FACULTY OF CIVIL ENGINEERING
AND ENVIRONMENTAL SCIENCES
BIALYSTOK UNIVERSITY
OF TECHNOLOGY

ASSOCIATION
OF SANITARY ENGINEERS
AND TECHNICIANS

INNOVATIONS – SUSTAINABILITY – MODERNITY – OPENNESS
ENERGY

edited by
Dorota Anna Krawczyk
Iwona Skoczko
Ewa Szatyłowicz

SERIES OF MONOGRAPHS
VOLUME 40

Bialystok 2020

Patronage

Bialystok Univeristy of Technology

Silesian University of Technology

University of Córdoba

Faculty of Civil Engineering and Environmental Sciences Bialystok University of Technology

Student's Branch of the Polish Association of Sanitary Engineers and Technicians

Association of Sanitary Engineers and Technicians

INNOVATIONS – SUSTAINABILITY – MODERNITY – OPENNESS
ENERGY

VOLUME 40

edited by
Dorota Anna Krawczyk
Iwona Skoczko
Ewa Szatyłowicz

Printing House of Bialystok University of Technology
Bialystok 2020

Reviewers:

Alicja Siuta-Olcha, Ph.D., D.Sc. (Eng.), Associate Professor
Edyta Dudkiewicz, D.Sc. Eng.

Copy editor:
Trevor Coldron

Technical editing, binding:
Printing House of Bialystok University of Technology

© Copyright by Politechnika Białostocka, Bialystok 2020

e-ISBN 978-83-66391-29-1 **DOI 10.24427/978-83-66391-29-1**

The publication is available on license
Creative Commons Recognition of authorship – Non-commercial use – Without dependent works 4.0 (CC BY-NC-ND 4.0)
Full license content available on the site creativecommons.org/licenses/by-nc-nd/4.0/legalcode.pl
The publication is available on the Internet on the site of the Printing House of Bialystok University of Technology

Faculty of Civil Engineering and Environmental Sciences
Bialystok University of Technology
45E, Wiejska Street
15-351 Bialystok
www.wb.pb.edu.pl

Association of Sanitary Engineers
and Technicians in Bialystok
2, M. C. Skłodowskiej Street
15-950 Bialystok
www.pzits.bialystok.pl

Table of contents

Authors

Prof. Frida Bazzocchi – University of Florence, Faculty of Engineering, DICEA Department of Civil and Environmental Engineering

Research fellow Cecilia Ciacci, PhD – University of Florence, Faculty of Engineering, DICEA Department of Civil and Environmental Engineering

Assoc. Prof. Katarzyna Gładyszewska-Fiedoruk, PhD, Eng. – Bialystok University of Technology, Faculty of Civil Engineering and Environmental Sciences

Assoc. Prof. Dorota Anna Krawczyk, PhD, Eng. – Bialystok University of Technology, Faculty of Civil and Environmental Sciences

Assoc. Prof. Vincenzo Di Naso – University of Florence, Faculty of Engi-neering, DICEA Department of Civil and Environmental Engineering

Andrii Pushchinskyi, MSc Eng – Bialystok University of Technology, Faculty of Civil Engineering and Environmental Sciences

Monika Šadauskaitė – Kaunas University of Technology Gymnasium

Assoc. Prof. Jolanta Šadauskienė, PhD, Eng. – Kaunas University of Technology, Faculty of Civil Engineering and Architecture

Ewa Szatyłowicz, PhD, Eng. – Białystok University of Technology, Department of Technology in Environmental Sciences

Sebastian Szatyłowicz, MSc Eng. – Białystok University of Technology, Department of Technology in Environmental Sciences

Rokas Tamašauskas – JSC "Planuotojai" Lithuania

Bernadetta Wądołowska, MSc Eng. – Bialystok University of Technology, Faculty of Civil Engineering and Environmental Sciences

Anna Justyna Werner-Juszczuk, PhD, Eng – Bialystok University of Technology, Faculty of Civil Engineering and Environmental Sciences

Agata Witkowska, MSc Eng. – Bialystok University of Technology, Faculty of Civil and Environmental Sciences

Evaluation of the influence of the primary energy factor of hydropower plants in the methodology for assessing the energy performance of buildings

Keywords: Primary energy; renewable energy; hydropower; energy efficiency

Abstract

There is currently no common or standardized procedure for certification of the energy performance of buildings, as each EU Member State takes into account the specificities of its own construction sector when implementing the provisions of Directive 2010/31/EU. This usually depends on two features: the purpose of the building and the climate. Therefore, the purpose of this paper is to evaluate the influence of the hydropower primary energy factor for assessing the energy performance of buildings. For this purpose, non-renewable primary energy factor values were analyzed regarding actual energy production and consumption data from 19 Lithuanian hydroelectric plants. The results of the studies show that the average value of the non-renewable primary energy factor of hydropower plants is 0.059.

