since 1961

Baltica

BALTICA Volume 27 Number 2 December 2014 : 141–150
doi: 10.5200/baltica.2014.27.23

Assessment of the riverine hydrokinetic energy resources in Lithuania

Darius Jakimavičius, Brunonas Gailiušis, Diana Šarauskienė, Aldona Jurgelėnaitė, Diana Meilutytė-Lukauskienė

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.* Vilnius. ISSN 0067-3064.

Manuscript submitted 16 September 2014 / Accepted 25 November 2014 / Published online 10 December 2014

Abstract The hydro-energy resources are considered as promising renewable energy sources, which emphasizes the need for assessment of theoretical hydrokinetic energy resources stored in Lithuanian rivers. This article presents the results of an investigation of the theoretical hydrokinetic energy in small and medium-size rivers. A total of 282 rivers (1487 segments) were examined and the relationships were established for evaluation of their hydrological and morphological indicators, such as river depth, width, and flow velocity. Only 41 rivers (328 segments) were identified as having a theoretical hydrokinetic potential. The total length of these valuable river segments reaches 2000 km. The estimated kinetic energy capacity calculated for a 1 km channel segment is 45.3 kW in South-eastern, 40.8 kW in Western, and 38.2 kW in Central Lithuania.

Keywords • *hydrokinetic energy resources • hydrological and morphological equations*

✉ *Darius Jakimavičius, Brunonas Gailiušis, Diana Šarauskienė (Diana.Sarauskiene@lei.lt), Aldona Jurgelėnaitė, Diana Meilutytė-Lukauskienė. Laboratory of Hydrology, Lithuanian Energy Institute, Breslaujos g. 3, LT-44403 Kaunas, Lithuania*

INTRODUCTION

River hydrokinetic energy could be regarded as the least renewable energy source. Some scientists vividly highlight that technology of the river current energy conversion system is probably at its infancy (Khan *et al.* 2008). The possibilities to use river hydrokinetic resources are particularly relevant and at the same time complicated and limited considering many social, environmental and technical factors: the main challenge here is both extracting more energy per unit of rotor swept area and doing it in a more economic and environment-friendly way (Lago *et al.* 2010; Zdankus *et al.* 2014). The primary criteria for the river feasibility are sufficient flow velocity and depth. The required minimal values of these factors in different literature sources contrast significantly (Gorban *et al.* 2001; Alaska Energy 2009; Briand, Ng 2010), it is recommended that flow velocity should be greater than 0.5 m/s and flow depth – at least 0.5–0.75 m. River runoff seasonality also has to be considered as a crucial factor for river suitability (Egre, Milewski 2002), not to mention often arising environmental obstacles (Cada *et al.* 2007; Alaska Energy 2009; Khan *et al.* 2009). At the same time river, hydrokinetic turbines are proposed as primary source of energy supply in rural areas (Kusakana, Vermaak 2013) and remote communities (Anyi, Kirke 2010).

Up to now only a few countries have managed to organize the evaluation of a kinetic energy potential of their rivers (Assessment… 2010; Assessment… 2012). Canadian scientists assessed available methodologies that could be employed in the determination of Canada's hydrokinetic potential, the available data sources and recommendations for the next phase, which is supposed to include a methodology validation (Assessment… 2010). Whereas it is already assessed, that the estimate of the theoretical resource for the continental United States (contiguous 48 states and Alaska) totals 1,381 TWh/yr. The assessment of the hydrokinetic resource in the 48 contiguous states is derived from spatially explicit data contained in NHD Plus – a GIS-based database containing river segment-specific information on discharge characteristics and channel slope. The attempts to assess river flow potential for hydrokinetic power generation are being made in the neighbouring Latvia as well (Kalnacs *et al.* 2013; Kalnacs *et al.* 2014).

In Lithuania, the use of river potential energy (of waterfall) is well studied (Jablonskis 2005). The estimated total theoretical hydropower potential of Lithuanian rivers is 585.12 MW (Jablonskis, Lasinskas 1962). Some of this potential was employed in the construction of hydropower plants or installation of dams, whereas the usage of the rest yet unused hydropower potential is limited to the environmental constraints (Jablonskis *et al.* 2008) or unusable due to small and inefficient devices. The possibilities to get energy from moving water, i.e. river kinetic power, have not yet been widely investigated. It was assumed that hydrokinetic energy resources could amount to hundreds of megawatts.

In Lithuania, there are two object groups of energy resources assessment: the large rivers – the Nemunas and the Neris and smaller rivers (or small and medium-size river group). These two groups differ in investigation extent, resource assessment methods, nature of riverbed use, flow formation characteristics and in kinetic energy density of river cross-section. The scientists (Punys *et al.* 2013a; Punys *et al.* 2013b) already made a start for the research of opportunities to use flow hydrokinetic resources of the largest rivers the Neris and the Nemunas. The aim of the study (Punys *et al.* 2013a) was to determine the main flow morphometric and hydraulic characteristics of the Neris riverbed, necessary for the assessment of hydropower resources by performing the numerical modelling. In the study (Punys *et al.* 2013b), hydraulic-geometric characteristics of the Nemunas for assessment of hydrokinetic resources were investigated.

This article presents the results of investigation of small and medium-size river hydrokinetic energy: the assessment of theoretical (potential) and primary technical hydrokinetic energy resources in the area; and the distribution of hydrokinetic energy resources in different river catchments and selection of the river segments that are the most favourable for practical use of energy. In the next stage, the assessment of technical hydrokinetic energy resources will be performed in order to find out what kind of new technologies could be applied for energy generation and in respect to possibilities to develop them in environmentally sensitive or protected areas.

