The Energy Research Institute of the Russian Academy of Sciences
SKOLKOVO Energy Centre, Moscow School of Management SKOLKOVO

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ИНЭИ РАН

# GLOBAL AND RUSSIAN ENERGY OUTLOOK 2019

Moscow 2019

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Moscow 2019

THE OUTLOOK WAS PREPARED BY:

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This document presents the results of a study involving the long-term forecasting of the world's energy markets and calculations carried out using the SCANER information modelling system. It presents a comprehensive assessment of trends in the development of the energy sector – globally, regionally, and nationally – including volumes of consumption, production, processing, energy trading, prices, the parameters of competition, the dynamics of the commissioning of new facilities, and volumes of $CO_2$ emissions. Three forecast scenarios – Conservative, Innovative and Energy Transition – reflect key uncertainties in the development of the energy sector. The development of the Russian energy sector is also examined, taking into account the impact of the situation in foreign markets.

The prospects for energy markets are analysed in detail, taking into account economic, demographic, technological, political, climatic, and other factors, and the reaction of markets and key players to these factors is examined.

The Outlook is intended for those involved in research and business, as well as for government officials engaged in the development of energy and the economy, and may be used for educational purposes.

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# MAIN CONCLUSIONS

- The overall direction in which the world energy sector is developing is already visible: influenced by the changes in the energy policy and the development of new technologies, the world is entering the 4th energy transition phase, characterised by the widespread use of renewable energy sources and displacement of fossil fuels. However, the pace of these changes and the speed of transition are associated with high uncertainty.
- Global primary energy consumption growth will slow down significantly by 2040, mainly due to energy efficiency.
- Rapid development of renewable energy will allow RES to provide 35-50% of world electricity production and 19-25% of total energy consumption by 2040. Of the fossil fuels, only gas will be able to increase its share in the global energy mix from 22% to 24-26%. Coal will reduce its share from 28% to 19-23%.
- The world will not be able to see the widely announced peaks of fossil fuel production due to exhaustion of reserves. Peaks do arrive, but not for the reasons of limitations on the production side, but rather on the demand side. Oil consumption peak is already approaching following the coal consumption peak.
- The oil market will lose from 870 to 1800 million tonnes of potential consumption due to growing vehicle efficiency and the wider utilization of transport on alternative energy sources. Electric transport is becoming the main alternative.
- Concerns (or dreams) of high prices for oil, gas and coal are a thing of the past. The world has entered an era of widespread technological and inter-fuel competition. A multitude of promising competing solutions are appearing in all consumption areas, ready to promptly offer an alternative and recapture the market should the dominant fuel rise in price.
- Electric cars are squeezing the oil market, but are giving a new impetus to electricity demand. This opens up additional opportunities for its production sources.
- Electric power is rapidly changing. Decentralized generation is developing rapidly, consumers are transformed from passive into active players of the system, electricity storage solutions are being actively sought and a transformation of electricity markets is beginning.
- Russia's budget revenues from energy exports will inevitably be declining. Growing gas exports will partially offset a decrease in the exports of liquid hydrocarbons. But a transition to more difficult conditions of hydrocarbon production will inevitably lead to the need to extend the beneficial tax regime and reduce tax burden, resulting in a reduction in budget revenues.
- The energy sector transition and the reduction in export budget revenues are leading to a reduction in the contribution of the oil and gas sector, which is an essential component of the Russian economy. But it is the very energy sector and the transformations taking place in it that can provide Russia with a new impetus for development and GDP growth. This should be done by realising the enormous potential for energy saving and creating additional demand for industrial products for the modernisation of the energy sector. This requires a strong economic and energy policy which would help Russia adapt to the Energy Transition. However, the available window of opportunity is literally limited to 7-10 years.

# SECTION 1

## GLOBAL ENERGY:

## AT THE THRESHOLD OF AN ENERGY TRANSITION

# INTRODUCTION

In the two and a half years since the publication of the last "Outlook", it has become evident that the global energy system has entered another period of radical shifts, under the pressure of the critical mass of technological innovation technologies and changing state energy policies. This creates enormous uncertainty, well evidenced by the wide range of projected key performance indicators characterising the future of the global energy sector. (Figure 1.1-1.7)

## COMPARISON OF THE MAIN PERFORMANCE INDICATORS WITH OTHER FORECASTS

**Figure 1.1 – Global primary energy consumption in 2040, mtoe**

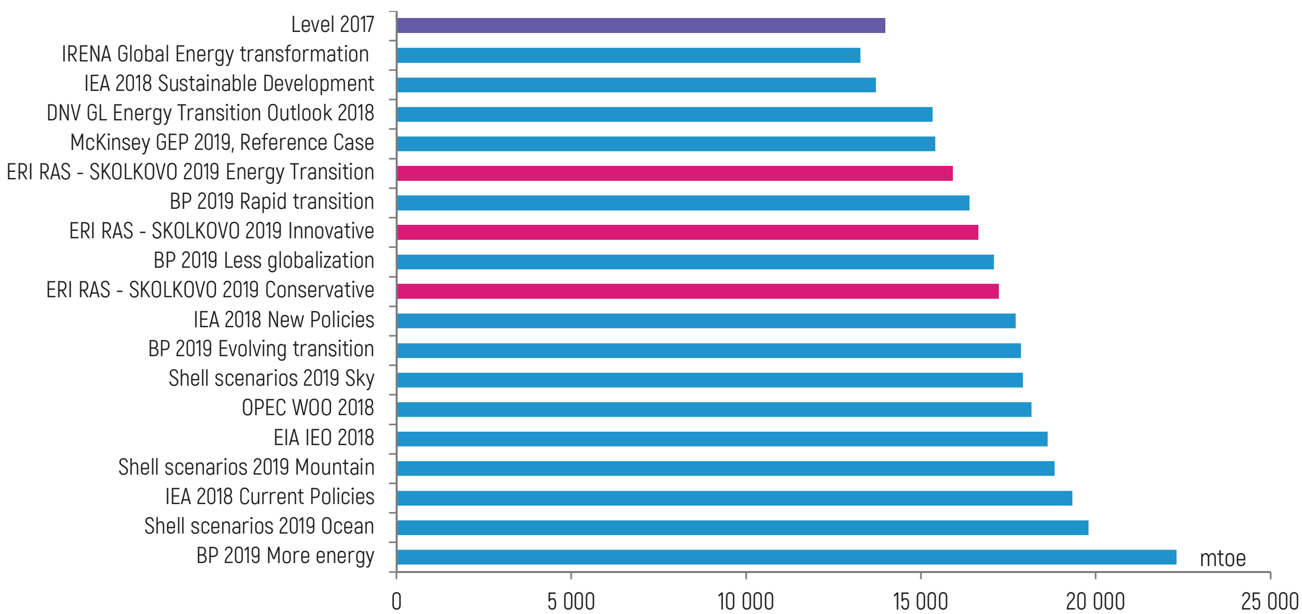
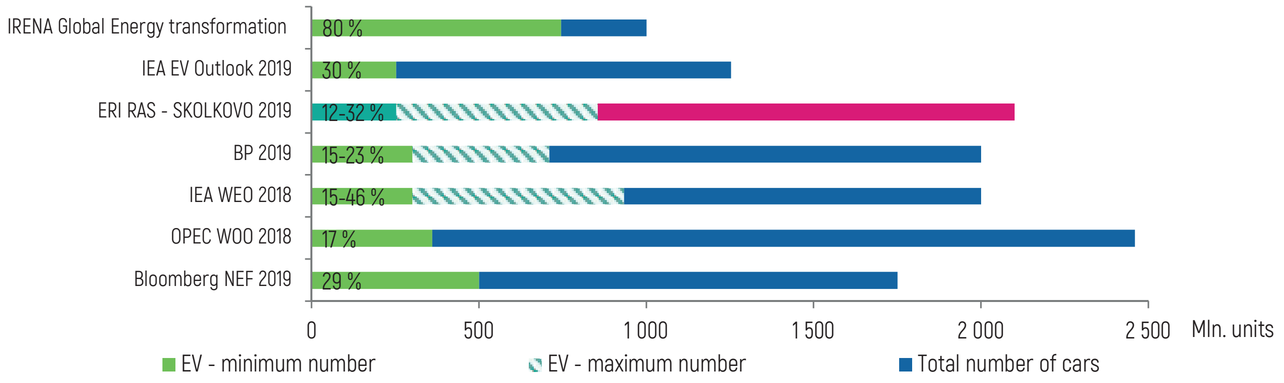


