Economics and Organization of Logistics
5 (2), 2020, 15–26

DOI: 10.22630/EIOL.2020.5.2.10

Marcin Wysokiński, Arkadiusz Gromada, Magdalena Golonko
Warsaw University of Life Sciences – SGGW

Economic and logistic conditioning of energy demand in logistics

Ekonomiczne i logistyczne uwarunkowania zapotrzebowania energetycznego w logistyce

Abstract. The study deals with economic and logistical conditions for the obtaining and use of various energy sources in the world. The first part presents the importance of energy in periods of human activity on Earth, from the time of gathering and hunting to modern times. It was pointed out how energy sources evolved based on successive innovations and inventions during subsequent periods of human development. The article presents the importance of individual energy sources in the modern world, indicating their logistical susceptibility in the field of extraction, storage and distribution. The length of periods of availability of non-renewable energy resources having the attribute of depletion was indicated using the Raw Materials Availability Index (RMAI). An analysis was made of the locations of individual energy resource deposits, stating that only a few countries have over 80% of global reserves, which means that other countries and societies depend on raw material monopolists.

Key words: energy, energy sources, economy, logistics

Synopsis. Opracowanie dotyczy ekonomicznych i logistycznych uwarunkowań pozyskiwania i wykorzystania różnych źródeł energii na świecie. W pierwszej części przedstawiono znaczenie energii w poszczególnych okresach ludzkiej aktywności na ziemi, począwszy od czasów zbieractwa i łowiectwa, aż po czasy współczesne. Wskazano, jak w trakcie kolejnych epok rozwoju ludzkości ewoluowały źródła energii poprzez kolejne innowacje i wynalazki. W artykule w szczególności zaprezentowano znaczenie poszczególnych źródeł energii we współczesnym świecie, wskazując ich podatność logistyczną w zakresie wydobycia, magazynowania i dystrybucji. Za pomocą współczynnika dostępności surowców (WDS) wskazano długość okresów dostępności nieodnawialnych surowców energetycznych mających atrybut wyczerpalności. Dokonano analizy miejsc występowania poszczególnych złóż surowców energetycznych, stwierdzając, iż zaledwie kilka państw dysponuje ponad 80% światowych rezerw, co powoduje, że pozostałe kraje i społeczeństwa są uzależnione od surowcowych monopolistów.

Słowa kluczowe: energia, źródła energii, gospodarka, logistyka

Introduction

All human activities and natural processes occurring in nature can be considered as energy transformations [Gradziuk 2015]. The progress of civilization is the pursuit of greater energy consumption, required to increase food harvest, to increase the efficiency and diversity of materials, or to produce more and more diverse goods and to create access to unlimited information. All this contributed to the increase in the population, organized into more complex social structures (states and transnational collectives) and contributed to the increase in the quality of life.

The long-term relationship between human achievement and dominant energy sources and changing prime movers is best seen when looked at in the context of epochs and energy transitions. The most obvious changes dictated by specific energy epochs can be observed in activities related to the extraction, transformation and distribution of energy.

Energy demand in hunter-gatherer societies was dominated by the provision of food, basic clothing and temporary shelters. Ancient, developed civilizations directed slowly increasing energy consumption into permanent shelters, the greater variety of cultivated and processed food, better clothing, transport and diversity of producers (charcoal was the dominant source of heat supply needed for smelting ores and firing bricks). In early industrial societies – with more pets, with the kinetic energy of water wheels and windmills, and with increasing coal mining – energy consumption per capita doubled, compared to that of the Middle Ages.

The divisions into specific energy epochs are unrealistic, however, not only because of the obvious national and regional differences during innovation and the widespread use of new fuels and engines but also because of the evolutionary nature of energy transformations [Melosi 1982, Smil 2010]. Specific energy sources and prime movers can be surprisingly constant, while new sources or techniques can only become dominant after a long period of gradual diffusion. As long as certain energy sources and prime movers work well in stable systems, they are easily available and highly cost-effective, their substitutes, even those whose attributes are better, will grow slowly. Draft animals, hydropower and steam engines have coexisted in industrialized Europe and North America for over a century. In the wood-rich United States of America, coal surpassed wood burning, and coke became more important than charcoal only in the 1880`s [Smil 2010].

