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TRENDS AND SCENARIOS OF THE WORLD ENERGY SECTOR DEVELOPMENT IN THE FIRST HALF OF THE 21st CENTURY

Globalisation and Sustainable Development
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(GU IES)

TRENDS AND SCENARIOS OF THE WORLD ENERGY SECTOR DEVELOPMENT IN THE FIRST HALF OF THE 21ST CENTURY

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Trends and scenarios of the world energy sector development in the first half of the 21st century /A.M. Belogoriev, V.V. Bushuev, A.I. Gromov, N.K. Kurichev, A.M. Mastepanov, A.A. Troitskiy. Under the editorship of V.V.Bushuev – M.: PH«ENERGYA», 2011 – 64 pg.

This publication contains substantive provisions of the global energy sector development forecast for the period up to 2050. The forecast of development of all key industries of the energy sector and the forecast of the energy sector trends in the leading countries and world regions has been built on the basis of the analysis of historical and current trends. The scenario approach used in the publication makes it possible to tie-in trends observed in various regions of the world, and in various industries of the energy sector, as well as to correlate technological, energy, economic, social and political factors. The analysis of quantitative trends and future-oriented structure of the fuel and energy balance is combined with the analysis of qualitative trends of the world energy sector development: reorganisation of energy markets and corporate structure of the energy sector, regulatory systems and geopolitical priorities of the leading countries of the world. This publication shall be a foundation for preparation of the White Book (a comprehensive survey of the today's world energy sector and a forecast of its growth which could be used as a basis for recommendations on priority directions and challenges of its development).

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INTRODUCTION

Long-term forecasting of the world energy sector development is a task that analysts have been facing for many years already. But a number of long-term problems which aggravated recently and some new circumstances which appeared lately have made this task especially vital. In the beginning of 2011 there were three important events which earmarked key issues of the global energy development (Fig. 1). Civil commotion in Arabian countries and war in Libya exacerbated the problem of balance between globalisation and regionalisation of the world energy sector. Leading world countries (the USA, the EU and China) announced programs aimed at decreasing the dependence on import of energy carriers. A sharp rise in oil prices began threatening a new shock for the world economy which has not overcome yet the consequences of the crisis. This price shock is likely to speed up the process of termination of the oil epoch, and in the long-term outlook there will be a trend of recession of oil prices and decline of the oil business. At last, the radiation catastrophe at Fukushima-1 nuclear power plant in Japan raised a critical concern of creation of an innovative electric power industry and, more widely, innovative development of the energy sector as a whole.

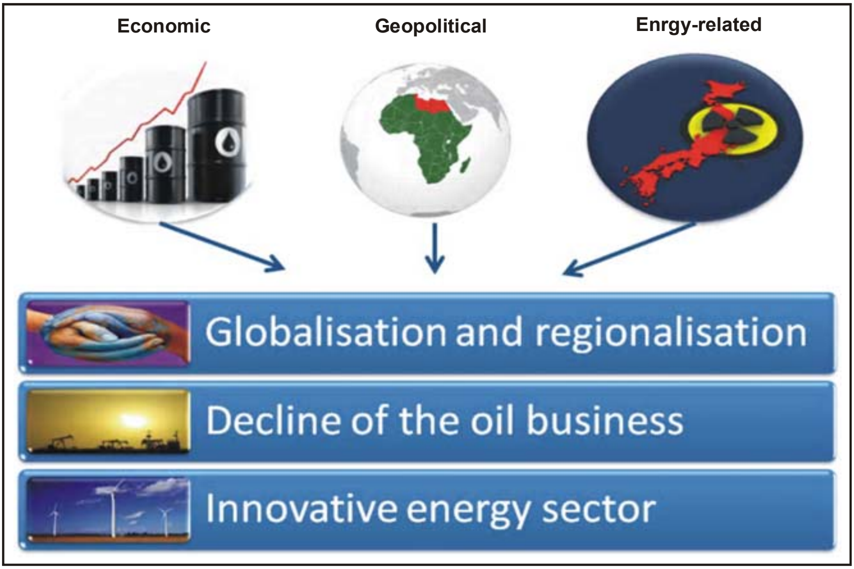

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Fig. 1. ***Key issues of the world energy sector development***

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Three trends: balancing between globalisation and regionalisation, completion of the oil epoch, decline of the oil business and creation of an innovative energy sector will largely determine the future of the world energy sector and economy. We are witnessing a qualitative shift in the world energy sector situation. This requires fundamentally new, non-referencel approaches to its forecasting.

The development of the world energy sector is governed by a compound complex of dynamically changing factors a substantial part of which lies outside of the energy sector – in the sphere of policy, economy, and social dynamics. To resolve the forecasting task, it would be reasonable to use a scenario approach. In our understanding a scenario is a point of convergence of interrelated demographic, economic, technological, political, sociocultural, ecological and energy trends.

This requires construction of complex world development scenarios extending beyond purely energy framework. Since the 1970s the world accumulated a significant experience of research of the future of the world energy sector with the use of mathematical simulation and qualitative scenario approaches [9,10,11,12,16,17,19,22]. Within the framework of this publication GEM (Global Energy Model) and MACRO (Macroeconomic Model) models of Melentiev Institute of Energy Systems (ISEM, city of Irkutsk) are used. The interaction of analytical units and models is presented on Fig. 2.

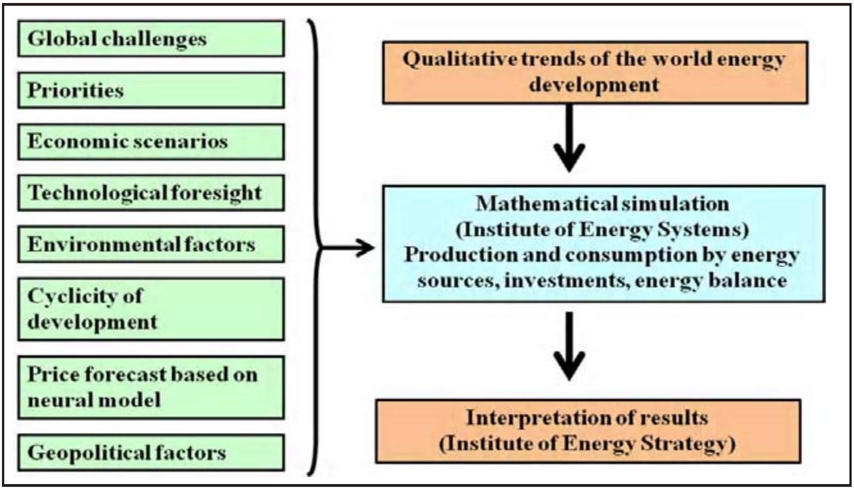

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Fig. 2. ***The world energy sector forecasting diagram***

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The forecast of the world energy sector is based on the analysis *of world challenges and energy development priorities* determined through an expertise on the ground of long-term development trends.

With reference to the said challenges and priorities *macroeconomic scenarios* are formed. A retrospective analysis makes it possible to predict further dynamics of key parameters of the world development, and not only to extrapolate current trends, but also to predict their discontinuation due to achievement of their development limits or to the growth of contradictions between them. Thereupon scenario paths of the world economy development serving as initial data for MACRO model are determined.

The technological progress has a decisive impact on the energy structure. The forecast has been performed on the basis of the *technological foresight* carried out in the Institute of Energy Strategy with the use of findings of the Expert Club of the Industry and Energy Sector and other independent expert organisations. The foresight results have been taken into account in parameters of technologies factored-in in the GEM model.

Resource and ecological restrictions serve as boundary conditions for the world energy sector forecast. They determine the scope of development of fuel energy sector industries on the global level, and, in particular, in specific countries and regions. The driving force of energy development is not so much problems of shortage of fuel and energy resources or environmental impact, but political and economical circumstances associated with these problems. To account for these restrictions, we used data on world's reserves of energy resources and levels of CO_2 emissions preset by the scenarios and factored-in in the GEM model.

Thus, macroeconomic scenarios, technological foresight, resource and ecological restrictions represent a basis for calculations with the use of GEM (global energy model) and MACRO (macroeconomic model) models. But there is a number of factors, which are not reflected to the full by simulation methods; therefore the results of calculations are processed by expertise.

First, it is necessary to consider *cyclicity of development*. Forecasting on the basis of linear trends or their combination does not give exact results since it does not take into account the role of cycles of various duration. Meanwhile this is exactly in critical points of cycles that many important events occur. We superimpose the results of the forecast of

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cyclic oscillations on the long-term trends determined by means of the model thus obtaining more adequate results.

Secondly, we take into account the forecast of world prices for oil and other energy products developed separately *with the use of neural model* featuring a self-training capability and enabling to reveal the multitude of price behaviour trends and cycles. Finally, one should allow for the effect *of geopolitical factors* which is fairly significant for the energy development.

Model calculations rely upon various initial data determined through the analysis of current trends. The simulation yields dynamics of the world energy sector development (in terms of primary and final energy production and consumption figures by world regions) for the period up to 2050. The obtained data serve as a basis for the analysis of the energy sector development qualitative trends including changes expected in the markets, in political and social processes at given volumetric parameters. The final result of forecasting is formed by superposition of model calculations carried out on the basis of scenario assumptions, and expert evaluations of the world energy sector development qualitative trends.

The energy sector is regarded by us as a complex dynamic system of contradictions associated with major today's global development issues: demographic, resource, financial, technological, and ecological ones. It has own development trends which cannot be reduced to external effects and determine selective sensitivity of the energy sector to them.

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SECTION 1

ECONOMY AND ENERGY SECTOR DEVELOPMENT TRENDS AND CYCLES

Throughout its history the world system has been developing under a hyperbolic law[1], or in a blow-up regime [4,6]. This law describes the dynamics of variation of population, GDP, energy consumption, and so forth. Since 1960 we have been witnessing a change of the global system growth behaviour and its exit from the blow-up regime. Hyperbolic growth of the world system is not a homogeneous process. Long periods (phases) of relatively sustainable development are interleaved with short phase transition periods when the growth regime and the very basis of the society evolution change. This transition may proceed with varying speed and in various ways or not take place at all, therefore the phases are divided by acute crises when several development scenarios become possible.

1.1. World economic and energy development dynamics

In 1800-1970 world system dynamics was determined by the next long-term hyperbolic growth phase, industrial one. Within the limits of the industrial phase several growth waves were observed divided by grave crises accompanied by the development paradigm change [3,7]. These are the crisis of the early 1930s, the crisis of the early 1970s and the crisis of the late 2000s (Fig. 3). The crisis of the early 1930s resulted in a sharp increase of the state influence on the economies of the USA, Germany and the USSR. This process coincided with an accelerated industrialisation and a sharp growth in demand for electric power for industrial needs and for oil motor fuel.

The crisis of the early 1970s was caused by transition of the USA and the Western Europe to post-industrial development (Fig. 4) and the end of the “cold war”. The role of private enterprise sharply increased, global economy was liberalised and monetised, Keynesian regulation was superseded by a monetary one. Nuclear energy development accelerated, the demand for gas as a fuel for the energy sector serving small and medium businesses and housing and municipal services increased.

[1] Hyperbolic growth describes dynamics of a system when not only absolute but also relative growth rates of a certain parameter increase as the parameter increases

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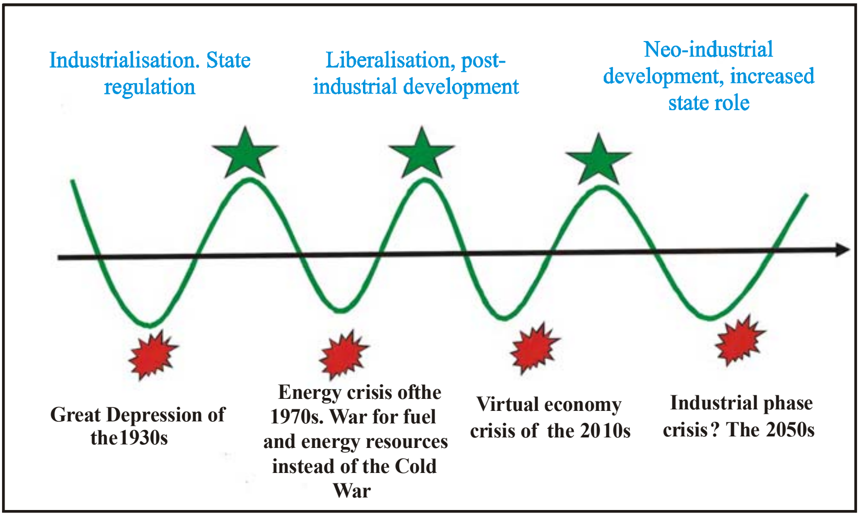
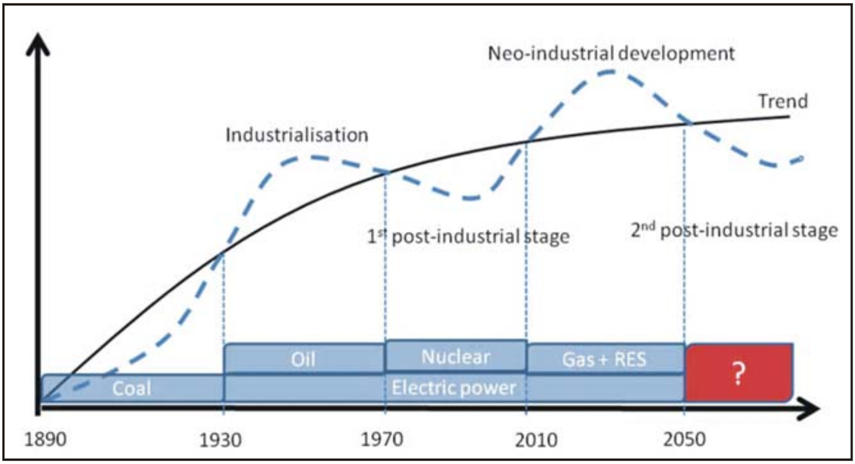


Source: *IES.*

Fig. 3. ***Global industrial development trends***

Crisis of the 1970s ended by transition to the post-industrial development phase. Its three basic components are: globalisation, informatisation and liberalisation [1,5]. Key indicators of world dynamics after 1970 changed drastically. Economic growth rates decreased from 4-5% per year in 1945-1970 to 3% per year in 1970-2010. Energy consumption growth rates dropped from 5% per year to 2% and less.



Source: *IES.*

Fig. 4. ***Global industrial development trends***

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By the end of the 2000s the rates of economic and energy growth approached historical maxima of the 1950-1960s, maximum rates being observed in developing countries. But in the 2000s, upon involvement of leading developing countries in the world economy, globalisation limits were reached. The development of the informational sphere began acquiring fairly speculative nature manifested in the hi-tech economy boom in the USA and its subsequent crisis in 2001. The potential of globalisation, informatisation and liberalisation exhausted which was clearly demonstrated by the global financial and economic crisis of 2008-2009.

A necessity for the next change of the development paradigm arose. This required reinforcement of the state role, transition of major hydrocarbon resources under control of national oil and gas companies (instead of domination of multi-national companies), development of regional self-reliance and national energy security principles, intensification of energy conservation efforts and development of renewable energy sources (RES).

