Quantitative analysis of diversification in energy consumption

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In the paper presented the method for the quantitative analysis of diversification in energy consumption has been developed. The consumption of primary energy was considered as a market for a separate good with a number of competing companies (types of energy) on the market so that the technique for assessing the level of economic concentration of the market on the base of Herfindahl-Hirschman index was used and the level of diversification of energy consumption has been calculated. The method proposed allows the following: definitely quantitatively assess current situation in diversification of generic structure of energy consumption; provide content interpretation and simplicity of calculation; estimate the impact of different directions on the level of diversification; conduct cross-country comparison of the level of diversification; promote conscious choice of priority directions of diversification; support the development of target indicators in perspective diversification; assess the level of achieving the target indicators.

Index Terms **- primary energy, energy consumption, diversification.**

Diversification is one of the key directions to provide global energy security. It aims at providing and reaching the "diversity or versatile development" [1] supply and demand for energy resources, sources of energy, geographical and sectoral markets, transportation routes and means for transporting energy resources [2,3]. All these directions of diversification or some of them are important for major countries, regions, sectors or enterprises. [4,5,6,7,8,9,10,11,12].

To this end, diversification of energy consumption's generic structure is noteworthy. As it was mentioned in [13], it is of universal pattern and intrinsic of both global power engineering and power engineering of all types of countries including developed, developing and countries in transition.

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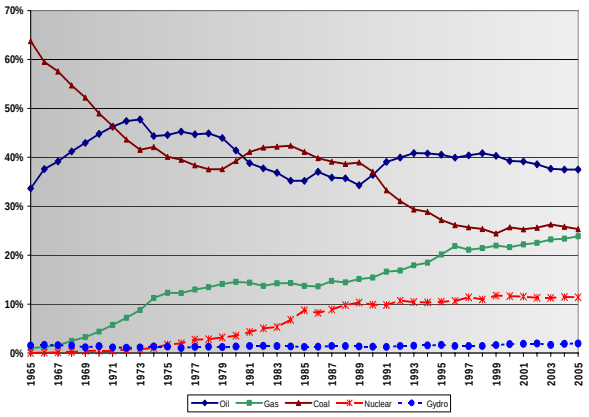
Researching the consumption dynamics of five main types of commercial energy coal, oil, gas, nuclear and hydro power, revealed a wide range, level, rate and directions in diversification of generic structure of power consumption in different countries. For instance in France and Sweden development of nuclear power engineering has been the main direction of diversification, while Germany (Pic.1), Great Britain and Hungary have been substituting coal by natural gas and very cautiously developing nuclear energy, especially after Chernobol disaster.

Brazil and Peru make efforts to increase the share of hydro power, while China and India are trying to reduce the share of coal in their energy balance, which made respectively 69, 6 and 55 per cent in 2005.

Analysis shows intention to include in energy balance as many types of primary energy and maximal alignment of their hares in energy consumption is common for energy policies in major countries of the world. A great number of countries set target quantitative indicators on



Pic.1 Evolution of the structure of energy consumption of Germany

diversification, in addition to that specific direction of diversification are defined basing

on real conditions in each and every country [5,11,14,15,16,17,18,19,20].

To assess diversification of energy consumption's generic structure, it is often used a technique for assessing the quantity of energy types used and of their share in energy consumption. For example, such indicators as the share of fuel and/or share of carbonless energy, and/or share of renewable energy in total amount of energy consumed are used as energy indicators of sustainable development. [21].

However, when the share of certain type of quantity of energy simultaneously changes, the technique doesn't give a crystal clear answer on how the level of diversification changed compared to previous period. Besides, the technique does not allow making cross-country comparisons.

To make an unbiased assessment of current level, intensity and dynamics of diversification of power consumption's generic structure, to promote the choice of priority directions in diversification, to develop its perspective and target indicators and asses the levels of reaching the targets, to make unbiased comparisons we need a technique providing definiteness, interpretability of content and simplicity of calculation.

The current research has been aimed at solving the above task.

