Acta Montanistica Slovaca Volume **21** (2016), number **4**, 287-297

Aspects of classification of energy sources in terms of their position in the sector of the economy

Vojtech Dirner[1] *and* ***Zdeněk Pavelek***[2]

The paper deals with the study of problems relating to classification of energy sources, in particular from the perspective of their position in covering of energy needs of country or economic sector. Classification of energy sources is currently often viewed as a set of fixed categories, but taking a closer look and making a deeper analysis can defined a number of criteria that might determine the final importance and position of resources in the context of complex connections. The composition of energy sources was analysed on a sample of nine countries, which was conceived with the intent to cover various kinds of standard and specific types of energy mixes. In the paper, several criteria for assessing the quantitative and qualitative nature of energy sources were defined. Sectoral, temporal, spatial and scale framework for the validity of the assessment were also defined. In the analysis, the attention was focused on the electricity sector and partially on the sector of transport. The results of the analysis indicate that in different conditions, the same energy source or group can be categorised in a different way, which may have a significant impact on the application of legislation in terms of the use of control, support and regulatory instruments. The analysis took into account in particular the aspects, which complement the recently published papers analyzed this complex issue.

Key words: *alternative energy sources, sustainable energy, energy sources classification*

Introduction

One of the most important and accepted classifications on a global scale is a classification of energy sources according to the International Energy Agency (IEA). The IEA was founded in 1974 to help countries co-ordinate a collective response to major disruptions in the supply of oil. While this remains a key aspect of its work, the IEA has evolved and expanded. It is at the heart of global dialogue on energy, providing authoritative statistics and analysis. Classification according to IEA is also used in agenda of OECD. IEA in Energy Statistic Manual (2005) also defines basic parameters of particular fuels and terminologically defines all relevant terms. Organization of United Nations used classification of energy sources in accordance with The System of Environmental-Economic Accounting (SEEA). SEEA contains the internationally agreed standard concepts, definitions, classifications, accounting rules and tables for producing internationally comparable statistics on the environment and its relationship with the economy. The SEEA framework follows a similar accounting structure as the System of National Accounts (SNA) and uses concepts, definitions and classifications consistent with the SNA in order to facilitate the integration of environmental and economic statistics (System of Environmental-Economic Accounting Definition, 2016). The classifications mentioned above create a hierarchical structure of natural energy sources, which is more based on a hierarchical exhaustively listing of various sources, or group of sources. Classifications do not include other parameters that would in some way reflect the technological or environmental aspects of utilisation of particular energy source.

Document (blog.enerdynamics.com, 2016) deals with the system of division of the individual energy sources in terms of terminology and hierarchical structure. The authors also analysed individual aspects of the interpretation of terms that relate to the clarity and precision of the importance of renewable energy sources. For a comprehensive view of energy sources in terms of their classification, it is necessary to analyse them in an analogous way also from the perspective of other criteria, such as "position", which describe a category of traditional / alternative. In some countries, the classification of energy sources as was published in (world-nuclear.org, 2015) is used, where the division into traditional / alternative is equivalent to the division into conventional / unconventional. The criterion of mentioned division is not justified by certain characteristics; energy sources are only exhaustively listed in their primary form.

Methodology

The subjects of analysis were energy sources (that are currently used) in the context of their inclusion in the existing and used classifications of energy sources. Emphasis was placed on the position of sources, which is

[1] *Prof. Vojtech Dirner, Ph.D.*, VSB-Technical University of Ostrava, Faculty of Mining and Geology, 17.listopadu 15, 708 33 Ostrava, Czech Republic, vojtech.dirner@vsb.cz
[2] *Zdeněk Pavelek, Ph.D., MBA,* VSB-Technical University of Ostrava, Faculty of Mining and Geology, 17.listopadu 15, 708 33 Ostrava, Czech Republic, zdenek.pavelek@vsb.cz

generally understood as a belonging of energy source to the group of traditional or alternative energy sources. During the work with information, sources were evaluated by interpretative clarity, spatial and temporal affiliation and versatility. In assessing the possible inclusion of various energy sources, quantitative and qualitative factors were taken into account in relation to the interpretation of the characteristics of energy sources, respectively kinds of energy. There are these aspects:

- the scale of assessing source,
- region,
- timeframe,
- economic framework represented by indexes of GDP and GCI,
- technological aspects related to the availability and rate of utilisation of energy sources represented by index CF and its modifications,
- interpretative homogeneity of source,
- interpretation clarity - the incidence of disputes.

The subject of analysis was a sample of nine countries assembled according to their different concepts of energy mixes and structures. The selected sample represents characteristic countries from different world regions (Czech Republic, Slovak Republic, France, Ireland, Iceland, Canada, Japan, Costa Rica, Qatar). For listed countries, the electricity sector, as a selected sector of the economy, was separately analysed. Sector of transport was analysed partially when temporal and spatial aspects were considered.

