 611	176 370	83,3	4,0	50,7	2 276	2 071	56,9	2,7
4. Hungary	93,0	9 798	113 731	31,9	8,0	86,0	225	57	2,8	0,7
5. Moldova	33,8	3 474	6 118	0,9	1,0	29,5	361	64	36,1	6,3
6. Poland	312,7	38 422	425 941	166,6	12,0	38,4	2 318	2 385	19,5	1,4
7. Romania	238,4	19 638	170 892	65,1	36,0	151,0	16 798	6 744	46,7	26,2
8. Slovakia	49,0	5 435	81 154	27,1	7,0	142,8	4 537	2 493	64,8	16,4
9. Ukraine	576,6	42 418	84 235	164,6	22,0	38,2	11 380	6 162	51,7	6,9
Eastern Europe 9	**1 701,1**	**146 397**	**1 149 433**	**618,3**	**107,6**	**63,2**	**41 555**	**23 149**	**38,6**	**6,7**
Russian Federation	17 172,0	144 300	1 393 900	1 072,0	1670,0	97,3	180 524	50 624	10,8	16,8
10. RF European Part	**4 000,0**	**110 000**	n/a	**807,6**	**229,0**	**57,3**	**65 300**	**19 465**	**28,5**	**8,1**
Eastern Europe 10	**5 701,1**	**256 397**	n/a	**1425,9**	**336,6**	**59,0**	**106 855**	**42 614**	**31,7**	**7,5**
11. Lithuania	65,3	2 810	38 668	4,0	2,0	30,6	425	1028	21,4	10,0
12. Latvia	64,6	1 953	24 926	6,4	4,0	61,9	2 917	1 563	72,9	45,4
13. Estonia	45,2	1 318	21 098	12,2	0,4	8,8	26	6	6,5	0,2
Baltic states	**175,1**	**6 081**	**84 692**	**22,6**	**6,4**	**36,5**	**3 368**	**2 597**	**52,6**	**14,7**
14. Bosnia&Herzegovina	51,1	3 791	15 288	17,8	24,0	469,4	5 594	2084	23,3	31,5
15. Croatia	56,6	4 154	46 640	12,8	12,0	212,0	7 036	2 202	58,6	54,9
16. Macedonia (FYR)	25,7	2 073	9 723	5,6	6,0	233,3	1 551	660	25,9	27,6
17. Serbia	77,5	7 058	34 616	39,3	19,5	251,3	10 665	3 030	54,8	27,1
18. Kosovo	10,9	1 908	6 070	6,00			126	86		2,1
19. Montenegro	13,8	622	3 954	3,1	8,0	582,4	1 802	651	22,4	57,4
20. Slovenia	20,3	2 066	40 418	16,5	9,0	443,9	4 306	1 177	47,8	26,1
Former Yugoslavia	**255,9**	**21 672**	**156 709**	**101,2**	**78,5**	**306,8**	**31 080**	**9 890**	**39,6**	**30,7**
Eastern Europe 20	**6 132,1**	**284 150**	n/a	**1 550,6**	**421,5**	**68,7**	**141 303**	**55 101**	**33,5**	**9,1**

Note: Normalised generation based on the data up to 2015.

The data on the economic potential are diverse and highly dependent on the relevant national policies, including the tax and electricity tariff systems. Most storage schemes (except pure pumped storage) are multipurpose projects and therefore should be financed at some stage by all beneficiaries. In particular, state or local administration support may be expected in case of projects serving water retention, flood protection and inland navigation purposes. The approach to these issues may differ not only from country to country, but also from project to project which makes any long-term feasibility assessments really difficult. The value mentioned typically for the whole territory of Russian Federation is 852 TWh/a. However, the value of 363 TWh/a or even lower is encountered nowadays ever more frequently. The values indicated for the European part are between 162 [7] and 69.5 TWh/a [19], respectively. With the last value adopted, one may conclude that almost all available potential in European Russia has been already harnessed.

The situation may get even more complex in case the environmental constraints are included into considerations. The restrictive policy of Lithuanian authorities has downgraded the available technical potential of the country by a factor of 7 in result of exempting most of the rivers from any hydropower infrastructure construction and even requiring dismantling the existing weirs at some watercourses. The remaining potential cannot be considered a physical, technical or even an economic parameter as it clearly depends on the current interpretation of EU directives by the ruling politicians. On the other hand, it is to be noticed that preliminary environmental qualification of prospective hydropower plant locations by a strategic government document may be of great help for potential investors as it enables avoiding the unnecessary effort and costs of environmental processing of sites without any major chance for a positive administrative decision. An example of such a document is the "Concept of harnessing the hydropower potential of watercourses of the Slovak Republic within the horizon of year 2030" as adopted by the Slovak Cabinet in 2011 [20]. Hydropower development strategy exists among others also in Romania where *Hidroelectrica* assumes erection of altogether 22 plants of total 385 MW capacity in the period 2004-2025 [21].

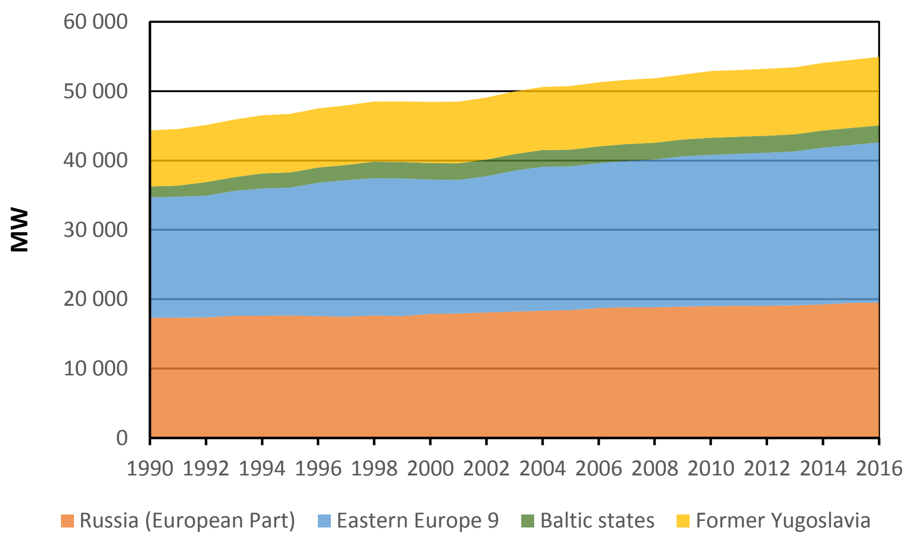

Fig.2 Installed capacity of the East European hydropower sector (since 1990)

Looking at the installed capacity diagram as shown in Fig.2, one can see a steady growth trend of 400 MW/year or 0.8 %/a within the 1990-2016 period (as referred to the mean value). However, the true image is much more complex as developments of deep consequences for the political and economic status of the region and significant global impact took place at the same time. It is enough to mention the Eastern Block collapse followed by that of the Soviet Union, political system transformations within the region, heavy crisis in Russia and some other post-Soviet republics, disintegration of Yugoslavia followed by the Balkan wars, EU enlargement and the current conflict in the East of Ukraine. In result of changes in the economic situation, but also in the energy sector doctrine as well as political plays with local green NGOs and pure incompetence of relevant authorities, the hydropower sector has fallen into stagnation or even recession in some countries. This concerns in particular some new EU member states with green movement having a profound impact on the public opinion as well as implementation of the WFD and the habitat directives as it can be surely observed in Hungary and Lithuania and to some extent also in the Czech Republic, Poland and Romania. In practice, any further development of conventional (renewable) hydropower in most EU member states has been restricted to the small hydro sector.

On the other hand there are some countries within the region - especially outside the EU and with unfavourable balance of own energy carriers - truly committed to increase the installed hydropower capacities in order to enhance their energy sovereignty. This approach can be noticed now in most Balkan states [6, 22] as well as in Ukraine [23÷25] and Belarus [26, 27]. A moderate, but steady rise of installed capacity can be stated also in the Russian Federation [28, 29]. However, the progress within the European part (0.5 %/a) is slower than that in the whole Russian territory (1.1 %/a within the 2009-2016 period) and even lower than the East European average.