It is well known that diversification process is reverse to concentration. Therefore, if we consider consumption of primary energy as a market for a separate good with a number of competing companies (types of energy) on the market, we can use the techniques for assessing the level of economic concentration of the market and calculate the level of diversification of energy consumption.

Economic theory suggests a system of quantitative and qualitative indicators, which allows assessing the level of economic concentration: the threshold share of the market, coefficient of concentration, index of Herfindahl-Hirschman, index of Linde, index of Lerner and others. Each and every of these indices has certain advantages and disadvantages described in economic literature [22,23].

In our case the most clear borders of change and exact explanations of the value gives the index of Herfindahl-Hirschman, therefore it is suggested to calculate the level of diversification on energy consumption in different countries using the formula:

$$K_{\mathrm{d}} = 1 - \sum_{i=1}^{n} q_i^2 , \qquad (1)$$

where K_{d} - coefficient of diversification,

$\sum_{i=1}^{n} q_i^2$ - index of Herfindahl-Hirschman,

n - the number of primary energy used;

q - share of i type of primary energy in total consumption.

Values of this coefficient can be situated in between:

$$0 \le K_{\mathrm{d}} < 1 - \frac{1}{n} , \qquad (2)$$

In addition to that, the more its value is, the higher is the level of diversification of the generic structure of energy consumption. When only one type of energy is used, meaning when diversification is absent, this coefficient equals zero.

An important specific of the formula is the possibility to determine exact numeric ranges of the diversification coefficient (the degree, the level of diversification) depending on the number of energy types used; under provision the shares are distributed evenly:

Number of energy types	1	2	3	4	5	10	20	50	100
K_{dp}	0	0,50	0,67	0,75	0,80	0,90	0,95	0,98	0,99

Disparity of the quantity of actual diversification co-efficient corresponding its maximum value means that types of energy are distributed unevenly. In addition to that, the more is the difference, the greater is the unevenness of the structure.

It is vividly seen in the table 1, where diversification coefficients are demonstrated by 64 countries of the world for 2005. They have been calculated for British Petroleum using retrospective statistical data during the period of 1965-2005. [24].

TABLE 1 COEFFICIENTS OF DIVERSIFICATION OF GENERIC STRUCTURE IN ENERGY CONSUMPTION

Countries	Number of types of energy	2005	Countries	Number of types of energy	2005
Slovak Republic	5	0,770	Italy	4	0,619
Canada	5	0,752	Peru	4	0,617
Bulgaria	5	0,742	Denmark	3	0,608
Finland	5	0,727	India	5	0,598
Germany	5	0,725	Thailand	4	0,598
Romania	5	0,721	Argentina	5	0,597
Turkey	4	0,718	Malaysia	4	0,596
USA	5	0,709	Philippines	4	0,588
New Zealand	4	0,704	Netherland	4	0,577
Sweden	5	0,702	Egypt	4	0,553
Columbia	4	0,700	Mexico	5	0,548
Lithuania	5	0,694	Poland	4	0,543
Japan	5	0,693	Ireland	4	0,537
Austria	4	0,693	Greece	4	0,532
France	5	0,692	Hong Kong	3	0,531
Czech Republic	5	0,691	Azerbaijan	3	0,526
Great Britain	5	0,691	Iran	4	0,523
Switzerland	5	0,690	Portugal	4	0,510
Chile	4	0,687	Iceland	3	0,500
Republic of Korea	5	0,680	Saudi Arabia	2	0,487
Ukraine	5	0,677	Algeria	4	0,480
Taiwan	5	0,665	Norway	4	0,478
Hungary	4	0,658	Kuwait	2	0,470
Venezuela	4	0,658	China	5	0,467
Australia	4	0,656	UAE	2	0,445
Pakistan	5	0,651	Bangladesh	4	0,412
Spain	5	0,646	Belarus	3	0,411
Brazil	5	0,645	South Africa	4	0,375
Russia	5	0,643	Turkmenistan	2	0,372
Indonesia	4	0,640	Ecuador	3	0,357
Kazakhstan	4	0,639	Qatar	2	0,332
Belgium	5	0,631	Singapore	2	0,215

Having the highest coefficient of diversification, Slovakia and Canada have most evenly diversified structure of energy consumption. Out of the countries using four types of energy, Turkey and New Zealand have relatively even structure. Qatar and Singapore have the least diversified structure with most vividly seen uneven distribution of the types of energy. These countries also have the smallest coefficient of diversification. Out of countries using five types of energy Mexico and China have the least even structure. This is supported by the data in Table 2 containing the shares of different types of energy used by these countries in 2005.