STUDY AREA AND DATA

In Lithuania, there are 30,000 watercourses longer than 0.25 km. Their total length is 64,000 km. The average dense of Lithuanian river net is 0.98 km/km^2. Twenty-six km^3 is an average annual amount of water that drains Lithuanian rivers (Galvonaitė *et al.* 2013). According to different river runoff forming factors, Lithuanian rivers are divided into three hydrological regions: Western, Central and South-eastern that differ according to hydrological regime and river feeding type. The rivers selected for the investigation represent all these regions. Numerous river resources determined by abundant precipitation lead to the idea to evaluate what energetic resources are stored in our rivers. As it was already stated for this evaluation, small and medium-size Lithuanian rivers were selected (Fig. 1).

The assessment of theoretical hydrokinetic energy resources included 282 rivers (1487 segments) from all three hydrological regions. Primary technical assessment (taking into account the limiting conditions:

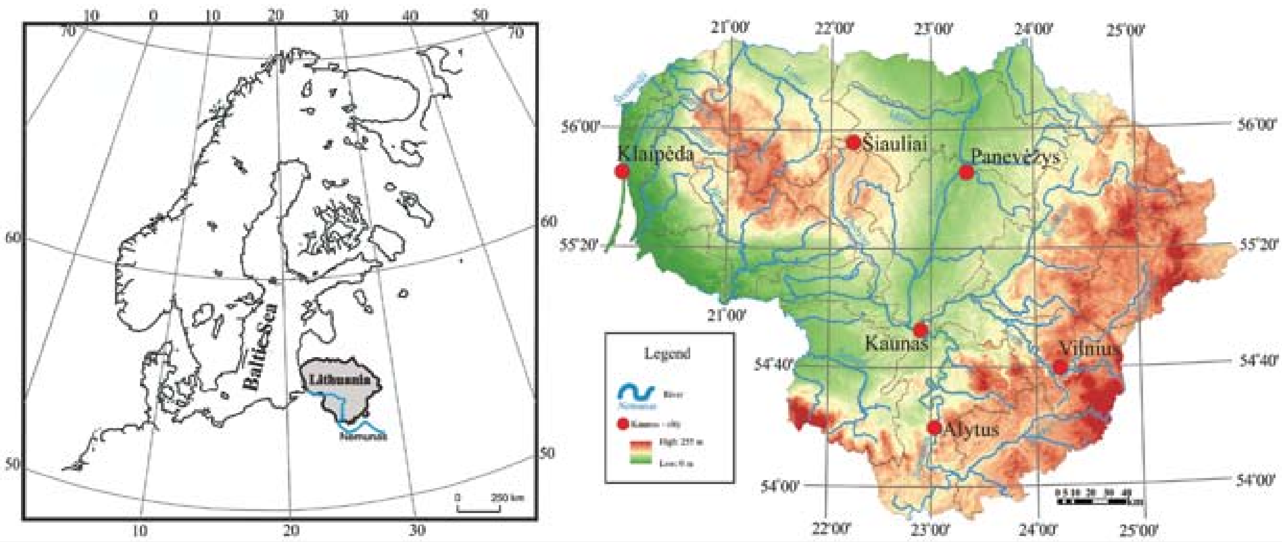

Fig. 1 Location of the studied objects. Compiled by D. Jakimavičius, A. Jurgelėnaitė, 2014

minimal depth and flow velocity) was performed only for 41 rivers (328 segments). There was no coincidence that analysis of the rivers was accomplished considering their belonging to a certain hydrological region. These regions differ for precipitation, catchment morphology and in different contribution of the underground feeding. Such peculiarities determine the specifics of hydrological regime and have significant impact on the river water availability and hence on river hydrokinetic resources as well. For the assessment, a huge amount of data was used: the average multiannual discharge (Hydrometeorological... 1925–1989; Lithuanian... 1990–2012), and river bed slope and segment length (Gailiušis *et al.* 2001; Jablonskis, Lasinskas 1962).

METHODS

The assessment of hydrokinetic energy resources in river catchments was performed and presented using geographical research methods (geographical information systems (GIS), topographic maps) and numerous available hydrological monitoring data. The most important physical geographical factors – river runoff and river bed slope were determined and applied evaluating potential hydropower resources of the territory using the standard hydrological engineering equation that relates theoretical hydraulic power (P_{th}, Watts) to discharge (Q, $m^3 s^{-1}$) and hydraulic head or change in elevation (ΔH, m) over the length of the segment, where γ is the specific weight of water (9800 N m^{-3}) (Assessment… 2012):

$$P_{th} = \gamma Q \Delta H \quad (1)$$

Plain rivers flow in the territories of scoured geological formations. Therefore, the flow forms a channel that is characterized by the relationship between the geometric and hydraulic characteristics (width, depth and flow velocity) and major influential factors: flow discharge and slope. The relationship reflects the average flow conditions in a limited area with relatively uniform geological conditions. This existing relationship can be explained by flow endeavour to create flow velocity structure, which would determine the least loss of flow energy to overcome resistance. The impact of the relief lithogenic background is crucial. Gravity is the force that causes river water to create kinetic energy in the bed.

The selected river cross-section in the intended investigation can be accurately described by these hydro morphological indicators: the average flow width b (m), the average flow depth h_{avg} (m), which is calculated dividing the cross-sectional area by the flow width, and the average flow velocity v (m/s).

The product of these indicators in each river cross-section expresses the river discharge (m^3/s)

$$Q = b h_{avg} v \quad (2)$$

In the estimation of total hydrokinetic potential of river flows in the whole territory of Lithuania, the identification of river segments with hydro morphological indicators favourable to use is of great importance. Favourable to use hydro morphological indicators are understood as the minimum flow depth, width and velocity values that can technically be used or comply with the environmental limitations.