A spectacular result of a change in the national policy under influence of green NGOs was the well-known dispute over the Gabčikovo/Nagymaros multipurpose project at the Danube segment of the Slovak-Hungarian border. The project was initiated in 1977 with an agreement reached by Czechoslovak and Hungarian governments. In the end of eighties Hungary suspended its involvement under pressure of local ecological circles. Shortly afterwards Slovakia decided to continue the project on its own by diverting the major portion of Danube waters into a navigable canal at its territory and erecting there the Gabčikovo power plant of 720 MW capacity. The installation produces annually ca. 2 TWh of "green" electricity bringing alone an 8 % contribution to the national grid. The environmentally valuable segment of the original Danube riverbed has been thus bypassed, but lacking agreement on the previously envisaged Visegrád/Nagymaros dam downstream of the Gabčikovo canal outlet prevents stabilisation of water level within the protected area.

The pronounced impact of political developments and economic situation on the hydropower sector within the region can be explained also by following the installed capacity diagram within the current borders of the Republic of Poland (Fig.3). Like in many other countries of the region, the history of hydroelectric industry began here with quite small installations erected in the end of XIXth century. Few years before World War I, the demand for electricity at the former German territories rose to a level allowing entering much larger schemes, including multipurpose projects accomplished on the public/private partnership basis. Over 100 years after its erection the masonry dam of the Pilchowice scheme at Bober river (Lower Silesia) is the second high structure of this kind in Poland. The highest one is Solina dam at San river in the South-Eastern part of the country, erected in the second half of sixties together with a recently upgraded pumped storage power plant (currently: 200 MW, including 60 MW in reversible units).

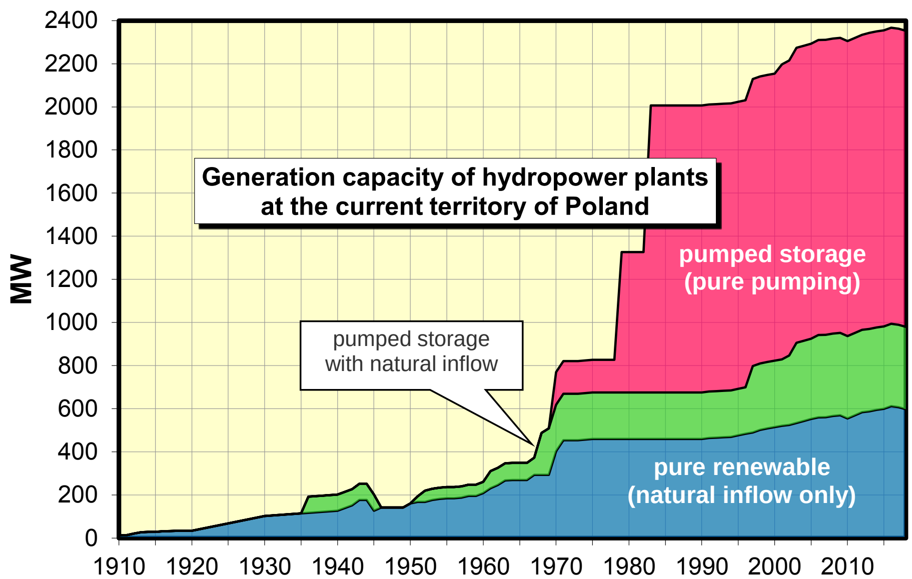

Fig.3. Generation capacity of hydropower plants at the current territory of the Republic of Poland

The sector growth at current Polish territories accelerated in twenties and later on in sixties. However, commissioning of the Wloclawek HPP (160.2 MW) at Vistula river in 1970 put the end to development of classic large hydro in Poland as so far. The already organised building site of the next dam in the Lower Vistula Cascade was closed in result of the fateful economic and political crisis of 1980/1981. Numerous attempts to revive the project later on have appeared ineffective until the recent days. Wloclawek remains the largest classic hydropower installation in Poland and most probably this state will not change in future.

Two major projects on the long way to commissioning of Solina and Wloclawek power plants are easily discernible from Fig.3. The first one is the Dychów (German: Deichow) pumped storage power plant (79 MW in turbine units + 20 MW in storage pumps) located at the Bober river, close to its estuary to Oder (former German territory). The plant was commissioned in 1936 with the purpose to supply Berlin with electricity in the peak load hours. The second one is Roznow HPP (50 MW) at Dunajec river in the South of Poland, erected in consequence of a disastrous flood of 1934, but commissioned only under Nazi occupation conditions. Both installations suffered in 1945. Roznow units were put out of operation by retreating German troops who dismantled and damaged the governors. The original Dychów hydroelectric equipment was completely dismantled and sent to the Soviet Union as a part of the initiated action of war reparations. The full capacity of Dychów power plant was restored only in 1961 after installing hydraulic units of LMZ manufacture. 10 years ago the power plant was upgraded to 90 MW rated capacity.

The post-war economic strategy of the Republic of Poland, as well as some other Eastern Block countries, was to develop its heavy industry as a basis for future production of consumable goods. However, with the energy sector heavily dependent on coal supplies this implied also that a major portion of the heavy industry production was to be used by the mining industry. In fact, attaining significant net progress in the national economy required doubling electricity supplies every decade. With its modest technical potential the Polish hydropower sector had no chance to take part in this fatal race as a meaningful supplier of energy in the load basis. However, it was generally recognised - from the beginning of sixties at latest – as a significant regulation and safety tool in the hands of the national grid operator. 3 years after commissioning of the Solina Hydropower Plant with two prototype pump-turbines of ČKD Blansko manufacture, the Żydowo Pumped Storage Power Plant (2×50 MW in reversible units and 1×50 MW in Francis turbine unit) was put in operation in Pomerania. This was the beginning of a major investment programme of erecting 10 pumped storage installations in Poland. The programme included Porąbka-Żar (500 MW) and Żarnowiec (currently 716 MW) plants, both successfully commissioned in 1979 and 1983, respectfully. Another extensive investment scheme was the vast Vistula Programme assuming erection of multipurpose barrage cascades at the Upper, Middle and Lower Vistula. The Lower Vistula Cascade alone was planned to provide over 4300 GWh of annual electricity generation and ca 1340 MW installed power, in greater amount easily available for the grid operator as a swift regulation band. The vast reservoir capacities were to be used for water retention and flood protection purposes as well as a source of cooling water for the thermal plants - planned to be erected along the river and supplied with Silesian coal using the water transport means. Developing the wastewater processing facilities at the towns located along Vistula was another component of the project. It is worthwhile to be emphasised that one of significant arguments for developing water storage capacities at this time were alarming reports on falling level of underground waters and the deepening water deficit across the country.

The example of Poland is very symptomatic for the East European region and the development of its hydropower sector. Due to reasons explained below some phenomena and processes typical also for other Comecon[1] countries could be observed here in an extremely sharp light. It can be seen also, how vulnerable the hydropower industry may be to the adopted national economic strategy or lack of this strategy. Polish economic situation in the end of 1970-ies was grimmer than that in the neighbouring countries. The main reason was the irresponsible - wishful thinking based - policy of investing huge financial means in ineffective economy and increasing consumption at the same time. The economic crash at the end of this period was especially painful for the hydropower sector. Both hydropower development programmes got shrunk and eventually stopped. The only two major projects still under development were Żarnowiec and Niedzica pumped storage power plants. Żarnowiec PSPP was already a highly advanced investment venture. Its top priority significance was due to planned operation in parallel with a nuclear power plant, under construction at the other side of Żarnowiec Lake. Eventually the nuclear project was stopped and closed in the beginning of nineties under extremely strong pressure of environmental movements. Unfortunately, used extensively in a fierce political campaign. Żarnowiec PSPP keeps still its position of the largest hydropower installation in Poland.

Niedzica project (including pumped storage power plant of 92 MW capacity) was developed by the Regional Water Management Authority in Cracow with the purpose to protect the upper Dunajec valley against the flood threat. With an almost 15 years delay, in July 1997, the filling of the reservoir was completed in one day by a millennium floodwater. In completely different economic and political reality. There exists an opinion that the project paid back on the single day of floodwaters wave top passing Niedzica. This did not stop some fierce green opponents from claiming that investing in rescue equipment would have been a much better choice.