Each crisis would provoke a change of trends of the world energy sector (Fig. 5) which would derail from a steady exponential growth path

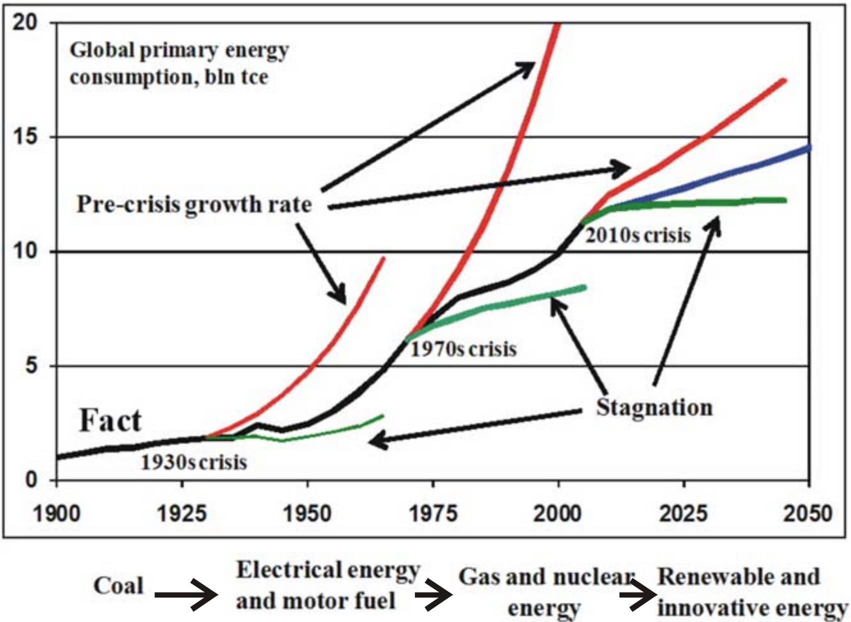

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Fig. 5. ***Global energy development trends***

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Table 1. Interrelation of economic and energy growth

Development stage	GDP energy intensity	Primary energy resources consumption growth rates, % per year	GDP elasticity in terms of primary energy resources consumption	Dominating energy sources
Pre-industrial	L	Low	–	Non-commercial biomass energy
Industrial	M	4 – 5	0,8 – 2,2	Coal, oil
Developed industrial society	H	2	0,4 – 0,8	Oil, electric power
Transition to the post-industrial stage	M	0 – 1	0,0 – 0,3	Diversification of the fuel and energy balance, natural gas, nuclear power, inception of transition to RES
Post-industrial	L	<0	<0,0	Inexhaustible energy sources

Notes: L – low growth rates, M – medium growth rates, H – high growth rates.
Sources: *IES.*

characteristic of a pre-crisis period (1945-1970, 1980-2005). During crises world energy consumption growth rates would decrease and even become negative, while after a crisis a new steady exponential growth path would be formed. Change of priority energy sources was a key consequence of the industrial phase crisis of the 1970s and the post-industrial phase crisis of the 2000s for the energy sector, though fuel and energy balance trends varied languidly due to their referencel character. The crisis of the 1970s prompted a shift from using oil to the use of natural gas, nuclear energy and – temporarily – coal (Table 1). The crisis of the 2000s brought about a shift from using fuel energy sources to renewable energy.

Whereas before the 1970s the gap between developed and developing countries in terms of most social and economic indicators used to increase due to the growth acceleration in developed countries, in subsequent years it started diminishing. Yet, as numerous world-system researches [2] demonstrate, the world industrial system can only exist within the limits of the Centre – Semiperiphery – Periphery model. Accessible space for extraction of resources was exhausted in the 1970s, and in the 2000s exhausted was accessible space for arrangement of production facilities. In the 2030s we may expect a crisis due to exhaustion of potential market outlets. Improvement of the living standard (accompanied by deceleration of population growth) in developing countries will cause saturation of largest market niches for building infrastructure and production of basic

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industrial goods. Proceeding from the duration of waves, by 2030 one may also expect a crisis of transition from the fifth to the sixth Kondratiev wave.

1.2. New energy civilisation

Long-term trends of world economic and energy development testify that in 2010-2050 we may expect an emergence of a new energy civilisation based on energy efficiency in a broad sense. The world energy sector is currently exiting the hyperbolic growth regime which is accompanied by respective alteration of its quality characteristics. This process requires transition from the non-balanced fuel energy to the balanced non-fuel energy. From the point of view of its depth this transition is only comparable to transition from traditional energy of the pre-industrial society based on biomass burning to the industrial energy based on fossil fuel burning.

The key features of the new energy civilisation will be the following (Fig. 6). Firstly, this is a transition to "general energy production" on the basis of energy integration into all technical systems including both production, and residential ones ("active house").

Secondly, there will be a radical improvement of controllability of energy flows and a transition from "raw energy" to "smart energy" and to

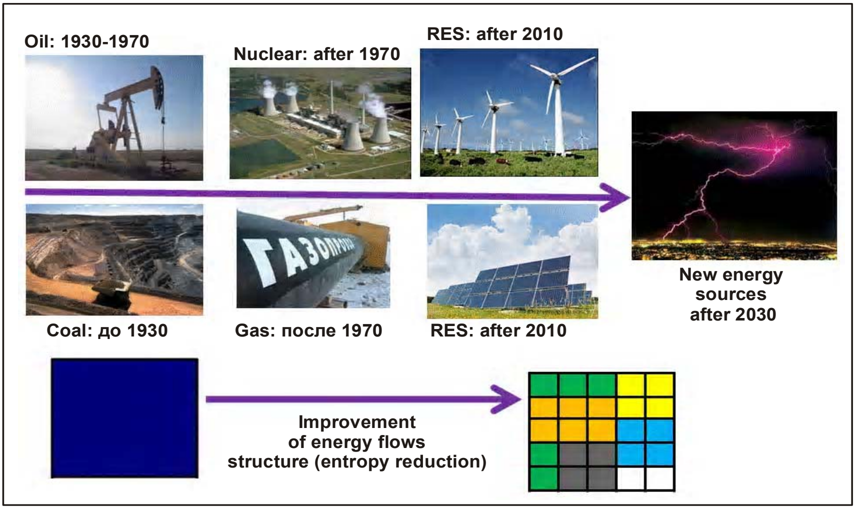

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Fig. 6. ***Transition from "raw" to "smart" energy***

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intellectual systems, starting from electric power systems, and then in other energy sector branches. The energy sector intellectualisation is under way, the role of purely technological industrial processes within the energy sector decreases and the role of management systems and information technologies increases. Simultaneously, principal energy sources are being changed. Thirdly, there will be a shift from fossil fuels towards renewable and new energy sources. Fourthly, there will be a drastic improvement of energy efficiency, and its growth will become a sustainable process and a key criterion of energy development. Fifthly, the organisation of the energy markets will change, there will be a transition from raw materials market to energy services market, and then to the energy technology market. Sixthly, the largest energy services sector will be created which will deal with energy saving management and optimisation and will become a basis for the energy efficiency enhancement. Seventhly, competitive alternatives to motor fuel for transport will appear which will occupy a significant market share and will lead to a gradual decline of the oil epoch. Eighthly, the structure of generating capacities in the electric power industry will change due to a sweeping growth of renewable energy share and a rapid progress of respective technologies. Principles of organisation of electric power systems will change considerably ("smart grids", energy sector decentralisation, its integration with the technosphere, real-time energy consumption management, electric power accumulation and transfer processes, etc.). A rapid progress in renewable and nuclear (fast neutron reactors) energy technologies is anticipated in the energy sector. At last, the role of streamlined energy consumption processes will increase.

1.3. Technological picture of the world

The technological picture varies swiftly and in the long term (in 2010-2050) may bring about drastic changes in the global energy sector, a true energy revolution [10,11,17]. Besides a rapid progress and implementation of existing production processes and patterns, by 2030 we may expect emersion of conceptually new energy technologies and energy sources. The direction and the dynamics of changes depend upon the scenario of development of the world system as a whole and the energy sector in particular.

Key technological trends in the world energy sector will include not only the development of specific innovative technologies, but also a basic change of the technological development organisation. Currently this

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technological development occurs mostly in the form of elaboration and subsequent implementation of specific independent know-hows, and in the process of practical use of such know-hows, one often faces significant economic and technical challenges. Existing technological platforms largely have a formal character and represent a compilation of available engineering solutions. In future the technology will develop proceeding not from the offer of R&D products, but from the demand for integrated technological solutions. Such an approach will provide a guaranteed ready market and a great demand for R&D products. Furthermore, a modular technology organisation principle and compliance with customer requirements at optimum costs will be adopted.

The world is on the threshold of the energy revolution which will mark a transition from the industrial to the post-industrial energy production. Preconditions of the energy revolution originated in developed countries in the early 21st century. Energy sector of the industrial phase is based on large centralised energy sources using fossil fuel and focused on gross energy flow. Energy sector of the post-industrial phase will be based on decentralised energy sources focused on renewable energy sources and sustainable energy management. In fact, it will be a transition from a "raw" energy industry to the "smart" one. The main trends of the energy revolution will be energy conservation; "smart grids" ("smart energy" in the broad sense); new-generation power systems; decentralisation of the energy sector; renewable energy sources; alternative transport power supply; carbon markets. Nowadays each of the mentioned trends is a large branch of economy (with a turnover amounting to tens and even hundreds of billions of dollars) demonstrating steady and very high growth rates. All these trends have passed the "point of no return" and have entered the stage of irreversible vigorous growth.

1.4. World energy sector development scenarios

The transition to a new energy civilisation in 2010-2050 may occur in a number of different ways depending on the world energy sector development scenario. The scenarios are built on the basis of methodology taking into account energy, technological, economic, ecological, political, and social development factors. The scenarios are essentially a method of "linking together" various complex trends.

The reference scenario implies continuation of the post-industrial phase and a grave crisis after 2030 due to achievement of the industrial phase growth limits. It suggests an expansion of the industrial energy sector in

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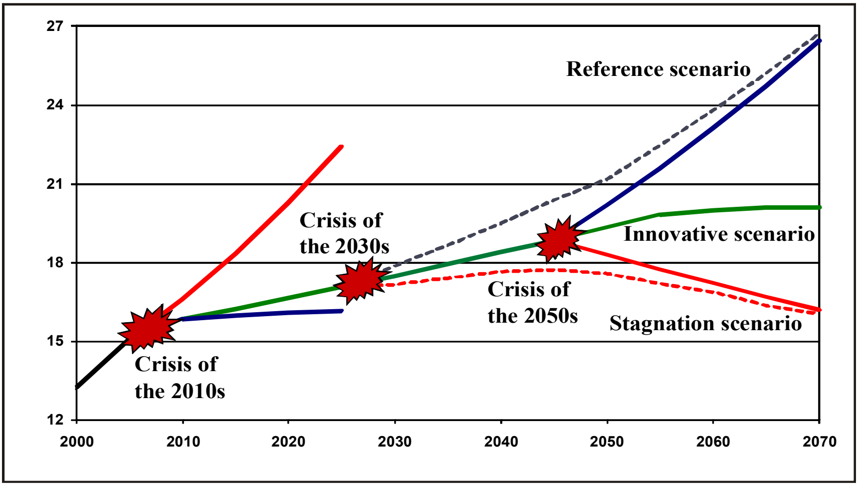
developing countries and a slow development of the post-industrial energy sector in developed countries. As a consequence, a quick growth in demand for energy carriers including fossil fuel of all kinds, resulting escalation of contradictions, and deterioration of ecological situation (Fig. 7) are inevitable. From the point of view of dominating energy carrier, this scenario may be called “carbon-based”.

The stagnation scenario implies a managed development through an ecological paradigm and creation of an information society. The stagnation scenario assumes the use of a package of political, economical and legal mechanisms to control the risks of the reference scenario. The rates of energy growth in developing countries will be substantially lower.



Source: *IES.*

Fig. 7. ***World energy development scenarios***

The innovative scenario implies overcoming of the industrial phase growth limits and transition to a new phase by 2030. Comprehensive development of a human being and related technologies (biological, informational, social, cognitive ones) [26] will be a key feature of the new phase. The innovative scenario assumes creation of a new-type energy sector in developed countries and in some leading developing countries. This will make it possible to reduce geopolitical and ecological risks, to increase energy supply quality, to create new technological opportunities for the end user.

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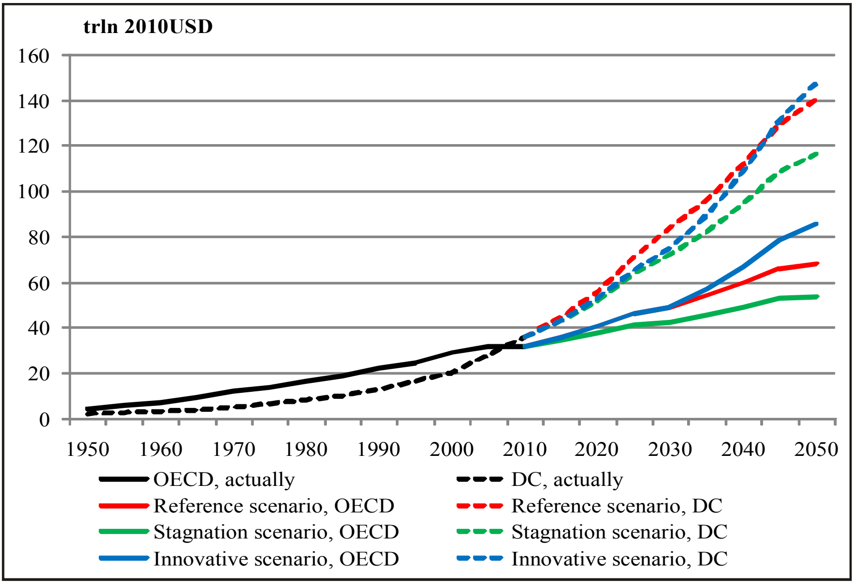
SECTION 2.

GENERAL TRENDS OF DEVELOPMENT OF THE ENERGY SECTOR

Scenarios of development of the world energy sector substantially differ from the point of view of general energy development trends – global GDP energy intensity dynamics, primary and final energy consumption by kinds, as well as greenhouse gas emissions.

2.1. Economic growth trends

The scenarios differ both in GDP dynamics, and in major growth factors. The reference scenario is a continuation of industrial growth, the stagnation scenario is actually a post-industrial development with a focus on virtual economy, while the innovative scenario is basically a neoindustrial development. The world GDP in 2011-2050 will grow 2.4-4.1 times, depending on the scenario. According to the reference scenario by 2050 the GDP of developed countries will increase 2.1 times



Notes:
1.OECD – developed countries; DC – developing countries.
2.In fixed prices as of 2010.

Source: *IES calculations with the use of [13].*

Fig. 8. ***Dynamics of global GDP in 1950-2050***

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as compared to the 2010 level, and that of developing countries, 3.9 times (Fig. 8). The gap in growth rates between these groups of countries will be maximum, as rapid industrialisation of developing countries will be combined with slow post-industrial development in developed countries.

According to the stagnation scenario by 2050 the GDP of developed countries will increase 1.7 times as compared to the 2010 level, and that of developing countries, 3.1 times. Growth slowdown in this scenario will be particularly notable in developing countries. According to the innovative scenario by 2050 the GDP of developed countries will increase 2.7 times as compared to the 2010 level, and that of developing countries, 4.1 times. Growth acceleration will be even more so considerable in developed countries which will manage to reach a qualitatively new level of development.

2.2. Dynamics and structure of primary energy consumption

World consumption of primary energy depends upon the global GDP growth rates, upon the structure of this growth, and the efficiency of conversion of primary energy into the final. The reference scenario contemplates a denial of the transition to the new energy civilisation, the stagnation scenario – implementation of some of its elements, while the innovative scenario – full implementation of its potential. As a consequence, the reference scenario is an energy wasteful one: it is characterised by medium and high GDP dynamics and high energy consumption dynamics (Fig. 9). The stagnation scenario is an energy-saving scenario with low GDP growth and slow energy consumption growth. The innovative scenario is an energy-efficient scenario accompanied by a rapid GDP growth and a moderate energy consumption growth. Thus, it is the energy efficiency that is the central element of the new energy civilisation.

In 2011-2050 world consumption of primary energy will come up 1.22-1.61 times. Under the reference scenario consumption of primary energy in developed countries by 2050 will grow 1.22 times as compared to the 2010 level, and in developing countries,1.92 times. A rapid industrialisation in developing countries will call for a massive increase of consumption of energy carriers.

According to the stagnation scenario by 2050 consumption of primary energy in developed countries will increase 1.04 times as compared to the 2010 level, and in developing countries, 1.42 times. Post-industrial

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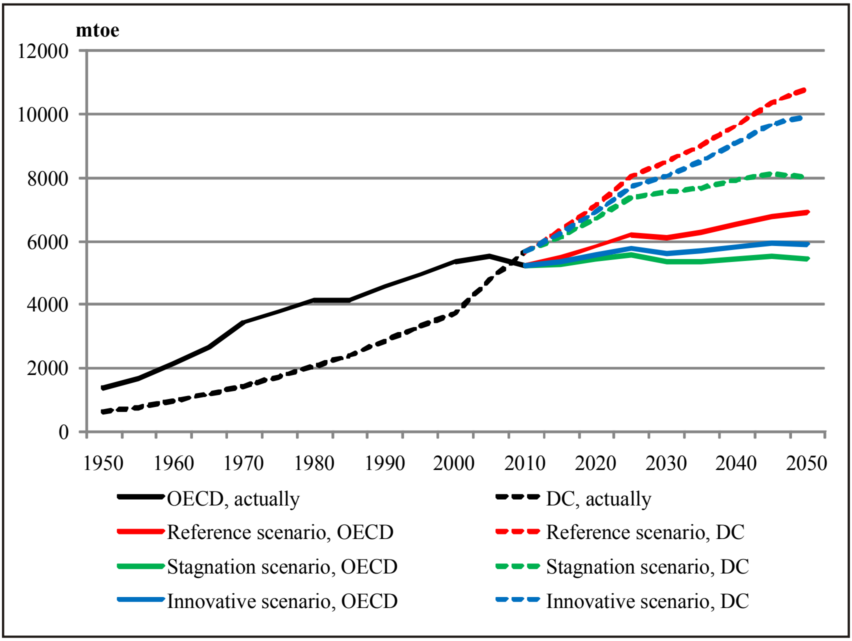

Notes: OECD – developed countries. DC – developing countries.