The specifics of the status of energy sources and their structure in selected countries

Based on data published in (eea.europa.eu, 2016) and (bp.com, 2014), which are also partly summarised in 0 and 0, it is possible to characterise main characteristics of the total consumption of primary energy sources as well as the electricity mix in the sample of selected countries.

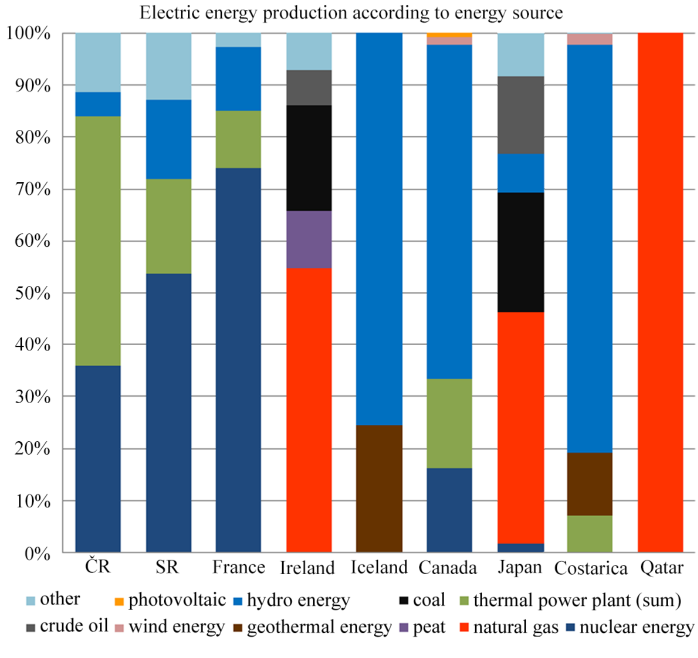

Fig. 1. Representation of energy sources in the electricity sector for the sample of selected countries, according to (eea.europa.eu, 2016) and (bp.com, 2014).

The Czech Republic represents the country with a typical continental energy mix of the country with significant coal reserves, and therefore sector of the electricity sector is dominated by coal, which is greatly complemented with the nuclear energy. Slovak Republic is a country without a major raw material energy source, where the overall composition of primary energy sources is built on the nearly balanced utilisation of coal, oil, natural gas and nuclear energy, supplemented by renewable energy sources (Blišťan and Blišťanová, 2012; Gavurova et al., 2016). In the electricity sector, the nuclear energy has more than a half share. On a global scale, France is a nuclear power, where nuclear energy is predominant in the overall energy mix over the second most used source - oil. In the electricity sector, the share of nuclear energy is 74 % (it was up to 78 % in the past decade). Ireland represents a country situated outside of Continental Europe, which is reflected in more than 50 % share of oil in primary energy sources, while oil and natural gas together reached 83 % share in primary energy sources. In the electricity sector, it has more than a half share of natural gas and typical energy source for island economies - oil. Peat has an outstanding position in the sector with 11% share of generated electricity. Iceland is a country with extremely favourable conditions for the exploitation of geothermal energy in the zone of the high and medium enthalpy. Geothermal energy represents up to 66 % in the total primary energy sources. In the electricity sector, hydropower has a dominant position with 75.5 %; the second source is high-enthalpy geothermal energy. Canada is a country with an economy built on the use of earth sources, which is a major exporter. Oil prevails among the primary energy sources with 32 % share; hydro power has also extremely high share with 26 %. The third major source is natural gas with 22 %. In the electricity sector, hydropower has absolute dominance with a share of 64.3 %. Approximately the same share has nuclear energy and thermal power (coal + natural gas) with a share of 16.3, respectively 17 %. Japan was, before the nuclear disaster in Fukushima, a typical strong island economy based on the principles of effectiveness. The primary energy sources were relatively evenly composed of nuclear energy, natural gas and coal. Although it is the island country, oil has an unusually low share of primary energy sources (8 %), even 2 % lower than renewable energy sources.

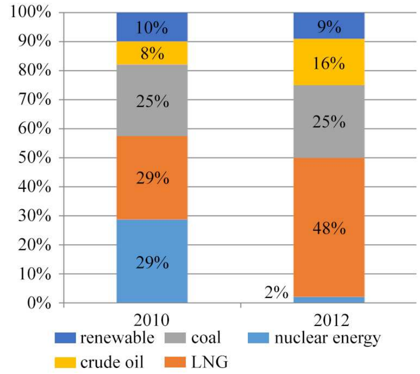

Fig. 2. Energy mix of Japan before and after Fukushima nuclear disaster (bp.com, 2014).