Dependences proposed by S. I. Rybkin (1947) are the following:

$$h = a_1 Q_{avg}^{x_1} k^{y_1} I^{z_1} \quad (3),$$

$$b = a_2 Q_{avg}^{x_2} k^{y_2} I^{z_2} \quad (4),$$

$$v = a_3 Q_{avg}^{x_3} k^{y_3} I^{z_3} \quad (5).$$

The establishment of such dependencies is possible, if these additional conditions are met: $a_1 \cdot a_2 \cdot a_3 = 1$, $x_1 + x_2 + x_3 = 1$, $y_1 + y_2 + y_3 = 1$, $z_1 + z_2 + z_3 = 0$.

The characteristics that determine the riverbed parameters and can be calculated for ungauged rivers were examined. The main indicators of the bed hydro morphology are as follows: average multiannual discharge as a measure of bed size, longitudinal slope of the river, which strongly determines flow energy power, degree of bed filling, which determines flow morphological and cross-section hydraulic characteristics, river silt and bottom sediment grain, which determines bed roughness.

In addition to these important factors, describing river flow, in each case it is necessary to know its distribution in space and time as well: average and maximum flow velocity ratio in cross-section and vertical, distribution of runoff during a year, which defines duration of potential usage of hydrokinetic energy, when flow velocity exceeds the thresholds.

Hydrological and morphological dependencies of small and medium-size rivers of Lithuania are created using methodology published by S.I. Rybkin (1947). The main point of this methodology – the evaluation of dependencies of investigated rivers bed parameters on the main bed-forming factors and use of these dependencies for ungauged rivers. It is easy to identify flow discharge, bed slope and average multiannual discharge for any cross-section of ungauged river. Each cross-section has the empirical dependences:

$$h = a_1 k^{y_1} \quad (6),$$

$$b = a_2 k^{y_2} \quad (7),$$

$$v = a_3 k^{y_3} \quad (8),$$

where h – average depth, m, b – average bed width, m, v – average flow velocity, m/s. Additional flow discharge integrity equation Q=hbv is used and for initial conditions: $a \cdot a_2 \cdot a_3 = Q$ and $y_1 + y_2 + y_3 = 1$, k – coefficient, Q – measured discharge.

RESULTS

River indicators and their dependencies on local landscape

The created hydro- and morphological equations (using the established values of exponents of equation members; Table 1) for Lithuanian rivers are the following:

$$h=0.29\, Q^{0.45}k^{0.39}I^{-0.2} \quad (9),$$

$$b=8Q^{0.30}k^{0.08}I^{-0.2} \quad (10),$$

$$v=0.43Q^{0.25}k^{0.53}I^{0.4} \quad (11).$$

The bed parameters of 14 riverbeds of different size were calculated according to 9–11 equations. Hydro- and morphological values of these riverbeds were not used for the establishment of equations. The average relative errors for calculated values of h, b and v consisted of 14.0, 17.9 and 19.0%. The maximum relative errors of 48–50% were estimated for minimal discharges and the smallest bed parameters.

River depth (*h*, m) and flow velocity (*v*, m/s) are the main characteristics that determine the suitability of a particular segment for the hydrokinetic energy production. The assessment of hydrokinetic energy resources was performed in the river segments with minimum depth of 0.5 m and minimum flow veloc-

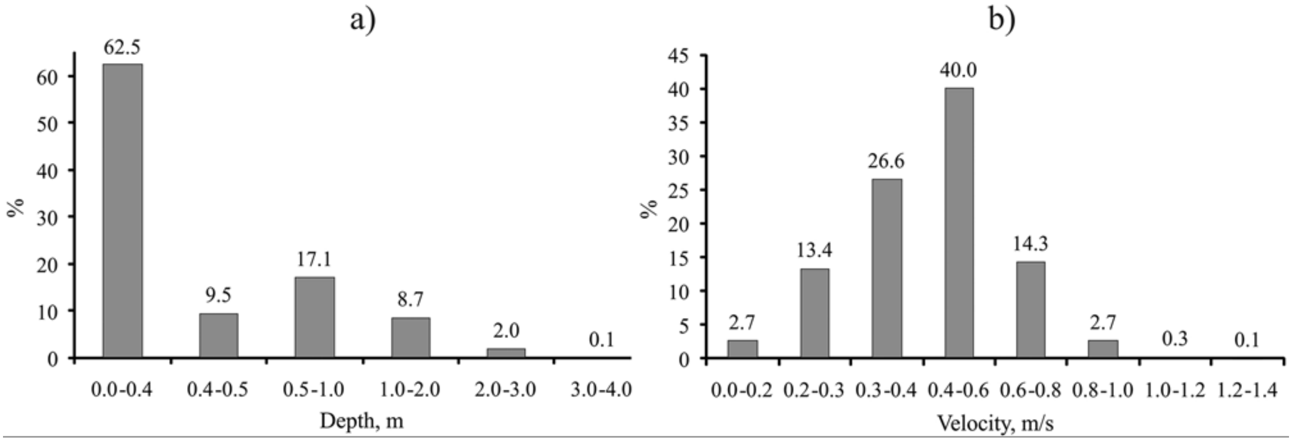

Fig. 2 Distribution of river segments (in %) according to depth (a) and flow velocity (b). Compiled by D. Jakimavičius, B. Gailiušis, 2014

Table 1 Exponents of hydromorphological equation members. Compiled by B. Gailiušis, 2014.

Physical geographical region	Y_1		Y_2		Y_3	
	average	range	average	range	average	range
Žemaičiai (Samogitian) Highland	0.42	0.26-0.60	0.10	0.02-0.21	0.48	0.34-0.68
Middle Lithuania Lowland	0.38	0.26-0.52	0.08	0.02-0.20	0.54	0.42-0.65
Baltic Southeast Highlands	0.39	0.22-0.69	0.07	0.02-0.20	0.54	0.32-0.65
Lithuanian territory	0.39	0.22-0.64	0.08	0.02-0.21	0.53	0.32-0.68

Table 2 Distribution of river segments according to depth (m) and flow velocity (m/s) in different catchments. Compiled by D. Jakimavičius, 2014.