Source: *GU IES calculations with the use of [8].*

Fig. 9. ***Dynamics of world primary energy consumption in 1950-2050***

development in developed countries will cause stagnation, and then energy consumption decrease (starting from 2030), while climatic and environmental policy will promote expansion of these trends to developing countries. Under the innovative scenario by 2050 consumption of primary energy in developed countries will come up 1.14 times as compared to the 2010 level, while in developing countries,1.76 times. Moderate energy consumption growth rates at high GDP growth rates will be determined by formation of the new energy civilisation.

The trend of primary energy consumption shift towards developing countries is expected in all scenarios, but it will show up to the largest extent in the innovative scenario, and to the smallest extent, in the stagnation scenario (Fig. 10). This is conditioned by different rates of formation of the post-industrial energy sector depending on the scenario.

From the point of view of the energy production structure a shift towards renewable energy (Table 2, Fig. 11) will be a key trend in all scenarios. The share of new RES (without large-scale hydraulic power

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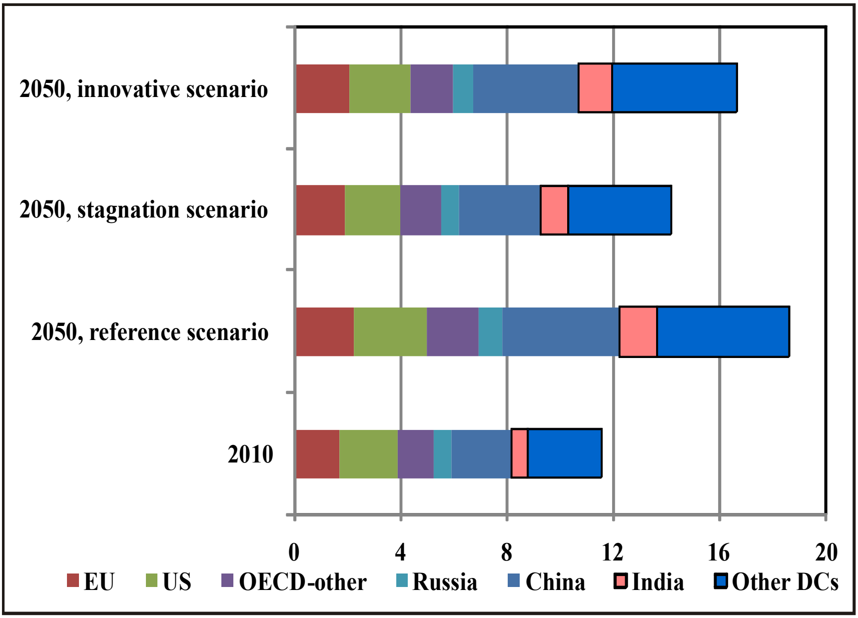

Source: *IES calculations.*

Fig. 10. ***Global primary energy consumption structure (by regions), bln toe***

Table 2. Global primary energy consumption by scenarios, Mio toe

	2010	**Reference scenario**		**Stagnation scenario**		**Innovative scenario**	
		2030	**2050**	**2030**	**2050**	**2,030**	**2,050**
Oil	3,882	4,627	5,018	4,441	4,188	3,641	2,757
Natural gas	2,653	3,952	4,522	3,306	3,483	3,292	3,092
Coal	3,278	4,617	4,487	3,209	1,794	3,526	1,812
Nuclear energy	626	776	824	512	349	1,335	2,333
Biomass	650	600	600	600	600	300	200
Hydraulic energy	572	729	952	729	952	729	952
New RES	210	1,040	1,835	1,481	3,019	1,860	5,846
In total	**11,871**	**16,342**	**18,239**	**14,279**	**14,386**	**14,683**	**16,993**

Source: *IES using data of [12].*

industry) by 2050 will reach 10.1-34.4% of global primary energy consumption (in 2010 - 1.8%). Hydraulic power industry share will increase from 4.8% to 5.2-6.6%. Maximum development of renewable energy (especially solar one) will be observed in the innovative scenario, and minimum development (mainly wind energy) – in the reference scenario.

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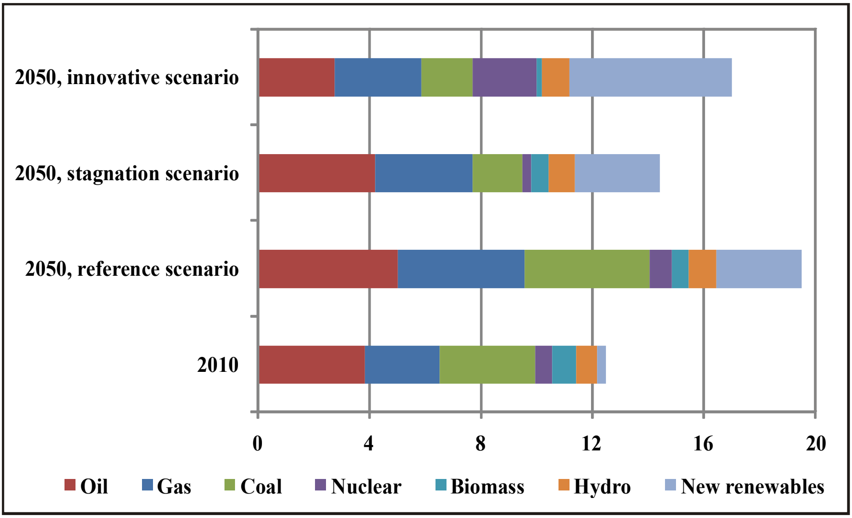
Oil share in all scenarios will decrease from 32.1% in 2010 to 16.2-29.1% in 2050 (Fig. 11). As it may be seen, the degree of oil share drop within the fuel and energy balance may vary significantly. It depends first of all upon prospects of development of motor transport power supply sources alternative to oil products. Natural gas share may either decrease or increase (from 18.2% in 2050 according to the innovative scenario to 24.8% in the reference scenario) as compared to the current level (22.3%). Such dual dynamics is explained by the fact that with toughening of climatic policy natural gas consumption at first increases due to coal replacement, and then decreases as a result of competition on the part of RES. Coal share in all scenarios will decrease from 27.5% in 2010 to 10.7-24.6% in 2050. We believe that scenario of a fast growth of coal consumption and increase of its share in the energy balance is not realistic. The extent of decrease of the coal share within the fuel and energy balance depends upon rigidity of ecological restrictions and the rate of their adoption by developing countries.

Nuclear power industry is notable for the maximum uncertainty. There are fundamentally different scenarios of its development ranging from abandonment (the reference scenario) or even decommissioning (the stagnation scenario) to fast development on a new technological basis (the innovative scenario). By 2050 nuclear energy share may amount to 2.4-13.7% as compared to 5.3% as of today. An average scenario is the



Source: *IES calculations.*

Fig. 11. ***Global primary energy consumption structure (by energy sources), bln toe***

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most probable one since both rapid growth and fast dismantling of the industry will entail serious problems.

At last, biomass share will decrease gradually as compared to the current level of 5.5%. The use of modern kinds of biomass will grow rapidly while the consumption of conventional kinds will decrease. They will be superseded either by fuel energy sources (in the reference scenario) or by RES (in the innovative scenario).

2.3. Dynamics and structure of final energy consumption

During energy sector evolution a continuous tendency may be seen to raise the qualification level of used energy kinds including the level of controllability of the energy flow and its density. After 1970 the trend of the energy use qualification growth became a determining one for the energy sector dynamics in developed countries, including development of energy consumption management systems, energy saving efforts, as well as expansion of electric power share in final energy consumption that in the future may lead to the building of an “electric world”. Due to enhancement of efficiency the consumption of final energy gradually approaches the consumption of primary energy, but improvement of qualification of used energy (often accompanied by increase in number of energy transformations) partially neutralises this effect.

In 2011-2050 global final energy consumption will grow 1.30-1.68 times (Table 3), somewhat outrunning primary energy consumption due to enhancement of the energy use efficiency (it should be noted that the relationship between them depends upon a number of conditional assumptions in calculation of the fuel and energy balance, therefore it should not be absolutised). Final energy consumption is determined by three largest sectors: production (including industry and services sector), transport, and residential sectors. In 2011-2050 they will play approximately equal role in consumption growth in the reference scenario. In the stagnation scenario all, and in the innovative scenario major part of growth, is concentrated within the industrial sector. The maximum energy saving potential is concentrated within transport and residential sectors, while energy consumption growth in the industry is inevitable (Table 3).

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Table 3. Dynamics of final energy consumption by sectors, bln toe

Sector	2010	Reference scenario		Stagnation scenario		Innovative scenario	
		2030	2050	2030	2050	2030	2050
Industrial sector	2,2	3,1	4,1	3,0	3,9	3,7	4,0
Residential and services sector	3,2	4,3	4,9	4,0	3,9	3,9	4,0
Transport sector	2,3	3,2	4,0	2,4	2,0	2,2	2,2
Other sectors	0,1	0,1	0,2	0,1	0,2	0,2	0,2
Total	7,8	10,8	13,0	9,5	10,0	10,0	10,4

Source: *IES calculations.*

Consumption of primary energy in the world industry is today 2.4 bln toe - more than one third of total final energy consumption. By 2050 it will increase as much as 1.6-1.7 times and reach 3.9-4.1 bln toe. The main ways of improving energy efficiency in the industry will be utilisation of secondary raw materials, membrane technologies and transition to non-thermal reaction activation methods (electron-beam, laser, electrothermal, photothermal) in the chemical industry, the use of ultrasound (resonance cutting) and fibre lasers in metal working (Table 4).

Fuel consumption in the residential sector in the world amounts to 3.0 bln toe or more than one third of total final consumption. By 2050 it will increase 1.3-1.6 times and reach 3.9-4.9 bln toe. Global energy consumption for heating, ventilation and air conditionings is 3.4 bln toe (40% of total consumption). Lighting systems consume approximately 3.6 tln kW•h or 19% of global electricity consumption. Electric power consumption by household appliances in 2005 was 6.3 bln kW•h (without lighting) or about 30% of total electric power consumed in the world.

Heat supply optimisation, luminescent lamps, white LEDs, implementation of lighting management systems, improving efficiency of household appliances will be major innovative directions of development in the residential sector. Besides, such integrated solutions as “energy-efficient house” (both “passive” and “active”) and “energy-efficient city” concepts will play a crucial role in the residential sector (Table 4).

In the 2010s building energy consumption standards will become compulsory at new construction in Great Britain, the USA and the EU. “Active houses” are actually houses featuring not only reduced consumption, but also energy production capabilities (biofuel, solar energy). However, the “active house” technology has not progressed

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Table 4. Basic innovatives in the final consumption sphere

Industrial sector	Residential sector	Transport sector
Mature technologies		
Use of recoverable raw materials	Heat supply optimisation	Enhancement of internal-combustion engines
Energy consumption management	Improving efficiency of electronics and electrical equipment	Optimisation of energy consumption by technical systems
Emerging technologies		
Membrane technologies non-thermal reaction activation methods	Luminescent lamps, LEDs, lighting management systems	Second-generation biofuel
New metal working methods	"Energy-efficient house" and "energy-efficient city" concepts	Hybrid cars Electric cars

Source: *IES.*

beyond the experimental stage yet. An "energy-efficient city" is in fact a synthesis of the "energy-efficient house" technology including technical, organisational and economic solutions providing for a low energy consumption (lighting, transport, network infrastructure, etc.) that assumes integration of energy generating facilities (on the basis of RES and secondary energy sources) into the urban space.

Consumption of primary energy in the transport sector amounts to 2.2 bln toe, or 25% of final consumption. 95% of transport energy needs are satisfied by oil products. 48% of fuel are consumed by cars, 17% - by heavy-duty trucks, 13% - by air transport, 9% - by light commercial vehicles (without international bunker fuel). Depending on the world energy sector development scenario, either a considerable growth (1.8 times), or a slight reduction of consumption (by 10%) are possible. Enhancement of the internal-combustion engine design and raising of efficiency of climate control and braking systems, electric cars and hybrid cars, transition from the first-generation biofuel (on the basis of agricultural crops) to the second-generation biofuel (on the basis of cellulose), and further – to the third-generation biofuel on the basis of special seaweed will be major innovative development lines in the transport sector.

Expansion of electric cars is currently restrained by their high cost and limited travel range before recharging. Creation of efficient storage batteries which is expected by 2020 will result in reduction in demand

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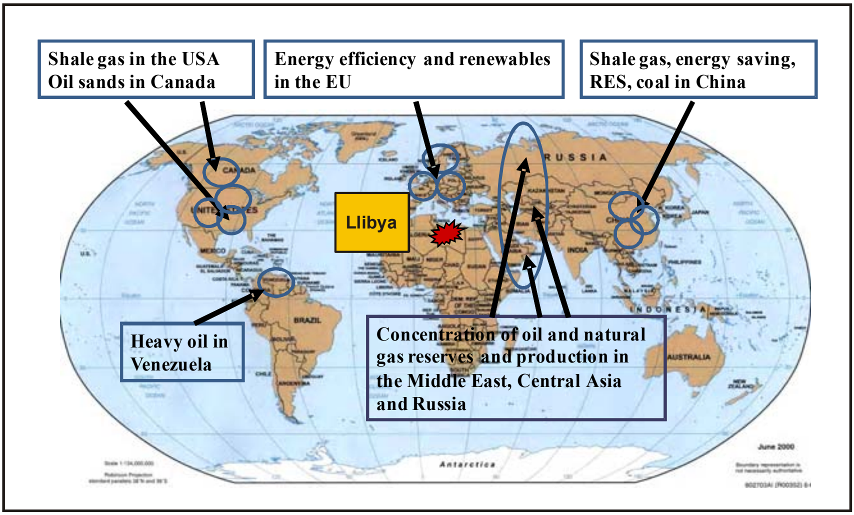
for oil products, growth in demand for electric power and change of the load pattern. Increment of the share of hybrid and electric types of transport will bring about a raise in consumption of lithium batteries and of some rare-earth metals (niobium, rhenium, tantalum).

2.4. Energy sector and globalisation and regionalisation processes

The energy is one of major factors of globalisation of the world economy. The process of modern financial and economic globalisation dates as early as the 1970s, and the energy crisis (first of all, oil “shocks” of the 1970s) became its manifestation. The world energy sector has reached a very high integration level. International oil trade accounts for 68.3% of its total consumption, and natural gas trade, 47.0% of its consumption. The share of import oil within the consumption structure of the OECD countries is 64%, EU countries – 76%, and East, South and South-East Asia countries – 43%.

The trend of the world division into self-sufficient regions, on the one hand, promotes intraregional integration, and on the other, partly counteracts the globalisation trend (Fig. 12). In the years to come we shall witness a convergence of globalisation and regionalisation processes in the energy sphere as it has already occurred in some industries. Global



Source: *IES.*

Fig. 12. ***World energy sector globalisation and regionalisation factors***

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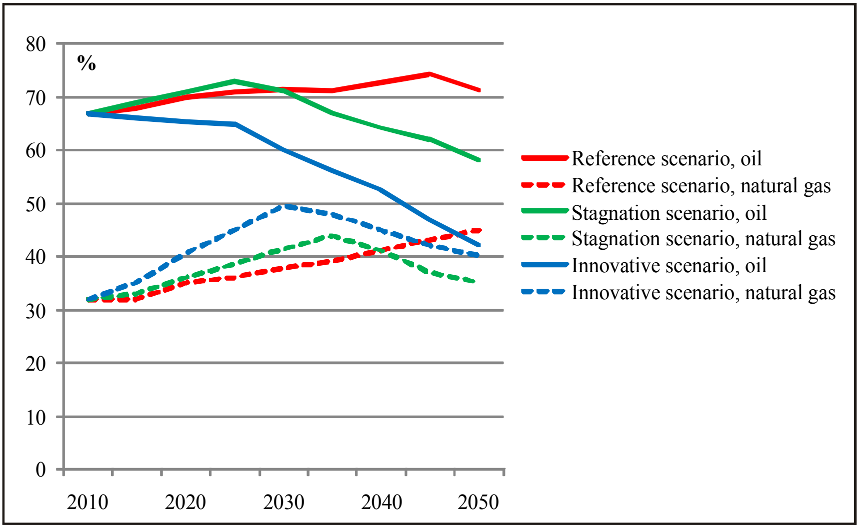
dominance of energy producers is being replaced by the dominance of energy buyers. And already in the nearest future this process will materially affect the existing energy picture of the world.

