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Assessment of hydrokinetic resources of small and medium-size rivers: the Lithuanian case

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Abstract The aim of the study is to assess hydrokinetic energy resources of small and medium-size rivers in Lithuania. The estimation of technical resources was carried out for river segments, where for average long-term runoff the flow velocity exceeded 0.4 m/s, and the average depth was more than 0.5 m.
The results of hydrological studies were used to calculate the average flow rate and the relationship between flow velocity and river depth. The width and depth of the river channel was estimated in accordance with physical and geographical factors.
Part of the favourable for use sites of rivers located within protected areas cannot be used for energy production because of the priority of environmental protection. Navigation, recreation and other factors also limit the use of streams for energy production. In addition, in winter due to ice phenomena, hydrokinetic devices in small and medium rivers should be protected from mechanical obstacles. Moreover, Lithuania is a flat country and available hydrokinetic resources of such plain rivers are very small. Their estimated capacity comprises 13.6 MW, and they can generate 79.4 GWh of electric energy per year.

✉ ***Keywords*** *• hydrokinetic energy • small rivers • medium-size rivers • hydrological methods*

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INTRODUCTION

An increasing demand for energy and climate change issues forces to look for new environmentally sound energy sources. River hydrokinetic resources are considered as promising renewable energy source, since it does not require building new dams and creating artificial water head (Khan *et al.* 2008). The possibilities to use these resources are at the same time problematic and limited because of existence of the economic and environmental factors (Koko *et al.* 2015; Lago *et al.* 2010; Zdankus *et al.* 2014). The primary criteria that describe the river suitability are sufficient flow velocity and depth. The necessary minimal values of these elements in different literature sources differ significantly although it is recommended that flow velocity be greater than 0.5 m/s, and flow depth – at least 0.5–0.75 m (Gorban *et al.* 2001; Alaska Energy 2009; Briand, Ng 2010).

Even if the mentioned criteria are met, there are plenty other issues that need to be addressed. Extraction of available river flow energy can be accomplished only after evaluating all possible environmental concerns related to hydrokinetic devices, including impacts on behaviour of aquatic organisms and their interaction with turbines, runoff seasonality, ice formation, river debris, as well as anthropogenic activities, such as recreation and navigation (Alaska Energy 2009; Cada *et al.* 2007; Egre, Milewski 2002; Hammar *et al.* 2013; Jacobson *et al.* 2012; Seitz *et al.* 2011). In this way, the assessment of a kinetic power potential of the rivers poses quite a challenging and ambitious task (Assessment… 2010; Assessment… 2012).

Assessment of hydrokinetic resources of small and medium-size rivers is particularly relevant and important in order to evaluate the entire renewable energy potential. In cases when natural resources are sufficient, making the decision of choosing one in economically reasonable way and in compliance with environmental regulations is also of great significance.

The relatively rich river net in Lithuania is the outcome of abundant precipitation characteristic for a humid continental climate, which prevails in the country. However, gradual river channel slopes allow installing hydrokinetic devices of only small capacity.

Most of the mentioned adverse impacts are avoided using flow hydrokinetic energy. In Lithuania, attention related to such kind of energy has been directed primarily to the large rivers: the Neris and the Nemunas. The theoretical hydrokinetic resources of these rivers were evaluated by (Punys *et al.* 2013a; Punys *et al.* 2013b; Punys *et al.* 2015), but in these studies, the assessment of conditions for hydrokinetic turbine installation and exploitation is missing.

The use of conventional potential energy of all Lithuanian rivers is well studied (Jablonskis *et al.* 2007); the evaluated total capacity of all these resources is 688.8 MW, and annual production – 6033.9 GWh. Lithuania has Kaunas Hydropower Plant with an installed capacity of 101 MW and more than 90 small hydro power plants with total capacity of less than 30 MW. The use of hydropower resources is limited by the strict environmental requirements (Jablonskis *et al.* 2007). Installation of dams is unacceptable because of significant negative impacts on water ecosystems, such as fragmenting the continuity of a river and causing negative effects on biota upstream and downstream from the impoundment, blocking movement of fishes and affecting habitat, as well as physicochemical conditions of streams by converting lotic habitats to lentic, altering the natural flow fluctuations, thermal regime, etc. These are priorities of the environmental policy acts of the Republic of Lithuania.

In the previous study (Jakimavičius *et al.* 2014), theoretical hydrokinetic resources of small and medium-size Lithuanian rivers were assessed considering the estimated necessary minimum values of depth and velocity. In the present study, the research will be continued in order to single out available hydrokinetic resources, i.e., the portion of the theoretical resources that could be used for electricity generation given existing technologies without any constraints. The paper will also reveal obstacles of using hydrokinetic devices related to fish migration and spawning season, environmental protection areas, navigation, runoff seasonality, hydraulic and hydromorphological conditions of selected river segments.