TABLE 2

	Share of used type of energy (%)				
	oil	gas	coal	atomic	hydro
Slovakia	19,2	29,1	23,6	22,0	6,0
Canada	31,5	25,9	10,2	6,6	25,7
Turkey	33,4	27,4	29,1	-	10,0
New Zealand	39,3	18,0	11,8	-	30,9
Mexico	**59,7**	30,3	4,1	1,6	4,3
China	21,1	2,7	**69,6**	0,8	5,8
Qatar	21,0	**79,0**	-	-	-
Singapore	**87,7**	12,3	-	-	-

Using the given coefficient, by means of calculating the coefficient per each year under consideration, it is possible to estimate the retrospective dynamics on how the type structure of energy consumption has been changed (Table 3).

TABLE 3 DYNAMICS OF CHANGES OF THE COEFFICIENT OF DIVERSIFICATION OF ENERGY CONSUMPTION'S GENERIC STRUCTURE

	1965	**1970**	**1975**	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**
World total	**0,666**	**0,666**	**0,669**	**0,682**	**0,713**	**0,719**	**0,726**	**0,723**	**0,727**
Slovakia	0,504	0,573	0,610	0,691	0,727	0,742	0,762	0,759	0,770
Canada	0,685	0,684	0,695	0,718	0,755	0,750	0,756	0,751	0,752
Bulgaria	0,529	0,546	0,577	0,641	0,706	0,725	0,743	0,734	0,742
Finland	0,578	0,468	0,482	0,588	0,684	0,704	0,732	0,737	0,727
Germany	0,479	0,557	0,625	0,652	0,680	0,697	0,710	0,719	0,725
Romania	0,595	0,607	0,632	0,648	0,653	0,657	0,679	0,664	0,721

Turkey	0,540	0,512	0,466	0,545	0,556	0,636	0,664	0,663	0,718
USA	0,670	0,665	0,671	0,682	0,703	0,712	0,718	0,708	0,709
New Zealand	0,652	0,626	0,629	0,647	0,700	0,709	0,695	0,700	0,704
Sweden	0,499	0,413	0,554	0,604	0,697	0,700	0,701	0,702	0,702
Columbia	0,656	0,656	0,635	0,677	0,709	0,705	0,687	0,694	0,700
Lithuania	н.д.	н.д.	н.д.	н.д.	0,597	0,669	0,681	0,675	0,694
Austria	0,716	0,695	0,686	0,684	0,715	0,714	0,702	0,705	0,693
Japan	0,556	0,449	0,422	0,520	0,628	0,620	0,645	0,660	0,693
France	0,615	0,563	0,546	0,620	0,714	0,702	0,701	0,699	0,692
Czech Republic	0,215	0,305	0,389	0,440	0,444	0,508	0,609	0,620	0,691
Great Britain	0,502	0,573	0,645	0,674	0,699	0,697	0,708	0,710	0,691
Switzerland	0,557	0,507	0,566	0,618	0,670	0,666	0,690	0,690	0,690
Chile	0,625	0,570	0,564	0,578	0,634	0,644	0,622	0,623	0,687
Korea	0,367	0,501	0,480	0,493	0,575	0,607	0,542	0,558	0,680
Ukraine	н.д.	н.д.	н.д.	н.д.	0,701	0,689	0,676	0,639	0,677
Taiwan	0,622	0,588	0,454	0,467	0,651	0,623	0,634	0,623	0,665
Hungary	0,455	0,600	0,634	0,652	0,694	0,715	0,702	0,695	0,658
Venezuela	0,498	0,527	0,563	0,564	0,607	0,634	0,639	0,646	0,658
Australia	0,545	0,562	0,612	0,642	0,662	0,659	0,661	0,658	0,656
Pakistan	0,640	0,629	0,645	0,651	0,671	0,674	0,657	0,627	0,651
Spain	0,600	0,518	0,475	0,489	0,620	0,644	0,627	0,588	0,646
Brazil	0,480	0,465	0,454	0,524	0,602	0,595	0,594	0,583	0,645
Russia	н.д.	н.д.	н.д.	н.д.	0,697	0,685	0,657	0,643	0,643
Indonesia	0,254	0,391	0,314	0,395	0,503	0,564	0,576	0,563	0,640
Kazakhstan	н.д.	н.д.	н.д.	н.д.	0,577	0,604	0,618	0,573	0,639