**Figure 1.2 – Vehicle fleet size and the number of electric vehicles, by 2040, mln. units, the share of EV in the vehicle fleet**

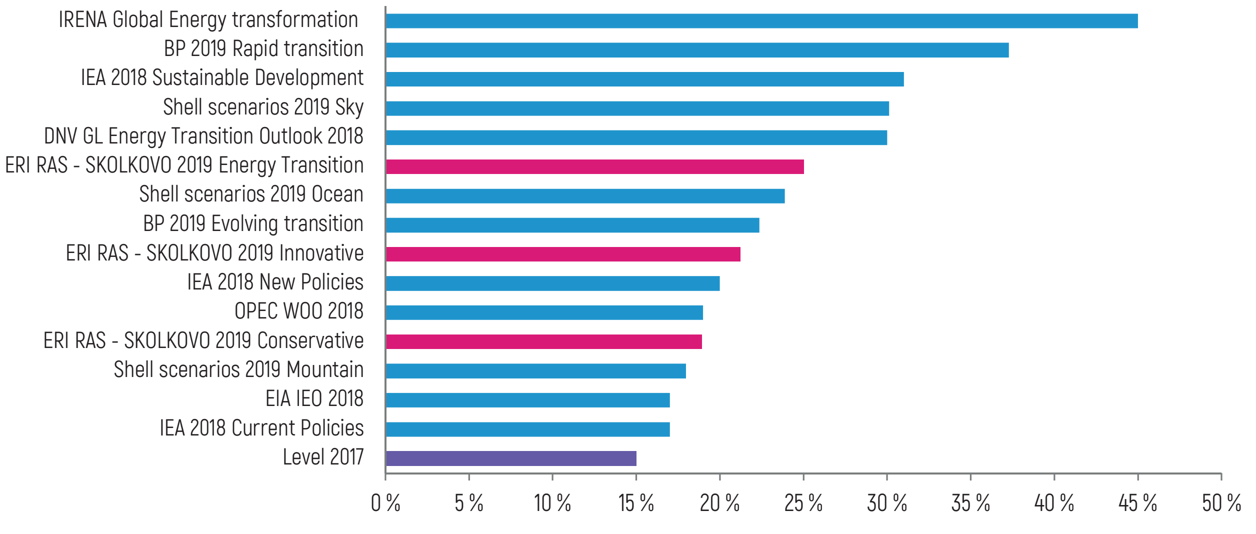



**The Conservative scenario** predicts that the current situation will remain the same both in terms of technological development and the government policy – this scenario assumes that the current trends will continue.

**The Innovative development (Innovative)** scenario assumes that technological advancements will accelerate and, most importantly, that barriers to the international transfer of technologies will be lifted. This scenario assumes that national priorities which have already been set in relation to promoting RES, supporting EV and fostering energy efficiency will be strengthened further.

**Within the Energy Transition scenario**, scientific and technological progress will accelerate further and all countries will focus on decarbonisation targets. Unlike the Innovative scenario, carbon neutral or low carbon technologies always take priority within this scenario.

**Figure 1.3 – The share of RES* in global energy consumption in 2017 and 2040, %**




* RES include solar, wind and hydro power, including large and small hydroelectric power plants, traditional and modern bio-mass

The methodology of Outlook-2019 is based on a model assessment of a wide scenario range of options for the development of world energy, depending on the speed of technology development and transfer and state energy policy.

**Figure 1.4 – The share of RES in global electricity generation in 2017 and 2040, %**

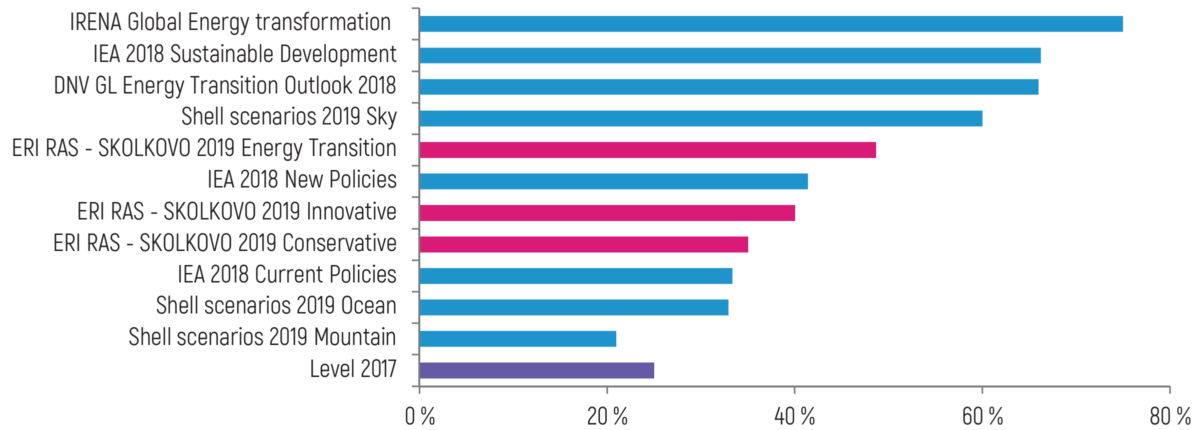
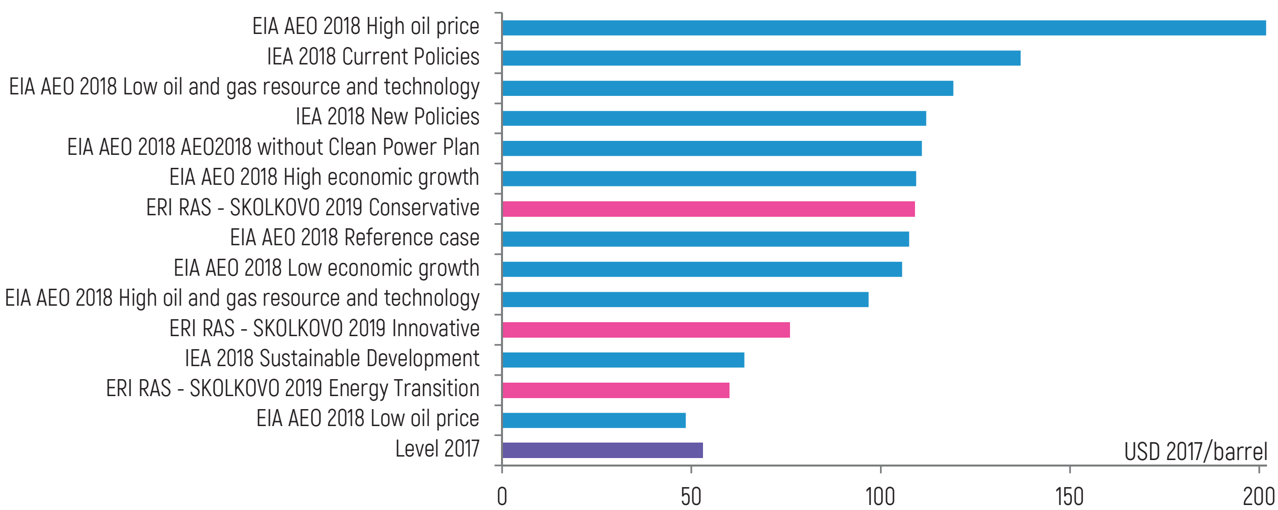



**Figure 1.5 – Oil prices in 2040, US Dollars 2016/barrel**




Outlook 2019 is an independent joint project of the Energy Research Institute of the Russian Academy of Sciences and the Energy Centre of the Moscow School of Management SKOLKOVO. It aims to develop an unbiased, balanced look at various options for the development of the global energy sector, to evaluate them quantitatively, including the impact on the Russian fuel and energy complex and the economy, as well as to formulate the main challenges for the Russian Federation and possible options for adapting to changes. As usual, the "Outlook" was not commissioned or financed externally, which ensures its complete independence from the interests of any stakeholders.