[1] Council of Mutual Economic Assistance, a body coordinating the economic strategy of the Eastern Block members

Niedzica Hydropower Plant remains the last large hydro installation erected in Poland so far. Any further growth in the hydropower installed capacity of Poland, having taken place since 1997, results from upgrading the existing installations and development of the small hydropower sector. However, a significant rise in normalised electricity generation – from 1,4 TWh/a in 1990 up to over 2.3 TWh/a 25 years later - seems to follow only partially from this investment. A significant factor was the change in the operation strategy of numerous storage plants and river cascades following both from the change in the national grid operator policy and from the European and national legislation. On the one hand, the grid operator has started to use extensively the newly refurbished blocks in thermal power plants for regulation according to the low speed daily grid load variations. Major industrial consumers have been also involved in grid regulation procedures by contracts promoting flexibility in electricity consumption. On the other hand, the ever more restrictive environmental requirements have substantially limited the headwater regulation band in storage power plants. Finally, in 2004 the green certificate system has been introduced promoting generation in the base load regime instead of regulatory services. The owners of hydropower installations have been encouraged to maximize their generation at all levels – hydraulic units, power plants and plant complexes/cascades.

Redevelopment of small hydro has been a global trend since the oil crisis in 70-ies. In Poland, a significant stimulus was permanent electricity deficit due to the power sector developing slower than the energy consuming sectors of industry. The ever more frequent outages of electricity supply at the distribution grid outskirts were especially painful for owners of large, newly upgraded agricultural greenhouses as well as milk and poultry farms. Electricity supply outages and failure to keep the standard grid parameters were typical also for some other countries, especially Romania and Bulgaria.

Under such circumstances, the Polish authorities switched the first "green light" for the private hydropower sector by a Cabinet decision of 1981. After decades of small hydro degradation. Both due to the official reluctance to private ownership and to keeping low electricity prices. The fatal policy oriented on keeping the living standards at acceptable level and stimulating the economic growth by keeping low energy prices was probably one of factors contributing substantially to the economic decline of the whole Eastern Block. The revival of private hydropower in Poland was slow and difficult. Still in 1985 the number of small private installations did not exceed the threshold of 12 and 5 years later there were only 67 such plants in operation with total capacity close to 3 MW. Today the private hydropower sector in Poland counts over 620 installations. According to the "Energetyka Wodna" quarterly, in 2017 over 160 SHP projects were under preparation. 57 of them – with total capacity of 23 MW – have already passed the environmental assessment procedure [30].

The regional leader in the number of small hydropower plants (< 10 MW) is Czech Republic which has surpassed the threshold of 1600 SHP installations with total capacity 334 MW in 2016. Higher installed capacity can be stated in Romania. The data of the Romanian Small Hydropower Association (ROSHA) show 612,6 MW capacity installed in 466 SHPs in the beginning of this year. According to the National Power System Operator 125 of them are owned by the public sector (*Hidroelectrica* company). ROSHA reports 102 private investors owning the rest of assets.

Unfortunately, the recent years have seen a substantial slowdown in the small hydro sector development in numerous EU countries. According to the EUROSTAT data, stagnation or even recession have hit in the recent 3 years not only the Baltic states and Hungary, but even Slovenia and Montenegro. Despite the already mentioned ambitious plans for further hydropower development in the former Yugoslavian republics (see also section 3). In this context it is worthwhile to mention that according to the Polish energy regulator, the installed capacity of Polish hydropower plants in the end of 2017 was by 5 MW lower than that in the end of 2016. The long expected commissioning of Świnna Poręba (4.5 MW) and Malczyce (9 MW) plants in the 2018/2019 years may change this trend for some time, but the long-term forecasts will depend on the progress of the "Wody Polskie" investments and more importantly - restoring profitability of small hydro projects and investors' belief in stability of the existing rules.

The East European hydropower sector shows lower proportion of the pumped storage capacity than the rest of Europe. In 2016 the pumped storage capacity of the region was roughly 10,2 GW which represented nearly 18.5 % of the total capacity of the East European hydropower - a value by 4.5 % lower than the European average. The reason should be sought in vast storage capacities of classic hydropower cascades - especially of Volga-Kama and Dnieper - which for a longer time provided sufficient regulatory power band for the Soviet Union grid. However, with development of the conventional and nuclear thermal power sectors and the stepwise exhausting of the most feasible hydropower potential at the European part of the USSR, it was already in 1960-ies that the studies on erecting the pumped storage power plants started here. Similar studies were conducted at this time already in some other countries of the region - Yugoslavia, Czechoslovakia and Poland. In Poland the first reversible hydraulic units were commissioned as early as 1968 (Solina HPP). As it can be seen from Fig.4, in 2016 Poland retained the leading position within the region with installed pumped storage capacity of 1782 MW, including 1406 MW in pure pumped storage. The situation may change soon as Ukraine continues the fairly advanced Dniester Pumped Storage Power Plant project with 2268 MW (7×324 MW) capacity planned in the turbine operation mode. When completed, the Dniester PSPP will represent the most powerful pumped storage installation in Europe. Under construction is also the Tashlyk pumped storage scheme with the target turbine mode capacity of 900 MW. Together with the Kiev PSPP (236 MW, in operation since 1972) as well as the Kanev PSPP (1000 MW) already under design [30] one may expect the total capacity of Ukrainian pumped storage to surpass the 4.4 GW level somewhere at the turn of twenties and thirties. The continuous rise in the pumped-storage capacity is of great significance for the Ukrainian grid operator who achieves an opportunity to lower the unfavourable involvement of thermal power plants in the grid regulation processes.

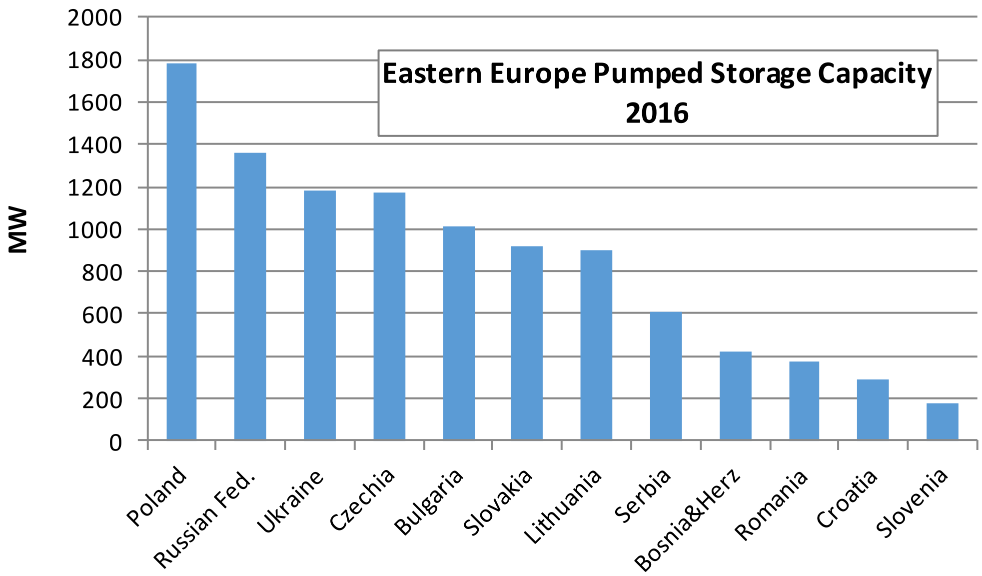

Fig.4. Pumped storage capacities within the East European region in 2016 [12]

After removing the consequences of a construction catastrophe at the Zagorskaya-2 PSPP building site, the RusGidro company will probably continue with the project (840 MW), now shifted to 2024. The completion of the project will result in surpassing the 2 GW threshold in the Russian pumped storage capacities. The other pumped storage projects under consideration within the region include the Ipel' PSPP (600 MW) in Slovakia and the Kozjak scheme at Drava River in Slovenia (2×220 MW). Further installed capacity development potential exists in the Kruonis PSPP in Lithuania (currently 4x225 MW), but with closed Ignalina Nuclear Power Plant and lost referendum on developing a new nuclear installation, the question of ancillary services demand is crucial. Additional reversible unit with variable speed capabilities may be a highly competitive tool for compensating the grid parameter fluctuations introduced by the wind power plants even outside the Baltic states region [32].

2. Challenges

2.1 Instability

The hydropower growth in some East European countries is slowing down. With the average growth rate in the renewable hydropower installed capacity falling from 0.63 %/annum to 0.58 %/annum between the 1995-2005 and 2005-2015 decades, the statistical data show the most significant deceleration in Slovakia, Lithuania and Poland (Table 2). Significant slowdown on the decade to decade basis may be observed also in Bulgaria and Estonia. However, with the growth rate above 1.0 %/a in the 2005-2015 decade, the 2 last countries remain still well above the regional and European average. 1 MW added to the Estonian capacity over the last decade implies also a 20 % increase in the total hydropower assets of this country.