DATA AND METHODOLOGY

Data

Lithuania has about 22 000 rivers and rivulets with a total length of more than 76 000 km. The average density of hydrographic network is 1.18 km/km^2 (Gailiušis *et al.* 2001). Lithuanian rivers vary in their hydrological regime and river feeding type, and therefore are divided into three hydrological regions: Western, Central and South-eastern (Fig. 1). These regions differ in precipitation (amount and prevailing types), catchment morphology and in contribution of the underground feeding. Such individualities determine the specifics of hydrological regime and have substantial impact on the river water availability and hence on river hydrokinetic resources as well.

The authors of this study used those river cross-sections, where greater than 0.4 m/s average flow velocities have been observed, and greater than 0.5

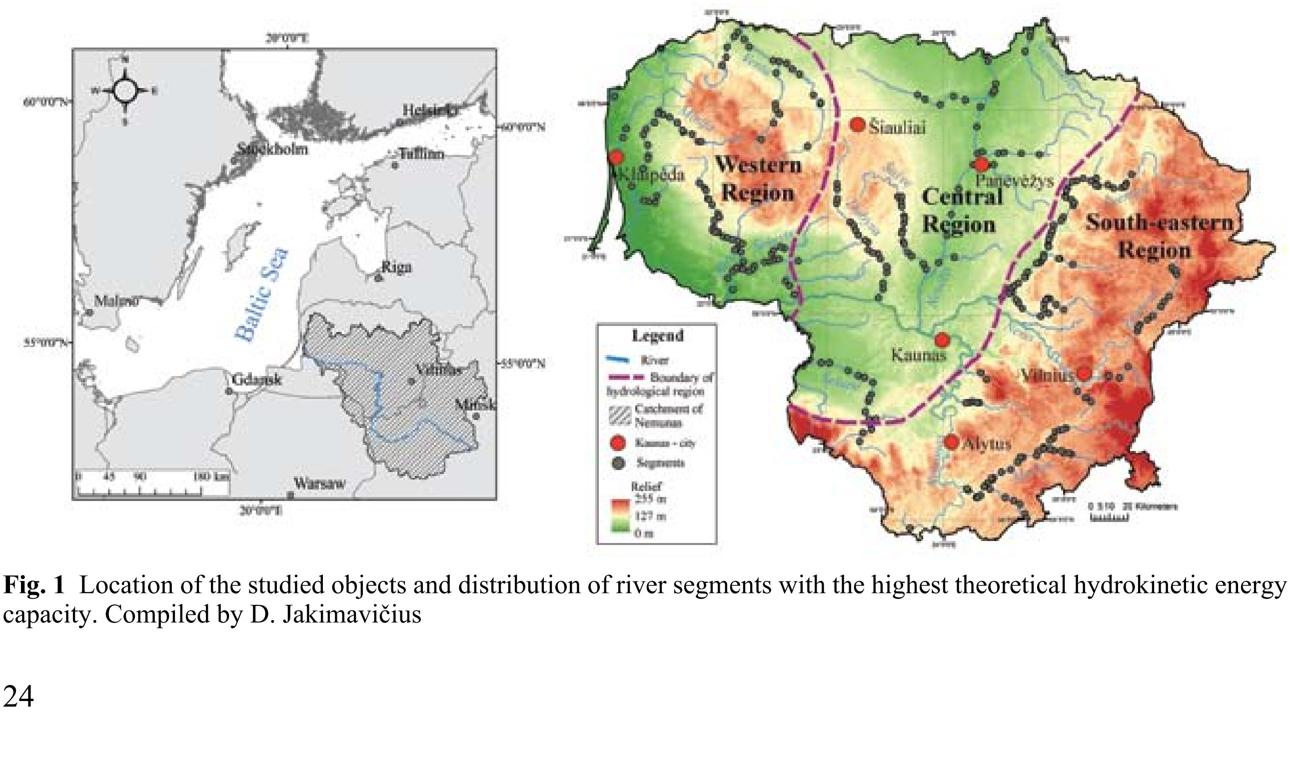

Fig. 1 Location of the studied objects and distribution of river segments with the highest theoretical hydrokinetic energy capacity. Compiled by D. Jakimavičius

m average depths have been estimated (Jakimavičius *et al.* 2014). The investigated rivers were considered as small and medium-size, and they comprise the country's river network without the largest rivers: the Nemunas (97 854 km^2) and the Neris (24 942 km^2).

At the beginning, for the assessment of theoretical hydrokinetic energy resources, 282 rivers were selected from all three hydrological regions. After a primary analysis, when the limiting conditions (the threshold depth and flow velocity) had been taken into account, 41 rivers remained (Fig. 1) for further investigation. The investigation was based on a massive amount of data published in the Hydrological Yearbooks of Lithuanian Hydrological and Meteorological Service (Hydrometeorological… 1925–1989; Lithuanian… 1990–2012) and other sources (Gailiušis *et al.* 2001).