**Figure 1.6 – Timeline for passing global peak oil demand according to the scenarios, mtoe**

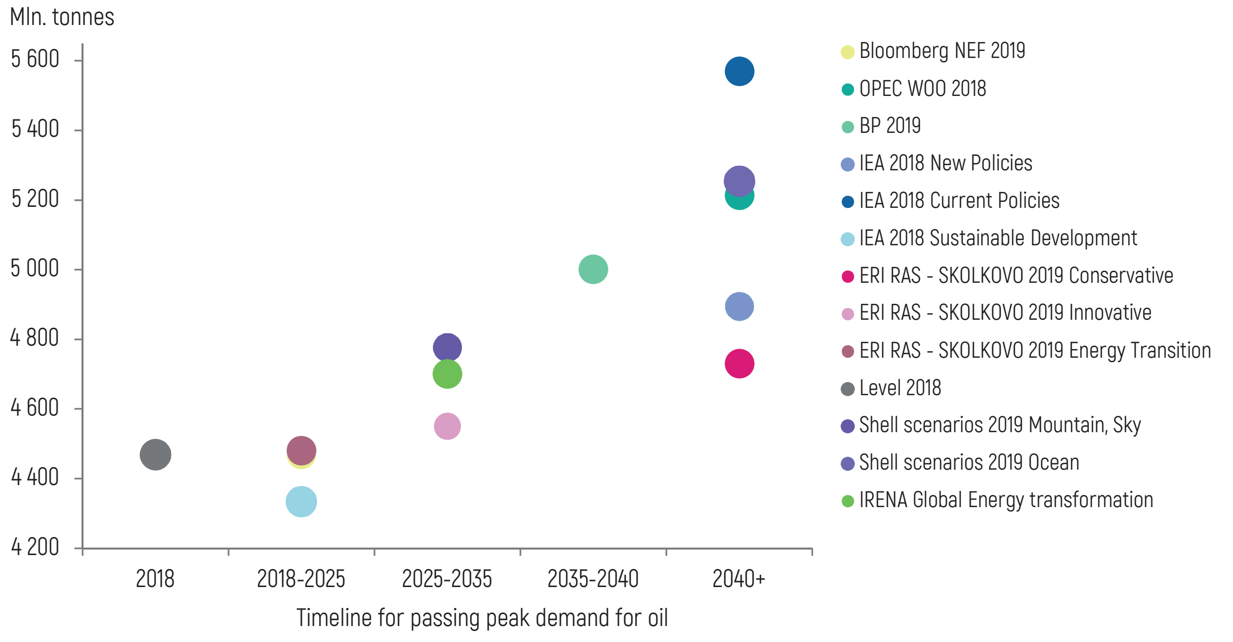
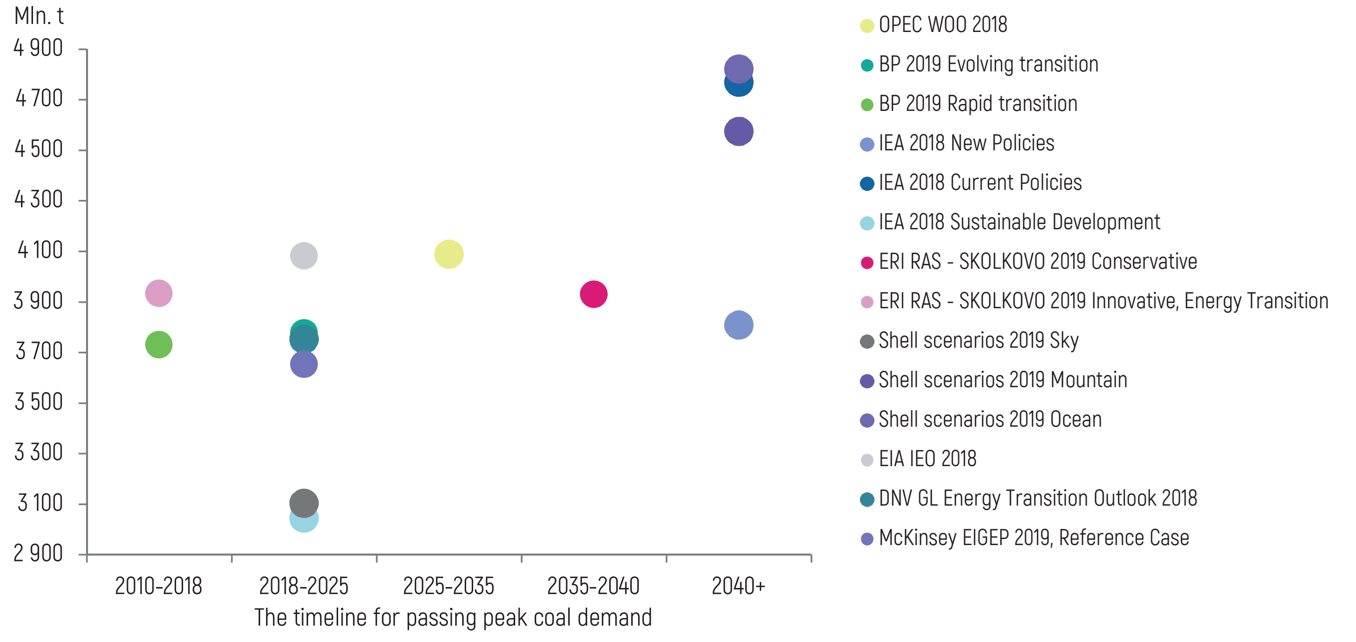



**Figure 1.7 – Timeline for passing global peak coal demand according to the scenarios, mtce**




Sources of Figures 1.1-1.7: IEA, IRENA, ERI RAS- SKOLKOVO, OPEC, Bloomberg, BP, Shell, DNL GL, McKinsey, The US Department of Energy