Significant change in the energy mix occurred after the accident in Fukushima. The share of nuclear power has been reduced by 93.1 % (from 29 % to 2 %), what was mostly compensated by an increase in natural gas consumption by 65 % and oil by 100 % (characteristic rapid compensation of loss of capacity in terms of the strong island economy without own raw material energy source). The electricity sector is completely dominated by fossil fuels (65 %). Costa Rica is the first country which officially declared the ability to achieve production of electricity exclusively from renewable sources. In 2014, 94 % of electricity was produced from renewable energy sources. Due to the fact that BP or EIA do not report overall primary energy sources, it is impossible to determine the share of individual sources accurately, but for analogous extensive economics, oil has a significant position among energy sources. Taking into account the ratio of energy produced and consumed, what is presented in 0, it is clear that self-sufficiency in terms of internal sources - renewable energy sources covers only the electricity sector and not whole primary energy sources.

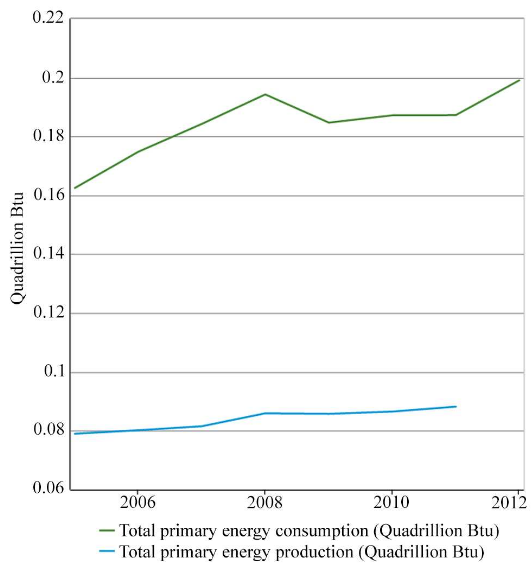

Fig. 3. Total energy consumption vs. production in Costa Rica (knoema.com, 2015).

The electricity sector is covered mainly with hydropower (78.45 %) and with a mix of other renewable energy sources with more significant geothermal, biomass and wind energy. Qatar is a country with rich natural sources (especially natural gas), whose capacity highly exceeds energy demands of the country´s economy itself. Energy mix is, due to the focus on own rich sources of carbohydrates, very austere. The natural gas accounts in primary energy sources by 77 % and oil 23 %. The electricity sector is covered by 100 % with natural gas.

Analysis of resources according to defined criteria of position in covering energy needs of sectors

As is reported in (Rybár et al., 2007; Blišťan et al., 2012), according to the position of criteria, it is possible to divide energy sources into two groups - traditional and alternative energy sources. This criterion cannot be freely generalised because it depends on several factors with quantitative and qualitative nature. In contrast to the assessment of energy sources in terms of renewability, as is reported in (Rybár, et al., 2015), when considering the position of the source it is necessary to take into account quantitative, spatial and temporal aspects. The basic quantitative factor is a level of participation of energy source, which is expressed as a percentage of total consumption of sources. When analysing energy sources according to this criterion, the determinative function has classification scale of sources. If it is based on the gross participation of energy sources in each country, as is mentioned in (eea.europa.eu, 2016) and depicted in 0, it is clear that it is not possible to differentiate energy sources according to criteria of position and thus it is not possible to describe energy sources as traditional or alternative.