Assessment of available hydrokinetic resources

An assessment of theoretical hydrokinetic resources was accomplished, when a discharge in a river segment is of 95% probability, flow velocity is greater than 0.4 m/s and flow depth exceeds 0.5 m (Jakimavičius *et al*. 2014). The river segment technical capacity P_t (W) obtained from a hydrokinetic device was calculated using equation:

$$P_t = \eta \frac{\rho}{2} \nu^3 A_t N, \qquad (1),$$

where η is device power coefficient (an average value of 0.3 was used (Lalander 2010), ρ is fluid density, kg/m^3, v – velocity, m/s, A_t – device swept area, m^2, N – number of devices.

The hydrokinetic capacity of a given river segment depends on the number of devices (N) that can be deployed and be used for energy production. This number is acquired assuming in-row spacing of *2D* (device diameters) between devices and *10D* between separate rows. Since turbines cannot be placed in the whole cross-section width due to smaller depths in littoral and interaction between separate turbines, the number of turbines in a given river segment of length L (m) will be equal to

$$N = \frac{B}{2D} \cdot \frac{L}{10D} = \frac{BL}{20h^2}, \qquad (2),$$

where B is a part of the river channel width, where depth is greater than the turbine diameter, m, h – depth equal to turbine diameter, m.

Duration of favourable to energy production flow regime was assessed using flow duration curves that were created applying hydrological methods (Vogel, Fennessey 1994).The next stage of this assessment was exclusion of river segments located in protected areas and coinciding with navigable waterways, where anthropogenic activities were limited. The protected areas included strict nature reserves, national parks, and sites important for bird and habitat conservation.

Hydromorphological conditions

Hydromorphological dependencies enabled calculating characteristics of river channel geometry (average depth) and hydraulics (flow velocity). Plain rivers flow through the rocks of sedimentary origin. Therefore, discharge, slope and resistance to flow are the major influential factors that determine river cross-section shape and flow velocity. In order to solve practical tasks, hydromorphological relationships summarizing information of large territories (Rybkin 1947; Leopold, Maddock 1953) and combining the main flow parameters with their forming factors have been proposed. Such relationships were created for Lithuanian small and medium-size rivers using 1540 discharge measurements of 86 rivers:

$$\begin{aligned} h&=0.29\overline{Q}^{0.45}k^{0.39}I^{-0.2}\\ b&=8\overline{Q}^{0.30}k^{0.08}I^{-0.2} \qquad (3),\\ v&=0.43\overline{Q}^{0.25}k^{0.53}I^{0.4} \end{aligned}$$

where h – average riverbed depth, m, b – average riverbed width, m, v – average flow velocity in cross-section, m/s, $\overline{Q}$ – average annual discharge, m^3/s, I – riverbed slope, $k = \frac{Q_i}{\overline{Q}}$ discharge modular coefficient, Q_i – discharge.

Average annual discharge $\overline{Q}$ of ungauged rivers was estimated by multiplying value of specific discharge (l/s·km^2) (from isoline map of annual runoff distribution (Gailiušis *et al.* 2001)) by the catchment area. The slope of river segment was defined using topographic map of scale 1:25 000 according to indicated (summer) water levels on channels.

RESULTS

Assessment of hydrokinetic resource indices of ungauged rivers

Hydrokinetic energy resources of a cross-section were calculated according to average depth, average velocity and duration of time favourable for operation of kinetic devices. These characteristics of ungauged rivers were evaluated with the help of regional dependencies, using hydrological methods, available measured and observed data (Assessment… 2010). Climate, size of river catchment area, lakes, forests and other physical geographical indices determined particular conditions for river energy extraction.

Small and medium-size plain rivers are characterized by low flow velocity; whereas the cut-in speed of some hydrokinetic turbines is 0.5 m/s (Vermaak *et al.*

2014; Yuce, Muratoglu 2015). Therefore, duration of average velocities in the river cross-section per year indicates opportunities of the river to generate hydrokinetic energy. Existing relationship between flow discharge and velocity (Fig. 2) enables to calculate the duration of flow regime favourable to hydroenergy production according to flow duration curve. The analysis revealed that in distinct rivers, this ratio is very strong (Fig. 2). In hydrological region of Western Lithuania, the correlation coefficient between discharge and flow velocity varied from 0.80 to 0.98 (0.90 in average), in hydrological region of Central Lithuania – from 0.74 to 0.96 (0.89 in average) and in hydrological region of South-eastern Lithuania it ranged from 0.83 to 0.99 (0.94 in average). The estimated relationships in different water measurement stations will allow defining the average flow velocities for the ungauged rivers. The relationship between discharge and flow velocity was estimated using data of 30 water measurement stations (WMS) (in 16 rivers).