### Table 1.1 – The main forecast parameters within the "Outlook 2019" scenarios

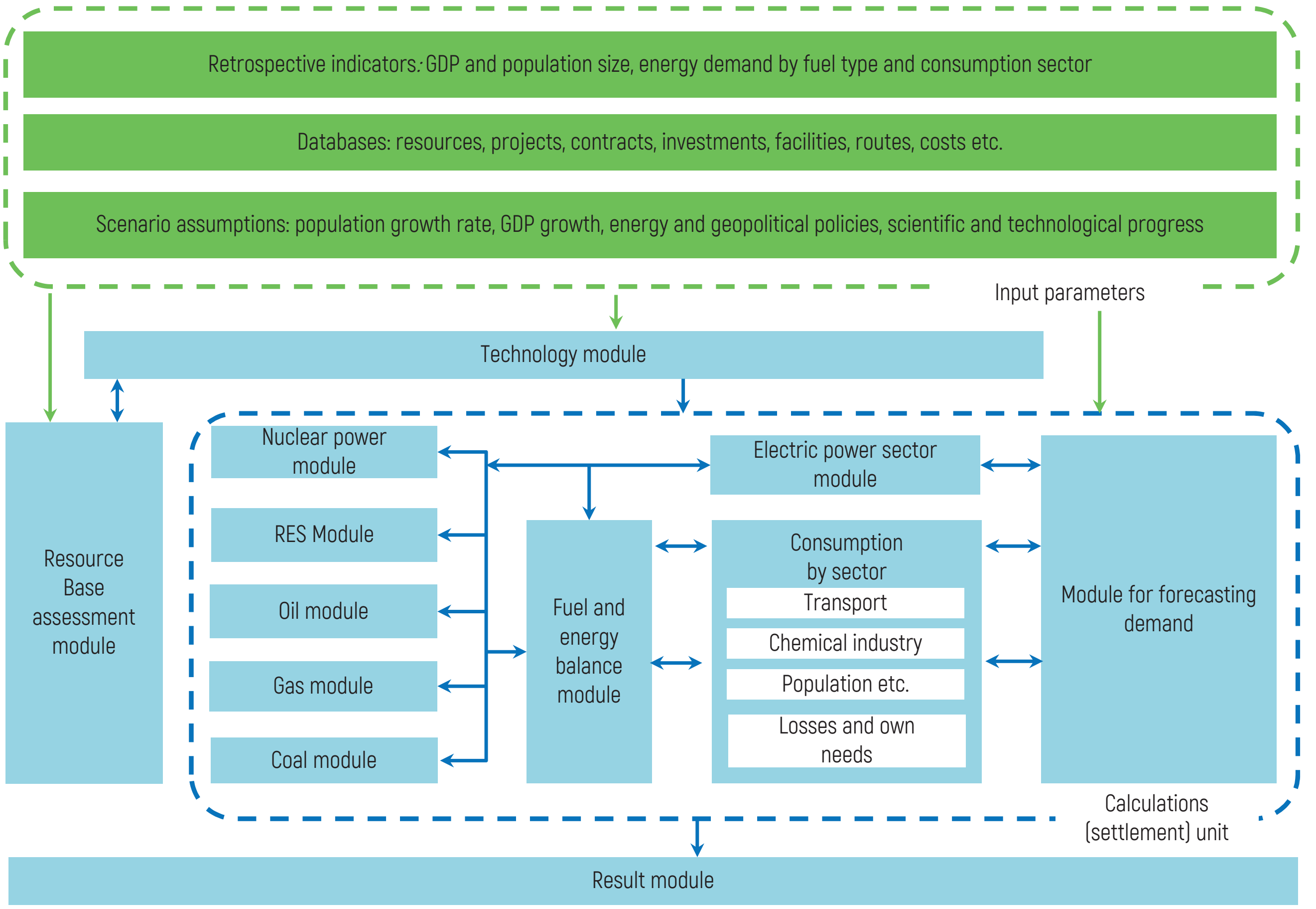
| The main forecast parameters | 2015 | 2040 **Conservative** (technology development and transfer and the current state policy remain the same) | 2040 **Innovative** (technology development and transfer accelerate; the current state policy remains unchanged) | 2040 **Energy transition** (technology development and transfer accelerate with the energy policies of all countries focusing on decarbonisation) |
|---|---|---|---|---|
| GLOBALLY | | | | |
| Primary energy consumption, mtoe | 13578 | 17205 | 16604 | 15904 |
| GDP energy intensity, toe/thousand USD 2017 | 0,98 | 0,70 | 0,69 | 0,66 |
| EV fleet, mln. units | 0,8 | 251 | 427 | 603 |
| The share of all RES in the electricity sector, % | 23 | 35 | 40 | 49 |
| The share of solar, wind, geothermal, tidal and wave energy in primary energy consumption, % | 5 | 18 | 22 | 30 |
| The share of all RES in primary energy consumption, % | 14 | 19 | 21 | 25 |
| The share of solar, wind, geothermal, tidal and wave energy in primary energy consumption, % | 1 | 5 | 7 | 9 |
| Petroleum product consumption, mtoe | 4267 | 4729 | 4212 | 3725 |
| Gas consumption, bcm | 3571 | 5110 | 5283 | 4968 |
| Coal consumption, mtce | 5484 | 5621 | 4846 | 4374 |
| Oil prices, USD 2017/barrel | 54 | 109 | 76 | 60 |
| Gas prices in Europe, USD 2017/thousand cm (2030 in brackets) | 253 | 318 (277) | 327 (291) | 289 (268) |
| Gas prices in Asia (China), USD 2017/thousand cm (2030 in brackets) | 299 | 409 (352) | 420 (359) | 386 (341) |
| $CO_2$ emissions, mln.tonnes | 31918 | 35261 | 32321 | 29372 |
| RUSSIA | | | | |
| GDP intensity, toe/thousand USD 2017 | 0,171 | 0,134 | 0,130 | 0,101 |
| Liquid hydrocarbons production, mln. tonnes | 534 | 485 | 457 | 412 |
| Gas exports, bcm | 215 | 307 | 354 | 297 |
| The share of all RES in the electricity sector, % | 17 | 15 | 16 | 21 |
| Gas prices (Moscow), USD 2017 | 69 | 71 | 84 | 137 |
| The share of the fuel and energy complex in GDP, % | 23 | 11 | 10 | 17 |
| The share of the fuel and energy complex in fiscal revenues, % | 26 | 15 | 12 | 20 |

Sources: ERI RAS, SKOLKOVO Energy Centre

As in previous years, the SCANER[1,2,3,4] information modelling system developed by the ERI RAS was used to prepare Outlook-2019. SCANER is a constantly evolving complex of optimisation and simulation models and databases describing the energy sector in 199 geographic hubs, 135 countries and groups of countries.

The global part of the model complex calculations is based on an iterative calculation along the entire production chain, with an economic and mathematical optimization of the fuel markets and taking into account technological indicators, as well as restrictions and stimulating mechanisms determined by the energy policy, in each segment (Fig. 1.8).

**Figure 1.8 – SCANER models for forecasting global energy sector development**



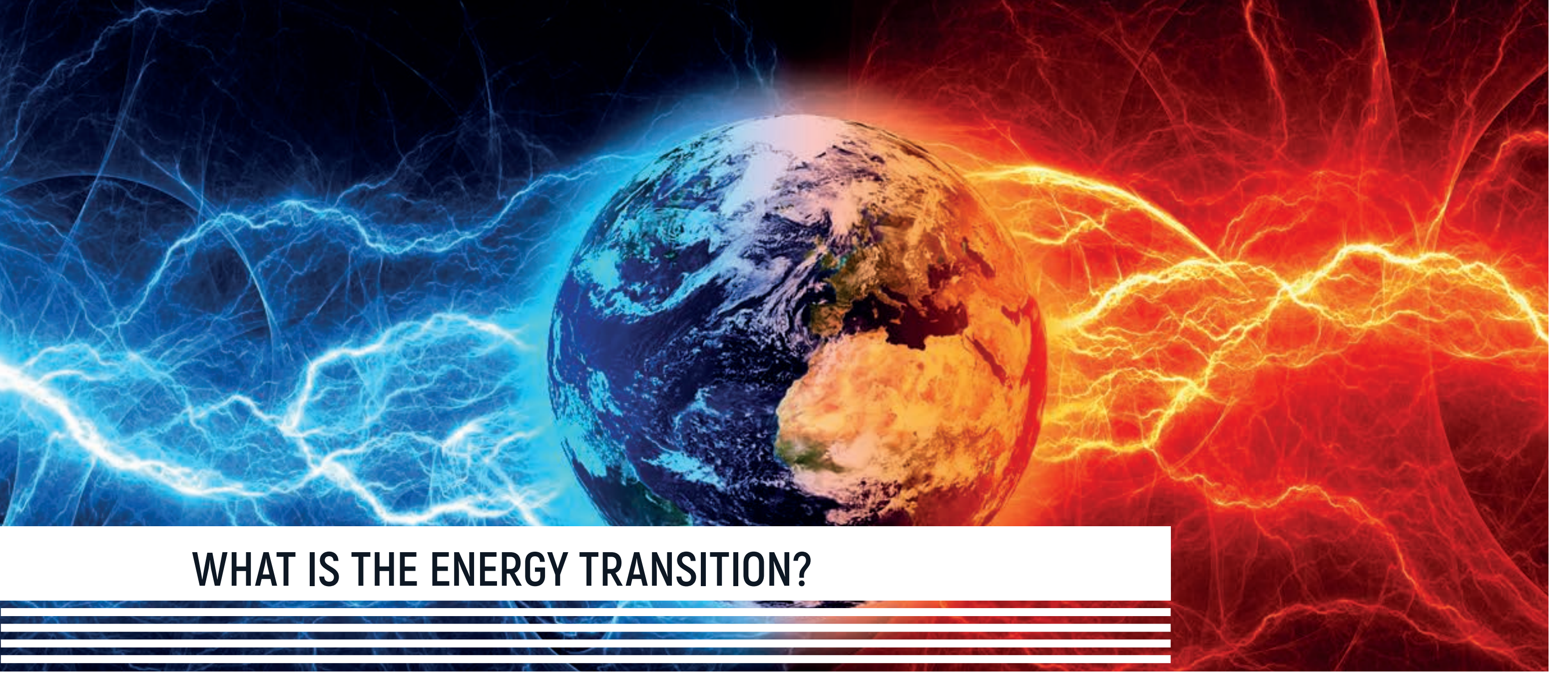

Source: ERI RAS

1 A.A. Makarov, F.V. Veselov, O.A. Eliseeva, V.A. Kulagin, T.A. Mitrova, S.P. Filippov, L.S. Plakitkina: Scaner. A super complex for active navigation in energy research, Moscow, ERI RAS 2011.

2 The evolution of global energy markets and its consequences for Russia, edited by A.A. Makarov, L.M. Grigoryev and T.A Mitrova, Moscow, ERI RAS – Analytical Centre of the Government of the RF, 2015.

3 A.A. Makarov, Systemic studies of the energy sector development, Publishing House of the Moscow Energy Institute 2015.

4 Prospects for the development of the global energy sector given the impact of technological progress, Moscow, ERI RAS 2019.