Number of segments	Small tributaries of the Nemunas (without the Nemunas)	Merkys catchment	Small tributaries of the Neris (without the Neris)	Žeimena catchment	Šventoji catchment	Nevėžis catchment	Dubysa catchment	Šešupė catchment	Jūra catchment	Minija catchment	Lithuanian coastal rivers catchment	Bartuva catchment	Venta catchment	Lielupė catchment	Mūša catchment	Dauguva catchment
total	146	107	55	35	147	155	51	125	120	91	27	25	135	42	216	10
where *h*>0.5	23	42	9	17	70	38	19	30	45	31	9	4	36	12	26	4
where *v*>0.4	91	72	34	24	106	59	38	53	104	78	15	22	71	19	63	4
where *h*>0.5 and *v*>0.4	12	40	8	14	59	23	19	24	41	23	4	4	29	9	19	–

Table 3 The average flow velocity *v* (m/s), depth *h* (m), width *B* (m) and slope *i* (‰) of the segments in different catchments. Compiled by D. Šarauskienė, 2014.

Characteristics	Small tributaries of the Small tributaries of the Nemunas (without the Nemunas)	Merkys catchment	Small tributaries of the Neris (without the Neris)	Žeimena catchment	Šventoji catchment	Nevėžis catchment	Dubysa catchment	Šešupė catchment	Jūra catchment	Minija catchment	Lithuanian coastal rivers catchment	Venta catchment	Bartuva catchment	Mūša catchment	Lielupė catchment
v	0.55	0.59	0.59	0.62	0.61	0.59	0.62	0.57	0.63	0.62	0.49	0.60	0.56	0.53	0.62
h	0.6	1.0	0.7	1.2	1.4	0.7	0.9	1.1	1.1	0.9	0.5	0.8	0.6	0.9	0.8
B	13.3	19.1	14.6	22.3	23.9	14.9	17.4	20.4	19.5	17.9	12.4	16.5	12.5	17.6	15.4
i	0.76	0.53	0.77	0.44	0.45	0.81	0.88	0.53	0.66	0.71	0.67	0.71	0.85	0.51	0.80

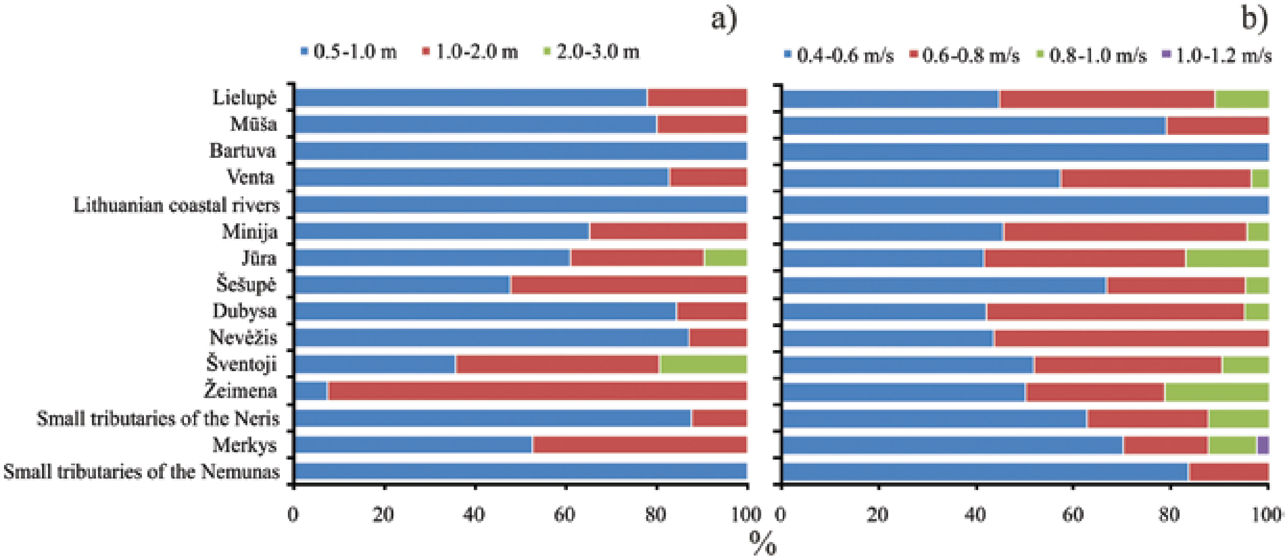

Fig. 3 Distribution of river segments' depth (a) and flow velocity (b) in different catchments (in %). Compiled by D. Jakimavičius, D. Šarauskienė, 2014

ity of 0.4 m/s. Available data revealed that only 415 (or 27.9%) river segments (out of 1487) were deeper than 0.5 m (Fig. 2a; Table 2) and 853 (or 57.4%) river segments had greater than 0.4 m/s velocity (Fig. 2b; Table 2).

In majority of the studied river catchments (in 10 out of 15), the average depth in the segment reached 1.0 meter. Greater depths dominated only in the catchments of Jūra (1.1 m), Žeimena (1.2 m) and Šventoji (1.4 m) (Fig. 3a, Table 3). The average flow velocities in the catchments did not exceed 0.7 m/s, whereas in the particular segments flow velocities ranged from 0.8 to 1.0 m/s or even exceeded 1.0 m/s. The smallest flow rates were typical for the catchments of Lithuanian coastal rivers and the small tributaries of the Nemunas: in 100% and 83.3% of the studied river segments respectively, the flow velocity was 0.4–0.6 m/s. In the catchments of the Nevėžis, Dubysa and Minija the average velocities in more than a half of the river segments varied in the range of 0.6–0.8 m/s. High flow velocities (0.8–1.0 m/s) were identified in the catchments of the Žeimena, Jūra and the small tributaries of the Neris: 21.4, 17.1 and 12.5% of all studied segments, respectively (Fig. 3b). The greatest velocities (over 1.0 m/s) were characteristic for the Merkys catchment. In most cases, the larger depths and flow velocities were defined for the greater bed slopes, i.e. in hilly territories, the smaller values – in the plains (Fig. 4). That confirms the direct impact of local landscape conditions on the river runoff and hence on energetic characteristics of a river flow.