According to relation between discharge and average flow velocity, curve of flow velocity duration can be created. The character of this curve depends on the same physical geographical factors, which describe the curve of discharge duration and value of its main parameter – coefficient of natural flow regulation φ (sometimes called a base flow index). Performed investigations (Gailiušis *et al.* 2001) reveal that the degree of natural regulation of river runoff is well reflected by coefficient φ:

$$\varphi = \int_0^1 t dk \ , \tag{4}$$

where t is the duration (days) of discharge, modular coefficient of which equals $k = \dfrac{Q_i}{Q}$.

The typical curves of discharge (expressed by modular coefficient k) and velocity durations are described in Fig. 3.

Observations reveal that rivers have long flow duration periods (200–250 days) with higher than 0.5 m/s velocities in Western Lithuania, where slopes are large (Table 1), and the amount of precipitation is large (up to 800–1000 mm per year). Whereas in Central Lithuania, rivers that flow on plains and get a small amount of precipitation (500–600 mm per year) are distinguished by 100–200 days long period per year, when their flow velocities exceed 0.5 m/s. In South-eastern Lithuania, river runoff is especially uniform because of the impact of runoff regulation factors (the prevailing subsurface feeding, permeable sandy soils); here, the periods of proper flow velocities, lasting longer than 200 days or, in some rivers, all the year, are observed.

Cartoschemes and recommendations for estima-

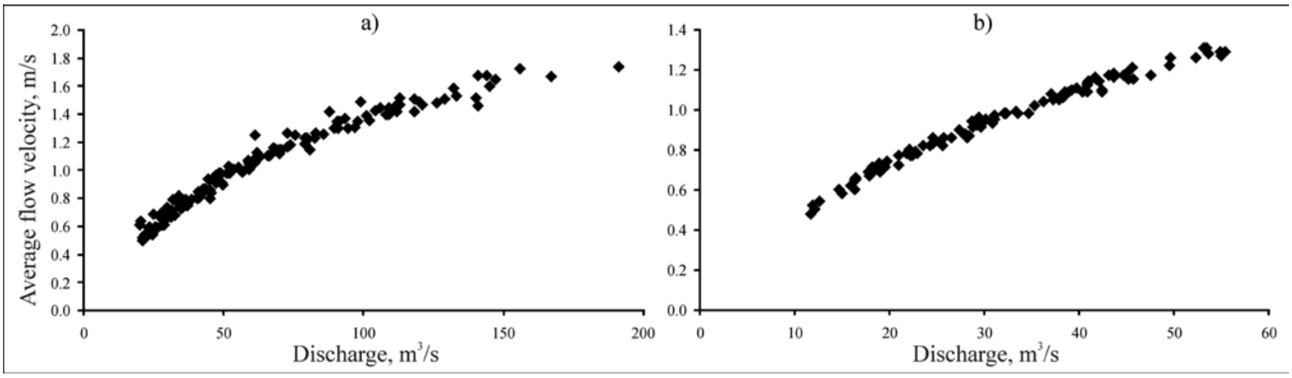

Fig. 2 The relationship between discharge and flow velocity: a) in the Merkys at Puvočiai WMS, b) in the Žeimena at Pabradė WMS. Compiled by D. Jakimavičius

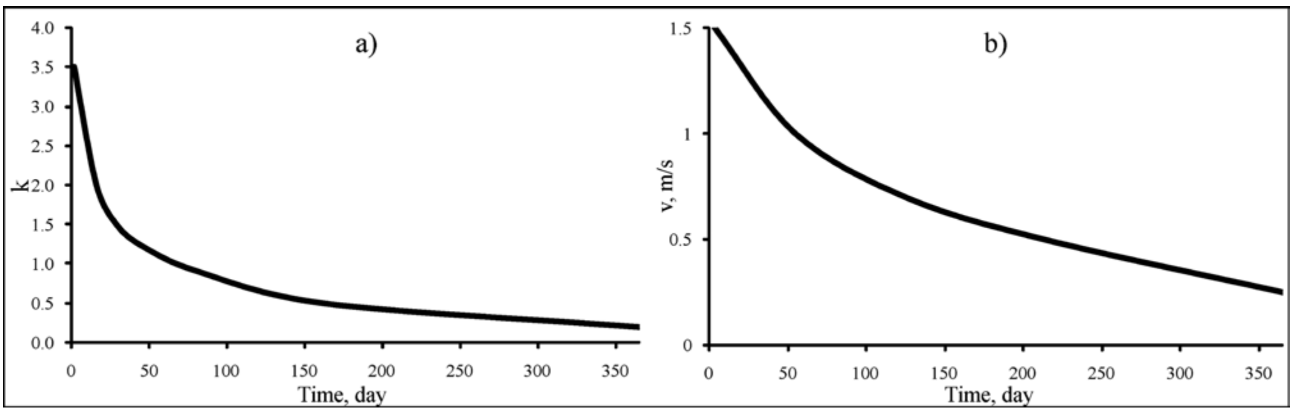

Fig. 3 Typical curves of discharge (a) and flow velocity (b) duration. Compiled by A. Jurgelėnaitė

tion of runoff regulation coefficient for ungauged Lithuanian rivers have already been prepared. It was established that water abundance of the year does not have impact on the value of this coefficient (Gailiušis *et al.* 2001). The same physical geographical factors determine the duration of river runoff and runoff regulation coefficient φ and can be used for evaluation of hydrokinetic energy resources for Lithuanian small and medium-size rivers (Fig. 4).