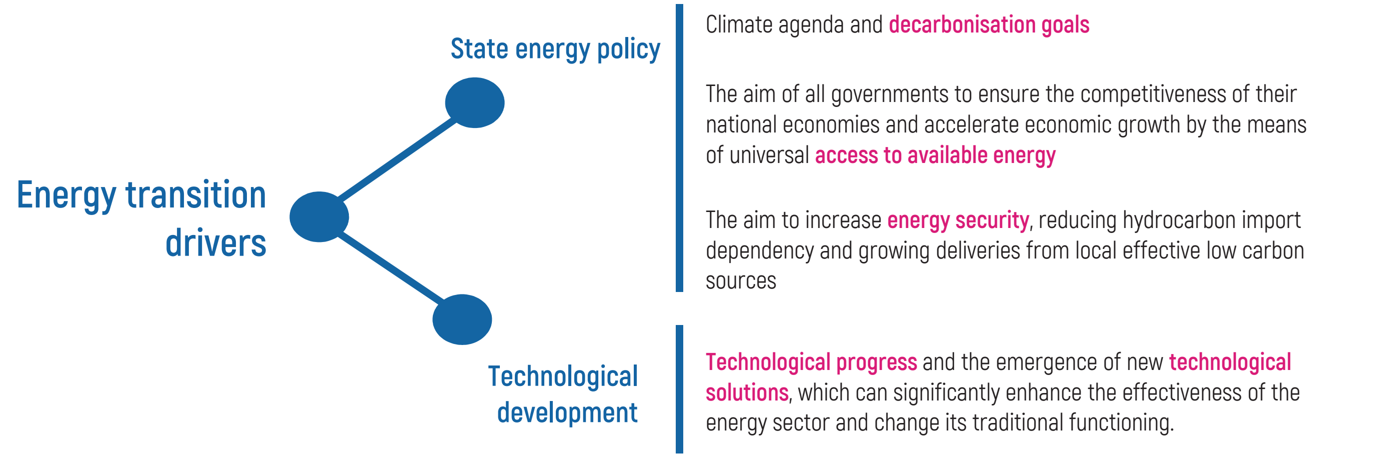


# WHAT IS THE ENERGY TRANSITION?

The global energy system has entered a new phase of a radical transformation.  Overall this set of shifts is usually called an Energy Transition; however, ideas about the rate of this transformation and the depth of this process vary considerably. The scenarios describing the transformation taking place at varying speeds will be discussed in the next section, and this section is devoted to analyzing the two main drivers of these transformations – the rapid development and the diffusion of new technologies and changes in energy policy (Fig. 1.9).

The overall direction in which the world energy sector is developing is already visible: influenced by the changes in the energy policy and the development of new technologies, **the world is entering the 4th energy transition phase**, characterised by the widespread use of renewable energy sources and displacement of fossil fuels. However, the pace of these changes and the speed of transition are associated with high uncertainty.

**Figure 1.9 – Energy Transition drivers**




Sources: ERI RAS, SKOLKOVO Energy Centre

The term «energy transition» was proposed by V. Smil and is used "to describe changes in the structure of primary energy consumption and a gradual transition from the existing energy supply scheme to a new state of the energy system"[5]. The current Energy Transition is another shift in a series of similar fundamental structural transformations of the global energy sector, this one being the fourth. From a quantitative point of view, the Energy Transition can be defined as a 10% reduction in the market share of a certain energy source over 10 years. The differentiation of energy transitions suggested by the same V.Smil[6] (Fig. 1.10) has now become classical and is the most well known:

- **The first energy transition** occurred from biomass to coal, when the share of coal in total primary energy consumption increased from 5% to 50% from 1840 to 1900. Coal became the primary energy source in the industrial world.
- **The second energy transition** is associated with the more extensive use of oil - its share increased from 3% in 1915 to 45% by 1975. The most intensive period of switching from coal to oil was in the years following the Second World War. The "motor age" and the dominance of oil began, ending in the late 1970s with an oil crisis.
- **The third energy transition** led to the widespread use of natural gas (its share increased from 3% in 1930 to 23% in 2017) due to partial displacement of both coal and oil.
- We are currently witnessing the start of **the fourth energy transition.** Over the past decade, important advances have been made in the commercialization of a wide range of unconventional energy resources and technologies – wind power plants, solar panels, batteries for electricity storage, etc. In 2017 the share of renewable energy sources (excluding hydro power) in total primary energy consumption was 3%, but it is growing rapidly.

In a narrower sense, the term "energy transition" is a translation of the German term "Energiewende". This term was first used in 1980 in a publication by the Ecological Institute (the Institute for Applied Ecology) of Germany, entitled "Growth and prosperity without oil and uranium"[7] and entered the international lexicon in the early 2010s, after the Fukushima Daiichi nuclear disaster. Energiewende, without a doubt, became an example for large-scale transformations around the world as one of the most ambitious projects for decarbonizing the energy sector within an entire country (reducing greenhouse gas emissions by 40% by 2020 and by 80-95% by 2050 from 1990 levels)[8,9,10]. This paper proved the possibility of economic growth and a sustainable energy supply without the use of nuclear power - due to renewable energy and energy efficiency.

[5] Vaclav Smil, Energy Transitions: History, Requirements, Prospects (Santa Barbara, Calif.: Praeger, 2010), vii. For alternative definitions, see Benjamin K. Sovacool, "How Long Will It Take? Conceptualizing the Temporal Dynamics of Energy Transitions", Energy Research & Social Science, vol. 13, 2016, 202-203.

[6] Smil, Vaclav. Energy and Civilization: a History. MIT Press, 2018.

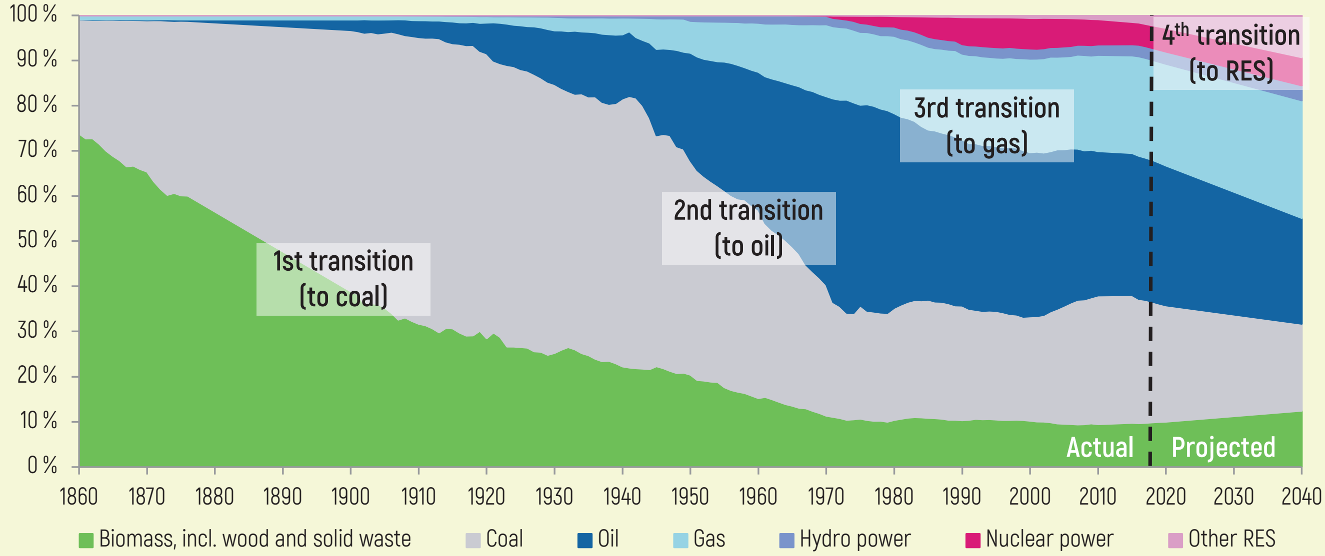
[7] Krause, Bossel, Müller-Reißmann: Energiewende – Wachstum und Wohlstand ohne Erdöl und Uran, S. Fischer Verlag 1980.

[8] Federal Ministry of Economics and Technology, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety: Energy Concept for an Environmentally Sound, Reliable and Affordable Energy Supply. Organization for Security and Co-operation in Europe. URL: https://www.osce.org/eea/101047 (2013). Access date: 06.05.2019.