By creating long-term patterns for the distribution of major prime movers in Old World pre-industrial societies, only suggestive approximations can be used. The most unusual feature of these patterns is the long dominance of human labor (Figure 1). Human muscles were the only source of mechanical energy from the beginning of the evolution of hominids to the domestication of draft animals, which began only about 10,000 years ago. Human strength was increased through the use of an increasing number of better tools, while the work of animals in the Old World remained limited for millennia by little use and inappropriate animal nutrition, and draft animals were absent in both the Americas and Oceania. Human muscles, therefore, remained indispensable prime movers in all pre-industrial societies.

The first inanimate prime movers began to make a noticeable difference in some parts of Europe and Asia only after 200 CE (waterwheels) and 900 CE (windmills).

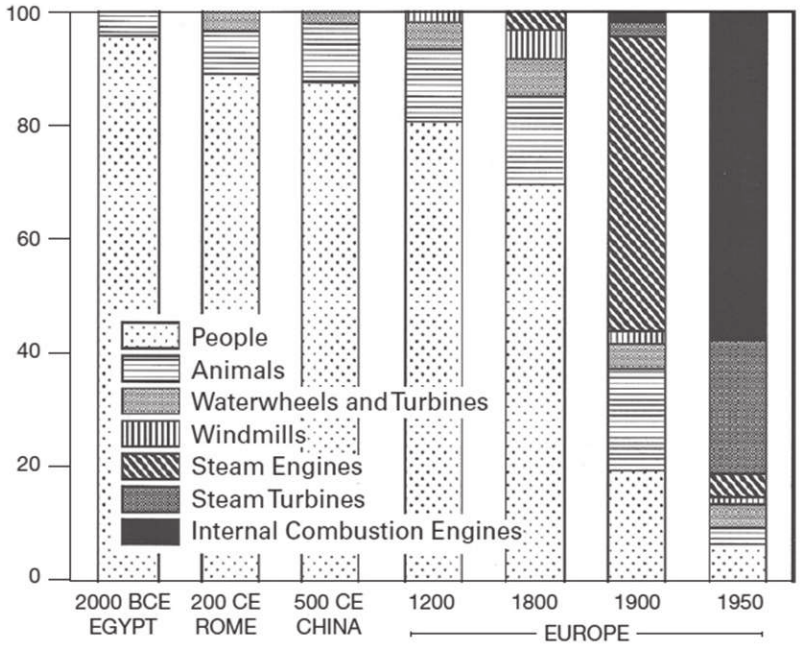

Figure 1. Approximate shares of prime mover capacities [%]
Rysunek 1. Szacunkowe udziały w głównych zdolnościach napędowych [%]
Source: [Smil 2017].

The gradual improvement of these devices allowed the replacement and acceleration of many tiring, repetitive tasks, but the replacement of animate work was slow and uneven. Except for pumping water, waterwheels and windmills can do little to facilitate fieldwork.

Despite some significant differences between continents and regions, typical fuel consumption levels and dominant ways of using prime movers in old cultures were quite similar. An ancient society that can be distinguished for significant advances in fuel consumption and the development of the main prime movers is China of the Han dynasty (from 207 BCE to 220 CE). The innovations they created were adapted elsewhere not only hundreds but thousands of years later. The most important Chinese contribution was the use of coal in the production of iron, drilling for natural gas, the production of steel from cast iron, the widespread use of curved moldboard iron plows, or the beginning use of collar harness.

Early Islam brought innovative designs for wind and water machines (windmills), while maritime trade in this kingdom benefited from the efficient use of triangular sails. But the Islamic world has not introduced any radical innovations in fuel consumption, metallurgy or the use of animals. Only medieval Europe, borrowing from earlier achievements of Chinese, Indian and Muslim societies, began to introduce many innovations. What made European medieval societies differ in terms of energy consumption was their increasing dependence on the kinetic energy of water and wind. These elements were used by more and more complex machines, ensuring an unprecedented concentration of power.

Late medieval and early modern Europe was thus a place of broadening innovation, but the overall technical efficiency of China at that time was more impressive. At the end of the 15th century, however, Europe was on the road to accelerating innovation and expansion, while a developed Chinese civilization was soon to begin its long and deep technical and social involution. Until 1700, Chinese and European levels of typical energy consumption and average well-being were still very similar [Allen 2011]. At that time, the progress of Western European countries significantly accelerated. In the energy sphere, this development was illustrated primarily by growing crops, new iron metallurgy based on coke, better navigation, new weapon designs, enthusiasm for trade and the pursuit of experiments. Others saw the basics of this success dating back to the Middle Ages. The positive influence of Christianity on technical progress in general, and the desire of medieval monasticism to be self-sufficient in particular, were important components of this process [White 1978, Basalla 1988].

