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The Dnieper Cascade as part of International Waterway E40

Abstract: The Dnieper River has long played an important part in the development of local economy, including the transport sector. However, it was not until the construction of a cascade of hydroelectric power plants in the 20th century that it was possible to make extensive use of the river's resources and to improve the navigation conditions. Water transport in Ukraine began to decline with the dissolution of the Soviet Union and the consequent political and economic transformations. Today, the depreciated infrastructure is one of the barriers to the development of inland water transport. However, the ongoing work to restore the Dnieper transport importance will enable Ukraine to take advantage of its geographical location that coincides with important trade routes connecting Europe with Asia. The purpose of this paper is to present the economic context of the Dnieper Cascade operation as well as its limiting and development factors by analysing literature resources, statistical data and legal documents.

Keywords: Dnieper River, cascade, International Waterway E40, inland water transport, water power engineering, water management, dams, Ukraine

1. Introduction

Since the beginning of civilisation, rivers have served a number of functions, one of them being transport, which ensured survival and development of communities (Gan, 1976). The current economic and environmental advantage of water transport is one of the reasons for which the European Agreement on Main Inland Waterways of International Importance (referred to as the AGN Agreement) has been concluded (European…, 1996). The document was created to provide an organisational and legal framework and to establish a coherent classification of European waterways, depending on the size of potentially operated vessels.

The objective of this study was to present the Dnieper as part of the European waterway network, to describe its historical use and to present the current limitations and possibilities of its development as a waterway of international importance.

The analysis was carried out on the basis of the available literature, legal and programming documents as well as statistical data collated in tables and figures, with special regard to the period between 1991 and 2015.

2. Economic exploitation of the Dnieper

Already in the early days of Kievan Rus', the Dnieper River was a key part of the international trade route connecting Scandinavia with the Byzantine Empire. Its importance has varied throughout history, however, it has always remained an important but not obstacle-free water transport route. The navigation obstacles were the Dnieper Rapids (Ukrainian: *Dniprovi porohy*) that cartographers tried to put on maps in order to facilitate the navigation (Khvedchenia, 2012).

In the 1930s, the construction of dams began with the aim to tame the lower reaches of the Dnieper. The complete cascade was built in 1975 when the Kaniv dam, the last dam in the Dnieper Cascade was put into service. The location of the Dnieper Cascade in relation to the E40 waterway is shown in Figure 1, while the basic technical parameters of the Hydroelectric Power Plant and reservoirs are presented in Table 1.