The countries having shown true acceleration in the sector growth within the recent two decades include Belarus, Croatia, Latvia and Ukraine. Progress on a decade to decade basis is to be noticed also in Hungary and Moldova. The statistical data for individual post-Yugoslavian republics show highly differentiated dynamics, but the overall growth in the hydropower capacity of 1 %/a can be noticed over the territory of former Yugoslavia. The steady although quite modest growth (0.4÷0.5 %/a) prevails in the European part of Russian Federation, Czech Republic and Romania.

Table 2. Growth in the renewable hydropower sector capacities within the 1995-2015 period [10, 18]

	Country/subregion	Capacity, MW	Growth, MW		Growth rate, %/a		Change factor
		2015	1995/2005	2005/15	1995/2005	2005/15	
1.	Bulgaria	2 206	583	222	3,44	1,06	0,31
2.	Czech Republic	1 613	111	99	0,76	0,63	0,83
3.	Slovakia	1 812	175	29	1,03	0,16	0,16
4.	Hungary	57	1	8	0,21	1,51	7,32
5.	Poland	982	230	57	2,84	0,60	0,21
6.	Romania	6 731	255	465	0,42	0,72	1,72
7.	Moldova	64	3	5	0,52	0,81	1,56
8.	Belarus	37	5	25	5,57	9,96	1,79
9.	Ukraine	4 697	11	216	0,02	0,47	19,15
10.	Russ. Fed. (European Part)	19 239	734	908	0,41	0,48	1,18
	Eastern Europe 10	**37 438**	**2 108**	**2 033**	**0,61**	**0,56**	**0,91**
11.	Estonia	6	4	1	13,33	1,82	0,14
12.	Latvia	1 589	15	53	0,10	0,34	3,46
13.	Lithuania	128	16	4	1,38	0,32	0,23
	Baltic States	**1 723**	**35**	**58**	**0,21**	**0,34**	**1,61**
14.	Bosnia and Herzegovina	1 746	231	296	1,73	1,85	1,07
15.	Croatia	1 915	23	111	0,13	0,60	4,65
16.	Macedonia (FYR)	632	117	92	2,43	1,57	0,65
17.	Serbia	2 322	-	101	-	0,44	-
18.	Kosovo	46	-	1	-	0,22	-
19.	Montenegro	667	-	9	-	0,14	-
20.	Slovenia	1 075	222	96	2,56	0,93	0,37
	Former Yugoslavia	**8 403**	**593**	**706**	**0,80**	**0,88**	**1,09**
	Eastern Europe 20	**47 564**	**2 797**	**2 685**	**0,63**	**0,58**	**0,96**

The situation of an analyst commenting the hydropower status basing on statistical data shown in tables and diagrams is completely different from that of a private investor risking the earnings of his whole life by investing in a small hydro project that may appear unprofitable at some stage. Quite irrespectively of the usual technical and business risk, including that linked with unsuccessful, but quite expensive and time-consuming environmental procedure.

Instability in the rules of play, including also retroactive impact of some acts of law and other regulations, is a true nuisance for numerous investors within the region. Both small and large ones, often reluctant to take any risk at all in view of their responsibility before the relevant supervisory board or a politician representing the state owner. The challenge of instability in the legal environment, but also the whole policy towards the sector, goes far beyond the scope of this contribution. The reasons may go as deep as insufficient maturity of the democratic system allowing politicians to play with the living economic tissue, to change their policies and strategies without any major consensus and consultation with professionals, and to conduct frequent staff changes at positions requiring high professional competence and long year experience.

2.2 Sustainable growth and environmental thinking

"Sustainable" is an English, self-explanatory word overused in Europe and worldwide since the beginning of nineties of the previous century. Better or worse translated into various languages, sometimes confused with the term "balanced". Unfortunately, frequently interpreted as a requirement to keep to specific local environmental priorities while neglecting the global ones.

Environmental priorities are often contradictory and globally balanced thinking is lacking in the same way as readiness to a reasonable compromise. The requirement to keep the ecological system in its current state - usually far from the original one - often stands in contradiction with the need of increasing retention as a counter-measure to the climate change and lowering of the ground water level. It is enough to mention that with only 6.5 % of annual rainfall kept in the storage ponds Poland - a country located in the mild climate zone - has been suffering for a longer time from the ever-rising water deficit on the one hand and the flood threat on the other one. Local priorities, such as those of the angling associations, stand often in contradiction with fundamental global environmental goals, just to mention lowering the carbon dioxide emissions in result of increasing the green energy input to the energy mix or sparing the fossil fuels for future generations. In some countries, the hydropower sector is able to contribute substantially to the energy mix just by increasing its generating capacity. In the other ones (e.g. Poland and the Baltic states) even more pronounced effect can be attained by using energy capacities of hydropower reservoirs to rise grid flexibility and its capability to accept unstable sources of renewable energy. Unfortunately, the existing storage capacities are often neglected and battery storage is strongly promoted instead rather than in addition to pumped storage. Irrespective of the limited capacities and heavy environmental burden after battery lifetime has come to the end.

The purpose of this consideration is not to list all the environmental and other benefits coming out of hydropower and to confront them with the arguments of opponents. Instead, it is rather to emphasise that the balanced, multi-aspect approach and fair weighing of all arguments are missing on numerous occasions - not only in the course of environmental procedures, but also and most importantly when designing the relevant legal regulations. This mental problem is to be mentioned at this place, as it seems to stand in the background of a number of other challenges, just to mention an unfavourable impact on the media, education system, research & development infrastructure and eventually - on the hydropower image in the eyes of society. Educational aspect is especially painful as in some countries (e.g. Poland) it concerns all levels of education, including professionals to be employed by the power plant owners as well as by design offices and equipment suppliers.

2.3 Law and economy

The economic position of each electricity generating company is based on a proper balance of several components, including income (remuneration for supplied electricity, including possible additives following from the relevant support mechanism), operation and maintenance costs, investment in new capacities, taxes and other fiscal and non-fiscal burdens. In the beginning of nineties, numerous East European countries supported already the small hydro sector by the feed-in-tariff system and some procedural facilitations. The storage hydropower plants and cascades run in the swell operation mode could benefit from additional profit for the peak-load operation and their high availability including running under frequency and power or voltage control system. With implementation of the European directives on promotion of energy from renewable energy sources, the support systems became more generous although in some countries the hydropower sector suffered much worse access to investment incentives than the other renewables. At the same time the growing influence of green movements as well as implementation of the Water Framework Directive and the habitat directives have not only effectively hampered the growth of installed capacity, but also left numerous storage power plants without possible benefits following from the peak-load operation. In Poland this situation was acceptable for the plant owners so long as the green certificates system remained stable.

Lowering support for renewable energy sources in the beginning of the current decade was a general European trend resulting both out of the global economic crisis and the assumed policy of decreasing state intervention into the competitive energy market. After years of subsidizing generation of green electricity, the European governments appeared more willing to support the investment process instead. In Poland the change of support mechanism was not a well organised process. Firstly the green certificate system was allowed to collapse in the beginning of the decade in result of stopping the systematic increase of the indicative annual target of renewable energy contribution to the electricity mix. Despite swift rise of the input coming from biomass co-firing in thermal power plants and the systematic growth of the wind energy sector. Then only at the turn of 2016 and 2017 a stepwise transition to an auction system was initiated. In the meantime numerous SHPs fell in financial difficulties and the general feeling of uncertainty resulted in slowing down the investments. With severe consequences for suppliers of equipment and services.

Even after 2016 numerous Polish SHPs (< 5 MW) could not restore their profitability as entering the system required a number of conditions to be fulfilled including investment into substantial rehabilitation of the older installations. Furthermore the risk of profitability loss after the 15 years support period has remained. A solution for the most heavily affected installations will be probably introduction of a feed-in-tariff system for SHPs with capacity below 1 MW. The relevant legislation is processed now by the Polish Parliament [33]. As shown by several analyses conducted by the Polish Hydropower Association [34÷36] this will not remove the problems of some other power plants with capacity below 5 MW or even higher. Especially, as some storage power plants, previously used extensively in the peak-load operation, show very high "overcapacity factor", a feature equivalent to a low number of hours of the annual installed power use.