Most likely, the international trade share in oil consumption will start to decrease already in the 2020s, and in natural gas consumption – in the 2030s though there are sensible differences between the scenarios (Fig. 13).



Source: *GU IES calculations.*

Fig. 13. ***International trade share in oil and natural gas consumption***

In the reference scenario in 2011-2050 a rapid globalisation of the natural gas market will continue, and the international trade share in oil consumption will slowly grow. On the contrary, in the stagnation and even more so in the innovative scenario we expect a decrease in the international trade share for oil. As far as natural gas is concerned, a swift growth in 2011-2030 will be followed by a rather rapid downfall.

2.5. Energy and climate change

The issue of climate change prevention has become a key environmental challenge vital both from political and international points of view. Anthropogenous nature of climate change is currently recognised by most scientific organisations and political forces though some specialists esteem that the main driving factor of this process are natural cycles of various origin and duration.

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At the Copenhagen Conference in December, 2009 and in Cancun in December, 2010 the world countries failed to finalise a new agreement which would substitute for Kyoto Protocol after 2013. The Copenhagen Agreement is not legally binding because of the position of largest developing countries (China, India, Brazil, and the Republic of South Africa). Nevertheless, the role of climatic factor in the energy development will increase. We may expect imposition of "carbon protectionism" measures by leading developed countries if emissions in the producer country are not charged with "carbon" taxes or obligations to decrease emissions.

We expect development of national emission trading systems. In 2009 the volume of trade in all carbon markets (including international, national, and regional ones) was $125 bln. Should national markets be introduced in the USA, Japan and China where this question is being under consideration, by 2020 carbon trade market volume may exceed $1.3 bln. To motivate transition to low-carbon energy, the cost of 1 tn of CO_2 emissions should reach $100-125 while according to the existing agreements it is about $30.

It is believed that average global temperature change by more than 2.0-2.4 °C as compared to the pre-industrial level will entail unpredictable threshold consequences. To limit the temperature trend below critical value, world CO_2 emissions in the energy sector should be reduced by 2050 by 50% as compared to the 2000 level (to 14 Gt). The maximum level of emissions, most probably, will be attained by 2020 (30 Gt of CO_2 per year), and then it should start to reduce. Therefore a deep restructuring of the world energy sector is essential to prevent catastrophic climate changes.

According to the reference scenario, if the world proceeds further along the industrial development path, despite a deceleration of the economic growth rates this will cause continued resource consumption and waste production growth. The priority of economic growth and technological constraints will interfere with an efficient ecological and climatic policy. By 2050 world CO_2 emissions in the energy sector will reach 41.6 bln tn (Fig. 14). Cumulative CO_2 emissions will amount to 1600 bln tn. Hotbed gases concentration by 2050 will attain 800 ppm of CO_2 equivalent that will induce global temperature raise by more than 3.0 °C and an increase of frequency of catastrophic natural phenomena.

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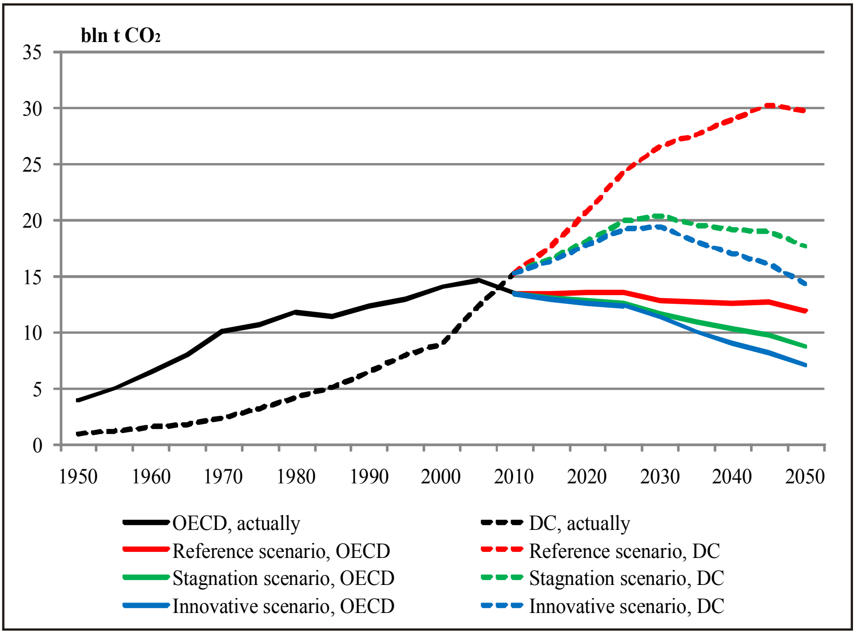

Note: OECD – developed countries, DC – developing countries.
Source: *GU IES calculations using data of [8,14].*

Fig. 14. ***GO_2 emissions in the energy sector in 1950-2050***

Under the stagnation scenario deceleration of economic growth rates, post-industrial development model, reinforcement of the ecological paradigm will result in retardation of resource consumption and waste production growth rates, and then to their stabilisation. By 2030 global CO_2 emissions in the energy sector will reach 32.0 bln tn, and by 2050 they will decrease to 26.7 bln tn. Cumulative CO_2 emissions will amount to 1300 bln tn. Hotbed gases concentration by 2050 will attain 550 ppm of CO_2 equivalent.

In the innovative scenario a transition to the cognitive development phase will give a chance to make the climatic policy a tool of innovative development. By 2030 global CO_2 emissions in the energy sector will reach 30.8 bln tn, and by 2050 they will decrease to 21.3 bln tn. Cumulative CO_2 emissions will amount to 1000 bln t. Hotbed gases concentration by 2050 will attain 450 ppm CO_2 equivalent that will make it possible to avoid catastrophic natural aftereffects.

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SECTION 3
INDUSTRY TRENDS

World energy sector development scenarios, on the one hand, depend upon the trends of development of specific energy sector branches, and on the other, form these trends through a systematic demand of users for an energy of certain type. This demand, in its turn, is determined by particularities of economic development.

3.1. Oil industry trends

As of today, oil products satisfy 95% of total fuel needs in the transport sector (100% for air, 100% for sea, 95% for motor, 70% for railway, and up to 70% for urban passenger transport). The transport sector accounts for 61% of total consumption of oil products, motor transport (including freight motor transport) share being 48%. There is a high interdependence of the transport sector and the oil industry. While other kinds of fuel and energy resources are interchangeable to a certain extent, until recently oil has had no real alternative as a raw material for production of motor fuel.

In case of combination of a quick growth of the vehicle fleet with continued domination of oil products, oil consumption in the transport sector (as large as 95%, the reference scenario) by 2050 will increase from 2.2 bln toe to 3.2 bln toe. Under this scenario, by 2030, physical shortage of oil production (up to 5-8% of its consumption) is possible. This will require extraction of nonconventional kinds of crude oil, manufacture of liquid products from gas and coal, will result in increased strain of the motor fuel balance, heavy prices and risks. In other scenarios consumption of oil products in the transport sector is much lower. In the stagnation scenario it is mainly due to retardation of the vehicle fleet expansion. In the innovative scenario fast enhancement of transport efficiency and spreading of alternative kinds of energy in the transport sector will be a paramount factor. In this case the share of oil products may be 45 to 60%. The role of electric cars will grow significantly after 2020. By 2050 over 50% of the car fleet may be hybrid cars.

Growth potential of energy kinds alternative to oil products in the transport sector is fairly great and cumulatively may reach 1500 million toe by 2050. Alongside with that, simultaneous development of all of the mentioned technologies is impossible for technological and economic reasons. The analysis shows that in the innovative scenario by 2050 their

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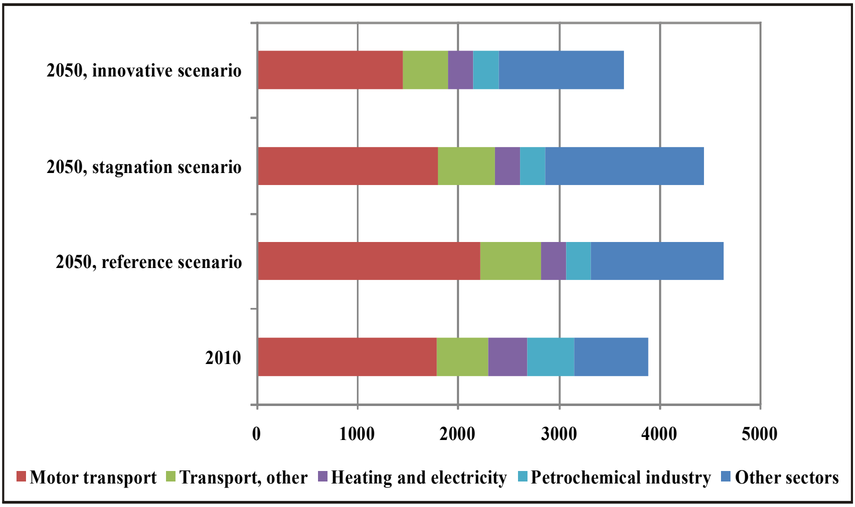
cumulative contribution to the transport power supply may reach 1100 million toe, or 60%.

Consumption of boiler and furnace fuels decreased 4 times since 1970 (to 700 million toe) and will continue to decrease further. Oil consumption in the petrochemical industry will continue to grow due to the necessity to satisfy demand for its products in developing countries, both industrial (in the process of industrialisation), and especially consumer demand (as the urbanisation goes on and the standard of living increases). These trends will determine oil consumption dynamics in 2010-2050 (Fig. 15). Dynamics of fuel consumption in the motor transport sector will be a key factor for the oil industry future.



Source: *GU IES calculations.*

Fig. 15. ***Global oil consumption in 2011-2050 (by sector), mln t***

Absolute volume of oil consumption in the OECD countries started to reduce since 2006 due to stabilisation of the motor fleet, decrease of fuel consumption per 100 km of run and saturation of the petrochemical market. In all scenarios this trend will continue, but at different rates. If in the reference scenario the decrease by 2030 will be 10% as compared to 2010, in the stagnation scenario it will be 15%, and in the innovative scenario, 21% (Fig. 16).

In developing countries, on the contrary, in all scenarios the demand will grow till 2030, but its value varies from 69% within 20 years in the reference scenario to 9% in the innovative scenario. After 2030 in the reference scenario the growth in demand will go on,

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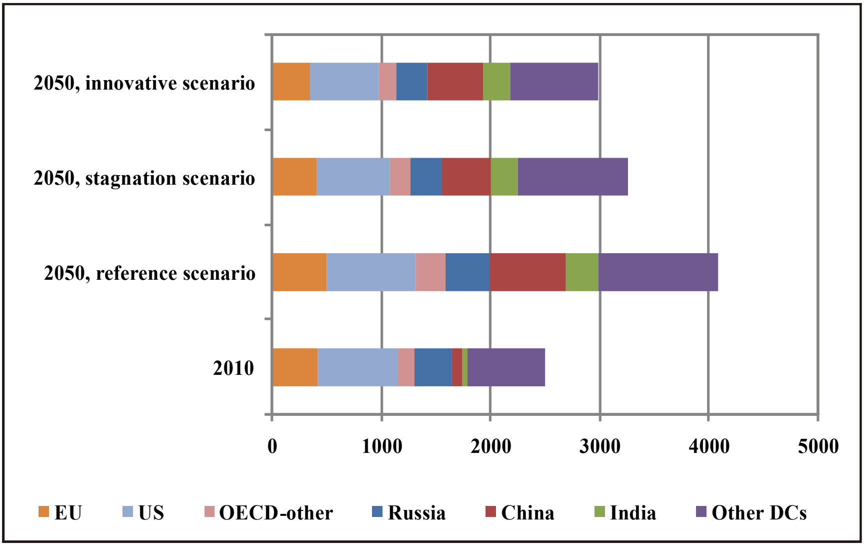
though at much smaller rates than earlier, and in the stagnation and innovative scenarios it will be followed by a recession, although slower than throughout the world.

Global oil consumption till 2030 will grow in the reference (20%), and stagnation (15%) scenarios and will decrease by 5% in the innovative scenario. After 2030 in the reference scenario the growth will continue (by 9% by 2050). In the stagnation and innovative scenario it will give way to a recession (by 6% and 25% accordingly).



Source: *GU IES calculations.*

Fig. 16. ***Global oil consumption in 2011-2050 (by regions), mln t***

The escalation of political and ecological risks will have a great impact.

The growth of political risks in the oil industry is conditioned by contradictions between national oil companies and international oil companies, as well as oil and gas sector privatisation and nationalisation processes in the developing countries. Emersion of the third important class of companies – national oil companies of net oil importer countries, especially Chinese companies (PetroChina, Sinopec, CNOOC) which are becoming competitors of international oil companies, became an additional instability factor. Growth of geopolitical risks in the oil industry is caused by dependence of world oil trade on critical points (Strait of Ormuz, Gulf of Aden – Red Sea – Suez Canal, Strait of Malacca and Sunda Strait - South China sea) located in the zones of geopolitical instability and providing up to 50% of world oil deliveries. In 2008

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international trade ensured 67% of global oil consumption, and by 2030 this percent may increase to 80%.

Large-scale accident at the British Petroleum deepwater shelf platform in the Gulf of Mexico sharply aggravated the significance of environmental issues in the oil industry. As a result of the accident the USA cancelled the decision on admission of oil companies to development of deep see oil fields. Other countries are going to limit the issue of licences for deepwater shelf operations. Meanwhile deepwater shelf reserves amount to 40-50 bln toe, or 20-25% of world reserves. The consequences of the accident will negatively affect investment appeal of the oil industry, in particular, that of British Petroleum, one of the leading international oil companies. At last, public response to the accident will expedite transition from oil and oil products to other kinds of energy carriers in developed countries. Therefore, this accident, which occurred at the moment of a latent internal crisis of the oil industry, may induce far-reaching consequences for the industry.

As to the pricing, presently oil prices are mainly driven by financial factors at leading world mercantile exchanges (Intercontinental Exchange, London, and NYMEX, New York). In the reference scenario such a structure will remain, but in the stagnation scenario regulation and climatic policy will have a strong impact on the market, while in the innovative scenario the role of speculative factors will fall down due to the increasing role of technological factors.

According to the GU IES forecast, in the reference scenario in the long run the oil price level will tend to decrease slowly despite periodic price hikes and drops conditioned by cyclic development of the world economy and the energy sector (Fig. 17). After price sinking to $40 per barrel by the end of the 2020s one may expect a sharp price surge up to $100 dollars in the early 2030s and a subsequent repeated recession. Upon that, price volatility will be quite significant.

In the stagnation and even more so in the innovative scenario conversion of the energy market into the energy services market will subordinate oil prices to prices for final consumer services or technologies. It will result in a long landslide of oil prices as the interfuel competition gets more intense and oil transforms into a “yesterday’s resource”. The price collapse will be especially rapid and deep in the innovative scenario because of decrease in production costs for other energy sources. By the end of the 2020s the price level in the stagnation scenario may be $60 per barrel, by 2050 – $50 per barrel (in the innovative scenario – $40 and $30 per barrel accordingly).

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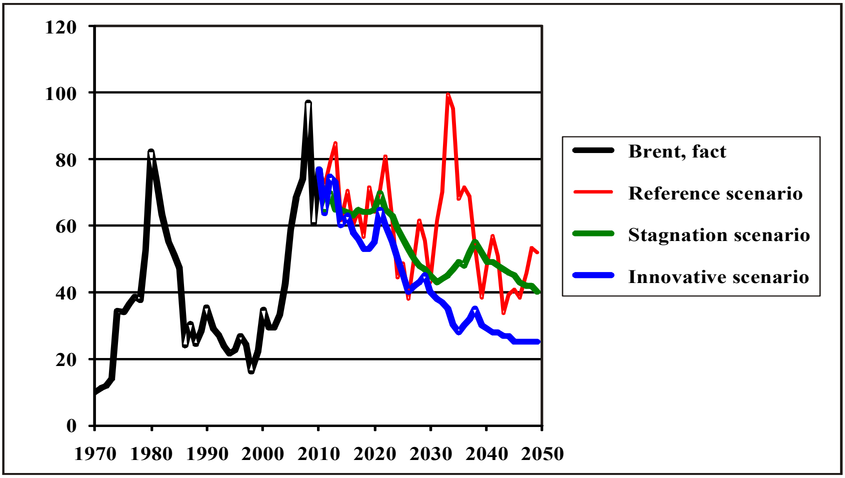

Source: *GU IES calculations.*

Fig. 17. ***World oil prices in 1970-2050, (in terms of 2009 US dollars)***

3.2. Gas industry trends

The gas industry enjoys the best prospects among fuel energy industries. The basic trends of its development are: 1) an outrunning growth in gas consumption, especially in nonsaturated Asian markets, 2) integration of regional gas markets into the global market thanks to the extension of LNG supplies, 3) pricing evolution in the gas market, 4) transition from the “oil geopolicy” to the “gas geopolicy”. The above trends became apparent in the 2000s and will persist in 2010-2050.