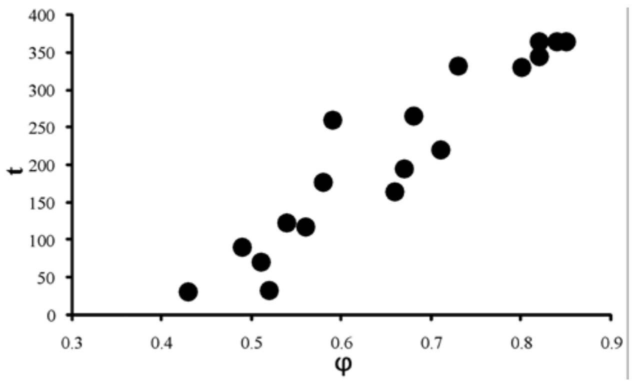

Fig. 4 Interdependence between duration of river runoff, when flow velocity exceeds 0.5 m/s, and runoff regulation coefficient of the studied Lithuanian rivers. Compiled by D. Šarauskienė

In case of small and shallow rivers, hydrokinetic turbines can be installed only in deep part of the river channel cross-section (i.e. in sufficient depth), where maximum flow velocities are observed. In assessing hydrokinetic resources, the shape of river cross-section is of great importance because it determines the potential number of turbines. Whereas cross-section portion of small depth and velocity is worthless in respect of energy generation. Theoretically, if "V" shape channel form is accepted, the average depth accounts for half (0.5) of maximum depth value; in case of rectangular form, this ratio is 1, and then the total width of cross-section can be used for turbine deployment.

A very strong relationship was identified between the maximum and average values of river depth: for

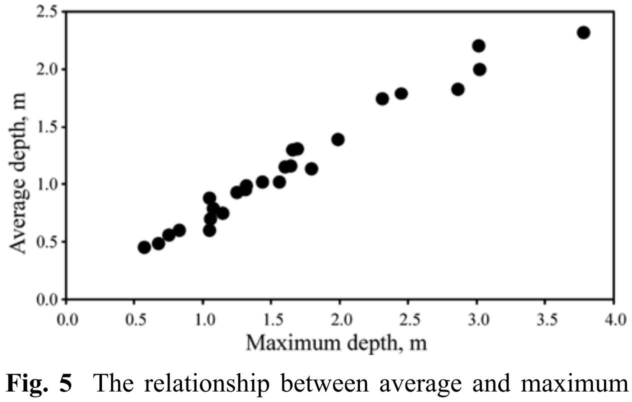

Fig. 5 The relationship between average and maximum depth of the studied Lithuanian rivers. Compiled by D. Šarauskienė

example, in the Minija at Kartena WMS, this relationship is as high as 0.99. In different hydrological regions, it ranges very similarly: in Western Lithuania, it varies from 0.94 to 0.99, in Central Lithuania – 0.93-0.99 and in South-eastern Lithuania – 0.95-0.99. Based on the analysis of cross-sections of the studied Lithuanian rivers (Fig. 5), a generalized ratio between average and maximum depth was accepted as 0.70. This means that in 70% of the cross-section width, the river depth equals or exceeds the average value.

Assessment of available hydrokinetic resources of small and medium-size rivers

In order to implement environmental objectives, which are of great priority in the society, certain restrictions for technogenic use of natural resources are applied. There are two types of limitations: with respect to territory and time. Environmental restrictions prohibit installation of the equipment in territories, where priority is given to conservation of biota species and productivity. In Lithuania, such activities are prohibited in *Natura 2000* territories, strict nature reserves and ichthyologic reserves.

In previous study (Jakimavičius *et al.* 2014) the estimated 328 river segments (about 2000 km in total) were identified as having a theoretical/technical hydrokinetic potential (they can be used when discharge is of 95% probability, flow velocity is greater than 0.4 m/s and flow depth exceeds 0.5 m). *Natura 2000* sites (Special Areas of Conservation (SACs) and Special Protection Areas (SPAs)) reduce the number of suitable river segments (Fig. 6 a) to 139: the capacity of 46 segments is greater than 0.1 MW, and the capacity of 93 is less than 0.1 MW (Fig. 6 b).