Discrimination of the storage hydropower plants in most European renewable energy support systems follows from using installed power as a measure of their capacity to generate energy on the annual basis and hence also as a basic parameter deciding on applying a relevant legislation. This "original sin", written down into European directives, is really painful for plants having been designed as regulatory installations and forced to be run in the basic load mode. The whole problem is discussed in more detail in paper [37]. In Poland the situation is even more difficult as the annually averaged duration of using the installed power for electricity generation is considered another parameter applied in the legislation. The supposed intention is to promote stability in energy generation. The effect is penalising installations capable to compensate fluctuations introduced into the grid by inherently unstable energy sources. Unfortunately, convincing politicians about their principally erroneous approach is not just a challenge, but rather a "mission impossible" for numerous East European hydropower associations.

With decreased income the efforts for restoring the economic balance have to be oriented on decreasing the activity costs. While any further lowering of the operation and maintenance costs shows its limits, the taxes and other burdens are to be taken under consideration. There exist severe doubts whether the costs of maintaining the multipurpose civil engineering infrastructure are fairly distributed among all beneficiaries. It is enough to mention that the average fee paid annually by Polish hydropower plants with capacity below 10 MW for the right to use this infrastructure represents almost a half of the income from the "black electricity" sale in Poland [36]. Also proper division of the investment costs of new multipurpose installations is of high significance. An interesting business solution was applied recently in the Czech Republic on the occasion of erecting a new dam at river Elbe. The main purpose is to facilitate inland navigation at the entrance to the Czech and Saxon Switzerland regions. The dam is also to be used by the hydropower sector. The investor of the hydroelectric power plant has to acquire a licence at the price of 1/3 of the dam erection cost. According to Mr Tomaš Kolařik, editor-in-chief of the "Vodní cesty a plavba" quarterly, similar financing schemes are planned also in case of other multipurpose projects in the Czech Republic [38].

Implementation of Water Framework Directive has stimulated numerous East European legislators to introduce the fees for using water for hydropower purposes. This time the Polish solution may be considered a truly reasonable one as the fee proportional to the amount o electricity generated has been adopted. It is to be hoped that a proper legislation will be adopted soon also in respect to those few installations which use water power to drive directly the mechanical devices. On the other end is the example of Romania where water fee is proportional to the amount of water having flown through the turbines. This solution puts the low head installations in extremely unfavourable position.

2.4 Law and environment – case study: Lithuania

Nowadays Lithuania is one of the rarest countries in the EU relying on large power import from its neighbours. This unfortunate situation emerged in 2009, when the Ignalina nuclear power plant was shut down. The requirement for closing the plant was put forward as one of the EU accession conditions. In 2016, Lithuania produced a total of 3.97 TWh of electricity. Half of this amount was generated by power plants using renewable energy sources (RES), including renewable hydropower sector (0.45 TWh), wind power plants (1.13 TWh) as well as solar, biomass and biogas fired power plants (0.44 TWh). The remaining amount of electricity was produced by conventional fuel-fired power plants. The largest share of electricity consumed in the country (about 72% of total consumption or 68% of total demand) was imported.

National energy independence strategy, introduced in 2018 foresees that power imports will be replaced by local electricity generation: it is planned that in 2020 electricity generation in Lithuania will account for 35% of total final electricity consumption (65% imported), in 2030 – 70% (30% imported), and in 2050 – 100%; The share of RES energy will be increasing. In 2020, 30% of the country’s total final electricity consumption will be from RES; in 2030 – 45%, and in 2050 – 80%. Hydropower role will remain as it was in the previous period – no significant development can be expected. At the present time, 98 small hydropower plants (SHP) are operating in the country with a total installed capacity of 27 MW and normalized power generation of 80 GWh/year. Kaunas HPP (100 MW) and the Kruonis pumped storage power plant (900 MW) represent the large hydro sector. The remaining potential of the country's two large rivers equals approximately 1.24 TWh/year. However, the environmental legislation in force precludes the damming of these rivers and eliminates this potential for large hydropower plants

The present situation reveals that Lithuania will not achieve its goal for 2020 in terms of contribution of hydropower specified in the National Renewable Energy Action Plan. There is no noticeable growth trend in SHP installed capacity from 2007. This is mainly due to the environmental legislation. Some 15 years ago an amendment to the National Water Law was made, and it produced a subsequent governmental act that made it illegal to construct dams on any of the country's largest rivers along with a very high number of medium and small watercourses or their fragmented stretches (approximately 170). The law decided that dams would affect the rivers 'from an ecological and cultural point of view.' This naturally decreased the economically feasible SHP potential and eliminated the potential for large hydropower (classified as more than 10 MW) [39].This so-called blanket ban is still in force in the country. Along this, nowadays a campaign for removing dam is actively taking place in the country. Recently European dam removal days, including a workshop were organised, officially supported by the Ministry of Environment. NGOs are aiming at removing physical barriers in the rivers for fish migration. Operating SHP plants are mainly subject to this campaign. Lithuania is a lowland country; therefore, to harness river power, an impoundment is needed. Ecologists claim that a free-flowing stream transforms into a lake-like water body due to the impoundment.

An assessment of energy potential from the new stream-reach development in the country identified some 117 GWh/year of environmentally compliant potential (remaining or available for development). Economically feasible and environmentally sustainable SHP (micro or mini) generation potential exists in the hundreds of historic mills, and weir sites - mainly low head schemes - non-powered sites in the country. Some 210 historic water mill sites have been identified so far. Nearly half of them are obsolete, their weirs need total refurbishment. The total capacity of these sites is not impressive (16 MW with the expected power generation of 66 GWh/year), but the non-energy benefits might exceed the value of the energy generated. Most individual hydro schemes would be small: there are 110 sites with a capacity larger than 50 kW and 55 sites with a capacity larger than 100 kW [40].

Approximately 500 embankment dams low in height, creating small reservoirs or ponds mainly designed for recreational and irrigation purpose are listed in the country. However, their total capacity and expected power generation is quite low (9 MW and 35 GWh/year, respectively). Estimated capacity of some 100 dams exceeds 20 kW, 30 dams are more than 50 kW, and only 12 dams are more than 100 kW.

When installing SHP plants by the existing dam there will not be any environmental issue. In the contrast to this, there is not always the case for historic water mills. Getting the necessary approvals for undertaking civil construction in such locations would not be likely today as a result of restrictive legislation. More than 100 historic water mill sites are in the river stretches designated as environmentally and culturally sensitive rivers, and their restoration is impossible. There is a ministerial order on removing the remnants of old weirs located in 33 river stretches that interfere with fish migration corridors is in force. These public investments can be avoided by attracting private capital and installing micro-hydropower turbines with minimal disruption to the flow of the water, including fish ladders, and consequently fostering rural tourism and water activities and diversifying rural businesses.

3. Opportunities

3.1 General

After years of decline and stagnation induced in numerous East European countries by the local pro-ecological movements and the EU environmental policy, the climate change and its consequences may stimulate revision of this policy - also at national levels - to a direction more positive for the hydropower sector. The new opportunities following from this highly expected revision may be summarised as follows:

a) increased use of available energy storage capacities in existing hydropower reservoirs;

b) pumped storage projects aimed at further development of energy storage capacities and capabilities to compensate fluctuations of grid parameters;

c) multipurpose projects oriented among others on development of inland navigation routes as well as new water and energy storage capacities in river cascades.

Despite substantial development of unstable energy sources, the existing energy storage capacities of hydropower reservoirs are used in some countries in an extent much smaller than in the eighties. The available storage capacity of Polish hydropower sector is estimated at the level exceeding 80 GWh. The use of this potential may be increased by the emerging power market - so far with duration of electricity supply at a specified power level assumed as the main parameter to be offered. Once decision is taken to allow further development of unstable energy sources the demand for capabilities of compensating fluctuation of grid parameters will rise giving chance not only for use of existing capacities, but also for new hydropower storage projects. The demand for energy storage may rise also in case of stating the residual lifetime of steam turbines used for grid regulation purposes has shrunk excessively or a decision to develop the nuclear sector has been taken. According to the authors' knowledge this is exactly the main reason of intense development of Ukrainian pumped storage as described in section 1.

Fig.5. The network of main waterways within the Central and Eastern Europe regions according to the AGN document [42] with major projects shown in red circles

In result of the refurbishment programme in recent decades, Polish thermal blocks are considered now to be technically suited for taking part in slow regulatory processes resulting out of daily peak load fluctuations. Still in the end of eighties it was planned to increase the capacity of Polish pumped storage sector by 4490 MW till 2020 by erecting 5 new plants [41]. These and later projects may revive in case of demand due to developing unstable energy sources. Despite lower energy effectiveness pumped storage may prevail over river cascades in swell operation both due to higher potential and the environmental reasons.