The level of saturation of the gas market by countries considerably differs today. Growth rates depend rigidly upon the level attained. In 2009 per-capita natural gas consumption in Russia was 2.92 tcm, in the USA – 1.92, in the EU – 0.94, in the Eastern Asia – 0.28 (in China – 0.07, in the Republic of Korea – 0.71, in Japan – 0.76 tcm). In the long term saturated markets will grow much more slowly than nonsaturated ones or even stagnate while nonsaturated markets will demonstrate a fast growth. Dynamics in the regional markets makes it possible to assume that the saturation level is between 1 and 2 thou. cu. m per capita, which means that the growth potential in the long-term outlook is very high.

Absolute volume of natural gas consumption in the OECD countries, in spite of decline due to the crisis of 2008-2009, will be recovered and will continue growing, though at smaller rates (Fig. 18). Toughening of restrictions regarding CO_2 emissions and raise in demand for thermal

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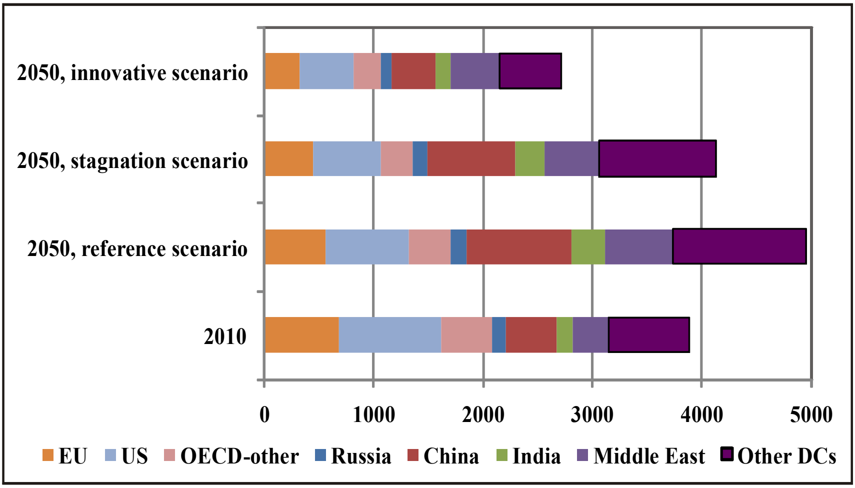

Source: *GU IES calculations.*

Fig. 18. ***World natural gas consumption in 2010-2050 (by regions), mln toe***

and electric energy will be major growth factors. In all scenarios this trend will persist until 2030, but at different rates. If in the reference scenario the growth by 2030 will be 80% as compared to 2010, in the stagnation and innovative scenarios it will be 32%. After 2030 in the reference scenario the growth will continue (by 18%) while in the stagnation and innovative scenarios it will start to decrease (by 6% and 7% accordingly).

In developing countries all scenarios predict a growth in demand though its value varies from 124% within 20 years in the reference scenario to 64% in the innovative scenario. After 2030 in the reference scenario the growth in demand will continue, however at much smaller rates than earlier (24%), and in the stagnation and innovative scenarios a decrease will start.

International trade ensured in 2010 only 30% of the world natural gas consumption compared with 67% of oil consumption. International trade will grow both due to deliveries of pipeline natural gas, and for account of liquified natural gas (LNG). Growth of LNG share is a long-term trend dating back to the 1980s. As of today LNG share in the international trade is 27.7%. In all scenarios LNG share will continue to increase. By 2030 it will range from 58% in the reference scenario to 50% in the stabilisation scenario (Fig. 19). The innovative scenario is an intermediate one. Widening of LNG deliveries will be instrumental in

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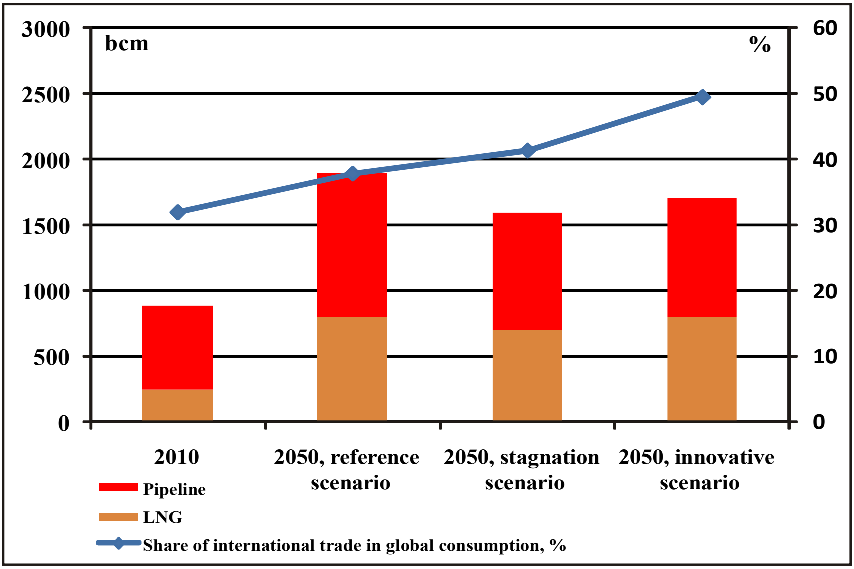

Source: *GU IES calculations.*

Fig. 19. ***World natural gas trade in 2010-2050***

gradual integration of regional markets into the world natural gas market. In the long run LNG deliveries from Middle East countries may occupy a balancing position between Atlantic and Pacific markets, but the transition to the full-fledged world natural gas market is possible only after 2030.

Market integration will result in a pricing model change. Modern gas market consists of a great number of local markets and four largest segments with different pricing models *(North American and British market* - spot market and gas-to-gas competition; *continental European market* - long-term contracts with a pegging to the oil products basket and spot market, *East Asian market* - long-term contracts with a pegging to the oil price, and *Russian market* - regulated tariffs). According to IEA, deliveries based on gas-to-gas competition pricing model account for 33% of total world deliveries, deliveries with a pegging to oil and oil product prices - 20%, deliveries at state-regulated prices - 38%, and non-market deliveries (double-end monopoly) - 9%.

In the reference scenario a shift to the gas-to-gas competition, in particular in the continental European market (on account of contracts with a pegging to oil prices) and in the East Asian market will be a major trend till 2030. In the stagnation and even more so in the innovative

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scenario there will be a principally new pricing model with a pegging to prices for final consumer services. It will be proliferated first of all in developed countries and may formally develop provided the competitive gas market is maintained though on the substance prices in the market will be determined by the final market of consumer services and technologies.

As the role of the oil industry decreases and the role of the gas industry increases, "gas geopolicy" will substitute for the "oil geopolicy". High concentration of natural gas reserves and production in the leading regions (Middle East – 30%, Russia – 45% and Central Asia – 15%), as well as growth of international trade and dominance of a limited number of suppliers and directions of deliveries will be preconditions of such "gas geopolicy". Critical points through which major part of hydrocarbons transported in the world passes (Strait of Ormuz, Gulf of Aden – Red Sea – Suez Canal, Strait of Malacca, Sunda Strait and South China Sea) will have a great bearing on LNG transit, as well as on oil deliveries. In the field of pipeline gas transit, in particular in the Central Asia, "pipeline wars" will continue, that will result in implementation of some competing projects of a doubtful economic justifiability.

3.3. Coal industry trends

The coal industry, unlike oil and gas industries, hardly faces resource problems. Instead, it encounters a number of technological and ecological restrictions and risks. Key trends of the coal industry development in 2010-2050 will be the following: 1) outstripping growth of coal energy sector in India and in China, 2) expansion of international coal trade, 3) development of new coal-based technologies, 4) improvement of economic performance of coal-fired power plants, 5) impact of climatic policy on the coal energy sector.

Specificity of the coal industry, as compared to the oil and gas industries, consists is a high degree of coincidence of geographical distribution of coal reserves, production and consumption. But ecological consequences of coal burning already in the 1970s forced to restrict the development of the industry. In the 1980s a "gas pause" began in the USA, Europe and the USSR. As a result by 2009 China accounted for 47% of world coal consumption, and in the 2000s, for 90% of coal consumption gain while in developed countries coal consumption was decreasing. In the long term coal consumption in China will inevitably decelerate due the energy consumption growth slowdown, a hard

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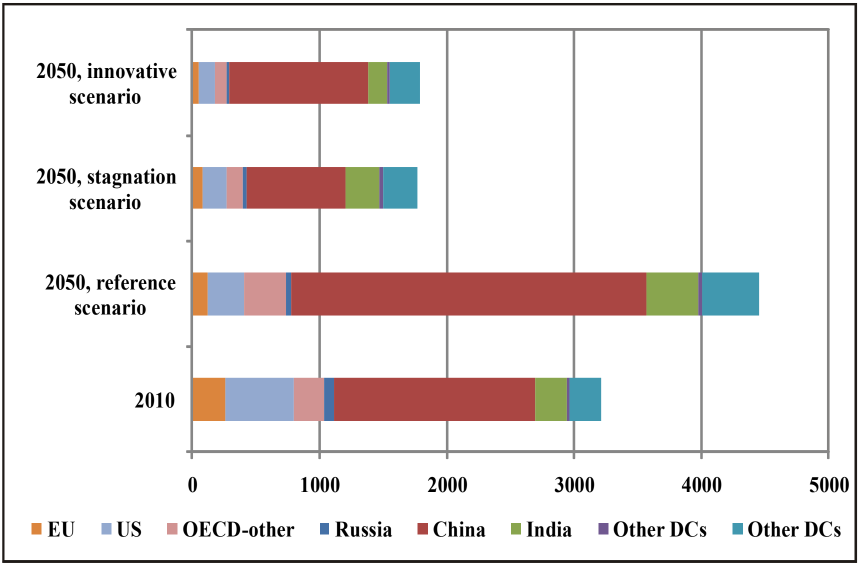
ecological situation in many big cities because of coal burning in low-efficiency boiler-houses, coal deficit (China has already become a net-importer of coal), and improved accessibility of other energy sources (renewables, gas, nuclear power). At the same time the "Indian factor" may replace the "Chinese factor": coal consumption in India is only 245 million tn, while coal-firing power plants with total capacity of 50 GW are under construction.

In 2010-2050 coal-based energy generation will depend upon technological factors (Fig. 20). In the reference scenario it will boast an appreciable growth (by 41% by 2030) on the basis of the "pure coal" technology. In the stagnation scenario it will start to decline (by 2% by 2030 and by 45% by 2050) due to a more rigid climate policy. In the innovative scenario the recession will begin later, but will proceed faster (8% growth by 2030 and 47% recession by 2050).



Source: *GU IES calculations.*

Fig. 20. ***World coal consumption in 2011-2050 (by regions), mln toe***

Comparatively low transportability, relative cheapness and coincidence of coal production and consumption regions restrict development of the international trade. In 2010 it only provided for 10% of the world coal consumption (400 million toe). The largest exporters are Australia, the Republic of South Africa, Indonesia, and the largest importers – Japan and the Republic of Korea. In the reference scenario, given a rapid growth of coal-based energy generation, China and India

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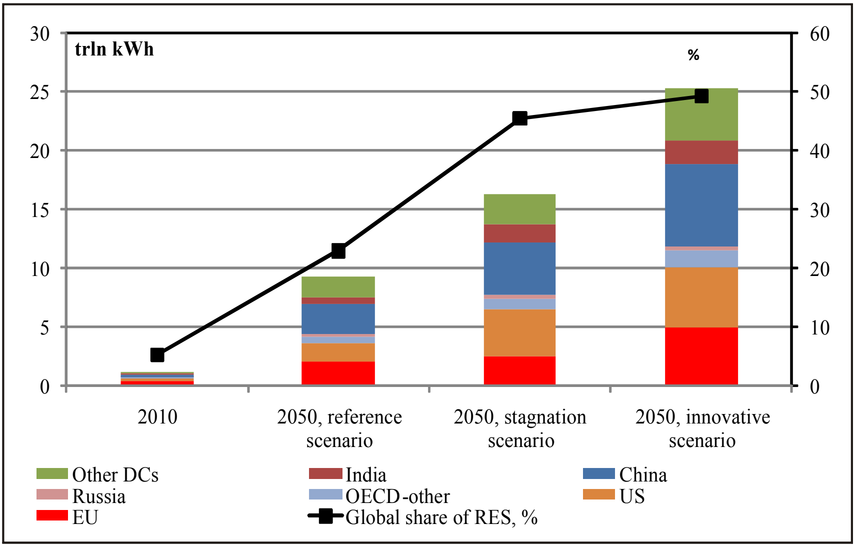
will not be able to ensure their self-sufficiency in terms of coal mining. By 2030 inter-regional trade in coal will increase by 80% (from 400 to 700 million toe, or 11% of the world consumption). In the stagnation and innovative scenarios coal consumption will grow slowly till 2030, and after 2030 it will start falling down. Consumption growth in the regions of low-cost coal-mining will promote consolidation of the industry.

3.4. Renewable energy trends

In the 2000s the renewable energy sector has been developing outperforming most forecasts and enjoyed a mighty boom. Total capacity of power stations using RES reached 367 GW (as compared to 49 GW in 2000), or 8% of world generating capacities. RES share in the global electric power industry capacity gain increased from 6% in 2004-2005 to 23% in 2008 and to 40% in 2009. At the regional level up to 40% of investments were made in Europe, and up to 30%, in the North America [15]. China holds one of leading positions in most branches of renewable energy sector and is implementing ambitious programs of their development. In a long-term prospect maximum RES growth rates are expected in the stagnation scenario. In the innovative scenario RES



Source: *GU IES calculations.*

Fig. 21. ***Global renewable energy production in 2010-2050 (by regions), trln kWh***

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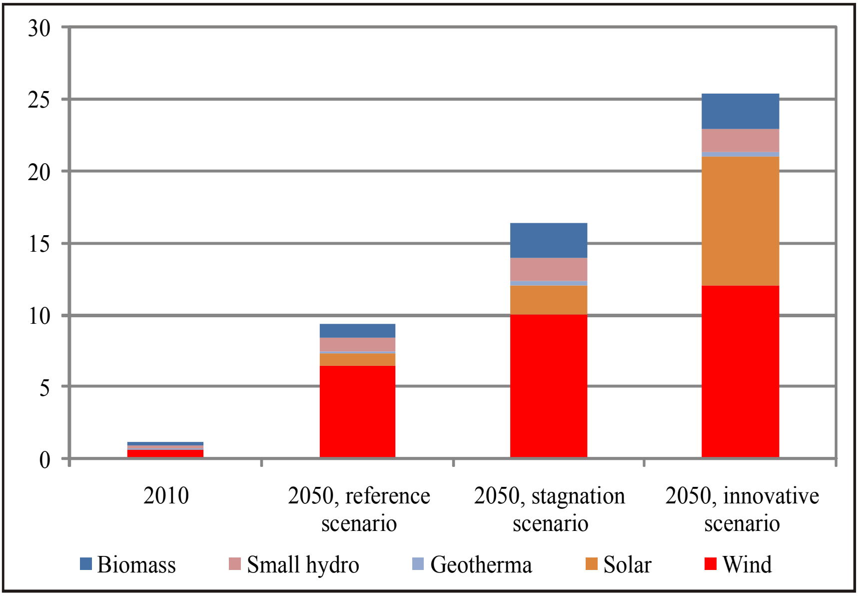
growth rates will be close to those of the stagnation scenario, while in the reference scenario they will be essentially smaller (Fig. 21).

In 2010-2050 a number of qualitative changes will occur in the renewable energy sector, namely: 1) outrunning growth of renewable energy sector, 2) adaptation of energy systems to a high share of RES and their integration into the energy market. Till 2015 growth dynamics will be determined by modern trends. Total capacity of wind turbines in the world will reach 500-600 GW, mainly on account of China, and capacity of solar power plants, 150 GW. Large producers of equipment for solar and wind energy generation will emerge. Major part of RES production gain in the innovative scenario as compared to the reference scenario will be obtained mainly on account of developing countries and solar energy sector while growth in developed countries and in wind energy generation is observed in the reference scenario (Fig. 22).