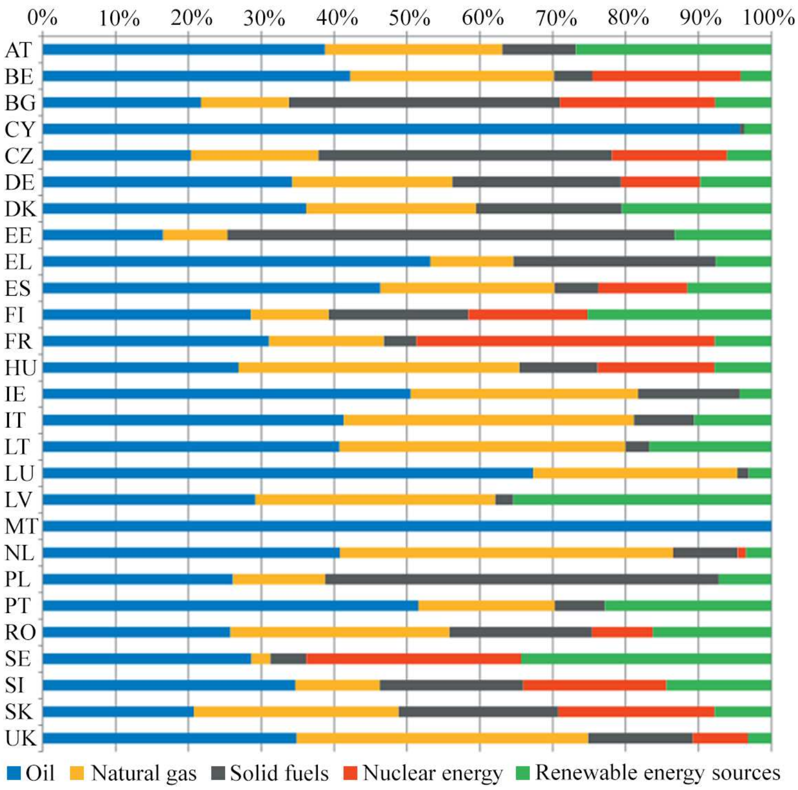

Fig. 4. Gross domestic energy consumption of EU countries in 2014 (eea.europa.eu,02016).

If the selected scale is set in a way to differentiate the sources that are usually reported together, as is depicted in 0, it is possible that the ratio of share of some source (fuel) will have a low level of participation in comparison to other sources in the analogue group. An example is the position of coal in the electricity sector in the Czech Republic, which represents 12.94 % share of the total coal consumption and represents 5.97 % of total fuel consumption in the sector. The next example is natural gas, which has 1.99 % share of the total consumption, which is 18.4 % less than in the case of biogas, which participates on total consumption with 2.44 %. The above facts show that the selected scale clearly influences the position of the source in quantitative expression. On the other side, it points out that in order to understand the position, the quantitative side is not expressed with a ratio of presence of energy source on the total energy consumption only with one indicator. Therefore, the energy source cannot be classified into the category of traditional or alternative only on the basis of the quantitative parameter.

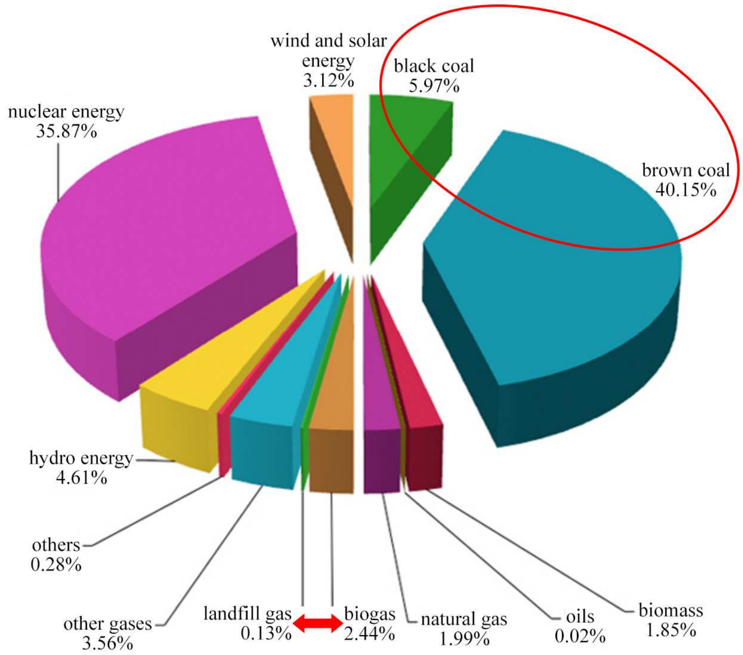

Fig. 5. Production of electricity from various fuels in the Czech Republic in 2013 (elektrina.cz, 2014).

Quantitative aspects are assessed within a particular location of the country in certain economic space. This belonging is based on economic indicators, which reflect the level of economics, economic structure and development of the country. Taking into account energy efficiency according to (Horodníková, et al., 2008), (Khouri, 2009) and (MacKay, 2008) a relevant indicator is the rate of economic level of the country, expressed as a GDP per capita relative to the energy consumption per capita (0).

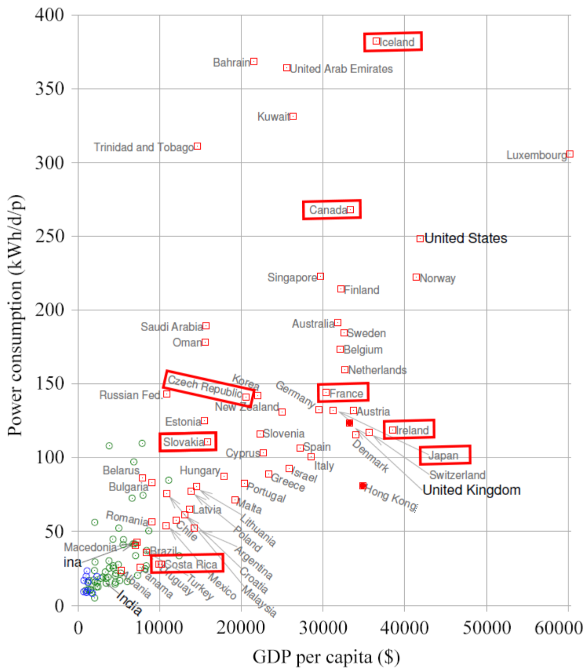

Fig. 6. Energy consumption per capita to GDP per capita (MacKay, 2008).