Important temporal restrictions are related to fish migrations and spawning season as well as bird breeding time. Since no hydrokinetic devices are intended to be installed in the protected areas, the mentioned restraints are not relevant.

Turbines are constructed from steel and must be immersed while operating. However, if a river discharge changes, turbine can emerge from water, and then such visual impact is regarded as visual pollution. River valley is part of a natural frame, and a river flow is a valley axis, where steel structure cannot be accepted as a natural landscape element.

Navigation activity is one more restriction that limits the use of hydrokinetic devices in some river segments. Hydrokinetic turbines cannot be installed in navigable waterways, since they impede boat traffic. However, only few Lithuanian rivers are used for water transport.

The exploitation of small and medium-size river hydrokinetic energy in a climate zone with ice phenomena is restricted by potential damage to turbines. Small depth and greater flow velocity are the main factors,

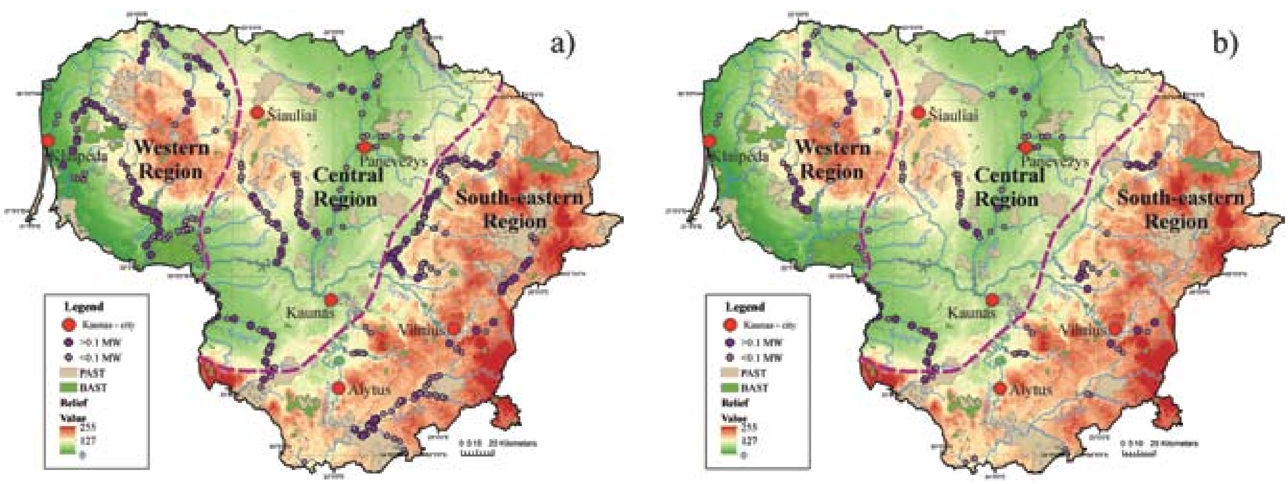

Fig. 6 Total technical hydrokinetic resources (a) and available hydrokinetic resources (after exclusion of river segments, located in *Natura 2000* sites) (b). Compiled by D. Jakimavičius

Table 1 The summary of hydrokinetic energy resources in different hydrological regions

Hydrological region	River channel slope (m/km)		Specific discharge (l/s·km^2)		Total length of useful segments (km)	Capacity of segments (kW/km)	Total capacity (MW)	Capacity of turbines (MW)	Available capacity (MW)
	min	max	min	max					
Western Lithuania	0.85	2.96	6	14	733.8	40.8	29.9	13.2	5.1
Central Lithuania	0.35	0.94	5	6	643.0	38.2	24.6	9.4	4.5
South-eastern Lithuania	1.00	2.82	7	10	609.9	45.3	27.6	13.3	4.0

because of which turbines are installed in the upper flow layer, i.e. near the top of the water column, and do not remain in river during winter. In Lithuanian climate conditions, rivers normally begin to freeze in the third decade of November. In small rivers, ice breakup usually occurs and clears in the middle of March. The average duration of ice phenomena is 120 days. Therefore, hydrokinetic energy of studied rivers cannot be used at least for one-third of a year.

Table 1 summarises the overall results of this study. The performed analysis indicated that the greatest hydrokinetic potential is characteristic for the rivers of South-eastern Lithuania; however, a total length of potentially useful river segments is the smallest in this region. The least potential to be used for energy production have the plain rivers from Central Lithuania. The greatest amount of hydrokinetic resources that can be used technically considering all described restrictions is located in river segments of Western Lithuania.