The energy fundamentals of nineteenth-century progress included the development of steam engines and their widespread use, both as stationary and mobile prime movers, smelting iron with coke, large-scale steel production, the introduction of internal combustion engines and electricity generation. The scope and speed of these changes were the results of a combination of energy innovations with new methods of chemical synthesis and more efficient ways of organizing factory production. It was also important to develop new modes of transport and telecommunications, both to increase production and to promote domestic and international trade. The accumulation of technical and organizational innovations has given Western countries (which include the new power – the United States) a huge share of global energy. With only 30% of the world's population, Western countries consumed about 95% of fossil fuels. In the 20th century, the Western world increased total energy consumption by almost 15 times. Although the share of Western countries in global energy consumption fell in subsequent years, at the end of the 20th century the countries of the then European Union and North America, with less than 15% of the world population, used almost 50% of the primary energy obtained. Europe and North America remained the dominant consumers of fuels and electricity per capita. China's rapid economic growth brought several changes. In 2010, China became the world's largest energy consumer, and in 2015 China's share in total energy consumption was about 32% higher than in the United States, but energy consumption per capita was only 1/3 of the United States average [BP 2017].

The purpose and the research methods

The main purpose of the research was to present the importance of individual energy sources in the 21st century and to present the periods of availability of individual non-renewable energy resources. The Raw Materials Availability Index (RMAI) was used, calculated according to the formula:

$$RMAI = \frac{R}{P}$$

where:
R – world reserves of raw material k, remaining at the end of the year t,
P – global raw material production k, in year t.

The study uses secondary research materials – scientific literature, scientific publications, as well as press articles and reports.

The method of literature studies was applied, which included studies of Polish and foreign economic and industry literature.

Results

Logistics comprises the movement, storage and handling of products as they move from a raw material source through the production system to point of use. Energy is needed to operate all these logistics activities, used within various logistics. One such system is road freight transport, which can be powered with different energy sources (e.g. fossil fuels, biofuels, nuclear energy or renewable energy), however, fossil fuels are by far the most popular energy source [Wehner 2018]. The globalization of production, procurement and marketing in recent decades, however, has increased the 'freight transport intensity', resulting in increased energy consumption and, consequently, a dynamic increase in greenhouse gas emissions [McKinnon 2012]. It is worth noting that in 2017, 27% of total greenhouse gas emissions in the EU-28 came from the transport sector [EEA 2019]. Storage is also an important energy-dependent logistics system. Electricity is necessary for the operation of both manually operated warehouses and automated warehouses. Without it, products and services offered by enterprises would not reach consumers. Currently, organizational activities and technical measures are used to reduce energy consumption and improve the efficiency of its use.

To reduce production costs, enterprises strive for greater automation of all repetitive processes occurring within the production chain. This creates a contradiction because the introduction of automatic devices means more energy consumption. Therefore, it is important to look for solutions that will be profitable and energy-saving at the same time.

In some countries, companies may benefit from state subsidies for investments leading to energy savings or increased energy efficiency. The goal of such a policy is to reduce energy consumption globally, which results from two important premises: firstly, the resources of non-renewable energy sources are limited and will be exhausted in several dozen years (this aspect was discussed in the paper), secondly, the consumption of energy based on non-renewable sources causes gas emissions greenhouse that threaten the stability of life on earth.

In the modern world, five main energy sources can be distinguished: crude oil, natural gas, coal, renewable energy, nuclear energy (Figure 2).

Despite the steadily decreasing importance in favor of other raw materials, over 30% of the world's energy comes from crude oil [Młynarski and Tarnowski 2016]. The crude oil market is one of the most developed. It is characterized by a high level of demand and supply law functioning. The costs of transporting crude oil over long distances are relatively small relative to the prices of the raw material itself and the volume of transmission. This means that crude oil is freely available in all parts of the world and competition on the market is very high. One of the key aspects is the security of supply and its diversification. Countries that are not dependent on regional suppliers can purchase raw material of almost any origin.