Belgium	0,509	0,553	0,598	0,636	0,707	0,698	0,691	0,644	0,631
Italy	0,530	0,449	0,456	0,502	0,572	0,559	0,568	0,578	0,619
Peru	0,366	0,399	0,403	0,413	0,485	0,483	0,490	0,507	0,617
Denmark	0,283	0,177	0,237	0,422	0,512	0,574	0,600	0,620	0,608
India	0,479	0,560	0,558	0,583	0,572	0,590	0,588	0,598	0,598
Thailand	0,147	0,191	0,162	0,109	0,497	0,507	0,508	0,542	0,598
Argentina	0,315	0,377	0,491	0,556	0,635	0,632	0,632	0,623	0,597
Malaysia	0,091	0,170	0,267	0,275	0,543	0,568	0,566	0,568	0,596
Philippines	0,087	0,077	0,111	0,142	0,409	0,300	0,255	0,320	0,588
Netherlands	0,447	0,530	0,542	0,554	0,596	0,609	0,606	0,596	0,577
Egypt	0,192	0,349	0,342	0,412	0,391	0,437	0,513	0,504	0,553
Mexico	0,562	0,570	0,530	0,520	0,521	0,494	0,513	0,493	0,548
Poland	0,195	0,298	0,339	0,349	0,350	0,395	0,414	0,455	0,543
Ireland	0,538	0,347	0,215	0,401	0,615	0,632	0,594	0,544	0,537
Greece	0,470	0,473	0,508	0,430	0,484	0,474	0,470	0,440	0,532
Hong Kong	0,087	0,000	0,000	0,000	0,478	0,498	0,467	0,519	0,531
Azerbaijan	н.д.	н.д.	н.д.	н.д.	0,500	0,482	0,526	0,521	0,526
Iran	0,514	0,483	0,446	0,345	0,402	0,462	0,490	0,480	0,523
Portugal	0,520	0,436	0,346	0,373	0,418	0,471	0,478	0,462	0,510
Iceland	0,494	0,490	0,444	0,457	0,524	0,526	0,535	0,517	0,500
Saudi Arabia	0,058	0,128	0,204	0,351	0,390	0,458	0,479	0,460	0,487
Alger	0,545	0,497	0,509	0,469	0,499	0,469	0,450	0,443	0,480
Norway	0,488	0,519	0,456	0,482	0,456	0,447	0,476	0,442	0,478
Kuwait	0,305	0,412	0,499	0,497	0,437	0,500	0,492	0,494	0,470
China	0,171	0,276	0,406	0,419	0,375	0,372	0,392	0,441	0,467
UAE	н.д.	0,320	0,488	0,495	0,493	0,496	0,494	0,451	0,445

Bangladesh	н.д.	н.д.	0,560	0,553	0,522	0,505	0,469	0,477	0,412
Belarus	н.д.	н.д.	н.д.	н.д.	0,411	0,478	0,513	0,495	0,411
South Africa	0,301	0,364	0,382	0,344	0,322	0,347	0,367	0,382	0,375
Turkmenistan	н.д.	н.д.	н.д.	н.д.	0,503	0,491	0,397	0,408	0,372
Ecuador	0,219	0,153	0,117	0,165	0,279	0,353	0,330	0,367	0,357
Qatar	0,000	0,180	0,165	0,174	0,342	0,302	0,185	0,213	0,332
Singapore	0,000	0,000	0,000	0,000	0,000	0,000	0,080	0,077	0,215