DISCUSSION

The previous study (Jakimavičius *et al.* 2014) was dedicated to the assessment of theoretical hydrokinetic resources of small and medium-size Lithuanian rivers. In the current study, the authors continued the investigation and made an attempt to evaluate practical constraints related to opportunities of using the selected potentially exploitable river segments. That is an assessment of free water flow (hydrokinetic) energy by singling out certain river segments with the greatest density of kinetic energy in the river cross-section. Hydrokinetic energy capacity of Lithuanian small and medium-size rivers (in 328 segments, where the average flow velocity is greater than 0.4 m/s and the average depth exceeds 0.5 m) comprises 82.1 MW, whereas only 35.9 MW can be captured by hydrokinetic turbines. Thus, over the year (excluding 4 months with ice cover) 210.7 GWh of energy can be produced. However, after considering the requirements of the protected areas, only in 139 segments of small and medium-size rivers, hydrokinetic turbines can be placed. Their capacity would comprise 13.6 MW, and they could generate 79.4 GWh of electric energy per year. This can cover only about 0.7% of total electric energy demand in Lithuania.

The methods of river kinetic resources assessment are at their initial stages (Behrouzi *et al*. 2016; Khan *et al*. 2008; Lalander 2010; Yuce, Muratoglu 2015). The appropriate method for this assessment is selected depending on the objectives, selected river size and available river data on runoff, morphometry and hydraulics. It is acknowledged that in cases of a large amount of data, river flow modelling gives reliable results (Lalander 2013). Although in large territories, physical geographical regionalization and methods of engineering hydrology are those, which enable the evaluation of hydrokinetic resources of small and medium-size rivers, when available data are insufficient.

CONCLUSIONS

The estimated resources of hydrokinetic energy of Lithuanian small and medium-size rivers (without the rivers Nemunas and Neris) comprise 82.1 MW. However, 61% of exploitable segments are located in the protected areas, where environmental policy acts of the Republic of Lithuania restrict their employment. Moreover, the use of hydrokinetic energy of studied rivers is limited because of ice phenomena, and thus the energy cannot be generated for about 120 days per year, i.e., only 67% of total hydrokinetic resources can be used. The mentioned exclusionary criteria reduce capacity of hydrokinetic energy to 13.6 MW and allow producing only 0.7% of total electric energy demand for the national economy.

The resources of hydrokinetic energy were estimated assuming that the flow energy can only be used in river segment areas, where the depth is greater than turbine diameter (it was assumed that this deployment area comprises 70% of the river width).

The methods for assessment of hydrokinetic resources were proposed for ungauged small and medium-size rivers. Although the presented investigation and resource assessment cover national topic, the paper has much broader policy significance, especially while looking to the future, as more improved, having smaller cut-in speed and more suitable for small rivers turbines may be developed. The proposed methods to use this renewable energy resource can be applied in other countries of plain terrain as well.

REFERENCES

Alaska Energy, 2009. *A Guide for Alaskan communities to utilize local energy resources*. Alaska Energy Authority and Alaska Centre for Energy and Power, 245 pp.

Assessment and Mapping of the Riverine Hydrokinetic Energy Resource in the Continental United States, 2012. Technical report. Electric Power Research Institute, Palo Alto, CA, USA, 80 pp.

Assessment of Canada's Hydrokinetic Power Potential: Phase I Report - Methodology and Data Review, 2010. Canadian Hydraulics Centre, National Research Council of Canada, 72 pp.

Behrouzi, F., Nakisa, M., Maimun, A., Ahmed, Y.M., 2016. Renewable energy potential in Malaysia: Hydrokinetic river/marine technology. *Renewable and Sustainable Energy Reviews 62*, 1270–1281. doi:10.1016/j.rser.2016.05.020.

Briand, M.-H., Ng, K., 2010. Kinetic energy recovery turbine technology: resource assessment and site development strategy. Issue 2. 1: *Energy resources and technologies, today and tomorrow*. Congrès Mondial de l'Énergie – World Energy Conference, 13–17 September 2010, 2815–2826.

Cada, G., Ahlgrimm, J., Bahleda, M., Bigford, T., Stavrakas, S.D., Hall, D., 2007. Potential impacts of hydrokinetic and wave energy conversion technologies on aquatic environments. *Fisheries 32 (4),* 174–181.

Egre, D., Milewski, J.C., 2002. The diversity of hydropower projects. *Energy Policy 30,* 1225–1230. doi:10.1016/S0301-4215(02)00083-6.

Gailiušis, B., Jablonskis, J., Kovalenkovienė, M., 2001. *The Lithuanian rivers. Hydrography and runoff.* LEI, Kaunas, 792 pp. [In Lithuanian, with English summary].

Gorban, A.N., Gorlov, A.M., Silantyev, V.M., 2001. Limits of the turbine efficiency for free fluid flow. *Journal of Energy Resources Technology-ASME 123,* 311–7. doi:10.1115/1.1414137.

Hammar, L., Andersson, S., Eggertsen, L., Haglund, J., Gullström, M., Ehnberg, J., Molander, S., 2013. Hydrokinetic Turbine Effects on Fish Swimming Behaviour. *PLoS ONE 8 12,* e84141. doi:10.1371/journal.pone.0084141.