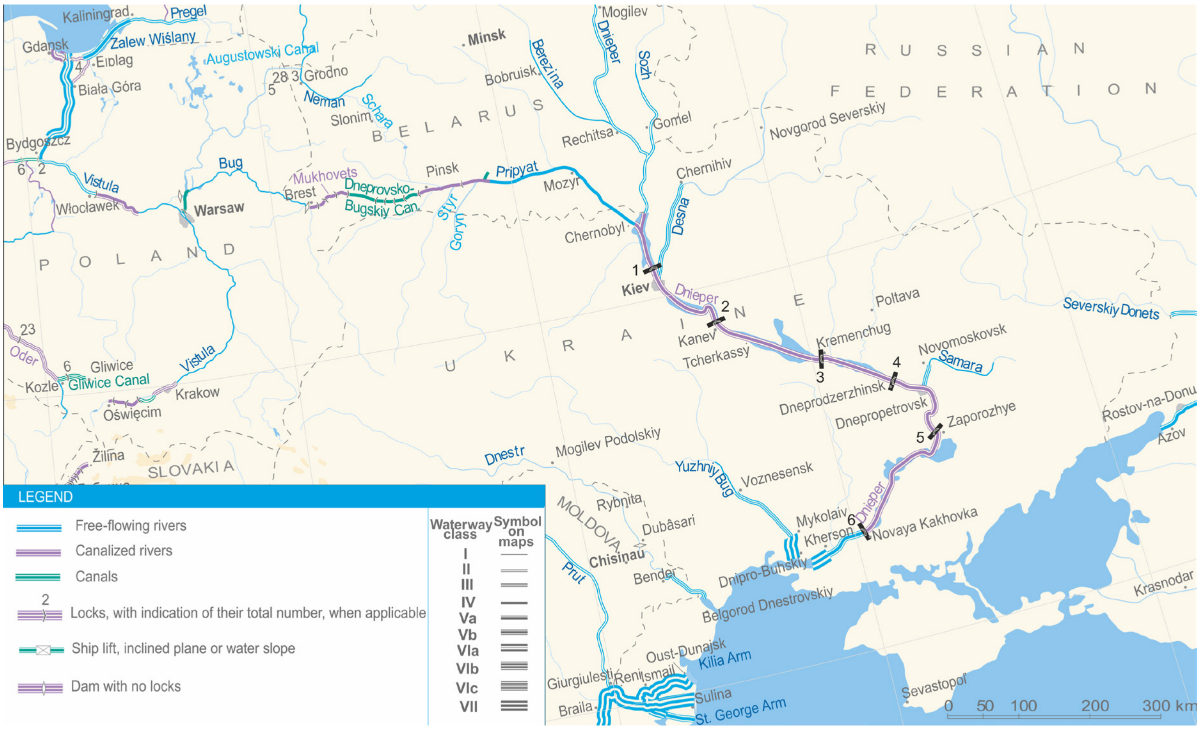

Figure 1. Location of the Dnieper Cascade in relation to the International Waterway E40. 1 – Kiev Hydroelectric Power Plant, 2 – Kaniv Hydroelectric Power Plant, 3 – Kremenchuk Hydroelectric Power Plant, 4 – Middle Dnieper Hydroelectric Power Plant, 5 – Dnieper Hydroelectric Power Plant, 6 – Kakhovka Hydroelectric Power Plant (based on: Map of the European Inland Waterway Network, 2012; Yatsyk, 2003)

Table 1. Characteristics of the Dnieper Hydroelectric Power Plants and reservoirs (based on: Hilchevskiy and Grebin, 2014; Vishnievskiy et al., 2011)

Name of hydroelectric power plant	Year of commissioning	Water surface elevation [m]	Reservoir surface area [thousands of ha]	Reservoir volume [km^3]		Installed power [MW]
				total	used	
Kiev HPP	1968	12.0	92.2	3.73	1.17	422.5
Kaniv HPP	1975	11.0	58.2	2.50	0.3	472.0
Kremenchuk HPP	1960	14.2	225.2	13.52	8.97	632.9
Middle Dnieper (Dniprodzerzhynsk) HPP	1964	10.5	56.7	2.46	0.53	369.5
Dnieper HPP	1932, 1947	34.3	41.0	3.32	0.85	1,513.1
Kakhovka HPP	1956	16.5	215.5	18.18	6.78	329.0
Total	-	98.5	688.8	43.71	18.6	3,739

The Dnieper Hydroelectric Power Plant was put into operation twice due to war damage, and after its expansion in 1980, the installed power was increased from 585 MW to 1,513.1 MW. In total, the Dnieper Cascade generates on average 9,255 GWh of energy per year. The production of energy will grow as a result of the second stage of modernisation works carried out since 2006 (Table 1). The first stage of the modernisation was completed in the period 1996–2002 (Ukrgidroproekt – obzor deyatelnosti, 2015).

In addition to producing electrical energy, the Dnieper Cascade serves a number of other important economic functions. According to the data contained in the Operating Rules for the Dnieper Cascade Reservoirs (Yatsyk, 2003), waters of the Dnieper River are supplied to 2/3 of the Ukrainian territory with a population of 30 million. The waters are used by 50 urban and industrial centres for municipal and production purposes, while 50 extensive irrigation systems provide water for 1,312,900 ha of farmlands. The Dnieper water is used in the cooling systems of four nuclear power plants and in fisheries. The study also highlights the valuable ecosystems that emerged after years of operation of the reservoirs.