н.д. – No data

Diversification coefficient $\Delta K_{dt}=K_{d1}-K_{d2}$ for the time period of t1 и t_2 can change due to involving a new type of energy $\Delta K_{vt}=K_{v1}-K_{v2}$, where K_{vt} - coefficient of the number of types ($K_{vt}=1-\frac{1}{n_t}$). It can also change because of changes in the evenness of distribution of the used types of energy $\Delta K_{pt}=K_{p1}-K_{p2}$, where K_{pt} - co-efficient of distribution of types ($K_{pt}=\frac{1}{n_t}-\sum_{i=1}^{n}q_{it}^2$). In case the number of energy types during the period under consideration doesn't change, the changes take place only because of changes in their shares. The results of assessment of how different factors influence the changes in the co-efficient of diversification during the period between 1985 – 2005 are presented in Table 4 by 64 countries of the world

TABLE 4 INFLUENCE OF FACTORS ON THE DYNAMICS OF CHANGES
IN THE COEFFICIENT OF DIVERSIFICATION OF GENERIC STRUCTURE OF ENERGY CONSUMPTION

	Countries	K_d		Changes		
		1985	2005	totally, % points	Including because of	
					types	alignment
	World	**0,713**	**0,727**	**1,4%**	**0,0%**	**1,4%**
1.	Slovakia	0,727	0,771	4,4%	0,0%	4,4%
2.	Canada	0,755	0,753	-0,2%	0,0%	-0,2%
3.	Bulgaria	0,706	0,741	3,6%	0,0%	3,6%
4.	Finland	0,684	0,727	4,3%	0,0%	4,3%
5.	Germany	0,681	0,725	4,4%	0,0%	4,4%
6.	Romania	0,652	0,721	6,9%	5,0%	1,9%
7.	Turkey	0,557	0,719	16,2%	8,3%	7,9%
8.	USA	0,703	0,710	0,7%	0,0%	0,7%
9.	New Zealand	0,700	0,704	0,3%	0,0%	0,3%
10.	Sweden	0,697	0,702	0,5%	0,0%	0,5%
11.	Columbia	0,709	0,700	-0,9%	0,0%	-0,9%