Introduction

Recently, the EU construction sector focuses on sustainable energy use and production. The EU has adopted a new climate and energy framework which includes delivering a minimum 27% share of renewable energy consumption by 2030 [1]. Taking into account the different climatic conditions and building traditions in EU countries, Member States commit themselves to develop national targets, increasing the number of buildings of this type, defining primary energy demand, that is needed for heating, cooling, ventilation and hot water preparation and a using of renewable energy sources in new buildings [2-7].

Lithuania has also adopted a revised National Energy Independence Strategy [8] 2018. The strategy envisages four main directions of Lithuania's energy policy: energy security, development of green energy, energy efficiency, competitiveness and innovation. Over the last few years, support for renewable energy has grown steadily at both national and European level. Therefore, in 2016 renewable energy sources accounted for 25.6% of total final energy consumption and 16.7% of total electricity consumption in Lithuania, mainly due to wind, hydropower and biomass. At the end of 2016, wind energy was the largest single technology, accounting for more than 63% of installed capacity, and hydropower and solar are the other main renewable energy sources, accounting for 15.8% and 9% respectively in the current structure. renewable electricity generation capacity. The share of local energy sources (local oil, peat, wood, geothermal, wind, solar and hydropower, as well as chemical process energy) in the country's primary energy balance was 24.7% and the share of renewable energy sources in the local energy balance was 80.6%. The contribution of hydropower to the absolute value varies depending on climatic conditions, with slight changes and amounts to 3.3% [9].

One of the parameters of renewable energy sources is the primary energy factor [10,11]. The primary energy factor $f_{P,tot}$ is a sum of renewable energy factor $f_{P,ren}$ and non-renewable factor $f_{Pn,ren}$. Renewable energy must account for a major proportion of the energy consumed in a building. Accordingly, the renewable primary energy factor $f_{P,ren}$ is equal to 1 according EN 15603 167 [10]. Meanwhile, the part of the energy from a non-renewable energy source is not known clearly, because the $f_{P,nren}$ depends on the additional energy consumed in the conversion device, which normally uses additional non-renewable energy, such as electrical energy generated from a common grid [11].

This is a very important part of the evaluation of primary energy from hydropower plants. As an ancient technology, hydropower is being challenged by climate change and other environmental concerns [12]. Water availability has different temporal and spatial fluctuations in different locations and water availability fluctuations indirectly and directly affect the different electricity generating technologies [13].

The analyzed literature did not give sufficient information about calculation of value of non-renewable factor. Only with sufficiently accurate data on hydropower renewable ($f_{P,ren}$) and non-renewable ($f_{P,nren}$) primary factors can the amount of renewable and non-renewable primary energy consumed in a building be objectively calculated.

Therefore the aim of this article is to calculate value of non-renewable factors for hydropower plants in Lithuania.

Methods

Data for the investigation (for the period 2007-2014) were collected from 19 hydropower plants operating in Lithuania [14], with the total capacity (107.3 MW) accounting for 79.2% of the total hydropower capacity in the country. The data were collected by interviewing hydropower plants owners/operators and by analyzing the reports of electricity transmission system operators in Lithuania

(Table 1). The main characteristics of the investigated hydropower plants was total installed power capacity, produced electrical energy and consumed electrical energy.

Table 1. The main characteristics of the studied hydroelectric power plants

N_o of hydropower plants	Installed power, MW	Produced energy, MWh	Consumed energy, MWh
1	100.800	324731	3646
2	2.914	12798.5	38.4
3	0.600	2921.4	52.6
4	0.360	1840.1	33.1
5	0.350	929.1	20.9
6	0.320	1430.6	23.3
7	0.300	1412.0	25.4
8	0.264	1028.1	18.5
9	0.264	1094.7	19.7
10	0.260	1174.5	21.1
11	0.260	1383.5	23.5
12	0.110	591.5	0.5
13	0.110	355.4	0.6
14	0.100	307.2	5.5
15	0.090	135.7	2.2
16	0.055	378.1	6.8
17	0.050	168.9	3.4
18	0.045	7.8	0.2
19	0.045	86.6	0.4

The value of the primary non-renewable energy factor $f_{P,nren}$ of hydropower plants was calculated using the methodology described in EN 15603 [10], where included is an energy calculation framework specifying how to define the various energy flows and how to establish the energy boundaries in the building. The total the total primary energy factor was calculated from Equation 1:

$$f_{P,tot} = f_{P,nren} + f_{P,ren} \tag{1}$$

where:

$f_{P,tot}$ – the total primary energy factor, kW·h;
$f_{P,nren}$ – the non-renewable primary energy factor, kW·h;
$f_{P,ren}$ – the renewable primary energy factor, kW·h.