Due to the need to mitigate the climate change effects, to the rising commercial exchange and to the resulting international commitments, multipurpose projects may be even a more realistic chance to accelerate hydropower development within the region. In this context, it is worthwhile to mention two major inland navigation projects following from the European Agreement on Main Inland Waterways of International Importance (AGN) [42]. The first one is the E40 waterway a missing element in the connection between the West European inland navigation network and the Baltic sea with Black Sea basin via Prypyat' and Dnieper rivers (Fig.5). The second one is the water corridor Danube-Oder-Elbe allowing to connect Danube with Szczecin harbour via Oder and with Hamburg via Elbe. Czech Republic and Slovakia ratified the document before its entrance into force in 1999. Belarus, Ukraine and Poland joined in 2008, 2010 and 2017, respectively.

3.2 E40 Waterway and the Lower Vistula Cascade

The Vistula cascade was proposed originally by a Polish engineer, T.Tillinger, as early as 1912. Later on, in 1919 and 1937 the concepts of the first power plants emerged. In 1945 T.Tillinger presented the first comprehensive concept, covering 41 dams with power plants of total electric power 1203 MW. In result of a detailed study by Hydroprojekt Warsaw Design Office and the Polish Academy of Sciences, conducted in 1950-ies, a mature concept of a multipurpose Lower Vistula Cascade with a class IV international waterway was derived. As the first installation, the Wloclawek Dam, with a hydropower plant of 160,2 MW capacity, was erected in the years 1962-1970 [43]. According to the concept of 1980, the cascade was to consist of 8 stages with total installed electric power of 1340 MW 4300 GWh annual generation, run in swell mode and providing over 1000 MW wide band of regulatory power. current update of the cascade configuration can be seen in Fig.6.

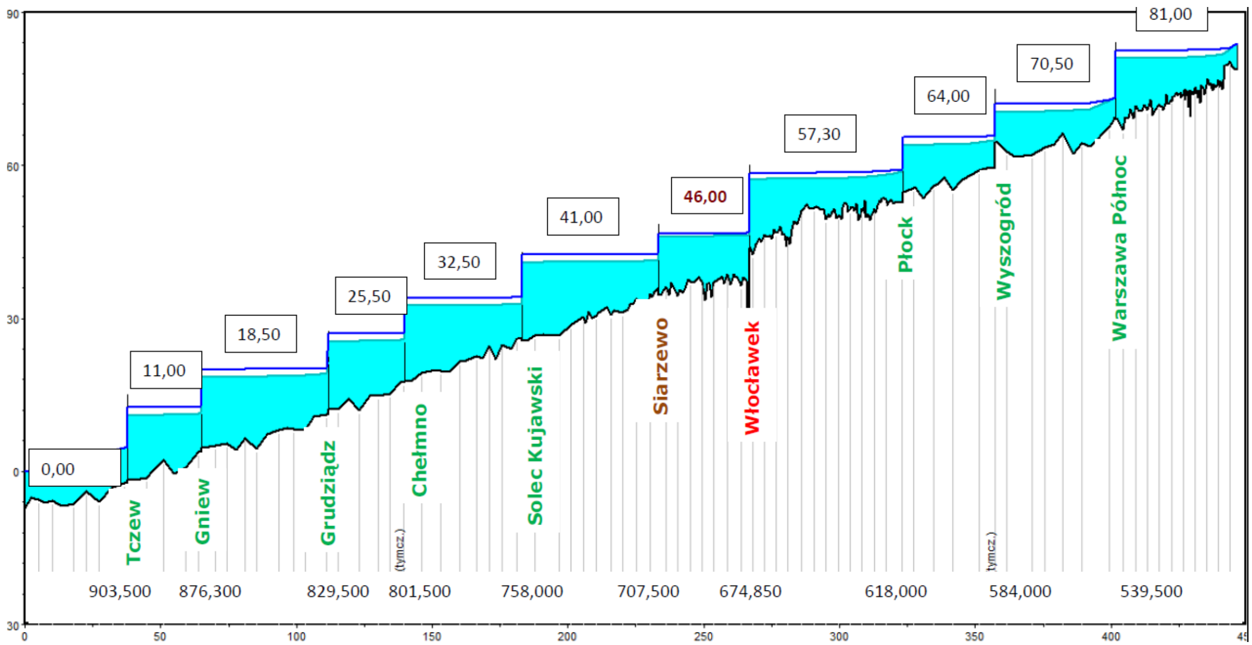

Fig.6 Lower Vistula cascade according to the Energa Invest *concept, still valid in 2017 [44]*

As already mentioned the whole project - including building site preparations downstream of Wloclawek - was cancelled in 1981. Some time later Wloclawek HPP stopped also running in the peak-load mode. The reason was river bed degradation downstream of the dam which was a result of too long delay in water levelling by the next cascade stage. As this could threaten the Wloclawek Dam stability, a provisional broad-crested weir was erected instead. A similar measure was applied downstream of Dębe HPP located at Narew river close to its outlet to Vistula. This time the reason was lacking levelling by the planned Wyszogród Dam (Fig.6). In 2009, the National Water Management Board (KZGW) ordered an expert opinion on further steps necessary in respect to the Wloclawek Dam. The order was issued under strong pressure of green movements demanding dismantling of the dam. Against the intention of the Ministry of Environment, the *Hydroprojekt* expert opinion recommended unambiguously to erect the next cascade stage. The above recommendation was repeated by the Water Management Board. Soon afterwards, the task was taken over by the *Energa Group*, the owner of Wloclawek HPP. The development of the barrage concept and preparation of the documents necessary for environmental processing were commissioned to the *Ove Arup* design office. The time schedule adopted was very ambitious. The environmental decision was expected to be received in 2011 and commissioning of the power plant – to be conducted in the end of 2016. The new dam (Fig.7) was to be erected close to the Siarzewo village which is a location shifted by several km downstream from the originally envisaged sites of Ciechocinek or Nieszawa. Numerous environmental precautions had to be undertaken as the whole Lower Vistula valley was covered by the Natura 2000 programme, which created a true challenge for the investor.

Eventually, a positive environmental decision was issued in the end of 2017. Soon afterwards, the green organisations addressed numerous protests to the General Directorate of Environmental Protection in Warsaw. Final decision is expected in the end of September At least partially. In fact, the current concept is a compromise between the requirements of environmentalists and expectations of power engineering specialists. Therefore, it is often criticised by both sides. The hard line environmentalists would like to see no dams at all while some power engineers are disappointed with halving the originally planned capacity to ca. 80 MW, which may put an end to the idea of using the cascade for regulatory swell operation. The assumed lowering of the use of the Lower Vistula potential below 4000 GWh/a is another reason of criticism in some circles.

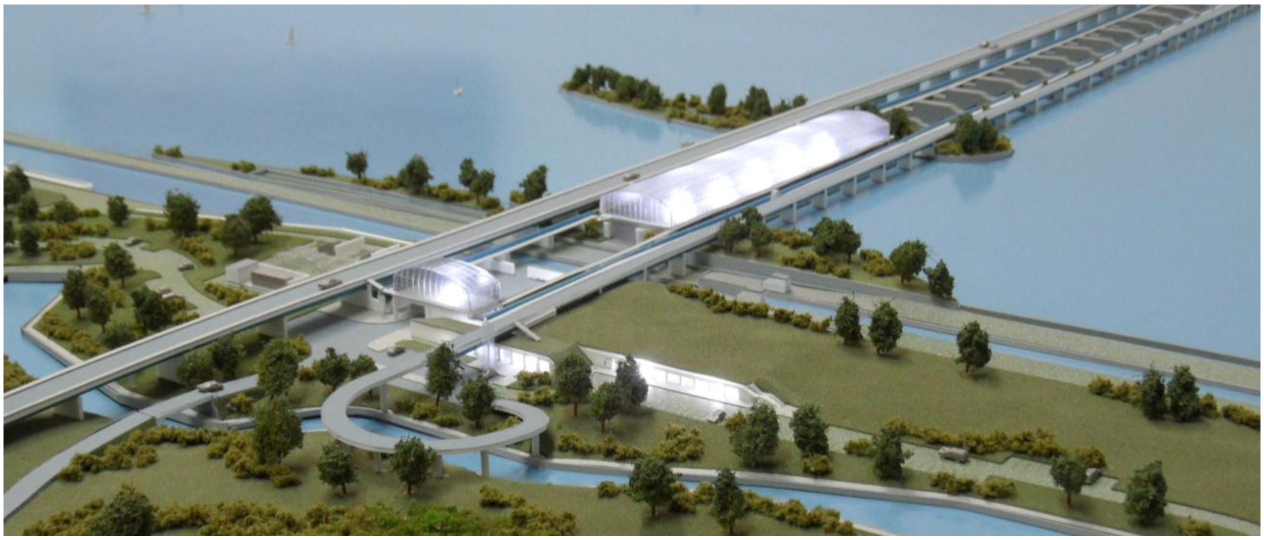

Fig.7 Siarzewo Dam in the Lower Vistula Cascade. A concept of the Ove Arup Design Office