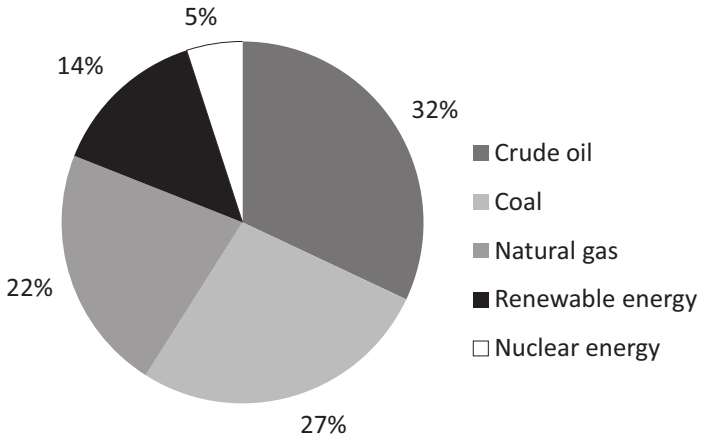

Figure 2. Structure of primary energy sources in the world in 2016
Rysunek 1. Struktura pierwotnych źródeł energii na świecie w 2016 roku
Source: own study based on [Key World Energy Statistics 2016].

Venezuela has the largest crude oil reserves. The resources in this country amount to approximately 47 billion tons (17.6% of global reserves). It is currently one of the poorest countries in the world, plunged into political and economic chaos. Saudi Arabia and Canada also have at least a 10% share in global resources. The world leaders also include Iran, Iraq, Russia, Kuwait, United Arab Emirates, Libya and the United States. The ten countries with the largest crude oil reserves hold over 85% of the global resources of this raw material (208.7 billion tons). Therefore, in the case of crude oil, there is a very high level of concentration of deposits in only a few countries.

In the context of the total dependence of humanity on non-renewable energy resources, the period of availability of these resources is very important information – each of them has the attribute of depletion. The question is, how long will humanity use these sources. In the case of crude oil, the RMAI is 50.6, so it can be assumed that with current resources, the period of its availability in the world will be less than 50 years, as the needs for this raw material are constantly increasing. This is a real example of a limited resource depleted.

Coal is the second most important in the energy mix – it causes a lot of controversy in the modern world and its assessment is ambiguous. It is a relatively cheap raw material (in particular as a fuel for electricity production), easily available regionally (high geographical dispersion) and relatively easy to extract, and therefore is a "convenient" source of energy. At the same time, its use causes environmental pollution, in particular when using its lower quality fractions. Thus, we are dealing here with a conflict between the need to protect the environment, energy security (diversification of energy sources) and ensuring the supply of cheap energy (in particular in developing countries), which translates into economic growth. Balancing these components and including some kind of compromise in energy policy is not an easy task. Also, this is complicated by the fact that the demand for coal is constantly growing (in 2014 its share of the energy mix was 30% – second position after crude oil), which makes it difficult to fight environmental pollution. A high degree of regulation of the coal market, investments in its mining and

processing imposes high restrictions and increases investment risk in this area [Młynarski and Tarnowski 2016]. World coal reserves at the end of 2016 amounted to 1139.3 trillion tons.

The largest coal reserves are in the United States – almost a quarter of the world's deposits. China has equally high reserves. Poland is in 10th place – 2.1% of the world reserves. In the case of coal, the highest concentration of reserves was found compared to oil and gas – 10 countries account for 91.3% of global resources. The average RMAI for all countries in the world is 153.3. Polish reserves, with current production of around 131 million tons, will be enough for the next 184 years.

Natural gas is another key energy resource for the world. Its main disadvantage as an energy raw material is its gas form, which hinders both extraction and transport. Therefore, its use depends, to a much greater extent than crude oil, on the regional availability of its resources. According to Młynarski and Tarnawski [2016], the use of natural gas in national economies increased only due to shifts in the structure of demand (wider availability of raw material in the form of LNG) and adjustment of supply (unconventional resources).

The country with the largest reserves of natural gas is Iran, which together with Russia and Qatar is responsible for almost 50% of the world's resources. The first ten countries with the largest gas reserves hold 79% of the global resources of this raw material (147.2 trillion m^3). After crude oil, this is another example of a very high concentration of deposits in several countries. In the absence of the possibility of excluding land inhabitants from energy consumption, there is a problem of uneven access to deposits. The average RMAI for all countries in the world is 52.5.