[9] Trüby J., Schiffer H.-W.: A review of the German energy transition: taking stock, looking ahead, and drawing conclusions for the Middle East and North Africa. Energy Transitions 2, 1-14. URL: https://doi.org/10.1007/s41825-018-0010-2 (2018) (Access date: 06.05.2019).

[10] Hager C., Stefes C.H.: Germany's Energy Transition: A Comparative Perspective. - Palgrave Macmillan, New York, 2016.

**Figure 1.10 – Structural change in global total primary energy consumption by fuel type in 1860-2040 and the four energy transitions**




Sources: ERI RAS, SKOLKOVO Energy Centre

A qualitatively new factor – decarbonisation and combating global climate change - has become the main driver in the fourth energy transition. This is unlike the previous three stages, when economic attractiveness of new energy sources prompted changes.


# NEW ENERGY POLICY PRIORITIES: Decarbonisation, air quality and a transition to low carbon energy sources

National energy policies have a great impact on the development of the global energy sector. Governments are able to significantly stimulate or, conversely, discourage consumption of a particular type of fuel and manage energy demand by applying fiscal instruments (taxes, subsidies), setting industrial standards for fuel and vehicles, as well as enforcing specific regulatory measures. At the same time, state support mechanisms often transpire to be such a powerful driver for changing the energy mix that they outweigh objective economic indicators.

Any government seeks to find the optimal answer to three requests from the society to the fuel and energy complex (the so called "Energy Trilemma" as defined by the World Energy Council):

- to ensure **availability of energy** in sufficient quantities and at reasonable prices;
- to ensure the **reliability and safety** of energy supply;
- to ensure its **environmental friendliness** (the requirement to minimize the anthropogenic impact of energy systems on the environment).

In the last decade, environmental challenges have become clearly prevalent over other issues in an increasing number of countries. The **decarbonisation** policy aimed at cutting greenhouse gas emissions in the global economy in the fight against climate change is the most important driver of the global Energy Transition. The proposals of the UN Climate Conference COP-21 in December 2015, which were largely focused on decarbonisation of the electricity sector, have become one of the most important symbols of state-level review of energy policies. Of the 162 national plans adopted, 106 place special emphasis on the accelerated development of renewable energy and 74 contain specific targets in relation to the use of renewable energy for generation, heating and cooling.

According to the World Bank (Fig. 1.11), by 2018, 46 national and 28 subnational jurisdictions (cities, states, and subnational regions) are putting a price on carbon[11].

[11] The $CO_2$ emissions trading system (greenhouse gas emission allowance trading system) is a market tool for reducing greenhouse gas emissions into the atmosphere.

However, in a number of countries, primarily in the developing countries of Asia, the priority now is not so much the climate agenda as the issues of local air quality, especially in large cities, where it is indeed becoming a serious social problem (Fig. 1.12).

In view of both decarbonisation policies and the fight against local atmospheric pollution, the interest of governments in renewable energy sources (RES) is growing.

Besides, RES create additional advantages: increasing energy security by reducing energy import dependency (for importing countries), lowering hydrocarbon consumption in the domestic market and freeing these resources for export (for exporting countries), the possibility of a cost-effective energy supply to areas cut off from centralized energy supply.

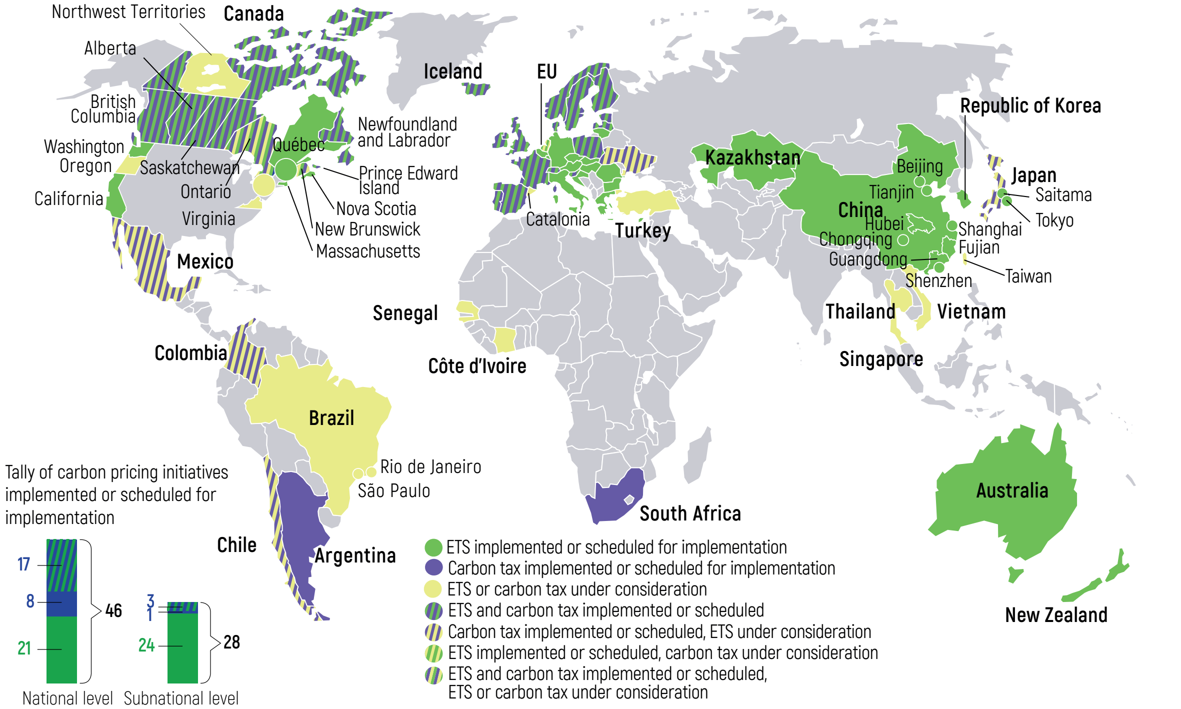
The practice has already confirmed the high potential impact of "carbon charges" on the energy mix: for example, in 2013 the UK introduced an enhanced carbon pricing system (compared to the European) - Carbon Price Floor combined with the Large Combustion Plant Directive. Immediately after the introduction of this system, the share of coal generation in the national energy mix began shrinking drastically - from 40% in 2012 to just 7% in 2017. It should be noted that cost pressure of a carbon-free agenda strongly depends on the regulators' decisions. For example, following the 2008 crisis, the EU made decisions to increase permissible $CO_2$ emissions within the framework of the world's largest emissions trading system - the European Union Emission Trading System. As a result, the price of a tonne of $CO_2$ fell three-fold in just one year. However, in 2017, these resolutions were cancelled – prompting a fourfold increase in the price of carbon dioxide that year.

Prospects for the development of the global energy system substantially depend on the policy of China, the world's largest economy. In recent years, China has formulated and implemented a number of strategies aimed at tacking climate change, reducing emissions and facilitating the country's transition to a low-carbon economy. This policy responds to both global efforts to combat climate change and China's own need to restructure its economy and reform its production and consumption patterns.

In 2014, China issued a mandate for the national energy security strategy. This will create an "energy revolution" to radically change energy consumption, production, technology and management. The 12th plan identified obligatory targets for increasing forest coverage, reducing energy intensity and carbon dioxide emissions, and growing the share of non-fossil energy sources (nuclear, hydro power, solar, wind, biomass, and geothermal) in primary energy consumption by 2015. And the key objectives of the 13th Five-Year Plan (2015-2020) are as follows:

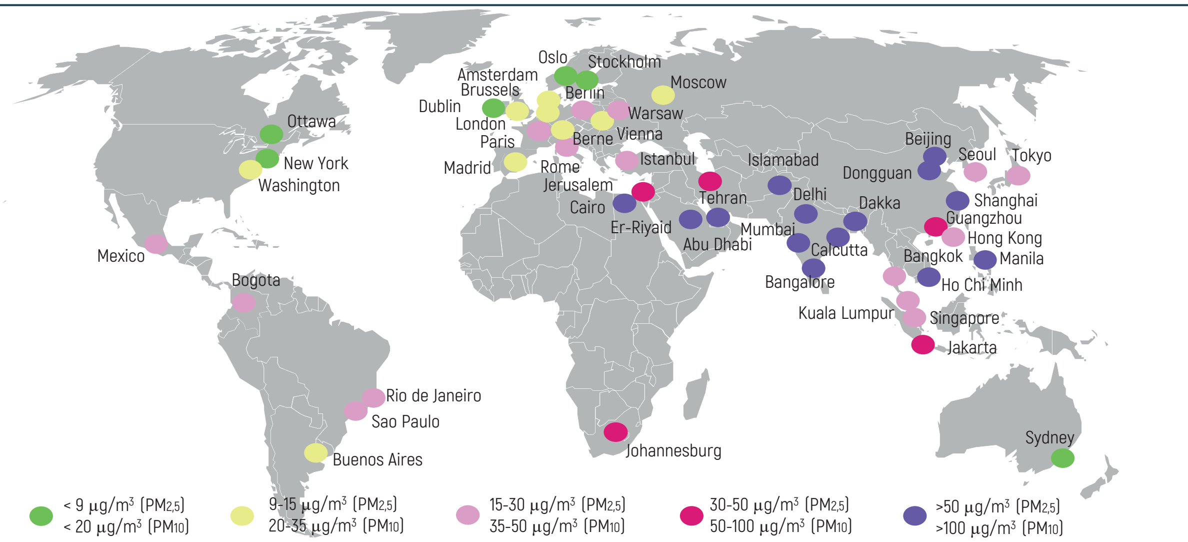
- to grow the share of non-fossil energy in total primary energy consumption by up to 15% by 2020 and to 20% by 2030
- to boost renewable energy installed capacity to 680 GW by 2020
- to close some coal production facilities which do not meet technical and environmental requirements (about 800 mln tonnes/year), and to deploy new improved facilities (about 500 mln tonnes/year).

## Figure 1.11 – Summary map of regional, national and subnational carbon pricing initiatives implemented, scheduled for implementation and under consideration (ETS and carbon tax)




Source: World Bank Group, State and Trends of Carbon Pricing 2019

## Figure 1.12 – The air quality index (AQI) in capitals and large cities of the 40 advanced economies, which form over 90% of the world GDP. *




* According to the WHO methodology, the "pollution" indicator is considered as the average daily content of harmful particles in the atmosphere of a city for a measured period of at least six months, air quality is shown as the worst indicator of PM10 and PM2.5.

Source: The World Health Organization, 2019

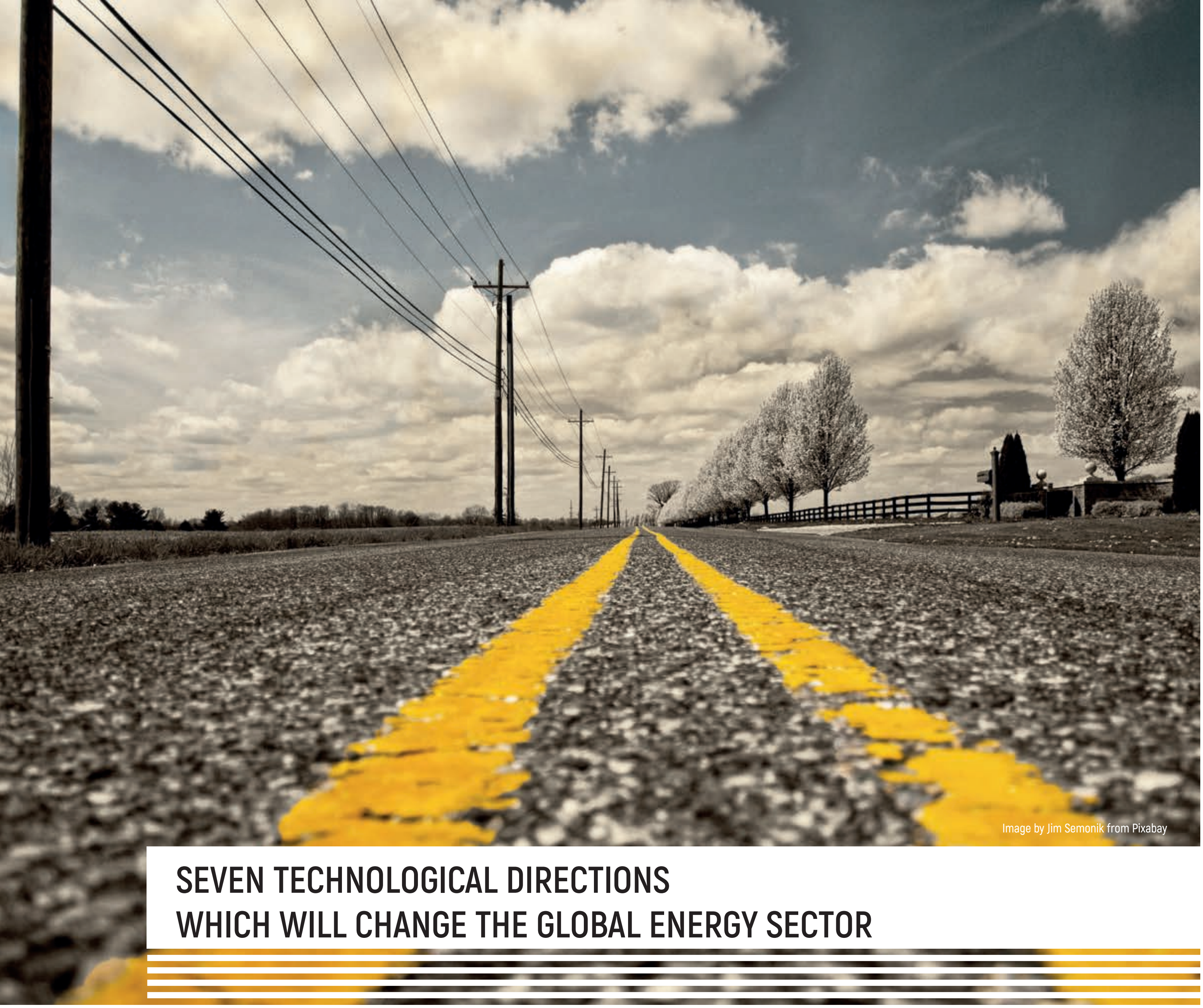


Image by Jim Semonik from Pixabay

# SEVEN TECHNOLOGICAL DIRECTIONS WHICH WILL CHANGE THE GLOBAL ENERGY SECTOR

Scientific and technological progress has always been the main driving force behind the development of anthropogenic energy (Fig. 1.13), ensuring the arrival of technological revolutions (for example, the invention of an internal combustion engine or the development of electric power) and major technological breakthroughs (among the latter examples, the development of shale oil and gas resources). The current Energy Transition is not associated with any technological revolution.  The accumulated critical mass of a whole complex of technological innovations both on the production and on the energy consumption side is prompting a gradual profound transformation of the entire energy sector.

> The current Energy Transition is not associated with any specific technological revolution.  The accumulated critical mass of a whole complex of technological innovations both on the production and on the energy consumption side is prompting a gradual profound transformation of the entire energy sector.