However, using the Lower Vistula for hydropower purposes is no more a top economic priority in the whole project. Since December last year, the leading investor of the Siarzewo Dam is the “Wody Polskie” (Polish Waters) state enterprise with *Energa Group* keeping its place in the newly established Steering Committee together with representatives of the Ministry of Maritime Economy and Inland Navigation and the Ministry of Environment. In fact, in view of a rapid development of Gdansk harbour, the key role was taken already some years ago by inland navigation. As shown by the recent analysis of social and economic impact of the Lower Vistula development [44, 45], in case the project is carried out according to the assumptions, the current value benefits within the 30 years of cascade construction may be as high as 100 billion zlotys (ca 23 billion €). Out of this sum 44 % is expected to be brought by the transport sector, 22 % - by avoidance of floods, 17 % - by tourism and less than 10 % - by generation of electricity on daily load basis (without income coming from possible grid ancillary services). Some assessments may change as according to the Cabinet information, a draft programme of the Vistula waterway development is expected only in 2020. It is just to be hoped that with the new project management model, all aspects of its multipurpose character will be respected and benefits not only for the active business stakeholders, but also for the whole national economy, environment and society will be optimally balanced.

As shown in Fig.5, restoring and raising quality of navigation conditions at Lower Vistula to a level higher than ever before will not be sufficient to establish convenient inland waterway connection between the Baltic and Black seas. For connecting Vistula with the West European network an upgrade of the E70 waterway is necessary. For connecting Vistula with the Black Sea basin it is essential to establish a high quality connection between Vistula and Prypyat'. Unfortunately, it is enough to look at the map to see that the original Bug river bed cannot be used for this purpose and an artificial canal is needed between Vistula and the Eastern border of Poland. Furthermore, due to the terrain level differences, water will have to be pumped into the canal. The costs can be lowered if water is pumped at night to a reservoir located close to the highest point of the waterway. Some part of energy used can be recovered by turbines running in the peak-load regime as it is proposed in case of the Danube-Oder-Elbe corridor (see section 3.3) or variable speed units put in operation when rising or lowering water level in the lock chambers. Pumping could be probably accomplished by making use of the lower energy demand at night (as in classic pumped storage schemes) and/or the power surplus generated by unstable energy sources.

3.3 Water corridor Danube-Oder-Elbe

The traceable idea of connecting Baltic and Black sea basins via Danube and Oder system rivers stems from the times of the Holy Roman Emperor Ferdinand III (mid XVIth century) who supported the proposal of Morava local parliament to connect the rivers of Oder and Morava [46]. Almost 150 years later, in 1700, the first concept of such a connection was published in a dissertation "Dissertatio de utilitate, possibilitate et modo conjunctionis Danubii cum Odera, Vistula & Albi fluviis, per canalem navigabilem" by Lothar Vogemont. Some further ideas and concepts were proposed by N.W. von Linck (1719), F.J.Maire (1785), Oelwein and Pontzen (1873). The last concept received also support of the Vienna parliament and was abandoned only due to economic difficulties within the Austrian-Hungarian Empire. The next concept, developed at the order of the Austrian-Hungarian Ministry of Economy included already connection to Elbe as well. The concept was a basis for a major state project initiated 10 years before World War Ist. The project has resulted in erection of several barrages at Elbe and advanced preparations to erect the other ones. After 1918 the concept was supported by Czechoslovakia which continued with erection of locks and dams at its segment of Elbe. As shown in an excellent monograph by J.Podzimek et al [46], a hydropower installation can be seen at each scheme erected at this time.

Even higher determination was shown by Nazi Germany, which forced Czechoslovakia to sign a relevant agreement immediately after the Munich Conference of 1938. Digging the canals was initiated both from the current Polish territory and from the territory of Austria, but the World War II events prevented any major progress. The true progress after WWII did not go much beyond the erection of new multipurpose weirs and upgrading the old ones at the already existing segments of the navigation node. However, as it can be seen in Fig.8, reproduced in [46] from a popular technical journal of 1958, the idea was still alive behind the Iron Curtain. Including the concept of using the navigation route water stages for hydropower purposes.

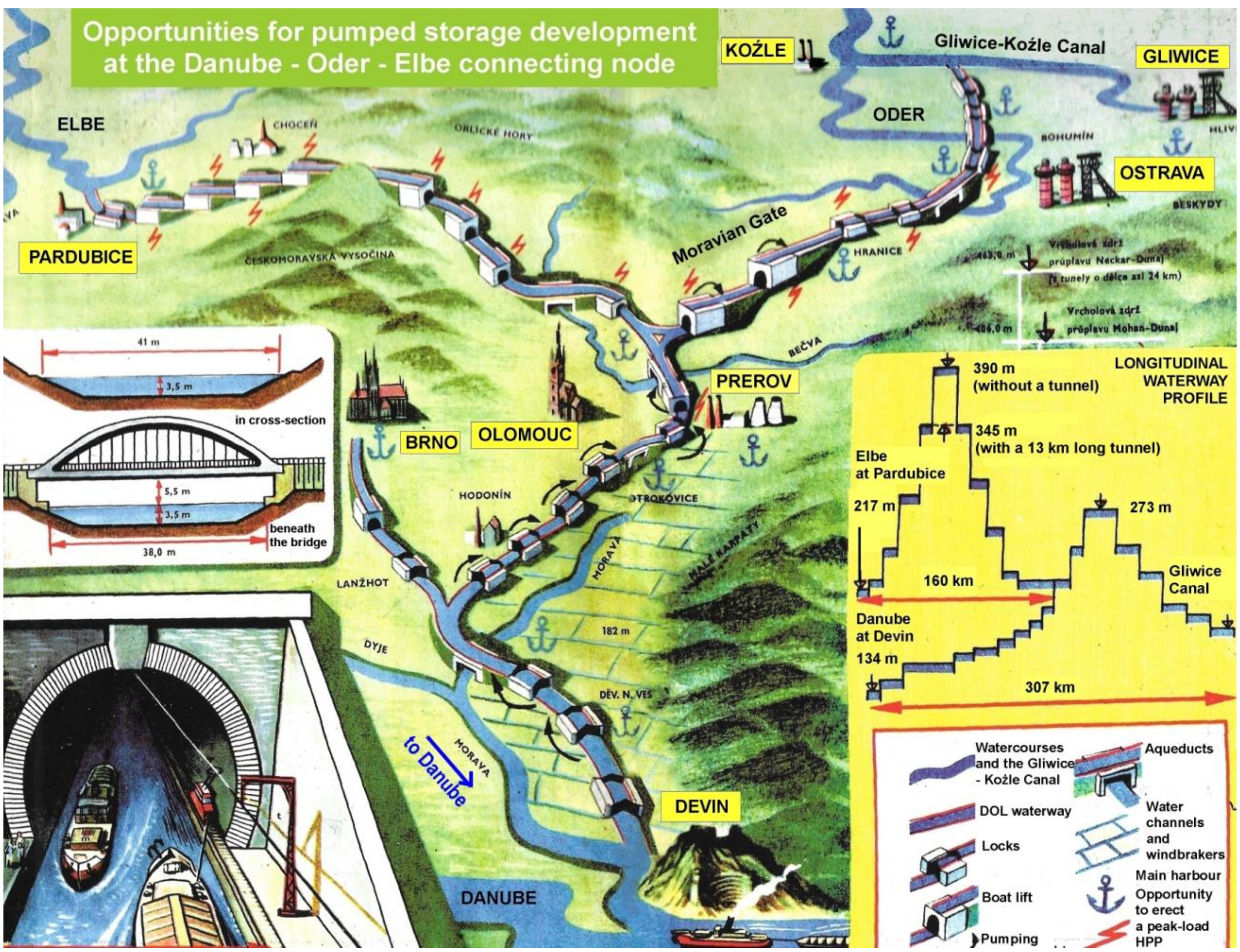

Fig.8 Danube-Oder-Elbe navigation node concept, "Věda a technika mladeži", 8, 1958, after [46]

The project was neither forgotten on the other side of the Curtain. In 1959 the UN Economic Commission for Europe counted it among 3 projects most significant for integration of the European inland navigation network. The other ones were Rhine-Main-Danube and Oder-Vistula-Dnieper connections. A new impulse came in the end of 1990-ies with the AGN agreement on main inland waterways in Europe. After joining the agreement by Poland in 2017 all the project stakeholders are involved and it is to be hoped they'll keep to their declarations.