Even though the Dnieper Cascade serves a number of economic functions, there are opinions questioning the economic sense of its operation in its current state, pointing out the possibility of more effective use of land being currently occupied by the reservoirs, as well as the risk of failure related to the functioning of the dams (Skrypnyk, Holiachuk, 2015).

Transport is also an important function performed by the Dnieper Cascade. The construction of the cascade has helped to create a shipping lane with a length of more than 900 km (Inventory of Main Standards and Parameters…, 2012; Yatsyk, 2003; Odbudowa Drogi Wodnej E-40 na odcinku Dniepr-Wisła…, 2015), a width of 80 m, and a transit depth of 3.65 m with local shoal patches of up to 2.65 m. In summer months, there is a risk of the transit depth dropping to 2 m. This would require additional technical measures, such as dredging and reducing the draught of vessels (Yatsyk, 2003).

In order to overcome the difference between the water levels resulting from the water impoundment by dams, each of them was fitted with a lock. The Dnieper Cascade lock parameters are provided in Table 2.

Table 2. Parameters of the Dnieper Cascade locks (based on: Ukrgidroproekt – obzor deyatelnosti, 2015; Yatsyk, 2003)

Name of locks	Year of commissioning	Lock chamber size [m]		Head [m]	Planned number of lockages per day	Average locking time [min]
		length	width			
Kiev	1964	150	18	11.5	36	38
Kaniv	1972	270	18	12.5	34	40
Kremenchuk	1959	270	18	17.0	36	38
Dniprodzerzhynsk	1963	270	18	12.5	45	30
Zaporizhia old	1933	120	18	38.7	24	57
Zaporizhia new	1980	290	18	38.7	36	38
Kakhovka	1955	270	18	17.0	32	43

The Zaporizhia locks are part of the Dnieper Hydroelectric Power Plant. The older one is a three-chamber lock, whereas the new lock has only one chamber.

There are nine inland ports on the Dnieper within the territory of Ukraine: Kiev, Cherkasy, Kremenchuk, Dniprodzerzhynsk, Dnipropetrovsk, Zaporizhia, Nikopol, Nova Kakhovka, Kherson (Eastern Partnership regional transport study…, 2015; Odbudowa Drogi Wodnej E-40 na odcinku Dniepr-Wisła…, 2015). Their total handling capacity is about 42 million tons per year, however, it is currently used to a very limited extent only (Eastern Partnership regional transport study …, 2015).

3. Current conditions and prospects for the use of waterways in Ukraine

According to the data provided by the State Statistics Service of Ukraine (Statistichniy…, 2016), in 2015 Ukraine had 1,600 km of waterways. The inland transport routes were used to ship 3 million tons of goods, which accounted for 0.21% of the total goods, and to perform shipping services at a level of 1.6 billion tkm, which corresponds to 0.5% of the total freight. As shown in Table 3, Ukraine uses its inland waterways to a very limited extent only, compared to some EU countries. Prior to the dissolution of the Soviet Union and the related political and economic transformations, the water transport services were at a level of 50 (Doubrovsky, 2005) to 60 (Behrens et al., 2016) million tons per year.

Table 3. Ukraine's inland waterway transport in 2015 compared to selected EU countries

Country	Length of waterways [km]	Freight transport [billions of tkm]	Modal split [%]
Austria	351	1.8	2.5
Belgium	1,516	10.4	15.6
Bulgaria	470	5.6	26.6
Croatia	1,017	0.9	6.9
Czech Republic	720	0.0	0.1
Finland	8,127	0.1	0.4
France	4,822	8.5	2.8
The Netherlands	6,256	48.5	43.1
Lithuania	446	0.0	0.0
Luxembourg	37	0.2	7.6
Germany	7,675	55.3	8.9
Poland	3,655	0.1	0.0
Romania	1,779	13.2	29.7
Slovakia	172	0.7	2.6
Ukraine	**1,600**	**1.6**	**0.5**
Hungary	1,864	1.8	5.0
United Kingdom	1,050	0.2	0.1
Italy	1,562	0.1	0.0