Increase in the absolute capacity gain and electricity production will be accompanied by a decrease in the relative growth rates. It will be conditioned by a number of reasons. First, the history of world energy sector shows that upon emersion of a new energy source the stage of its



Source: *GU IES calculations.*

Fig. 22. ***Global renewable energy production in 2010-2050 (by energy sources), trln kWh***

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quick growth in 30-50 years is followed by a saturation stage when its share in the fuel and energy balance is stabilised. The share of preceding energy sources remains; they do not disappear but occupy a certain niche. Secondly, as the industry grows in absolute terms, it becomes impossible to maintain ultrahigh growth rates due to shortage of building capacities, equipment, etc. Thirdly, the reference of created fixed assets makes decommissioning of existing generating equipment irrational. This will restrict the scale of changes. Fourthly, instability of energy production by wind and solar power plants and non-coincidence of generation and load peaks is a key problem. This problem can be solved through development of energy accumulation systems. Besides, it will be alleviated naturally as renewable energy gains scale and extends its geography. Fifthly, economic restrictions on RES use in many regions of the world will remain.

In many countries of the world in the 2000s development of RES received a considerable state support which became an important factor of the renewable energy production growth. During the period from 2000 to 2009 the number of countries using various forms of RES support increased from 40 to 60, while the amount of support, according to various estimations, was $100-150 bln per year. In the long term the role of a state incentive to the development of RES will decrease as far as the industry passes to the "mature" stage. There will be a shift from direct financing of RES (subsidies, tax rebate, grants, credits, etc.) to indirect institutional regulation through the electric power system operation rules.

3.5. Nuclear power industry trends

Basic trends of development of the nuclear power industry are quite contradictory and contain some significant uncertainties, namely: 1) eventual "nuclear renaissance", 2) problems relating to the production and technological base of the nuclear power industry, 3) nuclear power competitiveness.

In the 2000s construction of nuclear power plants which sharply retarded in the 1990s due to low energy prices and consequences of the Chernobyl Nuclear Power Plant accident greatly accelerated. Currently there are 53 reactors in 13 countries under construction, and about 130 reactors are being designed. In 2010 eleven nuclear reactors were put into operation, nine nuclear reactors are scheduled for commissioning in 2011, ten in 2012, twelve in 2013, and fourteen in 2014. Further development depends upon the world energy sector development

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scenario, and more specifically, upon NPP construction programs in the leading nuclear countries.

Decommissioning of reactors which were built in the 1960-1980s and reached the limit of their design useful life will have a significant bearing on dynamics of nuclear power capacities. Average term of service of operating reactors increases and in 2010 reached 25 years. This problem is most critical in Europe, the USA and Russia. It may be handled by extending useful lives beyond design limits and by increasing the design useful life of new nuclear power plants. By 2030 at least 180 GW of NPP capacities will be decommissioned.

Accident at Fukushima nuclear power plant, the consequences of which are not clear yet, will surely lead to a significant slowdown of NPP construction programs in developing countries and to accelerated decommissioning of old power units in Europe. It is unlikely that the European Union and other major nuclear countries will abandon nuclear power, but growth prospects of the industry have been seriously undermined. It is obvious that without a shift of the nuclear power industry towards an innovative development path, creation of new types of reactors and closed nuclear fuel cycle (Fig. 23) the industry will stagnate.

In the reference scenario NPP capacities in the world grow slowly due to decommissioning of power units with exhausted service life (by 2030 – 442 GW, by 2050 – 527 GW). In the stagnation scenario NPP capacities decrease rapidly: by 291 GW by 2030, and by another 185 GW by 2050. Only in the innovative scenario it is possible to implement the world nuclear power industry innovative development project (including creation of fast reactors and closed nuclear fuel cycle) promoting rapid growth of the industry (by 788 GW by 2030, and by 1,367 GW by 2050).

Actual cost of construction of a NPP in the 2000s was approximately $2500 per 1 kW of electrical output. Gradual transition to the 3rd, and then 4th generation reactors is expected. First 3rd generation reactors are already under construction (American-Japanese AP-1000 reactors in China, and European PWR reactors in Finland). 4th generation reactors may be developed in the 2010-2020s, and starting from 2030 their active construction will begin. Only in the innovative scenario it will be possible to realise advantages of serial construction of the 3rd and 4th generation NPPs and to decrease capital costs. Implementation of an enhanced fuel cycle will enable reduction of SNF handling costs and turning SNF from waste into a valuable resource for production of new nuclear fuel.

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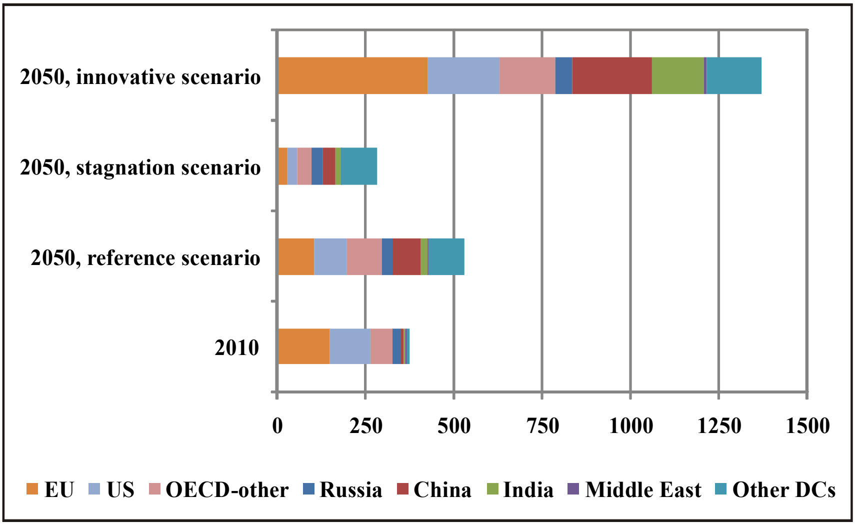

Source: *GU IES calculations.*

Fig. 23. ***World capacities of nuclear power plants in 2010-2050 (by regions), GW***

Actual cost of construction of a NPP in the 2000s was approximately \$2500 per 1 kW of electrical output. Gradual transition to the 3rd, and then 4th generation reactors is expected. First 3rd generation reactors are already under construction (American-Japanese AP-1000 reactors in China, and European PWR reactors in Finland). 4th generation reactors may be developed in the 2010-2020s, and starting from 2030 their active construction will begin. Only in the innovative scenario it will be possible to realise advantages of serial construction of the 3rd and 4th generation NPPs and to decrease capital costs. Implementation of an enhanced fuel cycle will enable reduction of SNF handling costs and turning SNF from waste into a valuable resource for production of new nuclear fuel.

Low reliability and high cost of construction (by 20-24% more expensive than usual reactors) are major problems of existing *fast neutron reactors*. But they make it possible to use uranium-238 (99.3% of natural reserves of uranium) while thermal reactors only use uranium-235 (0.7% of the reserves). Creation of fast reactors only makes sense in case of organisation of a closed nuclear fuel cycle (CNFC). Russia, which established itself as a leader in development of fast reactors, is currently constructing BN-800 unit. Works in the same direction have been started or resumed in India, China, France, the Republic of Korea and Japan.

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The necessity of transition to serial construction of power units and production of equipment is a fundamental challenge for the nuclear power industry. Due to a high unit capacity of power units (as a rule, 1 GW) their number is small. Until now the reactors have not been standardised completely; therefore the costs increase, the reliability decreases, the learning curve (cost reduction so far as capacities grow) is poorly implemented. Transition to a new technological level which will make it possible to implement fundamental advantage of the nuclear energy – independence of external deliveries of raw materials and environmental conditions will be vital for future development of the world nuclear power industry. In case of freezing of the current technological level the industry is doomed to stagnation or decline.

3.6. Electric power industry trends

The electric power industry in 2010-2050 will be the backbone of the world energy sector. A number of qualitative changes will be observed in the electric power industry, namely: 1) an outrunning growth of electric power industry and its shift towards developing countries, 2) reorganisation of the corporate and market structure of the industry, 3) integration of electric power systems of large regions of the world. Qualitative changes will be more pronounced in developed countries, while major part of the quantitative gain will be concentrated in developing countries. In 2010-2050 there will be deep shifts in the electric power generation technologies and organisation of electric power systems in the electric power industry.

Electric power generation technologies. Electric power generation technologies may be subdivided into two groups - mature technologies (we expect their reference development with some improvement of economic parameters), and emerging technologies (for them we expect a rapid enhancement of technical-and-economic performance, implementation of new technological solutions). Mature technologies include gas, wind, bio and hydraulic power generation technologies, as well as thermal reactors in the nuclear power industry (Table 5).

Emerging technologies include fast reactors, new coal-based generation technologies, solar cells. Coal industry technological development prospects are associated with power units with supercritical and ultra supercritical steam parameters, new coal burning methods (fluidized bed combustion, integral combined cycle coal gasification), coal gasification technologies. Prospects of technological development

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Table 5. Basic innovatives in the final consumption sphere

Mature technologies	Emerging technologies
Electric power generation	
Gas fuel generation	New coal-based generation technologies
Wind power plants	Photovoltaic generation
Hydraulic power industry	Bioenergy
Thermal reactors	Fast reactors
Electric power transmission	
Integrated power transmission systems	Superconductors and accumulators
Distributed generation	"Smart energy system"

Sources: *IES.*

of *solar photovoltaic generation* are associated with thin-film, multinode technologies.

Technological trends of development of electric power systems. The transition to the new-generation energy systems will be performed along three paths: 1) creation of energy system management systems ("smart energy system"), 2) development of long-range electric power transmission technologies 3) development of technologies for accumulation of electric energy within the energy grid, 4) development of distributed generation. *"Smart energy system"* is essentially a generalisation of "smart grid" technologies which are being developed currently and stipulates energy demand management. In the USA and in the European Union the development of "smart grids" on a national level is recognised as a key task [18, 20], and governments invest yearly $30-50 bln into development of respective systems. *Development of distributed generation* will result in formation of "virtual power stations" – groups of distributed electric power generators under common control. To this end both technological solutions (transition from asymmetrical to symmetrical grids), and organisational solutions (energy payment procedure, electric power system management procedure) shall be found. This will result in transformation of the energy market from the commodity market into the services market first, and then into technology market. Technologies of accumulation of electric power within the energy grid are necessary to improve capacity utilisation efficiency and power supply reliability. Indirect methods of accumulation of electric energy at the energy grid level may be implemented through creation of pumped storage hydraulic stations and flywheel accumulators. For the

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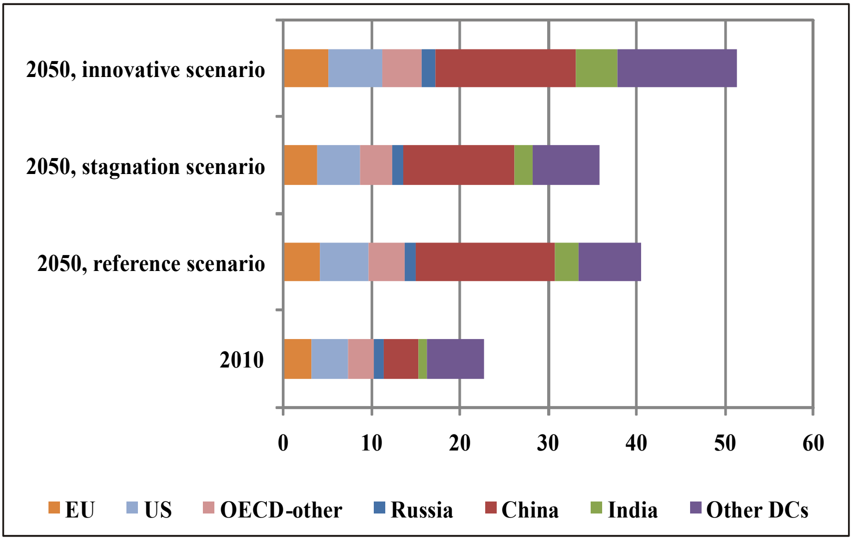
development of *electric power transmission* HVDC power transmission line technologies, and the use of superconducting materials are important. In the aggregate the above trends are reduced to creation of new-generation intellectual Unified energy systems (UES 2.0) with intellectual management integrated from production till final consumption stages.

On the basis of these technological trends in 2010-2050 the key trend of an outstripping growth of electric energy consumption as compared to the final energy consumption as a whole will continue. In 2030-2050 developing countries will continue to catch up with developed countries, but the gap in the growth rates will be smaller. As a result the share of developing countries in the world electric power consumption will increase from today's 48% to 52-56% by 2030 and to 56-69% by 2050 (Fig. 24).



Source: *GU IES calculations.*

Fig. 24. ***World electric power consumption (by regions), trillion kW·h***

Minimum growth of electric power consumption is expected in the stagnation scenario, and maximum growth, in the innovative scenario. The projected gain is extremely non-uniform by countries and world regions. Developing countries, just as in the 2000s, will account for the major part of the generating capacities gain. So, in China in the 2000s generating capacities were constructed at very high rates (500 GW of capacities were commissioned within 10 years). Predictably, in the 2010s

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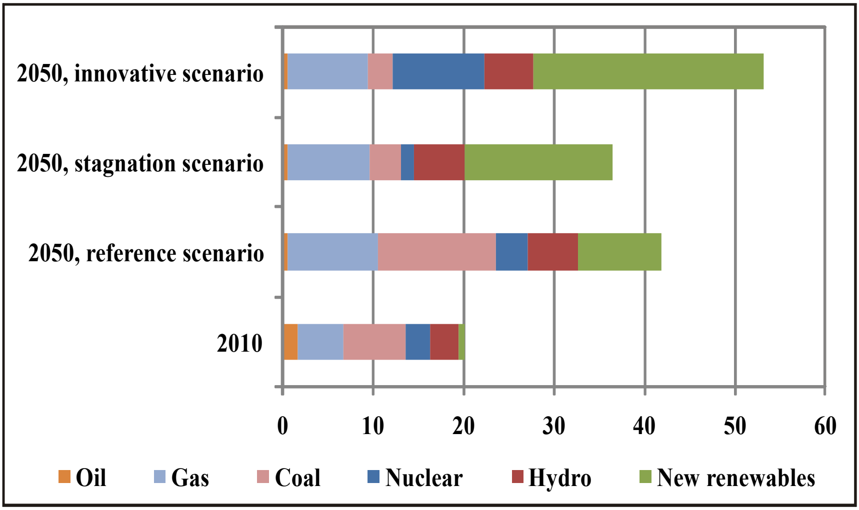

Source: *IES calculations.*

Fig. 25. ***World electric power generation structure (by energy sources), trln kW·h***

additional 300 GW of capacities will be commissioned thus enabling to satisfy growing demand.

In 2010-2050 the generating mix will undergo essential changes. Share of RES will increases up to 22% in the reference scenario and up to 45-48% in the stagnation and innovative scenarios (Fig. 25). In the reference scenario the importance of the coal energy industry, and in the innovative scenario, that of NPPs will increase.

An outstripping growth of world electric power industry and electric power industry shift towards developing countries will create a whole set of problems. First, large-scale construction of new generating capacities will be required. Depending on the scenario, capacities of world electric power industry should increase 2.0-2.8 times. Maximum investments will be required in the stagnation scenario owing to a fast growth of capacities of renewable energy generation at its relatively slow cheapening. Optimisation of generating capacities loading through creation of "smart grids" will make it possible to reduce the demand for new generating capacities.

International trade in 2008 provided barely 3% of the world electric power consumption, or 500 bln kWħh. Integration of electric power systems of large regions of the world after 2030 may become a key consequence of development of long-range electric power transmission

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technologies. In the reference and stagnation scenarios this trend will be weak and will only have a bearing on development of trade in electric power between individual countries though its scale will increase essentially (to 1,500 bln kWh). The innovative scenario predicts that after 2030 Unified Energy Systems of Europe, East Asia, North America, Russia and adjacent countries will be created and interconnections between them will be established. By 2050 this trend will result in formation of bases of the Unified Energy Systems of Eurasia, while the world trade will amount to 5,000 bln kWh.

Development of international trade in electric power requires the solution of not only technical, but also organisational (scheduling procedure), economic (payment procedure and creation of cross-border electric power markets) and political problems. The electric energy market is characterised by the least level of integration and the greatest variety of market models as compared to other energy markets. In the stagnation scenario it will evolve in the direction of the services market instead of the products market. In the innovative scenario, as a result of formation of new-generation electric energy systems it will be transformed into the technologies market.

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SECTION 4

WORLD ENERGY SECTOR DEVELOPMENT SCENARIOS

World energy sector development scenarios are regarded by us as a “point of convergence” of the whole set of technological, energy, social, economic and political trends. Therefore scenarios possess certain integrity, and their description makes it possible to reveal interrelations between industries which escape during industry-wise analysis.