In assessing the overall energy intensity or energy structure of the country, it is necessary to take into account economic power, which parameter is the country´s total GDP. Due to the economic raw material relationships, which are described in (Antošová, et al., 2013), (Bittner, et al., 2015) and (Cehlár, et al., 2013), Human Development Index (HDI) is currently used for a mutual comparison of the economic level of countries. HDI according to (Vlček, 2003) takes into account GDP per capita (according to purchasing power parity), the expected life expectancy, and education levels of the population. In terms of assessing the structure and nature of energy sources, HDI has similar meaning than GDP per capita. Taking into account aspects that are mentioned in (Čulková, et al., 2014), (Khouri, et al., 2011) and (Teplická, et al., 2015), the index of competitiveness is another useful economic indicators in the process of analysis of energy sources. Global Competitiveness Index (GCI) is published by The World Economy Forum (WEF), which according to (Xavier, 2009) states that national competitiveness reflects the ability to grow the national economy with help by a set of factors, policies and institutions, whose determine levels of productivity of a country. GCI itself also reflects institutional and educational factors, therefore finally does not reflect energy demands of the economy, respectively country, but it is useful for the classification of the country to the selected characteristic group, which have a specific nature in term of demand for energy sources.

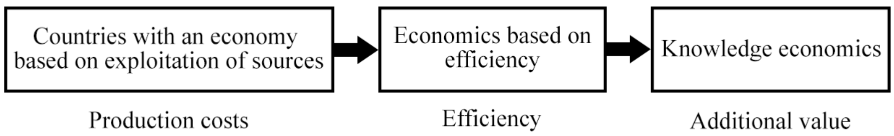

Fig. 7. Stages of development of competitiveness (Porter, 2009).

The diagram in 0 depicts stages of development of the competitiveness of economics. There are three groups of economics, which from the energy point of view have similar signs. Therefore, it is only possible to compare the energy structure of countries that are pertaining to the same group. As is reported in (Rybár, et al., 2007), it is not possible to speak about the position of energy source and its alternativeness in general. This evaluation must be assessed in the context of sector and technology. The basic sectors, which are characterised by their specification, are electricity sector, heat production for industry, heat production for housing and transport. Each of these sectors uses its specific platform of energy sources. This division can be further refined and differentiated, which brings further clarification of the meaning in a specific context. On that basis, we can formulate quantitative characteristics of energy sources in terms of their position and define traditional sources. Traditional energy sources currently represent base (key, core, supporting) energy sources in the sector, which are able to cover the requirements of the sector from the perspective of time and technology (availability of energy source, quality, respectively nature of the output) in the full range. The quantitative nature of each energy source is expressed through the ratio of participation of each energy source in the electricity sector in the sample of countries, what is depicted in 0.

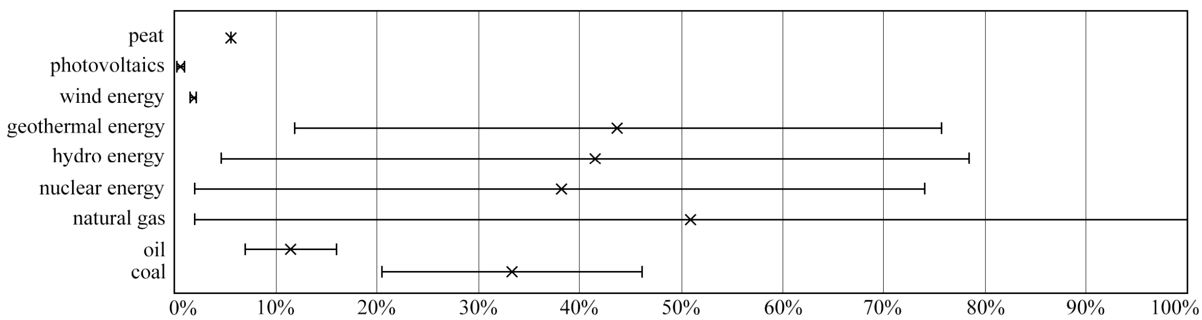

Fig. 8. Ratio of quantitative participation of each energy sources in electricity sector in the sample of countries.