It is assumed that all the energy supplied to the building is attributable to renewable energy because it is made from renewable hydropower plants energy. Accordingly, the renewable primary energy factor $f_{P,ren}$ is equal 1.

The value of the primary non-renewable energy factor $f_{P,nren}$ produced by hydropower plants is given by the formula (Equation 2):

$$f_{P,nren} = \frac{E_{a,nren}}{E_{b,ren}}; \tag{2}$$

where:

$E_{a,nren}$ – the amount of additionally consumed non-renewable energy (from the electrical grid) regarding the produced electricity of the hydropower plants, designed to supply into the building, kWh/year;

$E_{b,ren}$ – the amount of electrical energy, which is produced in hydropower plants and supplied into the building, kWh/year.

Geographical conditions of hydropower plants in Lithuania

The prospects for the use of hydropower depend on natural and geographical conditions. There are about 29.900 rivers and streams longer than 0.25 km in Lithuania – their total length is 63.7 thousand km. The number of rivers and streams longer than 3 km was calculated very accurately – 4418. There are 816 rivers longer than 10 km (3%) and 17 longer than 100 km.

As Lithuania is in the zone of excess moisture, its river network is dense (average density 0.99 km/km^2). In the central lowlands this density is one of the highest (1.45 km/km^2) and in the south-eastern plain one of the lowest (0.45 km/km^2). Due to the flat surface of the country, the slopes of the rivers are small, the water flow is slow, the beds are meandering (Šalčia, Kiauna, Merkys and Grūda are the most meandering). Most rivers are not very watery: only 155 average annual discharges exceed 1 m^3/s, of which 15 rivers exceed 10 m^3/s, and only two – 100 m^3/s. The highest flow is in the lower reaches of the Nemunas – 616 m^3/s.

Lithuania's hydropower resources are not large, and their efficient use is highly dependent on the hydrological and topographic conditions of the river. The relative energy capacity of Lithuanian rivers is incomparable with that of mountainous countries, which is 4 to 40 times higher (Fig. 1).

The largest hydroelectric power plant in the territory of Lithuania is located near the river Nemunas, where 100.8 MW power is installed. In Lithuania, except for the Nemunas and Neris rivers, it is possible to build only small hydroelectric power plants with a capacity of less than 10 MW (Fig. 2.). The contribution of small hydropower is about 1-1.5%. The reason is their low capacity, which is mostly limited by the relatively low heights of the river falls and the large areas of the formed pond. A similar percentage of electricity from total electricity generation is accounted for by EU small hydroelectric plants – 1.6% [15].

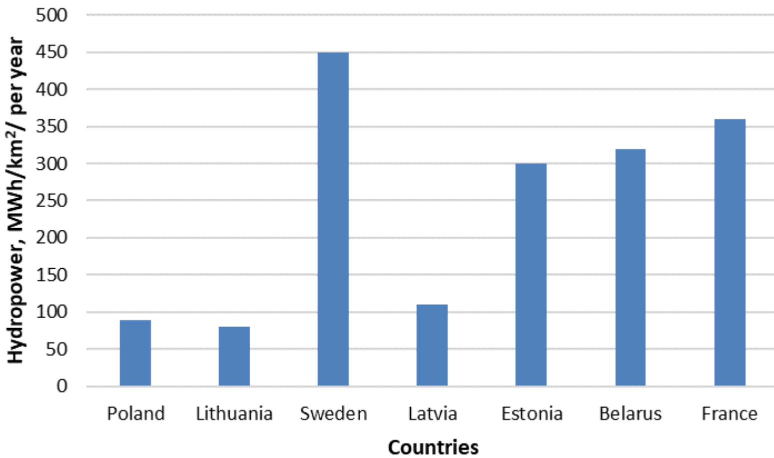

Fig. 1. Hydropower per 1 km² of the country area.
Source: [15].