As it was already mentioned, for the assessment of potential hydrokinetic resources the river segments were selected according to the average minimum values of depth and velocity (h>0.5 m and v>0.4 m/s). 328 river segments, i.e. only 22.1 % of the total amount, met the selection criteria and were used for further analysis. Fig. 4 illustrates the distribution of the selected segments in Lithuanian territory. In the

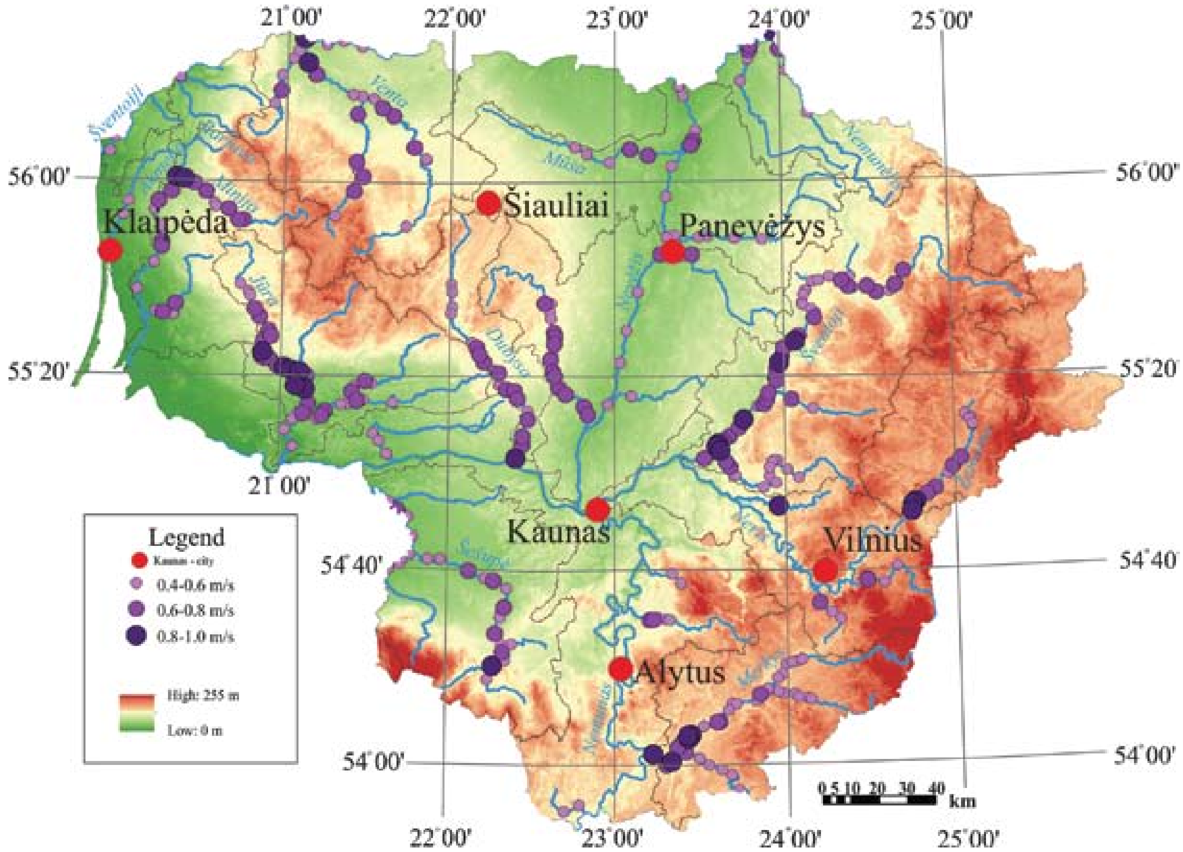

Fig. 4 River segments of different flow velocities (*h*>0.5 m). Compiled by D. Jakimavičius, D. Šarauskienė, 2014