Hydrometeorological Service of the Lithuanian SSR, 1925–1989. *Hydrological Yearbooks*. [In Russian].

Jablonskis, J., Jurgelėnaitė, A., Tomkevičienė, A., 2007. Hydropower in environment protection context. *Energetika 3,* 48–56. [In Lithuanian].

Jacobson, P., Amaral, S., Castro-Santos, T., Giza, D., Haro, A., Hecker, G., McMahon, B., Perkins, N., Pioppi, N., 2012. *Environmental Effects of Hydrokinetic Turbines on Fish: Desktop and Laboratory Flume Studies*. Report by Electric Power Research Institute (EPRI), 220 pp.

Jakimavičius, D., Gailiušis, B., Šarauskienė, D., Jurgelėnaitė, A., Meilutytė-Lukauskienė, D., 2014. Assessment of the riverine hydrokinetic energy resources in Lithuania. *Baltica 27 (2),* 141–150. doi:10.5200/baltica.2014.27.23.

Khan, M.J., Iqbal, M.T., Quaicoe, J.E., 2008. River current energy conversion systems: Progress, prospects and challenges. *Renewable and Sustainable Energy Reviews 12,* 2177–2193. doi:10.1016/j.rser.2007.04.016.

Koko, S.P., Kusakana, K., Vermaak, H.J., 2015. Micro-hydrokinetic river system modelling and analysis as compared to wind system for remote rural electrification. *Electric Power Systems Research 126,* 38–44. doi:10.1016/j.epsr.2015.04.018.

Lago, L.I., Ponta, F.L., Chen, L., 2010. Advances and trends in hydrokinetic turbine systems. *Energy for Sustainable Development 14 (4),* 287–296. doi:10.1016/j.esd.2010.09.004.

Lalander, E., 2010. *Modelling hydrokinetic energy resources for in-stream energy converters* (thesis). Department of Engineering Sciences, Uppsala University, 57 pp.

Lalander, E., 2013. *Hydrokinetic resource assessment: Measurements and models*. Acta Universitatis Upsaliensis. Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Science and Technology 1038, 72 pp.

Leopold, L.B., Maddock, T., 1953. *The Hydraulic Geometry of Stream Channels and Some Physiographic Implications*. U.S. Geological Survey Professional Paper, 252, 64 pp.

Lithuanian Hydrometeorological Service, 1990–2012. *Hydrological Yearbooks*. Vilnius. [In Lithuanian].

Punys, P., Adamonytė, I., Kvaraciejus, A., Žilinskas, S., 2013a. Hydraulic-geometric characteristics of the River Nemunas for the assessment of hydrokinetic resources. *Agricultural Engineering, Research Papers 45 (3),* 38–50. [In Lithuanian].

Punys, P., Martinaitis, E., Vyčienė, G., Vaišvila, A., 2013b. Assessment of the hydrokinetic energy characteristics of the river Neris using a one dimensional numerical HEC RAS 4.1 model. *Water Management Engineering 42 (62),* 61–71. [In Lithuanian].

Punys, P., Adamonyte, I., Kvaraciejus, A., Martinaitis, E., Vyciene, G., Kasiulis, E., 2015. Riverine hydrokinetic resource assessment. A case study of a lowland river in Lithuania. *Renewable and Sustainable Energy Reviews 50*, 643–652. doi:10.1016/j.rser.2015.04.155.

Rybkin, S.I., 1947. Morphometric classification of rivers. *Meteorology and Hydrology 4*, 38–47. [In Russian].

Seitz, A.C., Moerlein, K., Evans, M.D., Rosenberger, A.E., 2011. Ecology of fishes in a high-latitude, turbid river with implications for the impacts of hydrokinetic devices. *Reviews in Fish Biology and Fisheries 21*, 481–496. doi:10.1007/s11160-011-9200-3.

Vermaak, H.J., Kusakana, K., Koko, S.P., 2014. Status of micro-hydrokinetic river technology in rural applications: A review of literature. *Renewable and Sustainable Energy Reviews 29,* 625–633. doi:10.1016/j.rser.2013.08.066.

Vogel, R.M., Fennessey, N.M., 1994. Flow-duration curves. I: New interpretation and confidence intervals. *Journal of Water Resources Planning and Management 120 (4)*, 485–504.

Zdankus, N., Punys, P., Zdankus, T., 2014. Conversion of lowland river flow kinetic energy. *Renewable and Sustainable Energy Reviews 38,* 121–130. doi:10.1016/j.rser.2014.05.074.

Yuce, M.I., Muratoglu, A., 2015. Hydrokinetic energy conversion systems: A technology status review. *Renewable and Sustainable Energy Reviews 43*, 72–82. doi:10.1016/j.rser.2010.06.016.