4.1. Reference (hydrocarbon) scenario

The reference scenario assumes that the structure of the world energy sector as a whole will change slightly. Fast growth of the world economy, the major part of which will be attributable to developing countries, will not be compensated by increased energy efficiency. Consumption of all kinds of fossil fuel will continue to grow.

The passage by developing countries of a material-intensive industrialisation stage with a rapid growth of key industries and creation of the respective infrastructure, as well as raising of living standards is a basic precondition of the reference scenario. This process continues in China, is accelerated in India, is not completed in Latin America and South East Asia and just begins in Africa. A wide-scale growth in demand for energy resources of all kinds in most developing countries will result in a sharp increase of the fuel and energy balance tension both globally, and regionally (Fig. 26).

Principal changes in the world energy sector will be geopolitical, instead of technological ones. There will be a fundamentally new structure of the world energy carriers trade. Developing countries will become largest importers of all kinds of fuel and energy resources, and their dependence on import will be even higher that that of developed countries. By 2030 not developed countries, but Asian developing countries will be the most dependent on the world energy market. These countries will be more that others interested in the world energy market stability and an acceptable price level. Essential risks of the world energy sector will be connected with three factors: 1) instability and armed conflicts in the Middle East and in the Central Asia, 2) threats to shipping routes for transportation of energy carriers on the part of piracy, terrorism, local conflicts, 3) growth of contradictions between the countries and struggle for access to energy resources.

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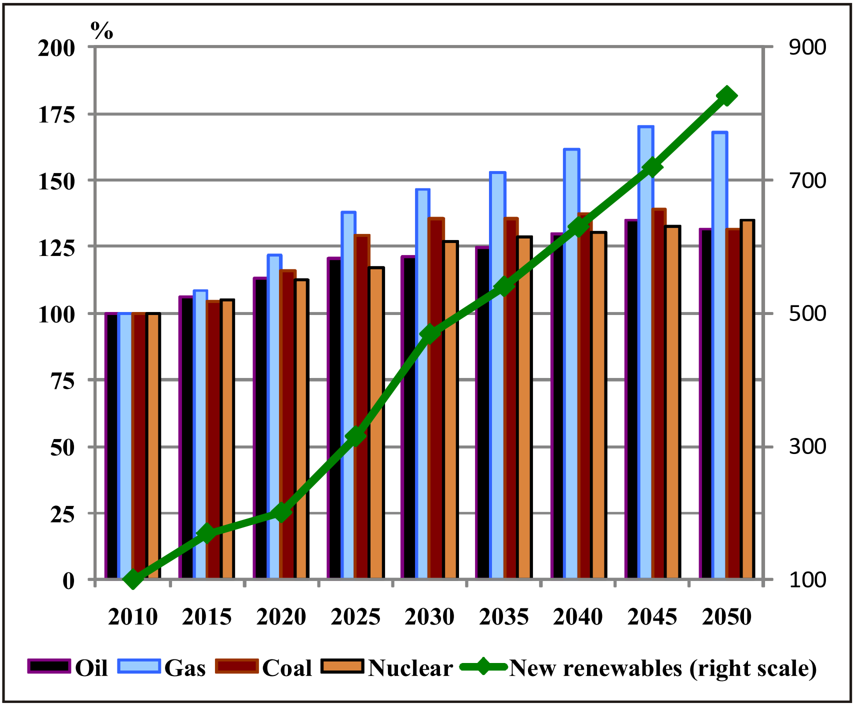

Source: *IES calculations.*

Fig. 26. ***Dynamics of consumption growth by kinds of primary energy in the reference scenario, 2010 = 100%***

The most tense situation will develop in the oil industry where growing demand will face significant offer restrictions. On the one hand, the tendency towards concentration of crude oil extraction in the Middle East will gain in strength, thereby increasing dependence of most countries and regions on oil import. On the other hand, the intention to increase the energy security level will necessitate development of deposits with difficult production conditions (Arctic regions, deepwater shelf, heavy oil, etc.). Altogether these two processes will result in growth of marginal costs and, accordingly, prices, as well as decrease of energy security. The "oil geopolicy" will still play extremely significant role. As a result, state regulation of the industry and the role of national oil companies will augment essentially. New exchange trade centres are likely to emerge in Asia near demand growth hubs.

Similar processes will occur in the world gas industry. Since currently the industry shows a low level of international integration (world trade in natural gas only amounts to 30% of global consumption as compared

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to 67% for oil), changes in the industry will occur in two stages. Till 2030 gradual formation of the world market framework will proceed, and the role of exchange trade will continue growing with underlying integration of regional markets. After 2030 growing demand in combination with insufficient offer will cause increase of marginal and average costs, production shift to new regions, escalation of the gas balance tension and international contradictions in this field. As a result "gas geopolicy" will become for many countries no less important than oil geopolicy.

In the *coal industry*, as in the 2000s, major part of growth will be concentrated in China. Against the background of growth in demand China and India may start importing coal that will become a key driver of the international trade growth, industry consolidation, and exchange trade development, especially in Asia. Technological modernisation of the coal-based electric power industry will be carried out with the use of advanced know-how.

In the *nuclear* as well as in the coal power industry, 1.35 times reference growth is expected by 2050 within the framework of the existing technological basis (2+ and 3rd generation thermal reactors). As a result, the need for uranium will increase quickly, secondary uranium sources will be gradually exhausted, uranium balance will become quite stressed, and the role of "uranium geopolicy" will increase.

Production of RES primary energy by 2030 will increase 5 times as compared to the 2010 level, and by 2050, 9 times (net of biomass generation and large-scale hydraulic power industry). Till 2015 RES will mainly grow on account of hydraulic power plants and coastal wind-driven powerplants. In 2015-2030 biomass and offshore wind-driven powerplants will join the growth leaders. Despite outstripping growth rates, the renewable energy industry by 2030 will constitute no more than 7% of global consumption of primary energy, and by 2050, 10%.

Electric power production at coal-fired stations by 2030 will increase 2.05 times and will amount to 35.6% of total electric power production, at gas power stations –1.92 times to 23.7%, at RES power plants – 5.54 times to 16.0%. RES, coal and gas generation will demonstrate maximum growth rates, while black oil - minimum growth rates. In the reference scenario some elements of "smart grids" relating to grid and generating capacities management will be implemented. Electric power transmission efficiency will be enhanced to a level sufficient for optimisation of existing electric power systems (Europe, Russia, USA, China), but not for restructuring of the world electric power industry.

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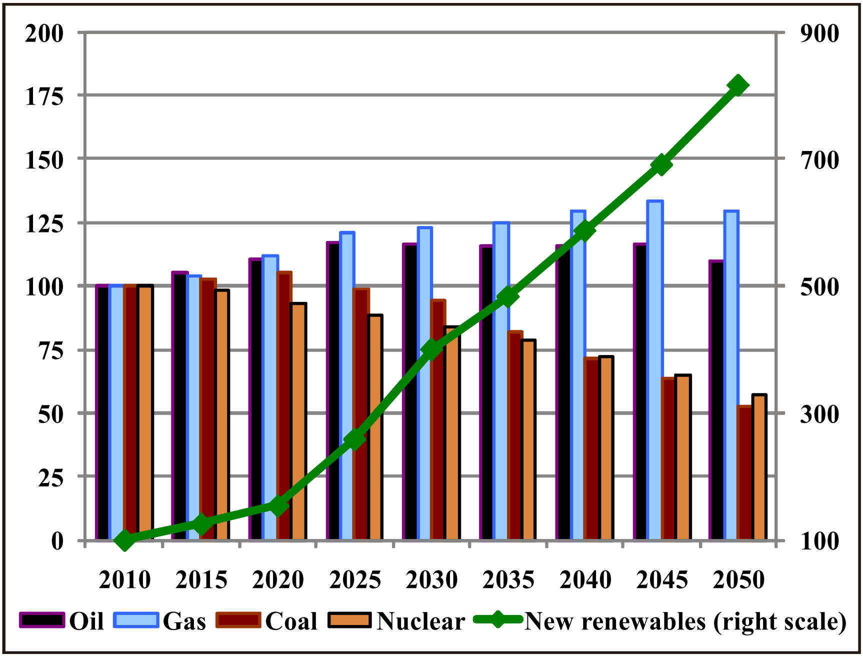
4.2. Stagnation (renewable) scenario

The transfer of existing technologies to developing countries in order to decrease energy intensity of the industrialisation process is the basic precondition of the stagnation scenario. Decelerated growth of the world economy will reduce total energy demand. However, it will be possible to only partially neutralise the demand potential growth (Fig. 27). A complex system of technological regulation of the world energy sector will be built, including global and local climatic agreements, climatic tax and customs tariffs, technological standards, etc.



Source: *IES calculations.*

Fig. 27. ***Consumption growth dynamics by primary energy kinds in the stagnation scenario, 2010 = 100%***

Oil consumption will continue growing, but it will be much slower than in the reference scenario (by 10% by 2010 as against 30% according to the reference scenario) that will result in a smaller concentration of oil production in the Middle East, an increased self-sufficiency level of some regions-importers, a smaller geopolitical intensity, an evolution from exchange pricing to a greater role of fundamental factors. Integration of the world natural gas market will be somewhat delayed, and in the long-term it will be a "buyer's market". Development of LNG trade will make

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the gas market much more competitive than today. "Gas geopolicy" will play a much smaller role than in the reference scenario.

In the stagnation scenario world *coal consumption* will fall appreciably. Till 2030 the industry will grow very slowly, and then a fast recession will begin. It will be driven by ecological (CO_2 emissions, local pollution), economic (emersion of alternatives, especially renewable kinds), and social (low labour productivity, high accident rate) factors.

In the *nuclear power industry* in the stagnation scenario a descending trend is expected, the industry will shrink almost 2 times. High construction costs, failure to design conceptually new reactors, remaining radiation safety problems will be preconditions of such development. Competition on the part of gas generation and renewable energy will be the main factor.

Production of primary energy using RES will increase by 2030 7 times compared with the 2010 level, and by 2050, 15 times (disregarding biomass and large hydraulic power plants). By 2050 RES share will attain 21%. In 2030 wind generation (72%) will prevail within the renewable energy industry structure, but by 2050 its share will decrease to 60% due to an advanced growth of electric power production from biomass and solar energy. By 2050 solar energy generation will become commercially viable. Small-size hydraulic power installations, geothermal energy and biomass-based generation niches will expand drastically.

In the stagnation scenario the *growth of the world electric power industry* will be almost the same as in the reference scenario. Decrease in economy growth rates and intensification of energy saving efforts will be compensated by accelerated electrification. Electric power production at gas power stations by 2030 will increase 1.65 times and will amount to 29.0% of total electric power production, RES-based electric power production –13.1 times up to 26.0% (without taking into account hydraulic power industry). Electric power production at nuclear power plants will fall by 18%, at coal-fired stations – by 11% to 20.5%, at black oil power stations – by 51% to 2.7%. In the stagnation scenario basic elements of "smart grids" will be implemented. Electric power system load profile regulation technologies will be widely spread.

The world vehicle fleet structure will undergo essential changes by 2050. Development of all existing alternatives to oil products and internal-combustion engine, especially of hybrid cars will be the main trend. Electric and hybrid cars fleet by 2030 will reach 8%, and by 2050 – 20%

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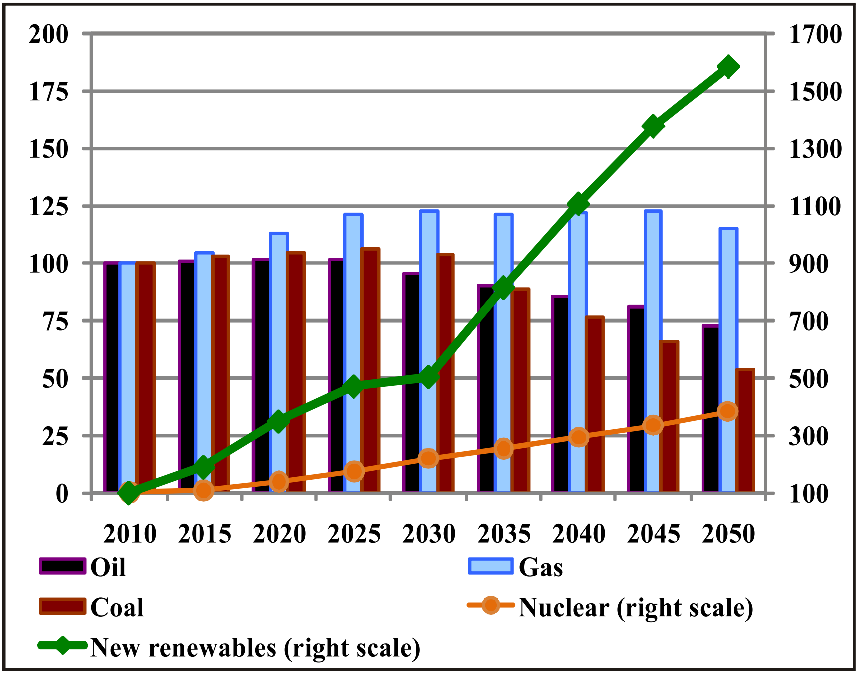
of the global vehicle fleet. Hybrid cars by 2030 will account for 11%, and by 2050, for 52% of the world car production. Purely electric cars will find a limited use. By 2050 their share in the vehicle fleet will not exceed 5%, and in production – 9%. Biofuel share by 2030 will reach 6% of the world motor fuel market, and by 2050 – 14%.

4.3. Innovative (renewable/nuclear) scenario

The innovative scenario assumes radical changes in the world energy sector and economy. Transition to a new phase of social, economic and technological development in the leading countries will be the basic precondition of the innovative scenario. Such a transition will have an induction effect on the developing countries industrialisation process, making it much less energy-intensive. Oil consumption will stagnate till 2020, and then it will start decreasing. After 2030 this process will accelerate, and by 2050 the decrease will reach almost 30% of the current level (Fig. 28).



Source: *IES calculations.*

Fig. 28. ***Consumption growth dynamics by primary energy kinds in the innovative scenario, 2010 = 100%***

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Car production and world vehicle fleet structure by 2050 will cardinally change. Development of hybrid and electric cars will be the main trend. The fleet of electric and hybrid cars by 2030 will amount to 14%, and by 2050, 80% of the world vehicle fleet; the necessary infrastructure will be developed. The share of electric cars by 2050 will reach 10% of total production, while production of cars with internal-combustion engines will be almost discontinued. Decline in oil consumption and promises of its further reduction will dramatically change the place of the industry in the world economy. Oil extraction in the regions with the most difficult conditions and the highest costs (shelf, starting from deepwater platforms, Arctic regions, etc.) will be curtailed. That will lead to reduction of marginal costs, and in combination with a slump in demand – to a long-term and deep drop in prices. Production may be concentrated in the Middle East as a region with low costs, but geopolitical importance of the oil industry will decrease, and its use as a tool of political pressure will become impossible. The state role in the "yesterday's industry" will start to diminish rapidly.

In the world gas industry consumption growth will continue till 2030. By 2050 world consumption level will still exceed the 2010 level by 15%. As in the oil market, demand recession will result in formation of the "buyer's market" and will not leave place for speculative operations. "Gas geopolicy" will play a minimum role. Dynamics of the *coal industry* is similar to its dynamics in the stagnation scenario, i.e. stagnation till 2030 and sensible decline by 2050 (to 47% of the current level). In the nuclear power industry in the innovative scenario there may be a qualitative breakthrough. By 2030 the *nuclear power* industry may increase two fold, and by 2050, four fold against the current level. An accelerated transition to standard 3rd and 4th generation reactors, as well as to fast reactors will become a foundation of such growth. This will make it possible to solve the uranium issue, the nuclear waste problem, to improve economic performance and safety of nuclear power plants.

Production of primary energy using RES will increase by 2030 9 times as compared to the 2010 level, and by 2050, 26 times (net of biomass generation and large-scale hydraulic power generation). RES share by 2050 will reach 34% (nuclear power industry share: 14%). Wind energy will predominate within the structure of the renewable energy generation in 2030 (70%), but by 2050 its share will decrease to 47% due to the growth of the solar energy share (35%). Thanks to a rapid technological progress RES energy price will diminish to the level of competitiveness with conventional energy sources.

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By 2030 world electric power consumption will reach 34.4 trillion kWh, and in 2050, 52.0 trillion kWh as compared to 20.3 trillion kWħh in 2010. This will bring the world energy sector closer to the "electric world". Electric power share in the world final energy consumption in the innovative scenario will grow from 21.7% in 2010 to 28.6% in 2030 and 36.8% in 2050. Nuclear and renewable energy will play the main role in the electric power industry dynamics. Production of RES-based electric power by 2030 will grow 16 times to 26.7% of total production, and by 2050, to 48%. Nuclear generation will increase by 2030 4 times, and its share will reach 20%.