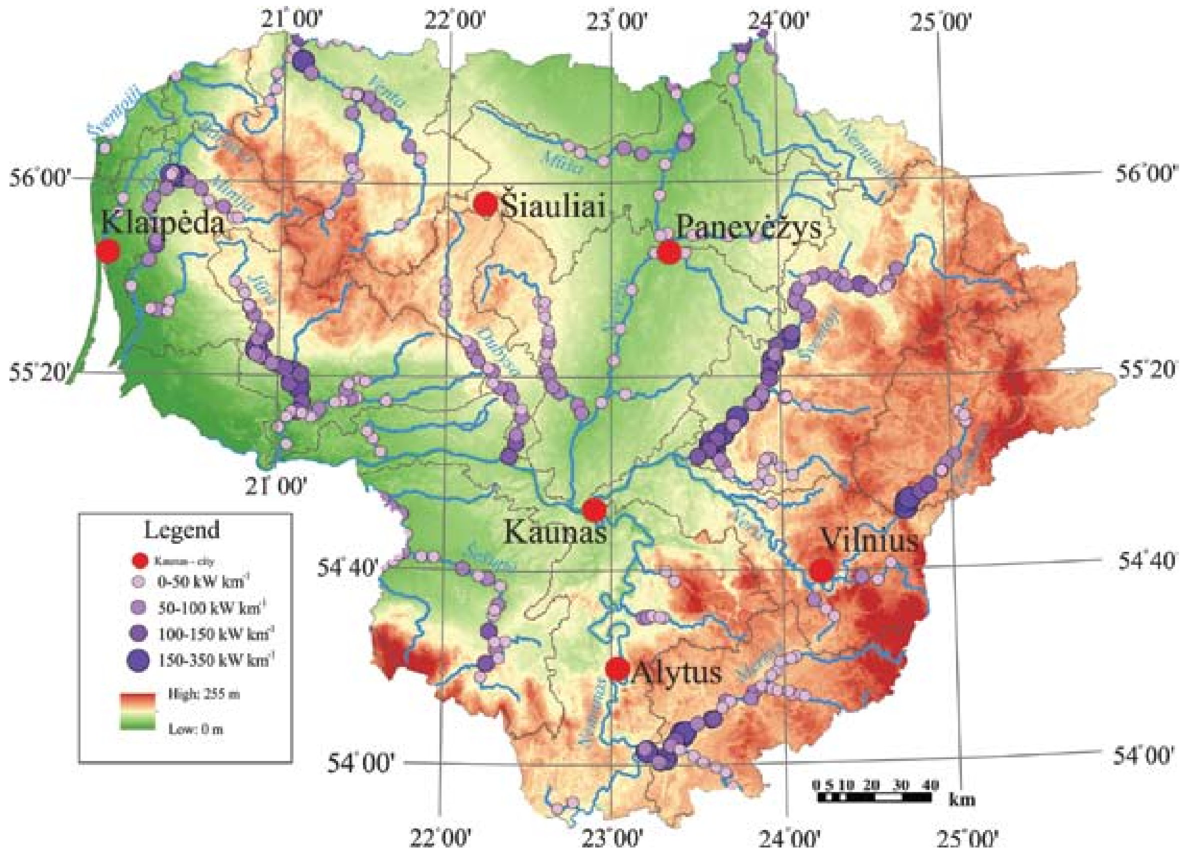

Fig. 5 Distribution of riverine theoretical hydrokinetic energy capacity in individual segments (kW km^{-1}). Compiled by D. Šarauskienė, D. Jakimavičius, 2014

hydrological region of South-eastern Lithuania that is very diverse in respect of geomorphology the majority of river segments that potentially could be used for kinetic energy production are located. In Central Lithuania, where the lowland is located, only fewer such segments were identified and they had smaller velocities. In the Western Lithuania the river segments with larger velocities and likely larger energetic resources were found on the slopes of West Žemaičiai Plateau.

The assessment of hydrokinetic resources

In the assessment of the potential to use riverine hydrokinetic energy, the estimation of theoretical capacity of particular river segments should be the first step. The rivers selected for the investigation represent all three Lithuanian hydrological regions that differ in their hydrological regime and river feeding type. Fig. 5 illustrates the accomplished assessment of theoretical hydrokinetic resources. The map provides potentially useful (in terms of energy production) river segments, dividing them into four classes according to their hydrokinetic energy capacity (0–50, 50–100, 100–150 and 150–350 kW/km). As expected, in different hydrological regions the river segments had different hydrokinetic capacity. In South-eastern Lithuania the greatest theoretical capacity was identified. In this region the rivers Merkys and Šventoji can be characterised as having the greatest potential for energy production. The hydrokinetic capacity in the particular segments reached 340 and 245 kW from 1 km of these rivers segments, respectively. Slightly smaller capacities were typical for the region of Western Lithuania. The rivers Minija, Jūra and Venta were distinguished by the largest capacities in this area. The maximum capacity of individual segments of these rivers was as large as 188.9, 182.5, 159.3 kW/km, respectively. In the hydrological region of Central Lithuania the smallest energy capacities were estimated; the greatest capacity values of particular segments were calculated in the rivers Nemunėlis, Dubysa and Šešupė: 142.7, 142.4 and 104.7 kW/km, respectively. The discovered patterns of riverine hydrokinetic energy distribution in Lithuanian territory are related to the local landscape features. That can be confirmed by very high correlation coefficients between bed slope and capacity (kW/km) (e.g. in the Bartuva catchment R=1.00, in the catchment of Lithuanian coastal rivers R=0.99, in the Žeimena catchment R=0.93).

Fig. 6 presents the average theoretical capacity in different rivers. The essential difference between Figs. 5 and 6 is that capacity in Fig. 5 is presented in individual segments, whereas in Fig. 6 it is expressed as the average of all investigated segments in particular river. The performed analysis showed that in the hydrological region of South-eastern Lithuania the average capacity is 45.3 kW from 1 km of river segment and varies from 18.4 in the Jara to 101.4 kW in the Šventoji. In the hydrological region of Western Lithuania theoretical capacity reaches 40.8 kW from 1 km of river segment, the greatest value was calculated in the Jūra (86.6 kW), and the least – in the Šventoji (of the Baltic Sea), where it was 16.5 kW from 1 km of river segment. The least theoretical capacity was characteristic for the Central Lithuania region, which does not have significant slopes (comparing to the other two hydrological regions). The capacities here ranged from 13.1 kW in the Kirsna