It is clear, according to the results presented in 0, that some sources as natural gas, nuclear energy, hydro energy and geothermal energy have a broad zone of utilisation, which excess 50% share of energy consumption of the sector. It points out that these sources can act in various positions and may have a different function in the base and regulatory part of the electricity sector and thus can be taken from this point of view as traditional sources. On the other side, sources as wind and solar energy are weak from quantitative aspect and it can be assumed that are not able to provide a base function in the energy mix of the sector in its current form, which means that they are alternative sources. Narrower zone in the case of coal is partially caused by the effort of countries to eliminate these energy sources due to the balance of CO_2. The previous definition of traditional energy sources did not include a quantitative aspect, not just because the quantity produced by more types of sources is sufficient in the current composition of regional energy mixes and sector, but also because of the qualitative aspect of sources. In common practice, the capacity factor (CF) is used as a qualitative parameter, which is in (nrc.gov, 2016) defined as the ratio of the net electricity generated, for the time considered to the energy that could have been generated at continuous full-power operation during the same period:

$$CF = \frac{E}{P * t} \tag{1}$$

where E is the amount of produced energy during the monitored period (kWh/year), P is installed power (kW), t is the length of the period (in hours per the calendar year - 8 760 hours). About values of CF, their estimating and determining is discussed in documents (blog.enerdynamics.com, 2016), (Boccard, 2009) and (Cavallo, 1995). Capacity factors greatly vary depending on the type of fuel that is used and the design of the power plant. For individual fuels used in standard power plant in electricity sector, approximate values of capacity factors according to (blog.enerdynamics.com, 2016) are: coal - 0.62, petroleum - 0.07, natural gas - 0.24, nuclear - 0.86, hydro - 0.38, wind - 0.27, solar - 0.15, geothermal - 0.58. Values of capacity factor for each energy source may vary depending on the specific technology, parameters of the fuel / energy source, operating conditions, the nature of power output, time, geographic location, and other factors that have to take into account when an accurate statement is necessary. As in the electricity sector, the capacity factor can be expressed for different kinds of energy and energy devices in other sectors. When energy sources in the electricity sector of some countries are depicted in the diagram that is analogous to unitary circle, in a way that the distance from the center of the circle is a quantitative parameter - the rate of participation of energy source and angle with x-axis represents qualitative parameter - capacity factor, then we can plot each source to the diagram as radial lines. For all countries in the sample, such diagrams are depicted in 0. Each quadrant then covers a group of sources with the similar quantitative side and therefore with a similar deployability.