Table 1. Reserves of raw materials in regions of the world
Tabela 1. Rezerwy surowców w regionach świata

Region	Energy reserves by region					
	crudeoil		natural gas		coal	
	[billion t]	[%]	[trillion m^3]	[%]	[billion t]	[%]
NorthAmerica	34.5	13.3	11.1	6.0	259.4	22.8
Central and SouthAmerica	50.8	19.2	7.6	4.1	14.0	1.2
Europe and Eurasia	21.8	9.5	56.7	30.4	322.1	28.3
Middle East	110.1	47.7	79.4	42.5	1.2	0.1
Africa	16.9	7.5	14.3	7.6	13.2	1.2
Asia (Pacific)	6.4	2.8	17.5	9.4	529.4	46.5
World	240.7	100.0	186.6	100.0	1139.3	100.0

Source: [BP 2017].

Middle East countries have the largest reserves of crude oil and natural gas. The share of the countries of this region in the total structure of reserves of individual raw materials is 47.7 and 42.5%, respectively (Table 1). However, Middle Eastern countries are poor in coal. Significant reserves of natural gas are located in the countries of Europe and Eurasia (over 30%). Pacific Asia, which is scarce in crude oil, has the largest coal reserves of 529.4 billion tons (46.5%).

Nuclear energy is also an important source. Its first applications after World War II took place mainly in military. Later, civilian applications were allowed, and the first nuclear power plant was launched in Russia in 1954 [Jezierski 2005]. Since then, nuclear power has developed rapidly. Further power plants generating electricity for civil purposes were built. Figure 3 presents the number of nuclear reactors operating in December 2017. In total, 448 reactors operated at that time in the world.

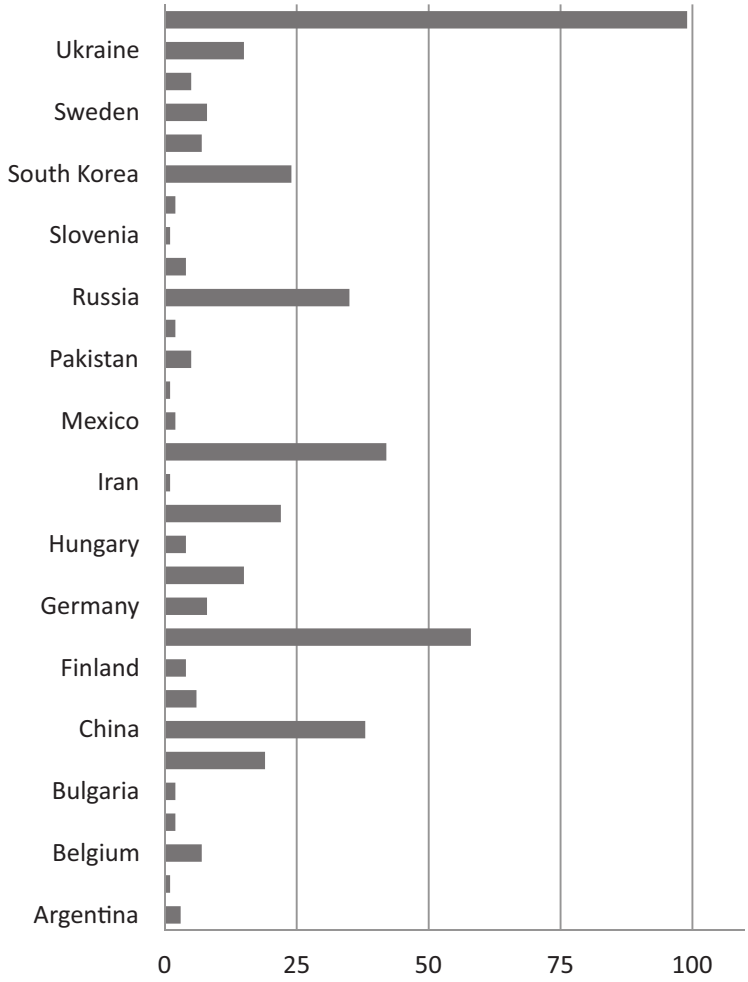

Figure 3. Number of nuclear reactors in the world by country
Rysunek 3. Liczba reaktorów jądrowych na świecie według krajów
Source: [IAEA, PRIS 2018].