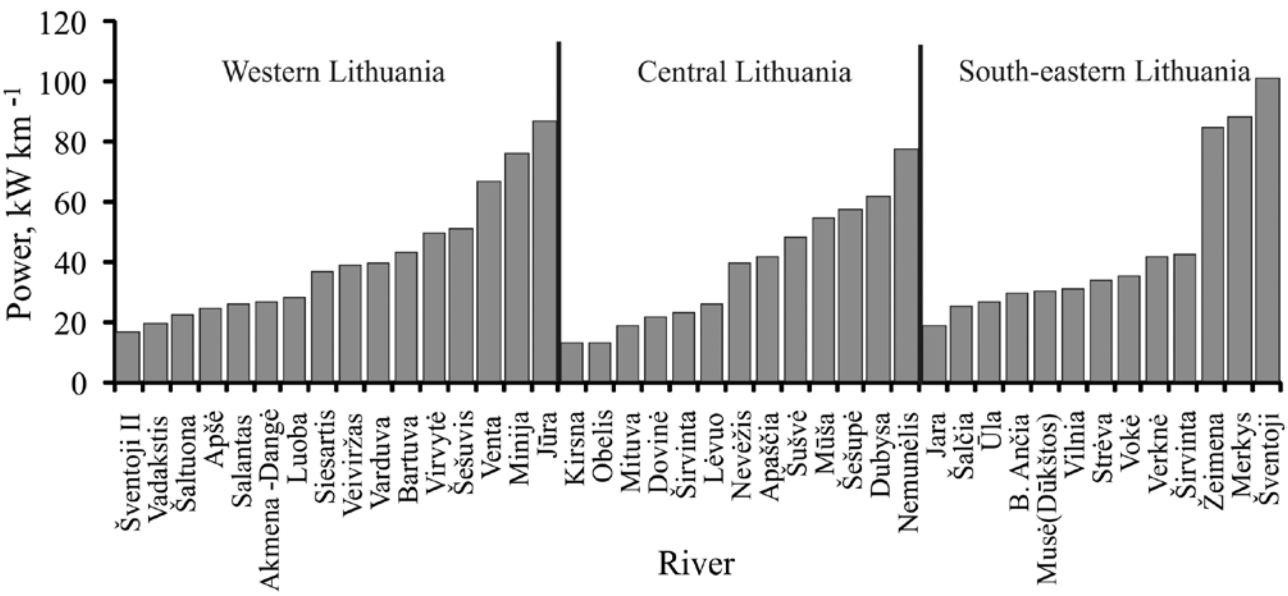

Fig. 6 Distribution of theoretical capacity in different hydrological regions of Lithuania. Compiled by D. Jakimavičius, D. Meilutytė-Lukauskienė, 2014

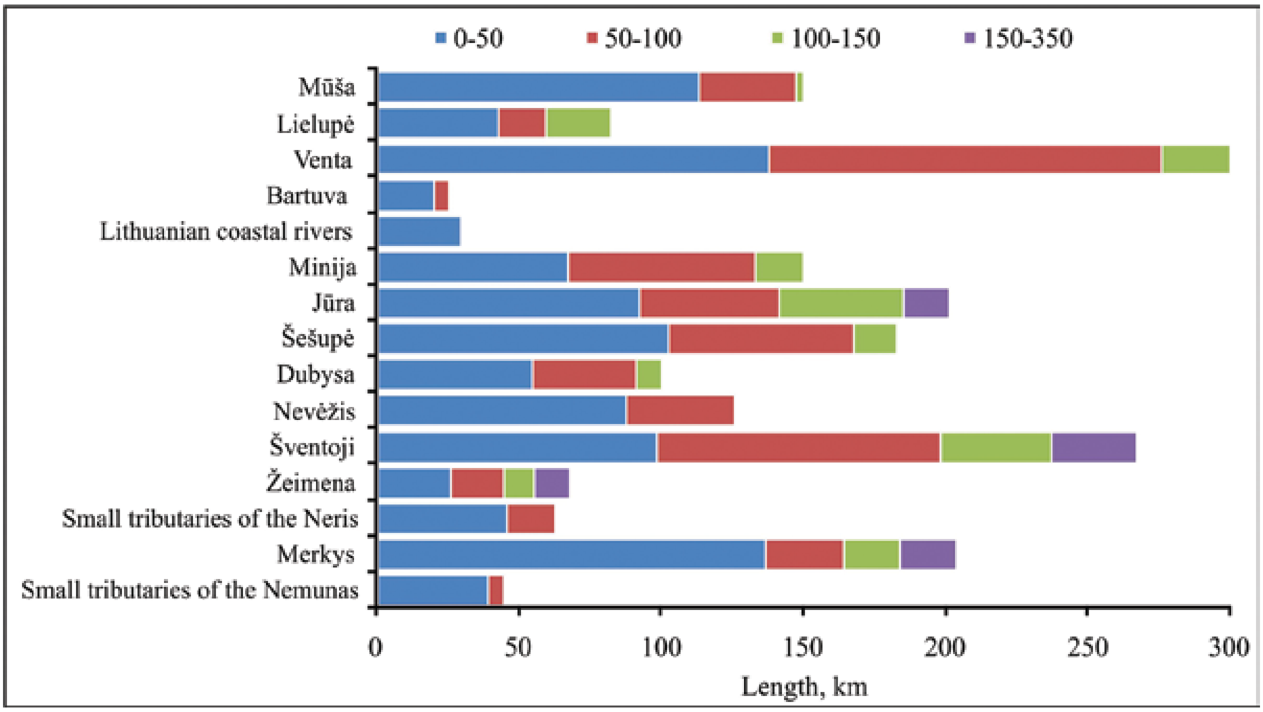

Fig. 7 Distribution of river segments according to their capacity in different catchments. Compiled by D. Jakimavičius, B. Gailiušis, 2014

to 77.9 kW in the Nemunėlis. The calculated average theoretical hydrokinetic capacity comprised 38.2 kW from 1 km of river segment.

For analysis of potential use of hydrokinetic energy, it is beneficial to know not only theoretical capacity values of individual rivers, but also the length (in km) of segments with particular capacities (in kW km^{-1}). The greatest lengths (of 200–300 km) of valuable segments were identified in the catchments of Venta, Šventoji, Merkys, and Jūra (Fig. 7). Slightly smaller lengths (of 100–200 km) of such segments were estimated for the catchments of Šešupė, Mūša, Minija, Nevėžis, Dubysa and the smallest ones not exceeding 100 km – in the catchments of Lielupė, Žeimena, Neris, small tributaries of the Nemunas, Lithuanian coastal rivers and Bartuva. These catchments are located in the uplands and in the slopes of uplands where gradients are higher (see Fig. 5).

The estimated total length of the segments with capacity not exceeding 50 kW/km is the greatest and reaches 1090.9 km (or 54.9%), segments with capacity of 50–100 kW comprise 615.1 km (31.0%), 100–150 kW - 203.3 km (10.2%) and the length of segments with the greatest total capacity of more than 150 kW – only 77.4 km (i.e. 3.9%).