Deep changes in the world fuel and energy balance will create principally new challenges for Russia for which it is hardly prepared now, and will require creation of a future-oriented energy sector in Russia (Table 6). Decrease in the global demand and prices for hydrocarbons will call for a radical restructuring of the national economy, its modernisation and innovative development.

Table 6. Main challenges for Russia in the innovative scenario

Trend	Challenge for Russia	Requirements to Russia
Deceleration of demand	Growth retardation	Modernisation
Shift of demand for hydrocarbons to Asia	Strong competition in Europe	Diversification of the export geography
Termination of the oil epoch	Economic crisis	Reduction of dependence on oil export
Climate policy	Russia's arrearage, export problems	Russia's model of operation in new markets
Outstripping growth of RES	Russia's arrearage, inefficiency	Accelerated development of RES in Russia
Regionalisation of the world energy sector	Export and investments are unclaimed	Optimisation of pipeline projects
New phase of development in developed countries	Irreversible arrearage of Russia	Innovative development
New-generation energy sector	Inefficiency of the Russian energy sector	Creation of a future-oriented energy sector in Russia

Source: *IES.*

Besides, formation of a new organisational structure of the world energy sector will be of a crucial importance for Russia. Most probably, a new pricing structure in the world energy market will be developed (based on cost of final energy services), where prices will be formed proceeding not from raw materials to consumer goods, but vice versa, on the basis of technological factors. The energy market will actually become a market of services, and then a market of technologies.

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After 2030 some countries (mainly developed ones) will began construction of new-generation electric power systems based on "smart grids" technology providing for the real-time management of electric energy production, transfer and consumption, as well as on combination of unstable (RES) and stable (NPP) energy sources. Enhancement of electric energy transmission capabilities will lead by 2030 to the formation of Unified Energy Systems of Europe, East Asia, North America, Russia and adjacent countries, as well as of interconnections between them. Due to a growth electric power consumption in the transport sector daily load patterns will be equalised and installed capacity utilisation factor will increase.

As a consequence, basic changes in the world energy sector will have a technological nature, while regulatory and geopolitical factors will recede into the background. An energy sector of a new type will be created: post-industrial, relying on non-carbon energy sources (RES and nuclear power), real-time complex energy consumption management systems, with participation of decentralised energy sources, with integration of the energy sector into the technosphere, with advanced energy saving methods. Fast growth of the world economy will be accompanied by a rapid improvement of energy efficiency. As a result, the energy consumption will grow though more quickly than in the stagnation scenario, but more slowly than in the reference scenario.

4.4. Comparison with forecasts of other research organisations

Comparison of the world energy sector development scenarios examined above with forecasts of other research organisations reveals deep discrepancies between the scenarios in terms of the basic parameter – predicted volume of energy consumption (Fig. 29).

The discrepancy between extreme scenarios of other research organisations (A1B IPCC and energy revolution scenario developed by Greenpeace) is as much as 3.3 times. We believe that the latter scenario is unrealistic, however even if it is not taken into account, the discrepancy reaches 1.8 times. It should be noted that IPCC scenarios used in the climate change forecast proceed from maximum estimations of the energy consumption amount in the future. At the same time Shell scenarios and the Greenpeace reference scenario specify rather close energy consumption values (19.5-22.5 bln toe), and the target scenario of IEA, somewhat higher energy consumption (25.7 bln toe). The level of

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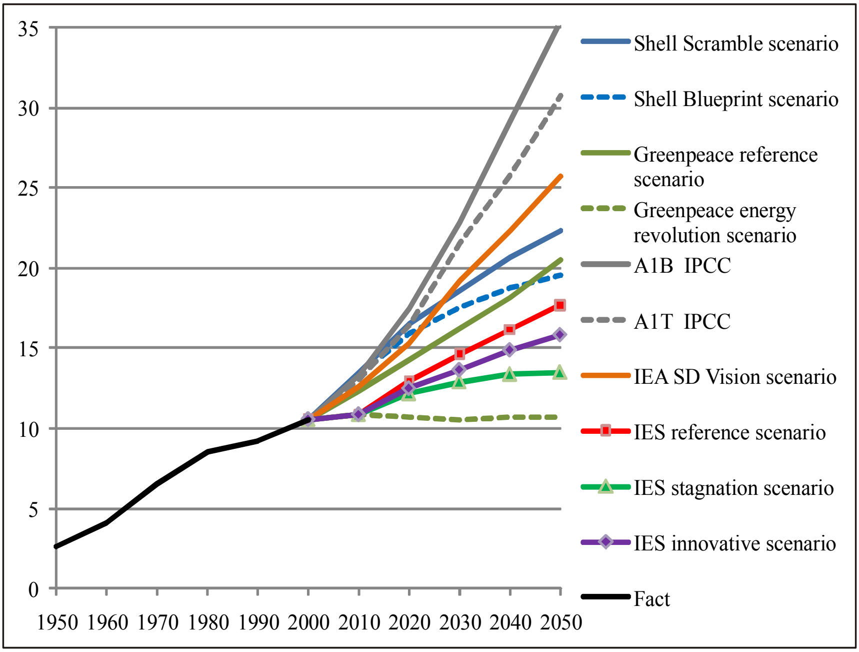

Source: *GU IES calculations using data of [10,11,16,17,19].*

Fig. 29. ***Dynamics of world consumption of primary energy, bln toe***

19.5-22.5 bln toe is a consensus forecast within the limits of the reference scenario.

The analysis of expected energy consumption growth rates reveals that IPCC's scenarios, in particular A1B, assume that in 2010-2050 the growth rates reached in the first half of the 2000s and essentially exceeding the level of the 1980-1990s will be maintained. Since key developing countries have passed the stage of energy- and material-intensive industrialisation and inevitable change of the development model, such high growth rates seem unrealistic. At the same time the energy revolution scenario suggested by Greenpeace, which assumes stagnation of energy consumption, contradicts all existing world development trends and is almost impossible.

As it can be seen, parameters predicted by our reference scenario are somewhat lower that those of most "optimum" scenarios suggested by other research organisations and much more lower that those of IPCC scenarios. In our opinion, industrialisation potential in developing countries is finite. The stagnation and innovative scenario also feature low energy consumption rates. Thus, one of key conclusions of our

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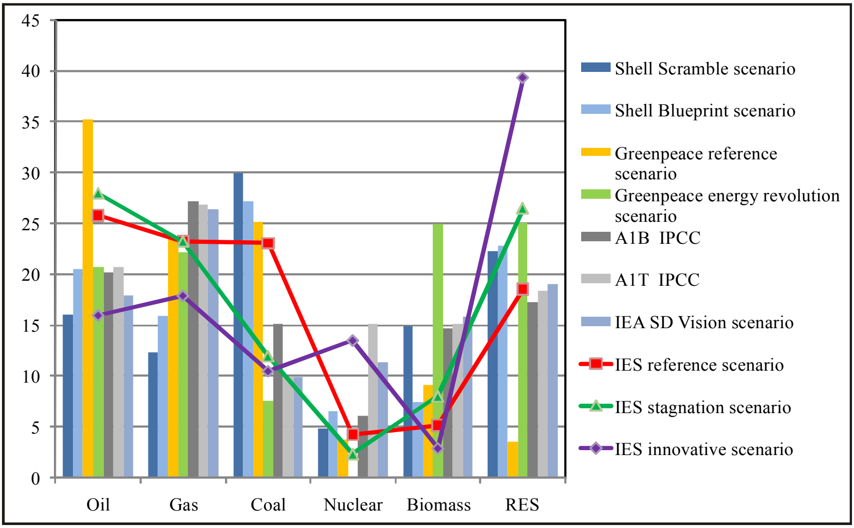
research is that the potential of further energy consumption growth is lower than the one anticipated by most other forecasts.

Despite slow changes of the energy sector structure in the past, foresight researches show a high variety of the world energy sector structure forecasts in the future (Fig. 30). It testifies to the fact that the world energy sector has entered a crisis period when its structure may undergo abrupt changes.

Greenpeace scenarios are distinguished by an extreme character. Shell scenarios, on the contrary, are optimised first of all from the economic point of view, instead of the ecological one, which explains a high share of coal. On the other hand, IPCC and IEA scenarios assume gas share growth to 26-27% and nuclear power industry share growth to 10-15%. These scenarios, as well as Shell scenarios, assume achievement of RES share of 17-22% in the fuel and energy balance.

If we consider the most realistic scenarios, the key uncertainty of the world energy sector structure consists in 1) the coal-to-natural gas consumption ratio (from 2.5:1 according to Shell to 1:2.5 according to IEA and IPCC, 2) the nuclear power industry share (from 3.7 to 15.1%). However, oil share decrease from 35 to 25%, biomass share growth from 7.4% to 15% (upon transition from conventional to new biomass kinds) and RES share growth from 6 to 17-22% is a consensus forecast.



Source: *GU IES calculations using data of [10,11,16,17,19].*

Fig. 30. ***World primary energy consumption structure in 2050,%***

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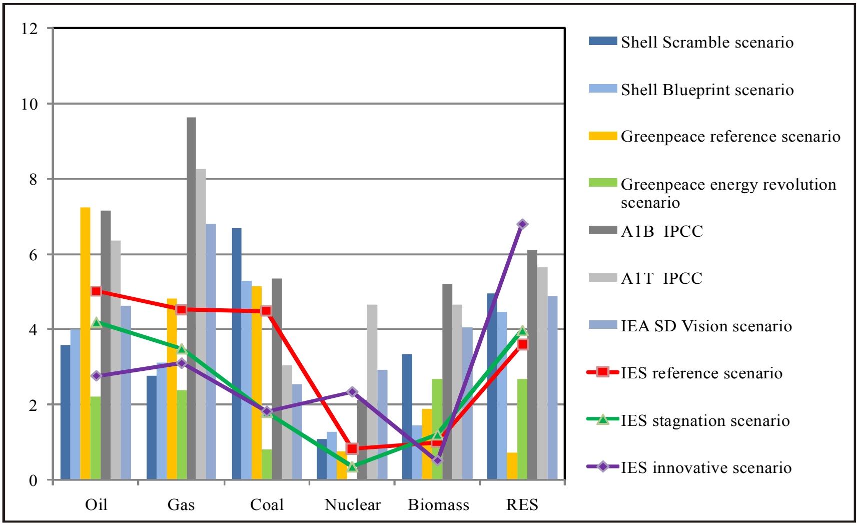
In terms of structure of consumption of primary energy, the reference scenario suggested by us is quite in the tideway of other scenarios, but it is distinct in a high share of oil. The stagnation scenario differs by lower shares of coal and nuclear energy and increased share of RES as compared to most other forecasts. At last, the innovative scenario suggested by us assumes rather a high share of RES and nuclear energy, and low biomass share. This scenario has no obvious analogues among scenarios of other research organisations.

In terms of absolute consumption volumes all the forecasts assume termination of the consumption growth trend for all kinds of fuel and energy resources (Fig. 31). IPCC scenarios differ by very high total amounts of energy consumption. In order for these scenarios to come true, annual oil consumption growth in 2005-2050 should be 1.0-1.3%, and natural gas consumption growth, 2.7-3.0%, which equals or is a little higher than growth rates of 2000-2005 being record ones since 1970. The probability of maintenance of such rates throughout 50 years, taking into account periodic crises, is rather low. Conservative estimates of Shell and IEA predict that by 2050 oil consumption will change no more than by 15% and will amount to 3.6-4.6 bln toe. High energy consumption level in IPCC's and IEA's scenarios also requires high volumes of RES and biomass consumption.



Source: *GU IES calculations using data of [10,11,16,17,19].*

Fig. 31. ***World consumption of primary energy in 2050, bln toe***

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Estimations of the coal and nuclear power industry prospects sharply differ depending on the scenario as these energy sources 1) unlike oil, have alternatives, 2) are exposed to criticism from the ecological point of view, 3) the future of the nuclear power industry depends on creation of a new technological platform – fast reactors and closed nuclear fuel cycle.

Shell scenarios and A1B scenario stipulate two fold growth of the coal energy sector, from 2.9 to 5.9-6.3 bln toe, while the nuclear power industry according to Shell scenarios will increase less than 2 times. On the contrary, A1B, A1T and IEA scenarios assume a sharp growth of the nuclear power industry (3-7 times, from 0.7 to 2.1-4.7 bln toe). The last figure requires year-on-year increase rates of 4.4%, which is possible only subject to implementation of the global nuclear power plant construction program surpassing in scales the programs of the 1980s, which is highly unlikely.

Thus, the consensus forecast of the world energy sector future by 2050 seems to be the following:

1. Oil consumption will change by 10-15% as compared to the current level (4.0 bln toe), both growth, and decrease being possible.

2. Natural gas consumption will increase 2-2.5 times to 5-6 bln toe that will sharply increase its importance within the energy sector, economy and policy.

3. Coal consumption may grow 2 times to 6 bln toe because of growth in demand for energy carriers in developing countries, but also may decrease due to toughening of ecological restrictions.

4. Biomass and RES consumption will increase 3-4 times to 2.5-3.0 bln toe for each of them.

5. Nuclear power industry prospects depend first of all on political solutions, but as of today, the forecast of 1.5-2.5-times nuclear energy production growth seems to be the most realistic.

6. As a consequence, by 2050 the structure of the world energy sector will become much more diversified. Total energy consumption will amount to 19-23 bln toe. It should be emphasised that these estimations refer to the consensus forecast of several western research organisations within the framework of the reference development path.

The reference scenario suggested by us assumes a moderate oil, natural gas and coal consumption growth and high RES consumption growth rates. The stagnation scenario anticipates essential decrease in

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consumption of coal and nuclear energy, stabilisation of oil consumption, and a moderate natural gas consumption growth. RES consumption growth approximately corresponds to the reference scenario (increased RES share is compensated by a lowered energy consumption). At last, the innovative scenario suggested by us involves particularly sharp growth of RES and nuclear energy production at a moderate growth of natural gas consumption and a recession of consumption of other kinds of fuel.

Our scenarios contemplate essentially smaller potential of fossil fuel consumption growth than scenarios of other research organisations, even the reference scenarios. We do not expect any sharp growth in demand for any kind of fossil fuel. There is a high uncertainty in the nuclear power industry: both growth, and recession are possible. On the contrary, we assess the renewable energy growth prospects substantially higher than most other researchers. However, the biomass consumption growth potential seems to be rather limited. Thus, the period of a large-scale energy consumption growth is coming to the end, and the transition to a new energy civilisation appears to us inevitable.

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CONCLUSION
RISKS AND OPPORTUNITIES FOR RUSSIA

The world energy sector development scenarios considered in this publication create for Russia both substantial risks, and new possibilities. In the reference scenario the set of risks will be conventional: competitive struggle in the world energy markets, geopolitical rivalry for control over production regions and ways of transportation of energy carriers, threats to the national sovereignty, terrorism and local conflicts, technogenic accidents, risks of technological backwardness of the Russian energy sector from the world level, moral and physical ageing of equipment. These risks lay in the field of the state energy policy and are being overcome to some extent. Besides, energy carriers export extension possibilities (in particular, to the Asian countries) factored-in in this scenario, may be implemented.

But stagnation and innovative scenarios comprise fundamentally new challenges which are hardly taken into account in the current state energy policy. In the stagnation scenario this is a challenge of climatic changes and climatic policy. Russia has not adopted yet sufficient measures to switch to carbon-free energy sector, which makes its positions within the world climate regulation system (emission quota system, penalties for exceeding quotas, decrease in export of fossil fuel, eventual tariff and non-tariff restrictions on deliveries of carbon-intensive goods, etc.) rather vulnerable. On the other hand, Russia almost does not use the potential of carbon markets, in particular, that of joint projects within the framework of Kyoto Protocol. The industry of renewable energy sources, energy services, and energy saving is being developed quite slowly in Russia, despite their immense market potential.

At last, the innovative scenario creates an extremely serious risk of a deep technological inferiority. Energy sector development in Russia and state policy in this area, including Energy Strategy of Russia for the period up to 2030, are in the spirit of the industrial-epoch energy sector and are focussed on extension of production of fossil fuel and power generation capacities. Insufficient attention is given to key trends in creation of the new-type energy sector – "smart grids", energy consumption management and energy information systems, technological energy saving, energy supply decentralisation. Meanwhile the innovative potential of Russia make it possible to use opportunities of this scenario for a radical improvement of efficiency of the energy sector and the national economy as a whole.

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To cope with the challenges of the future and to realise its inherent opportunities, the state energy policy shall be adjusted and focused on creation of the energy sector of post-industrial type. For this purpose it is necessary, on the one hand, to restrict branch lobbyism on the part of industrial energy sector branches, and on the other hand, to create favorable conditions for the development of new energy sector trends.

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