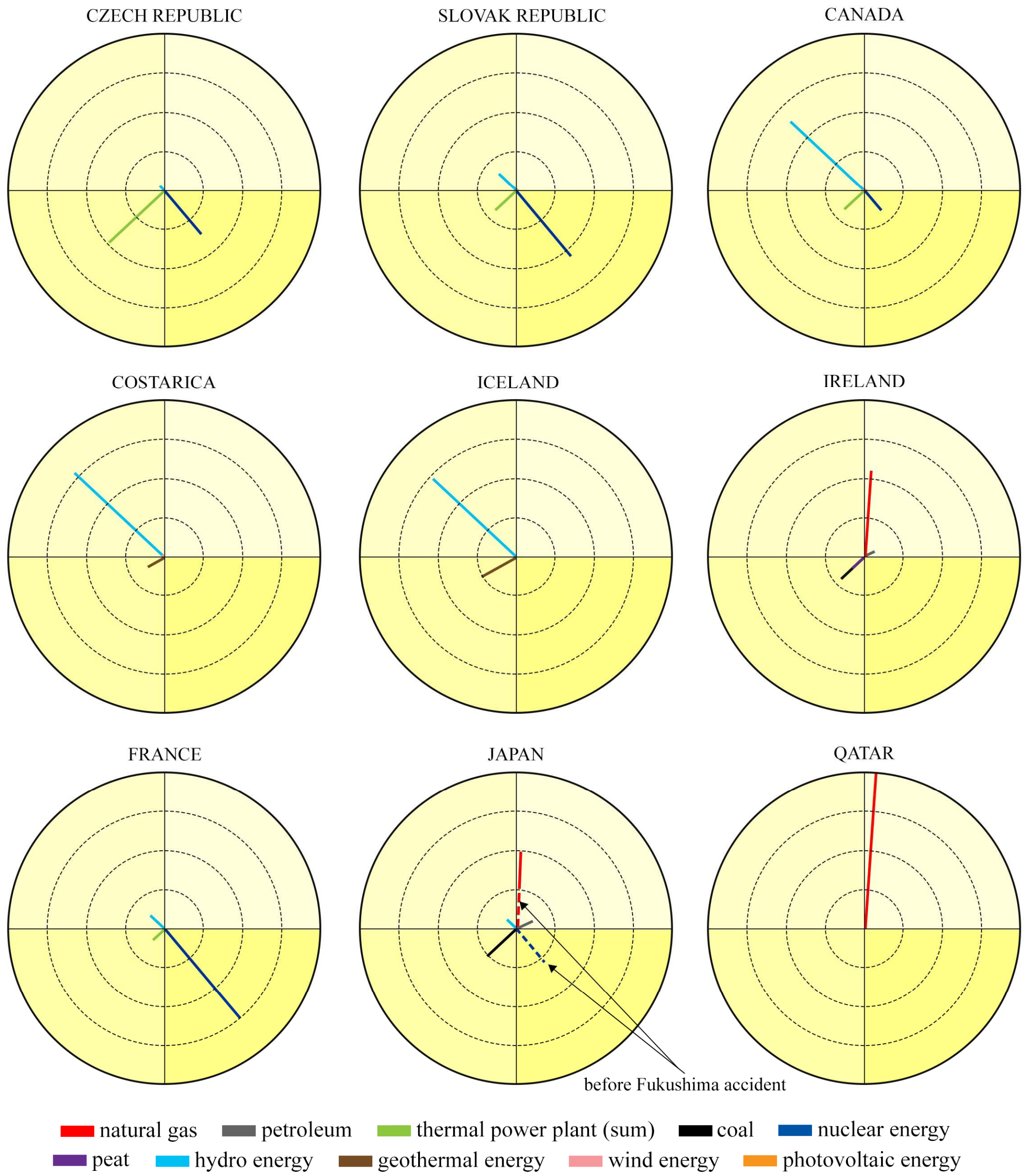

Fig. 9. Diagrams depicting qualitative and quantitative side of position of energy sources in the sample of countries

In the energy mix of most countries, regardless of its composition, various energy sources with different potential in summary expression are close to the 100 %. In the each country, sources with different potential have a different position, while the position of the line refers to the deployability of the source and the length of the line refers to the deployment of the source. There can be seen similarities between countries such as Slovakia and France, in which energy mixes mostly consist of nuclear energy and hydro energy. Countries such as Iceland, Costa Rica and Canada have similar energy mixes built on large natural potential (However, Canada and Costa Rica are completely different energy consuming economics). Japan and Ireland show signs of typical island countries dependent on imports of raw material energy sources. Due to the high industrial production in Japan, before the accident in Fukushima, there is evident need of a power source from the fourth quadrant - nuclear energy. The Czech Republic appears to be the country maintaining position of domestic coal with the support of nuclear energy. The unique position has Qatar, which covers the entire consumption with low *CF* source.

From the above mentioned, it is also possible to state that only a source, that is capable of reaching full coverage of energy needs with own availability can have the absolute dominant position in ensuring the energy needs of a particular sector, which would correspond to the maximum available capacity factor, which can be designated as $CF_{max} = 1$. On the other side, most energy technology or nature of the source do not allow to reach a high capacity factor, so it is actually possible to improve this parameter with adequate over-dimensioning of the capacity of each device, which is then able to cover the entire load curve of the system. Such as value of CF could then be considered, for example, for natural gas in the electricity sector in Qatar (opposed value from the normal average) or for oil in transport. If there is sufficient amount of fuel/energy, this source can reach a maximum value of the quantitative parameters, i.e. 100 % share of total energy production in the sector. This corresponds with the facts that in most countries, the energy requirements, especially in the electricity sector and heat production, cannot be covered from one source for capacity reasons. In order to take account this ability of source, which relates to its availability potential, we introduce parameter of potential capacity factor *CF´*. This parameter reflects that despite the limited effectiveness of the technology and its primary availability with sufficient over-dimensioning of the source, respectively with the suitable composition of power plants, it is possible to reach a complete coverage of energy consumption in the whole range of operational conditions caused by the nature of load curve of the system. In doing so, we introduce a general transformation of parameter *x*.

$$x' = \frac{x - \min(x)}{\max(x) - \min(x)} \tag{2}$$

Where *min(x)* and *max(x)* are minimum and maximum values that the *x* parameter can have. *CF´* is then:

$$CF' = \frac{CF - CF_{\min}}{CF_{\max} - CF_{\min}} \tag{3}$$

For *CF´*, it is valid that due to technological or potential limitations, it is impossible to introduce thus modified parameter for all energy sources. Even though parameter capacity factor defines energy source by the level of utilisation of installed capacity, it is not very informative in some cases. Such as in the case of peak power plant due to its very nature of the function and method of operation of these sources. For this reason, it would be appropriate to adjust the value of capacity factor in terms of the potential availability of source when it is needed. Thus modified capacity factor could be used as a universal qualitative parameter indicating the availability of energy source. The significance of this parameter is relevant only if it refers to the established, respectively technologically appropriate way of utilisation of technologies attaching to the individual energy mixes. This means that nuclear power plant should cover the base load range and has no regulatory function (e.g. at the peak load range), as well as pumping hydropower plant fulfils a regulatory function at peak load and has no function in covering the base load range.