The last source discussed is renewable energy, which comes from natural, repetitive processes of nature. The following types can be distinguished: water, sea currents, waves and tides, wind, solar, biomass, geothermal. So far, biomass has been the most important in the European Union. It is widely available and can be used in direct combustion processes (e.g. wood, straw, sewage sludge), processed into liquid fuels (e.g. rapeseed oil esters, alcohol) or gas (e.g. agricultural biogas, biogas from sewage treatment plants, gas landfill). However, the biomass share is decreasing. Solar and wind energy are becoming more and more important, their consumption in several years has increased 20-fold and 6-fold (Table 2), respectively [Gradziuk 2017].

Table 2. Structure of renewable energy sources in the world in 1965–2016 [%]
Tabela 2. Struktura odnawialnych źródeł energii na świecie w latach 1965–2016 [%]

Energy source	Years						
	1965	1975	1985	1995	2005	2015	2016
Traditional biofuels	90.83	86.94	83.84	82.28	78.62	66.79	65.18
Waterenergy	9.12	12.89	15.74	16.67	19.01	23.46	23.83
Solar energy	0	0	0.01	0.01	0.03	1.54	1.97
Wind energy	0	0	0.01	0.05	0.68	4.98	5.68
Other renewable sources (modern biofuels, geothermal energy, wave and tidal energy)	0.05	0.16	0.4	0.99	1.66	3.22	3.33

Source: own study based on [Ritchie and Roser 2016].

It is believed that energy from renewable sources is an alternative to energy from fossil fuels because its production does not involve the depletion of limited resources of energy resources. Therefore, firstly, it does not pollute the environment, and secondly, at least in theory, its sources are inexhaustible. Energy from renewable sources is gaining importance due to:

- continuous increase in human demand for energy due to both the increase in the human population and economic development;
- the gradual depletion of traditional energy resources, i.e. crude oil, coal and natural gas, which causes the need to look for alternative methods of obtaining energy;
- increased concern for the natural environment and the related need to reduce greenhouse gas emissions from the combustion of fossil fuels and other pollutants.

Today, renewable energy is mainly used in four sectors: for electricity production (e.g. wind, solar, hydro), in heating (e.g. geothermal energy), in transport (e.g. fuel cells) and as an energy source in areas deprived of other energy infrastructure for various reasons.

Norway is the only country in the world where the share of renewable energy consumption in the total structure of primary energy consumption is over 50% (Table 3).

Table 3. Countries with the largest share of renewable energy consumption in the total structure of primary energy consumption in 2016
Tabela 3. Kraje o największym udziale zużycia energii odnawialnej w ogólnej strukturze zużycia energii pierwotnej w 2016 r.

No.	Country	Share (%)
1.	Norway	67.86
2.	New Zealand	38.87
3.	Sweden	38.72
4.	Brasil	35.57
5.	Austria	32.53
6.	Switzerland	32.47
7.	Canada	29.43
8.	Portugal	28.08
9.	Columbia	27.05
10.	Finland	25.56

Source: [BP 2017].

Only in six countries of the world this ratio was above 30%. It is worth noting that among the leaders in renewable energy are three Scandinavian countries.

Conclusions

Energy resources have an impact on economic processes in the modern world. Their role and importance for the economy are decisive. Every type of human economic activity requires the use of energy. Agriculture, industry, production of goods or provision of services cannot function without energy, in particular from crude oil, natural gas and coal. Planet Earth without hydrocarbons would face a disaster. The challenge for humanity is therefore proper management of resources of these raw materials, which are exhaustible and unevenly distributed in the world. Several countries have over 80% of the world's reserves (in the case of coal, 10 countries with the largest deposits have 93% of the global reserves). This arrangement of energy potentials causes other countries and societies to depend on resource monopolists. Modern civilization is more than ever a "slave of energy", in particular those countries that have energy resources.