According to a rough estimation presented by J.Podzimek et al [46], pumping water necessary to keep the navigation node in operation will require the energy of approximately 190 GWh/a. A significant part of it may be recovered by installing hydraulic turbines of total capacity of 300 MW at consecutive water stages. Pumping at night hours or using the power surplus coming from unstable energy sources are assumed. A positive financial balance may be achieved in case of a favourable price difference in the acquired and sold energy.

3.4 Other waterways

The White Paper on Transport, as agreed in 2011 by the EU member states, assumes rail- and waterways to take over 30 and 50 % of European transport by the years 2030 and 2050, respectively. This will require not only supplementing the European waterway network with missing components, but also upgrading the existing water routes to an international class, compliant with the AGN requirements. At the territory of Poland the upgrading programme should cover both the E30 (Oder) and the E70 (Warta / Noteć / Bydgoszcz Canal) waterways (Fig.5). Upgrading the Oder waterway is already in progress. According to the statement by Polish Minister of Maritime Economy and Inland Navigation, the number of planned new weirs has been recently increased to 29 [47]. Unfortunately, this may imply lowering the use of Oder hydropower potential as weirs with head as low as 1÷1.5 m are now also under consideration. As generally known, such heads are accessible today only by some dedicated small hydro technologies.

Implementation of the AGN agreement will require upgrading of the water routes also in some other countries within the region, including Romania, Lithuania and Belarus. In the first two ones this may create a development opportunities for their hydropower sectors. After abandoning previous plans to connect Danube with Vistula via San and Dniester rivers, developing the Prut into a navigable waterway in Romania (E80-07 branch of the Danube main navigation route) brings still an opportunity to erect a cascade of 13 dams with hydropower plants of total capacity 120 MW and generation close to 340 GWh/a. Meaningful opportunities considered in Romania are also the Siret-Bărăgan Canal (7 HPPs with 180 MW of total capacity) and the Argeş–Dunăre segment of the E80-05 branch (6 SHPs of over 26 MW total capacity) [21].

Restoring the Nemunas waterway may be a true chance for Lithuanian hydropower sector as this will require changing the law and erecting dams and locks at the river. In the past Nemunas was intensely used for cargo shipments; currently, this activity is limited. One reason is that during the low-water period the navigation channel lacks sufficient depth. Recently, a cargo port has been established in Kaunas. With current plans to integrate Nemunas in the European inland navigation network as E-41 waterway, a range of possible depths for the navigation fairway are considered with only two of them - 2.5 m and 3 m - complying with class IV and V requirements, respectively. The 3 m shipping lane depth could be assured by building approximately five low-head dams (up to 3–5 m), one or two within the river reach in the city of Kaunas. Digital modelling of the river bed and valley showed that the area that would be inundated after the construction of these dams is smaller than the area which is inundated during the natural floods that occur once in ten years.

Another major issue is that the Nemunas riverbed downstream of the Kaunas Dam – the only large hydro installation in the country - has been eroded by 1–2 m. As a result, the water level has lowered, and during the dry period, the abutments of the bridges and embankment quays are exposed, displaying unpleasant scenery of the river landscape. Low-head dams with locks and fish ladders could mitigate this crucial issue, and the municipality of Kaunas is in favour of this action. In addition to restoring the historical river level and improving navigation channel standards, they would also mitigate the hydropeaking effects induced by the Kaunas HPP [48, 49]. The cost-effectiveness of the navigation dams can be strengthened if they are associated with power generation.

3.5 Pumped storage schemes

With observed difficulties in erection as well as use of large classic HPPS and river cascades for the energy storage purposes on the one hand and the expected rise of demand for grid ancillary services on the other hand (including compensation of grid parameter fluctuations) one may expect further rise of interest for pumped storage schemes [50]. A number of suitable sites have been identified over the past years within the region. In this context it is worthwhile to mention proposals to use the excavations of lignite and abandoned hard coal mines as lower reservoirs. Using coal mines for this purpose has been disputed for a longer time in Europe, but it is in Czech Republic where the first prototype installation (1 MW capacity) was put in operation several years ago and it is in Poland where feasibility and design studies in this direction are continued at the order of coal mining companies.

In view of its commitment to increase substantially the energy independence by widespread use of renewables, Lithuania may be expected to rise the Kruonis PSPP capacity within the coming years. In addition to the developments already discussed in the end of section 1, one should mention also the Serbian plans for Iron Gate III PSPP scheme (4×300 MW), much required due to a dynamic solar sector development in the country [22]. After the final stage of the project is concluded, the Iron Gate III power plant capacity may reach as much as 2400 MW. The Russian plans for the next large pumped storage installations, including Leningrad (1560 MW) as well as Kursk and Central PSPPs [28] will be probably shifted to some further future in view of the current economic situation.

3.6 Other projects and opportunities

Development of inland navigation routes, the need for water retention and flood protection as well as demand for swift grid regulatory tools are probably the most significant opportunities for the hydropower sector to join investment projects headed by others or to head them as a key investor. For the small hydro sector such an opportunity has been seen for years in the water dams and weirs erected some time ago without a hydropower use in view at this time or abandoned later on due to unfavourable economic and/or other conditions. The number of the most suitable sites will fall in case of continuous development. However, even then, depending on the state policy, this opportunity may remain valid for some time.

As mentioned before, there are still countries within the region which consider hydropower a significant and promising player in their energy mix. This statement refers in particular to Balkan states [6, 22], but also Ukraine [25] and Russian Federation which systematically increases its assets and declares interest in projects below 25 MW capacity at its European territory [28, 29]. In view of their substantial potential, Bulgaria, Romania and Slovakia may be also expected to conduct more friendly policy towards the sector in the near future.

Conclusion

The East European hydropower sector represents altogether 55 GW capacity which is about 23 % of the total hydropower capacity of Europe, estimated in 2016 at ca. 239 GW (including the European part of Russian Federation, with discrepancy of 8 GW between the data of IHA [9] and IRENA [10]). In the 2005-2015 decade the sector showed steady growth rate of ca. 0,76 %/a, remaining thus in compliance with the growth rate across the whole continent. The growth rate in the renewable component was lower and amounted ca. 0.58 %/a. The highest growth rate could be stated in the former Yugoslavian republics and the lowest one - in the Baltic states.

Despite high differentiation in the hydropower potential density and economic status, the hydropower sector in the East European EU member and candidate states suffers from non-technical constraints very similar to those in the western part of Europe. The background for this situation may be seen in the lack of a comprehensive, fairly balanced approach to assessing the environmental impact of hydropower. In effect, local environmental goals often prevail over the global ones, such as hydrological balance, flood protection, lowering CO_2 emission, sparing fossil fuels for future generations, not to mention significance of hydropower projects for energy safety and transport purposes.

Difficult or even critical situation of the sector in some countries results often from inconsequent and irrelevant state intervention into the economic rules with disregarding some functional features of fundamental significance for the electrical power system and the multipurpose character of the hydropower infrastructure. One of signs of such irrelevancy is excessive applying the installed power criterion in regulations promoting generation of electricity from small hydropower installations. Introducing the parameter representing duration of the annual use of this power is another example of a counterproductive legislation.

The most promising opportunities for hydropower sector in countries with restrictive environmental legislation follow from the multipurpose and pumped storage projects. Small hydro installations at already existing barrages remain also an option in most East European countries. With inland navigation purposes attaining key priority in the projects of river cascades it is to be hoped that the decision makers will respect all aspects of their multipurpose character and the benefits not only for the active stakeholders, but also for the whole national economy, environment and society will be optimally designed and balanced. With multipurpose projects it is possible to attain various benefits at relatively low investment price. Introducing additional features or enhancing them may be extremely difficult if not impossible after the project is ready.

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