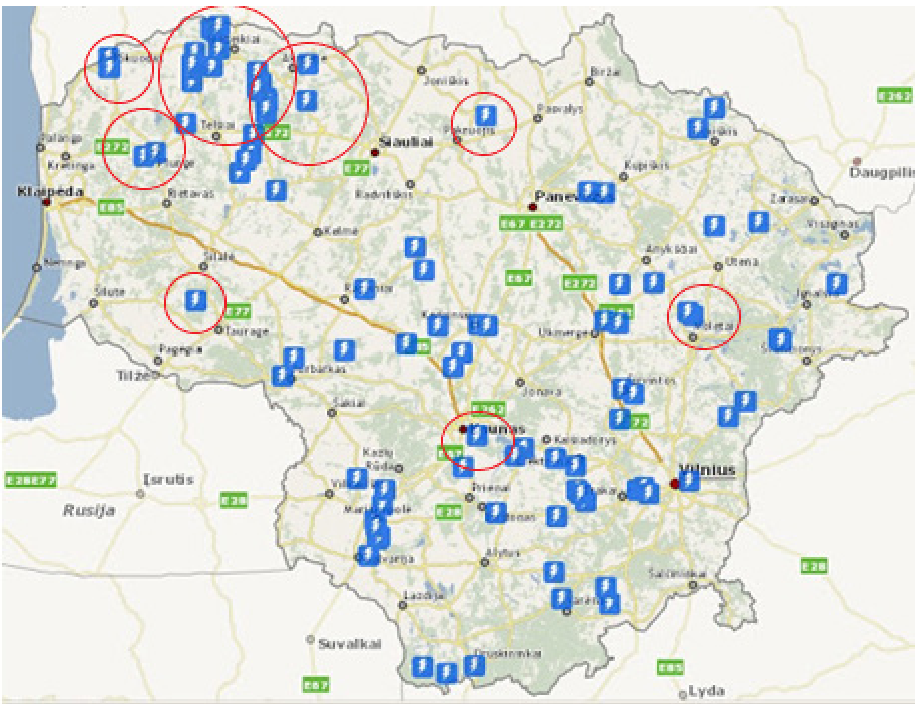

Fig. 2. The map of the small Lithuanian hydroelectric power plant (red area shows the investigated hydropower plants in this work)
Source: [15]

Results and discussion

The calculated values of the $f_{P,nren}$ factors of the analyzed hydropower plants are presented in Fig 3.

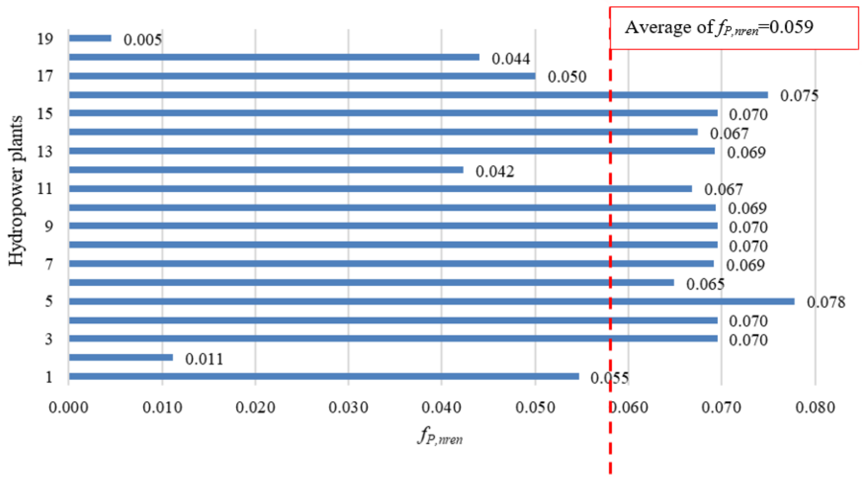

Fig. 3. Average annual values of $f_{P,nren}$ of hydropower plants in Lithuania.

Calculation results show that the average annual value of $f_{P,nern}$ ranges from 0.005 to 0.078. The lowest value was 0.005 and the highest value was 0.078. The $f_{P,enrn}$ value of hydropower plants operated in Lithuania is 0.059.

Analyzing produced and consumed distribution of electricity quantities by months, it was found that there is a direct relationship between these parameters. The average annual amount of energy used by hydroelectric power plants for its own use (for maintenance of a hydropower plant) is up to 1.24% of the total amount of electricity produced. The amount of electricity consumed is not constant and varies dynamically with the time of year, usually during the warm season less than the cold. Correspondingly, it can average 1.60% in winter and 1.06% – in summer.