Extraction of energy resources and their processing is invasive for the natural environment. The increase in the concentration of pollutants in the atmosphere as an effect of fuel combustion and the technological processes of many industries and transport disturbs the balance of energy exchange between Earth and space. This causes a rise in global temperature, and consequently melting glaciers and rising sea levels, ozone layer reduction, acid rain, smog, drought and other anomalies. Pollution with gases and dust as a result of energy production causes a disturbance in the proportion of natural air composition, harming human life and health and adversely affecting the development of plants and animals. The energy sector is responsible for almost 70% of global anthropogenic greenhouse gas emissions, which is a significant problem of ecological security and global air pollution. One of the directions limiting this negative impact is the development of energy based on renewable sources. Alternative fuels and the energy transformation towards a low-carbon economy based on civic energy (distributed, renewable energy sources) can be the future of energy. Europe is a prominent region in this respect, in particular Scandinavian countries. In Norway, the share of renewable energy consumption in the total structure of primary energy consumption is almost 70%, in Sweden 38%, and in Finland 25%.

References

Allen R.C., 2011: Wages, prices, and living standards in China, 1738–1925: in comparison with Europe, Japan, and India, Economic History Review 64(S1), 8–38.

Basalla G., 1988: The evolution of technology, Cambridge University Press, Cambridge.

BP, 2017: BP Statistical Review of World Energy 2017, [electronic source] https://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf [access: 10.03.2020].

EEA, 2019: Greenhouse gas emissions from transport in Europe, [electronic source] https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-12 [access: 26.06.2020].

Gradziuk P. 2015: Gospodarcze znaczenie i możliwości wykorzystania słomy na cele energetyczne w Polsce [Economic significance and possibilities of using straw for energy purposes in Poland], Monografie i Rozprawy Naukowe, IUNG-PIB, Puławy [in Polish].

Gradziuk P., 2017: Energetyka słoneczna Unii Europejskiej – stan i tendencje rozwojowe [Solar energy of the European Union – state and development trends], Roczniki Naukowe SERiA 19(1), 52–59 [in Polish].

IAEA, PRIS, 2018: Operational & Long-Term Shutdown Reactors By Country By TypeBy Region, [electronic source] https://pris.iaea.org/PRIS/WorldStatistics/OperationalReactorsByCountry.aspx [access: 10.03.2020].

Key World Energy Statistics, 2016: Key statistics on the supply, transformation and consumption of all major energy sources. Total primary energy supply, [electronic source] https://www.iea.org/statistics/kwes/supply [access: 10.03.2020].

McKinnon A.C., 2012: Reducing Energy Consumption and Emissions in the Logistics Sector, [in:] Energy, Transport & the Environment. Adressing the Sustainable Mobility Paradigm, O. Inderwildi., D. King (eds), Springer-Verlag, London, .

Melosi M.V., 1982: Energy transition in the nineteenth-century economy, [in:]: Energy and transport, G.H. Daniels, M.H. Rose (eds), Sage Publications, Beverly Hills, 55–67.

Młynarski T., Tarnawski M., 2016: Źródła energii i ich znaczenie dla bezpieczeństwa energetycznego w XXI wieku [Energy sources and their importance for energy security in the 21st century], Difin, Warsaw [in Polish].

Ritchie H., Roser M., 2016: Renewable Energy, Empirical view, [electronic source] https://ourworldindata.org/renewable-energy#empirical-view [access:10.03.2020].

Smil V., 2010: Energy transitions: History, requirements, prospects, Praeger, Santa Barbara.

Smil V., 2017: Energy and civilization. A history, The MIT Press, Cambridge.

Wehner J., 2018: Energy Efficiency in Logistics: An Interactive Approach to Capacity Utilisation, Sustainability 10, 1–19.

White L., 1978: Medieval religion and technology, University of California Press, Berkeley.

Correspondence addresses:

Marcin Wysokiński, PhD, habil.
(https://orcid.org/0000-0002-0741-8077)
Warsaw University of Life Sciences
Institute of Economics and Finance
Department of Logistics
166 Nowoursynowska St., 02-787 Warsaw, Poland
e-mail: marcin_wysokinski@sggw.edu.pl

Arkadiusz Gromada, MSc
(https://orcid.org/0000-0001-6185-8885)
Warsaw University of Life Sciences
Institute of Economics and Finance
Department of Logistics
166 Nowoursynowska St., 02-787 Warsaw, Poland
e-mail: arkadiusz_gromada@sggw.edu.pl

Magdalena Golonko, MSc
(https://orcid.org/0000-0002-8532-6741)
Warsaw University of Life Sciences
Institute of Economics and Finance
Department of Logistics
166 Nowoursynowska St., 02-787 Warsaw, Poland
e-mail: magdalena_golonko@sggw.edu.pl