Source: Prepared based on EU..., 2017; Statistichniy…, 2016

A decrease in the volume of inland water transport is reflected, among others, in the number of lockages completed per year. The number of lockages on the Dnieper has significantly decreased since the beginning of the 1990s and by the year 2000 there has been an over tenfold decline in lockages at some of the dams (Fig. 2). At most of the dams, the number

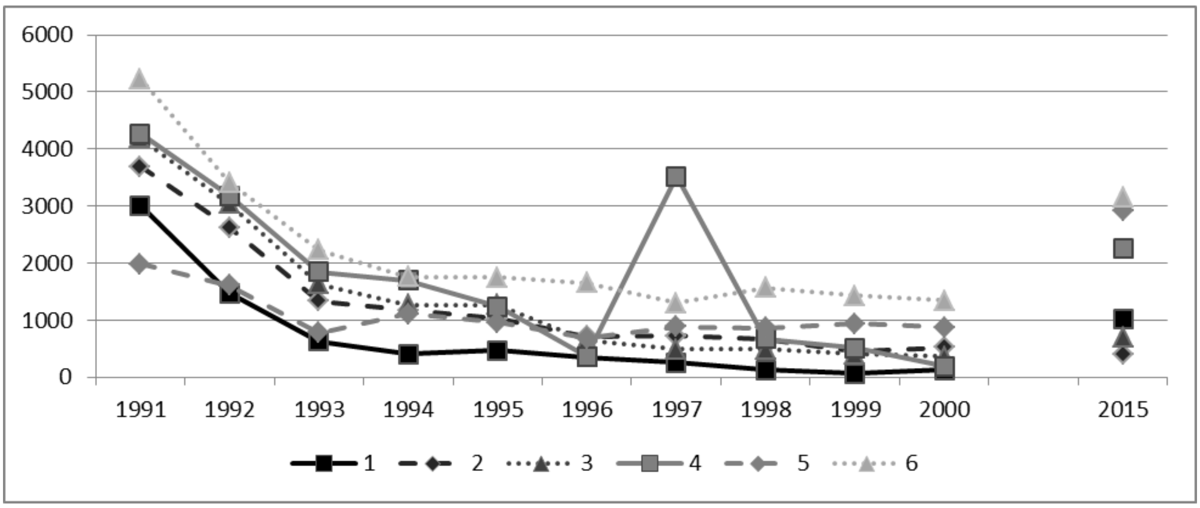

Figure 2. Changes in the number of lockages at the Dnieper Cascade locks in 1991–2000 and in 2015 (based on: Obukhov and Okulovich, 2008; Behrens et al., 2016): 1 – Kiev, 2 – Kaniv 3 – Kremenchuk, 4 – Dniprodzerzhynsk, 5 – Zaporizhia, 6 – Kakhovka

of lockages has currently increased again. In 2015, the numbers were as follows: 1,028 at Kiev, 408 at Kaniv, 701 at Kremenchuk, 2,254 at Dniprodzerzhynsk, 2,928 at Zaporizhia and 3,951 at Kakhovka (Fig. 2). Historically, the 1970s witnessed the record number of lockages. The highest number was recorded for the Kaniv lock, where almost 22,000 vessels passed in 1974 (Behrens et al., 2016).

The development of transport corridors connecting Europe with Asia through the Black Sea basin and the Caucasus is an opportunity for Ukraine's inland transport (Doubrovsky, 2005; Eastern Partnership regional transport study…, 2015). The European Union's policy identifying water transport as an important component of the logistics chain that enables freight volumes to increase while reducing greenhouse gas emissions, can also be helpful (White Paper on transport, 2011).

The AGN Agreement (European Agreement on Main Inland Waterways…, 1996) identifies the Dnieper Cascade as part of the International Waterway E40 that connects the Baltic Sea with the Black Sea. Apart from the E40 waterway, other routes of lesser importance have been delimited in Ukraine. They cover the estuary sections of the following rivers: E40-01 – the Desna River, E40-02 – the Southern Bug River, E80-09 – the Danube Branch and E90-03 – the Dniester River (Fig. 1).