The primary energy factor values of the hydropower plants $f_{P,nern}$ determined in this work were used to revise the methodology of assessment of energy performance of buildings in the Lithuanian Technical Regulation STR 2.01.09:2005 [16]. The mentioned standard provides the value of non-renewable primary energy factor $f_{P,nern}$ was 0.500. However, the $f_{P,nern}$ value set in this work is 0.059. The difference is 9 times. On the basis of these studies, the method of assessing the energy performance of buildings due to non-renewable primary energy factor when energy is produced from hydroelectric power plants are used was adjusted.

Analyzing the distribution of amount of produced and consumed electricity by the above hydroelectric power plants by months, the results show (Fig. 4) that there is a direct relationship between the amount of electricity produced and consumed in hydroelectric power plants. The average annual amount of energy used in hydropower plants for own use is up to 1.24% of the total amount of electricity produced. The amount of electricity consumed is not constant and changes dynamically depending on the time of year, usually during the warm season it is lower than during the cold season. Accordingly, it can reach 1.60% on average in winter and 1.06% in summer.

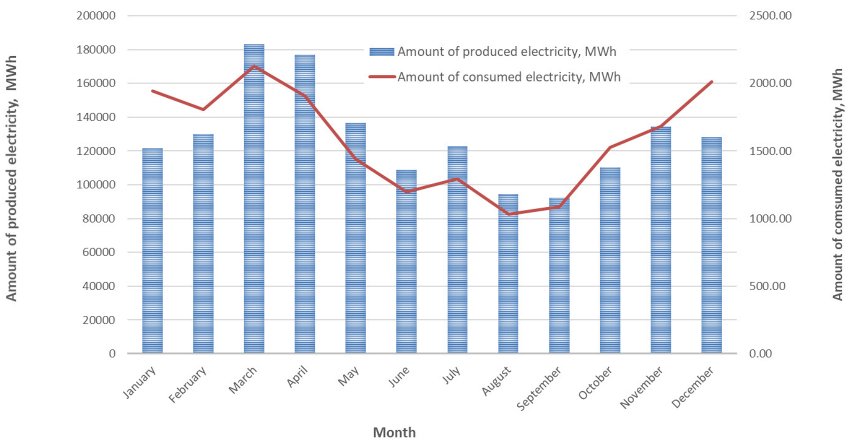

Fig. 4. The distribution of amount of produced and consumed electricity by the above hydroelectric power plants by months.

As the amount of electricity consumed varies regarding a month compared to the amount of electricity produced regarding the month, this causes changes in the monthly values of the non-renewable primary energy factor, which are presented in Figure 5. The results show, the average annual value of the $f_{P,nren}$ factor for hydropower plants is 0.059 (marked with a dotted line). The monthly values of the $f_{P,nren}$ factor range from 0.053 to 0.068, the lowest values were 0.053-0.054 in the April-August period, and the highest values were 0.067-0.068 in the December-January respectively.

The energy performance calculations for buildings assume that the value of the non-renewable primary energy factor is a constant. If these calculations took into account the fact that the value of these factors changes over the years, the results of the energy performance assessment of buildings would be more accurate.

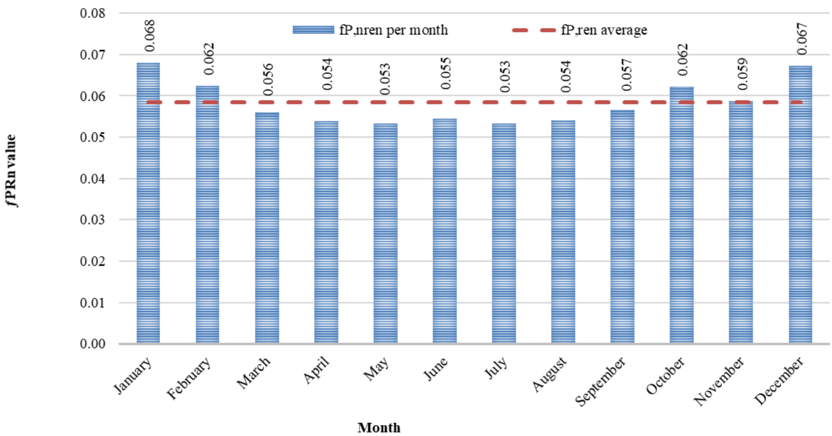

Fig. 5. The monthly values of the non-renewable primary energy factor.