DISCUSSION

The total length of river segments selected for investigation was 1986.7 km. These river segments could be used for hydrokinetic energy production taking into account technical constraints: they all have sufficient minimal depth (h>0.5 m) and flow velocity (v>0.4 m/s). In Lithuanian case, the opportunities to use rivers for hydrokinetic energy production are limited because of small depths: only 27.9% of river segments had sufficient depth, whereas more segments (up to two times) had necessary flow velocities and theoretically were suitable for use. Therefore, in order to efficiently use the kinetic energy stored in rivers it is recommended to search for such ways of energy intake (such as improvement of hydrokinetic devices), that would require shallower river beds. Then it would be possible to use the additional 9.5% of Lithuanian river segments with a depth of 0.4–0.5 m.

The other factors (except already mentioned constraints) that may prevent the rivers from their use for energy production: the presence of protected nature territories, urban structures (like bridges, hydro technical constructions), the absence of roads or electric lines. The classification of Lithuanian rivers to three different hydrological regions having typical hydrological regime and feeding type, tends to have similar hydrokinetic potential as well.

The identified patterns of hydrokinetic energy distribution in Lithuanian land area showed their relation to the local landscape features, and very strong correlation between bed slope and river segment capacity can confirm this. Further investigation should analyse this dependence and its peculiarities more precisely, since Lithuanian hydrology and morphological conditions are quite complicated.

CONCLUSIONS

The performed assessment of riverine theoretical technical kinetic resources showed that only 328 (i.e. 22.1%) out of the total 1487 investigated segments in small and medium-size rivers (without the Nemunas and the Neris) satisfied both the initial conditions that determined potential of their use: the average flow velocity greater than 0.4 m/s and the average depth greater than 0.5 m.

The most promising rivers in terms of their potential to be used for energy production are located in the hydrological regions of South-eastern Lithuania (the greatest capacities – 45.3 kW/km) and Western Lithuania (40.8 kW/km). These are the rivers Šventoji, Merkys, Minija, Jūra and Venta flowing through upland slopes, i.e. in the conditions of greater gradients. The capacities of riverine hydrokinetic energy are smaller in the hydrological region of Central Lithuania and on average they comprise 38.2 kW/km. In this region, the rivers flow in plain, therefore the smaller slopes determine smaller capacities.

The estimated total length of potentially useful river segments was 1986.7 km. The capacity of 54.9% of this total length was smaller than 50 kW/km. The rest 45.1% of river segment lengths, according to their capacity, are distributed as follows: 50–100 kW/km - 31.0%, 100–150 kW/km – 10.2% and over 150 kW/km - only 3.9%.

The assessed theoretical hydrokinetic energy resources of small and medium-size Lithuanian rivers are relatively small, but in future, as technology evolves, they may become significant.

ACKNOWLEDGMENTS

Authors acknowledge the useful advices and valuable comments made by Professor Kęstutis Kilkus (Vilnius) and Dr. Anna Mutule (Rīga).

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.

Anyi, M., Kirke, B., 2010. Evaluation of small axial flow hydrokinetic turbines for remote communities. *Energy for Sustainable Development 14 (2)*, 110–116.

Assessment and mapping of the riverine hydrokinetic energy resource in the Continental United States, 2012. 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.

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.

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

Galvonaitė, A., Valiukas, D., Kilpys, J., Kitrienė, Z., Misiūnienė, M., 2013. *Climate atlas of Lithuania*. Vilnius, 175 pp. [In Lithuanian].

Gorban, A. N., Gorlov, A. M., Silantyev, V. M., 2001. Limits of the turbine efficiency for free fluid flow. *Journal of Energy Resources Technology 123*, 311–317.

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

Jablonskis, J., 2005. The water-power balance of Lithuanian rivers. *Power Engineering 3*, 24–37. [In Lithuanian].

Jablonskis, J., Jurgelėnaitė, A., Tomkevičienė, A. 2008. Lithuanian hydropower and environment protection. *Environmental Engineering: 7th International Conference*, Vilnius Gediminas Technical University, May 22–23, 2008. Vilnius, VGTU Press "Technika", Vol. II, 557–562.

Jablonskis, J., Lasinskas, M., 1962. *Lithuanian river cadastre (discharges, slopes, capacities)*. Vilnius, T. 3, 640 pp. [In Lithuanian].

Kalnacs, A., Kalnacs, J., Mutule, A., Persis, U. 2014. Methods for estimation of the riverflow potential for hydrokinetic power generation. *Latvian Journal of Physics and Technical Sciences 51,* 3–10.

Kalnacs, J., Kalnacs, A., Mutule, A., Persis, U. 2013. Potential of the Lower Daugava for sitting hydrokinetic turbines. *Latvian Journal of Physics and Technical Sciences 50*, 3–14.

Khan, M. J., Bhuyan, G., Iqbal, M. T., Quaicoe, J. E., 2009. Hydrokinetic energy conversion systems and assessment of horizontal and vertical axis turbines for river and tidal application: a technology status review. *Applied Energy 86 (10),* 1823–1835.

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.

Kusakana, K., Vermaak, H. J., 2013. Hydrokinetic power generation for rural electricity supply: Case of South Africa. *Renewable Energy 55*, 467–473.

Lago, L. I., Ponta, F. L., Chen, L., 2010. Advances and trends in hydrokinetic turbine systems. *Energy for Sustainable Development14 (4),* 287–296.

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

Punys, P., Adamonytė, I., Kvaraciejus, A., Žilinskas, S.,

2013. 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., 2013. 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].

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

Zdankus, N., Punys, P., Zdankus, T., 2014. Conversion of lowland river flow kinetic energy. *Renewable and Sustainable Energy Reviews 38*, 121–130.