The entire length of the Dnieper Cascade is of water class V. In particular, the section between Pripyat and Kiev is of class Va, while the section between Kiev and Kherson – class Vb (Eastern Partnership regional transport study…, 2015; Inventory of Main Standards and Parameters…, 2012; Odbudowa Drogi Wodnej E-40 na odcinku Dniepr-Wisła …, 2015). Although the so-called Blue Book (Inventory of Main Standards and Parameters…, 2012) does not indicate any bottlenecks within the Ukrainian section of the E40 waterway, expert reports prepared by the team of J. Behrens, R. Destramps and A. Harkness (2016) show a very poor technical condition of the locks and route markings and the presence of local shoal patches. The costs of urgent repairs and maintenance works have been provisionally estimated at 11–20 million USD, although some sources estimate it at as much as 400–450 million US (Boniar et al., 2016).

Apart from the poor condition of the infrastructure, the other factors indicated as those limiting the development of water transport in Ukraine included an inadequate legal and organisational framework, inadequate funding and tariffs disadvantageous to carriers (Boniar et al., 2016). These problems can largely be solved by adopting a new law on inland water transport (Zakonoproekt Ukraini «Pro vnutrishiy vodniy transport», No. 2475a).

The challenge is also to modernise the other sections of the International Waterway E40. The following areas in Belarus have been identified as so-called bottlenecks: the Dnieper–Bug Canal together with the Mukhavets River and the Pina River, and the Pripyat River between Pinsk and the Belarusian–Ukrainian border. In Poland, the bottlenecks include: the Lower Vistula excluding the Włocławek Reservoir; and the Vistula-Bug junction (Inventory of Main Standards and Parameters…, 2012).

So far, the western slope of the Dnieper–Bug Canal has been modernised. Multiple modernisation alternatives for the other sections are currently under development. The proposal for Belarus includes further modernisation of the existing dams and regulation of the Pripyat River by constructing new dams. The proposal for Poland is to modernise the Lower Vistula by building a cascade. Depending on the variant chosen, the structures will be classic dams or weirs coated with inflatable rubber dams with a low accumulation of water. Three variants have been developed for the Vistula–Bug junction, requiring the construction of new navigable canals and the regulation of a section of the Middle Vistula (Odbudowa Drogi Wodnej E-40 na odcinku Dniepr-Wisła …, 2015).

The progressive modernisation of Ukrainian seaports, including their adaptation for the increased container ship traffic (Doubrovsky, 2005) and their subsequent integration with inland waterways also provide new opportunities for the Dnieper waterway development.

Work is also under way to design "Dnieper-Max" class vessels for the sea-river traffic (Egorov, 2013), which would serve the ports in the Black Sea basin and along the Dnieper Cascade without the need for additional freight handling.

It is estimated that, if necessary investment, organisational and legal activities are undertaken, the demand for water transport on the Dnieper can possibly reach 40 million tons in 2025 (Behrens et al., 2016). According to the UN guidelines, the initiatives undertaken should take account of the principles of sustainable development and seek to reduce the environmental impact (Inventory of Main Standards and Parameters…, 2012).

4. Conclusions

Since the beginning of the Ukrainian statehood, the Dnieper has functioned as one of the main economic and transport pivots. The construction of the cascade of dams has helped to better exploit the Dnieper's resources, which now serve both as water supplies for the population, agriculture, transport, industry, including electric power industry, and as resources for environmental purposes.

The Dnieper transport route forms part of the International Waterway E40 connecting the Baltic Sea with the Black Sea. Although its operating parameters allow the route to function as a route of international importance, investment is necessary to improve the condition of the infrastructure that has been depreciated and is currently not delivering its full potential.

The development of international transport corridors, both within Europe and those connecting Europe with Asia, is an opportunity for Ukraine's inland waterways to grow. The modernisation of the Polish section of the International Waterway E40 may be of key importance, while enabling the use of the entire route.

Water transport may also be used to a greater extent when supported by the dedicated laws and regulations that are currently being adopted in Ukraine, as well as by the development of the sea-river transport in the Black Sea basin.

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