12.	Lithuania	0,597	0,695	9,8%	0,0%	9,8%
13.	Japan	0,628	0,694	6,6%	0,0%	6,6%
14.	Austria	0,716	0,693	-2,2%	0,0%	-2,2%
15.	France	0,714	0,692	-2,2%	0,0%	-2,2%
16.	Czech Republic	0,444	0,691	24,6%	0,0%	24,6%
17.	Great Brittan	0,699	0,691	-0,8%	0,0%	-0,8%
18.	Switzerland	0,671	0,691	2,0%	0,0%	2,0%
19.	Chile	0,633	0,686	5,3%	0,0%	5,3%
20.	Korea	0,576	0,680	10,4%	5,0%	5,4%
21.	Ukraine	0,701	0,677	-2,3%	0,0%	-2,3%
22.	Taiwan	0,651	0,665	1,4%	0,0%	1,4%
23.	Venezuela	0,606	0,659	5,3%	8,3%	-3,1%
24.	Hungary	0,694	0,658	-3,6%	0,0%	-3,6%
25.	Australia	0,662	0,656	-0,6%	0,0%	-0,6%
26.	Pakistan	0,671	0,651	-2,0%	0,0%	-2,0%
27.	Spain	0,620	0,646	2,6%	0,0%	2,6%
28.	Brazil	0,602	0,645	4,3%	0,0%	4,3%
29.	Russia	0,697	0,643	-5,3%	0,0%	-5,3%
30.	Indonesia	0,503	0,640	13,8%	0,0%	13,8%
31.	Kazakhstan	0,577	0,639	6,2%	0,0%	6,2%
32.	Belgium	0,707	0,631	-7,6%	0,0%	-7,6%
33.	Italy	0,572	0,619	4,7%	-5,0%	9,7%
34.	Peru	0,485	0,617	13,2%	0,0%	13,2%
35.	Denmark	0,511	0,608	9,7%	0,0%	9,7%
36.	Thailand	0,497	0,598	10,1%	0,0%	10,1%
37.	India	0,573	0,598	2,5%	0,0%	2,5%
38.	Argentina	0,636	0,597	-3,8%	0,0%	-3,8%
39.	Malaysia	0,543	0,597	5,4%	0,0%	5,4%
40.	Philippines	0,410	0,588	17,8%	8,3%	9,5%
41.	Netherlands	0,595	0,576	-1,9%	0,0%	-1,9%
42.	Egypt	0,390	0,554	16,3%	0,0%	16,3%
43.	Mexico	0,521	0,548	2,7%	5,0%	-2,3%
44.	Poland	0,351	0,543	19,2%	0,0%	19,2%
45.	Ireland	0,615	0,536	-7,9%	0,0%	-7,9%
46.	Greece	0,484	0,532	4,8%	0,0%	4,8%
47.	Hong Kong	0,478	0,531	5,3%	16,7%	-11,4%
48.	Azerbaijan	0,500	0,526	2,6%	-8,3%	10,9%
49.	Iran	0,402	0,523	12,1%	0,0%	12,1%
50.	Portugal	0,418	0,510	9,2%	8,3%	0,8%
51.	Iceland	0,525	0,501	-2,4%	0,0%	-2,4%
52.	Saudi Arabia	0,390	0,487	9,7%	0,0%	9,7%
53.	Alger	0,499	0,481	-1,8%	0,0%	-1,8%
54.	Norway	0,457	0,477	2,1%	0,0%	2,1%

55.	Kuwait	0,437	0,470	3,3%	0,0%	3,3%
56.	China	0,375	0,467	9,2%	5,0%	4,2%
57.	UAE	0,493	0,446	-4,8%	0,0%	-4,8%
58.	Bangladesh	0,522	0,412	-11,0%	0,0%	-11,0%
59.	Belarus	0,411	0,411	-0,1%	0,0%	-0,1%
60.	South Africa	0,322	0,374	5,2%	0,0%	5,2%
61.	Turkmenistan	0,503	0,372	-13,1%	-25,0%	11,9%
62.	Ecuador	0,279	0,357	7,9%	0,0%	7,9%
63.	Qatar	0,342	0,332	-1,0%	0,0%	-1,0%
64.	Singapore	0,000	0,216	21,6%	50,0%	-28,4%

Table 4 shows that during the period between 1985-2005 a great majority of countries (51 out of 64 countries) increased the level of diversification in the structure of energy consumption only at the expense of aligning the shares of energy types used. Changes in the level of diversification in other countries took place at the expense of the share as well as of the number of types of energy used (for example, Romania, Turkey, Korea, Italy, Singapore).

If the data is available on a certain country's (or a supplying company's) share in supplying of each type of energy, the formula (1) can be used to assess the level of diversification of the energy supply in relation to geography or to suppliers. The given methodology can also be used at the level of different enterprises simultaneously using different types of energy for meeting their needs.

It is necessary to note that the co-efficient of diversification should not be used for qualitative characteristics of the energy consumption structure, because it is being shaped basing on a number of political, social, economic, technical and other factors. Different criteria should be used for that.

CONCLUSION.

On our view, the technique suggested allows the following:

- definitely quantitatively assess current situation in diversification of generic structure of energy consumption;
- provide content interpretation and simplicity of calculation;
- estimate the impact of different directions on the level of diversification;
- conduct cross-country comparison of the level of diversification;
- promote conscious choice of priority directions of diversification;
- support the development of target indicators in perspective diversification;
- assess the level of achieving the target indicators.

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