Analyzing the provided values of non-renewable primary energy factor in the current Construction Technical Regulation of the Republic of Lithuania [16], a significant difference is observed with the values of Primary energy factor set in this work (Table 2.)

Table 2. Comparison of values of primary energy factors (fP,nren, fP,ren, fP,tot) in hydropower plants

Primary energy factors	The values of primary energy factors	
	The values set in this work	The value according to STR 2.01.09:2005 [16]
$f_{P,nren}$	0.059	0.500
$f_{P,ren}$	1.000	1.000
$f_{P,tot}$	1.059	1.500

The values presented in Table 2 show that the average non-renewable primary energy factor of Lithuanian hydropower plants is equal to 0.059 and is 9 times lower than indicated in STR 2.01.09:2005 [16].

Conclusions

This is a detailed study of the hydropower plants of Lithuania shows, that the average non-renewable primary energy factor of Lithuanian hydropower plants is equal to 0.059. The results of the research will help to evaluate energy efficiency more precisely of buildings in Lithuania.

The average annual amount of energy used in hydropower plants for own use is up to 1.24% of the total amount of electricity produced.

Literature

[1] European Commission, 2018. 2030 energy strategy. https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2030-energy-strategy

[2] A. M. Basit, S. Dilshad, R. Badar, S. M. S. U. Rehman. *Limitations, challenges, and solution approaches in grid-connected renewable energy systems*. International Journal of Energy Research, 2020, 44(6), 4132-4162.

[3] Y. Wang, D.Y. Zhang, Q. Ji, X. Shi. *Regional renewable energy development in China: A multidimensional assessment*. Renewable & Sustainable Energy Reviews, 2020, 124, 109797.

[4] V. Gaigalis, V. Katinas. *Analysis of the renewable energy implementation and prediction prospects in compliance with the EU policy: A case of Lithuania, Renewable Energy*, 2020, 151, 1016-1027.

[5] N. Bamati, A. Raoofi. *Development level and the impact of technological factor on renewable energy production*. Renewable Energy, 2020, 151, 946-955.

[6] C. Scaramuzzino, G. Garegnani, P. Zambelli. *Integrated approach for the identification of spatial patterns related to renewable energy potential in European territories*. Renewable and Sustainable Energy Reviews, 2019, 101, 1-13.

[7] M. Jefferson, *Renewable and low carbon technologies policy*, Energy Policy, 2018, 123, 367-372.

[8] National Energy Independence Strategy of the Republic of Lithuania. 2018, approved by the Seimas of the Republic of Lithuania on 21 June 2018. https://enmin.lrv.lt/uploads/enmin/documents/files/Nacionaline%20energetines%20nepriklausomybes%20strategija_2018_EN.pdf

[9] Statistics Lithuania. Official Statistics Portal. https://osp.stat.gov.lt/en/statistiniu-rodikliu-analize?hash=8f127891-7e92-4ba3-a8c1-06448e2c3ebf#/

[10] EN 15603:2014. Energy performance of buildings – Overarching standard EPBD, European Union: Brussels, Belgium, 2014.

[11] ECOFYS. Primary energy factors for electricity in buildings, http://download.dalicloud.com/fis/download/66a8abe211271fa0ec3e2b07/ad5fccc2-4811-434a-8c4f-6a2daa41ad2a/Primary_energy_factors_report_ecofys_29.09.2011.pdf

[12] H. X. Li, J. David, D. J. Edwards, M. R. Hosseini, G. P.Costin. *A review on renewable energy transition in Australia: An updated depiction*. Journal of Cleaner Production, 2020, 242, 118475.

[13] S. Vaca-Jiménez, P.W. Gerbens-Leenes, S. Nonhebel. *Water-electricity nexus in Ecuador: The dynamics of the electricity's blue water footprint*. Science of the Total Environment, 2019, 696, 133959.

[14] Lithuanian electricity transmission system operator (Litgrid). http://www.litgrid.eu/index.php/paslaugos/kilmes-garantiju-suteikimas/ataskaitos/563
[15] J. Jia, P. Punys, J. Ma. *Hydropower, Handbook of Climate Change Mitigation and Adaptation*. 2nd ed / editors: Wei-Yin Chen, Toshio Suzuki, Maximilian Lackner. New York: Springer New York, 2017.
[16] STR 2.01.09:2005 Energy Performance of Buildings. Certification of Energy Performance. Edition 2012. Vilnius: Ministry of Environment of Republic of Lithuania. 2012.