If we have information about quality aspects of energy source, we can formulate the characteristics of energy sources in terms of their position and define alternative energy sources. Alternative energy sources are energy sources in the sector, that currently and partially replace, respectively substitute commonly used (traditional) energy source, while currently are not able to cover the requirements of the sector in terms of time, technology (availability of source, quality, respectively character of output) and capacity. To complement the context of the meaning of the term, it is possible to document the extended meaning of alternativeness, for example, in the sub-sector of electricity sector - nuclear energy, where are traditional energy sources on the base of uranium: uranium oxide including mixed uranium oxide + plutonium oxide (MOX) fuel. A thorium-based fuels, including mixed thorium-plutonium (Th-MOX) fuel, which can achieve a high utilisation factor for recycled plutonium, could be considered as an alternative energy source (world-nuclear.org, 2015).

The spatial aspect is related to the type of territorial unit, which is taken into account (country, region, continent). The time aspect is based on the development of raw material fuel, respectively sources base over time, which can be documented on several examples from history. In an understandable way, the traditional or alternative character of energy source in terms of time and space is defined in the sector of transport, while it is also evident that this criterion is not in correlation with the criterion of renewability of the energy source. For example, ship transport (river and sea) in the period before 3000 to 5000 years ago (Hattendorf, 2007), was driven by human power, which means that the source of energy was biomass. It was a traditional energy source. Later, wind power has become a traditional energy source. The first steam vessels have appeared in the late 18th century (Rodrigue, 2013). In a broader context, coal was clearly a traditional energy source in the 19th century in global rail and ship transport (loc.gov, 2016), while currently, oil has an analogous status, which is the most important source of energy from a global perspective in the whole sector of transport (aviation, shipping transport, rail, automobile traffic). In the case of railways, if we narrow down regional view, for example, to the territory of France (SNCF), where 15 687 km of lines are electrified (sncf-reseau.fr, 2016), then the traditional sources of energy will be nuclear energy, which stands for the production of electricity in France. In 2014, the share of nuclear energy in electricity production was 77 % (iea.org, 2014). We can conclude that in this case, primary electric energy and secondary nuclear energy represent a traditional energy source in transport. If we take into account the importance of electricity in the road (automobile) traffic, it is clearly an alternative energy source. France is currently the leader of the EU in introducing of electric vehicles into traffic. According to (ccfa.fr, 2014),0 electric vehicles represented 0.59 % of newly registered cars in 2014.

Conclusion

The analysis has shown that the substitution of the meaning of "alternative energy sources" and "renewable energy sources" is incorrect and leads to the development of communications and legislative inaccuracies and misinterpretations. The same situation is with the substitution of the meaning of "sustainable energy", which can be considerate as the equivalent of "renewable energy sources", and is used in this sense in the different literature sources. The practical importance of using the terms "alternative energy sources" and "traditional energy sources" is based more on a theoretical or strategic level, where it can help with analysis of trends in the fuel structure and technological base. By deeper analysis, while trying to include some energy source into a certain category, there are raising some issues that point to the fact that various sources are not in the mutually antagonistic position, but more or less show signs from one or other side, depending on conditions, a considerable period of time, location, etc. Presented analysis has shown that a currently used classification of sources is not always clear and classification of energy source to the certain category, which is monitored mostly by legislative framework, should be resulting from deeper analysis while taking into account broader context and factors. Presented paper complements and expands the part of energy sources classifications, which was presented by authors especially in (Rybár, et al., 2007), (Rybár, et al., 2008) and (Rybár, et al., 2015). Analysis showed that the energy sources cannot be classified in individual category on the basis of an exhaustive listing, but on basis of some justifiable characteristics, which they predominate, and on which the identification is necessary to obtain further information about circumstances of the use or energy source in terms of technology, region, time, etc. Finally, it can be stated that the source that in the quantitative point of view shows a low level of utilisation or from a qualitative point of view has low availability that is expressed through CF cannot be considered as traditional sources. There are exceptions to this rule due to exceptional conditions in the specific cases. In contrast to the assessment of criteria of the renewability or exploitability, where it is possible to precisely define the boundaries and principles of classification, assessment of source from the point of its position is affected by a number of qualitative and quantitative factors that do not allow unambiguous interpretation. As is reported in (Rybár, et al., 2015), due to increasingly complexity of energy mixes in countries, more sophisticated technologies, more complicated legislative framework in terms of environmental claims and supporting tools can be expected that up to now valid categories and meaning of classification will prospectively be replaced by more flexible and concise classification, that will represents the most important meaning and features that allow better orientation in the issue of effective application of regulatory mechanisms and will be based on technologically, environmentally and economically significant characters such as availability, CO_2 balance, real renewability, etc. From this perspective, the assessments and classification of energy sources into the category of renewable and traditional energy sources for the purposes of the legislation is rather irrelevant and has the meaning of additional information about the position of energy source within defined conditions and time.

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