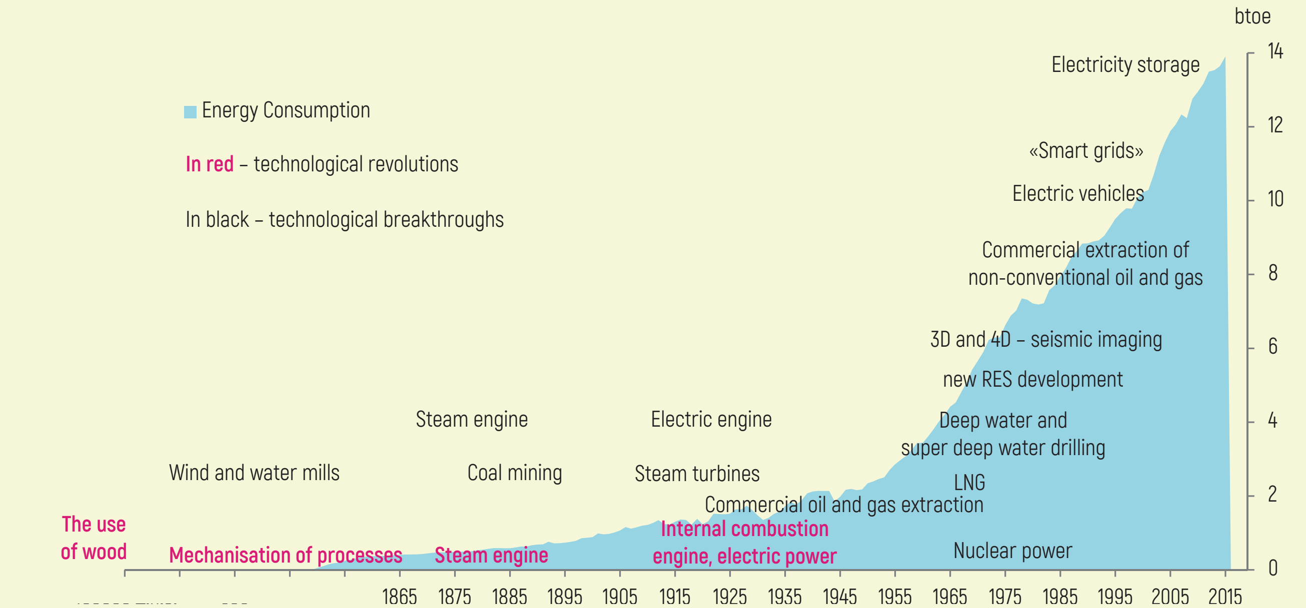
**A technological revolution:**

- enables to develop a new, usually more concentrated form of primary energy with a multi-fold expansion of the energy resource base
- provides the final energy of much higher value, radically improving production and life with a sharp increase in labour efficiency
- creates new energy and related markets

**A technological breakthrough:**

- Significantly expands an economically attractive resource base or ensures increased efficiency of the technologies used
- Leads to fundamental changes in the market conditions for the existing energy carriers

**Figure 1.13 – The history of technological revolutions and breakthroughs in man-made energy development**




Source: ERI RAS

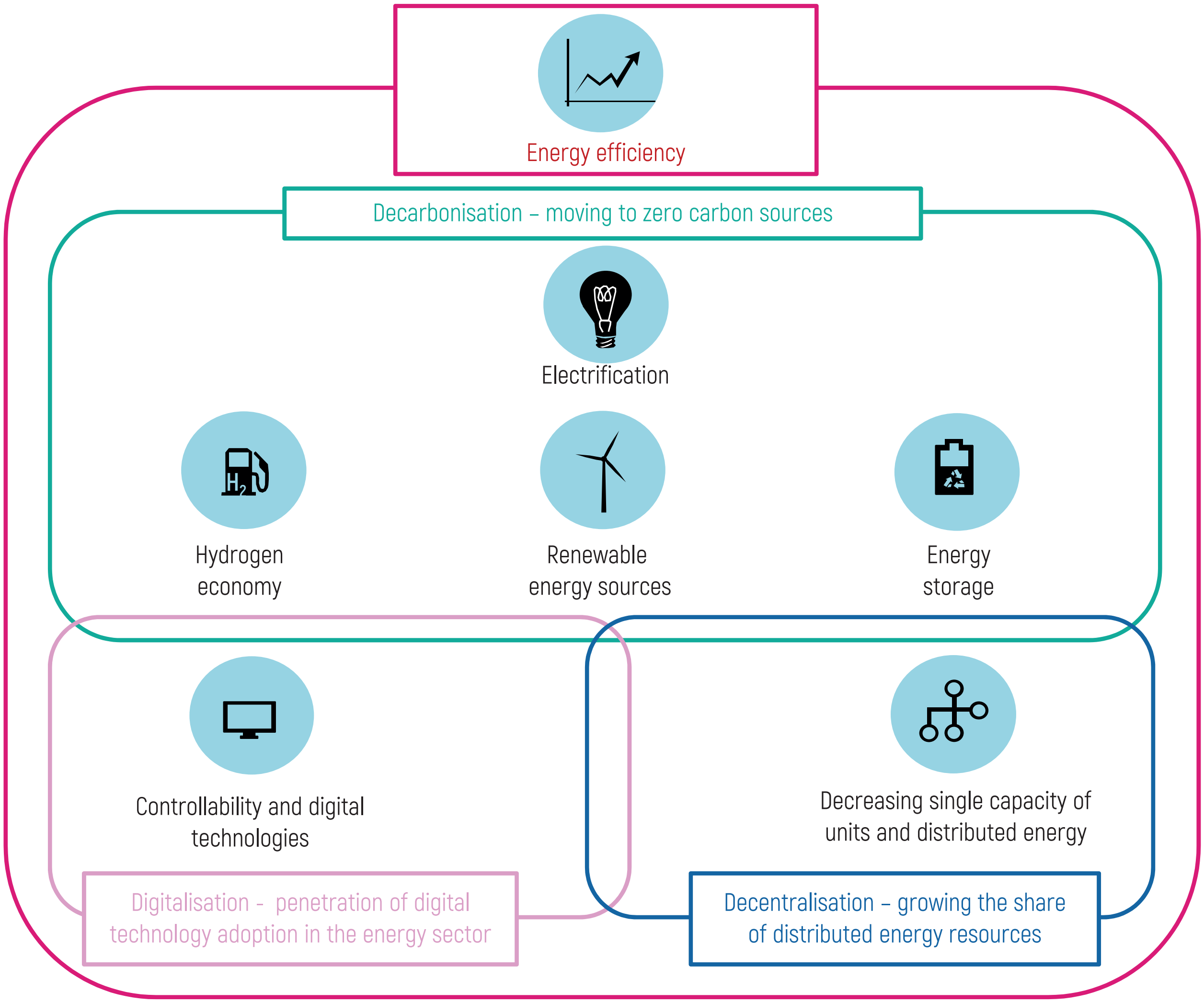
In the Oulook-2019, new technological revolutions, such as the development of cheap thermonuclear fusion, are not expected within any scenario. However, it assumes new technological breakthroughs based on those technologies that are already being tested: further reduction in the cost of renewable energy sources, electricity storage, development of digital and intelligent systems in the power industry, etc., which will provide the technological base for the Energy Transition.

From a technological point of view, the Energy Transition is a global transformation of energy systems encompassing four elements - energy efficiency and the so-called "three Ds"[12] - decarbonization, decentralization and digitalization. (Fig. 1.14).

[12] Di Silvestre M.-L. et al. How Decarbonization, Digitalization and Decentralization are changing key power infrastructures / Renewable and Sustainable Energy Reviews, Volume 93, October 2018.

These processes to a large extent complement and accelerate each other. Thus, reaching the goals for the production of carbon-free electricity is impossible without large-scale integration of renewable energy sources and energy storage systems. Widespread deployment of small renewable energy sources and accumulators, in turn, requires the development of distributed energy technologies of distributed energy and a qualitative leap in the construction and management of distribution grids. In this way decarbonisation accelerates decentralization. But managing such complex systems is only possible with the help of digital technologies - which is what determines the digitalization boom in the energy sector. Combined, these seven technological areas will form the core of the Energy Transition, contributing to an increase in the share of renewable energy sources and displacement of fossil fuels.

**Figure 1.14 – The main technological elements of the Energy Transition**




Source: SKOLKOVO Energy Centre

# 1. Increasing energy efficiency

Energy efficiency includes a vast group of the most diverse technologies which ensure increased energy efficiency, and plays a crucial role in the shifts occurring in global energy markets. These changes are taken into account within this forecast in the course of modelling. This is done via lowering the parameters for GDP energy intensity and per capita consumption in these sectors, as well as their electric intensity and per capita electricity consumption (Section 2, Fig. 2.2, 2.3). For the transport sector, this is done by reducing average specific fuel consumption across the fleet.

A slowdown in energy consumption growth is the main consequence of the introduction of the entire range of energy efficient technologies. As a result of increasing energy efficiency of consumers and of energy conversion, the world has an opportunity to stabilize primary energy consumption.

**Figure 1.15 – Technologies to increase energy efficiency in various sectors**

**Transport sector**

Increasing vehicle efficiency (reducing weight, using composite materials, enhancing aerodynamic performance, upgrading internal combustion engines (ICE), enhancing ICE and transmission efficiency, implementing digital control systems, vehicle hybridization)

**Industry**

Technologies aimed at increasing energy efficiency of industrial facilities, the use of secondary energy sources, electrification

**Residential and commercial sectors**

Technologies to increase energy efficiency of buildings (the use of new thermal insulation materials, novel architectural and design solutions in the design of residential and industrial buildings and constructions – «smart construction», active and passive houses, smart air conditioners and heating, the use of smart metrics and other measuring devices.

Technologies boosting efficiency of energy consumption.

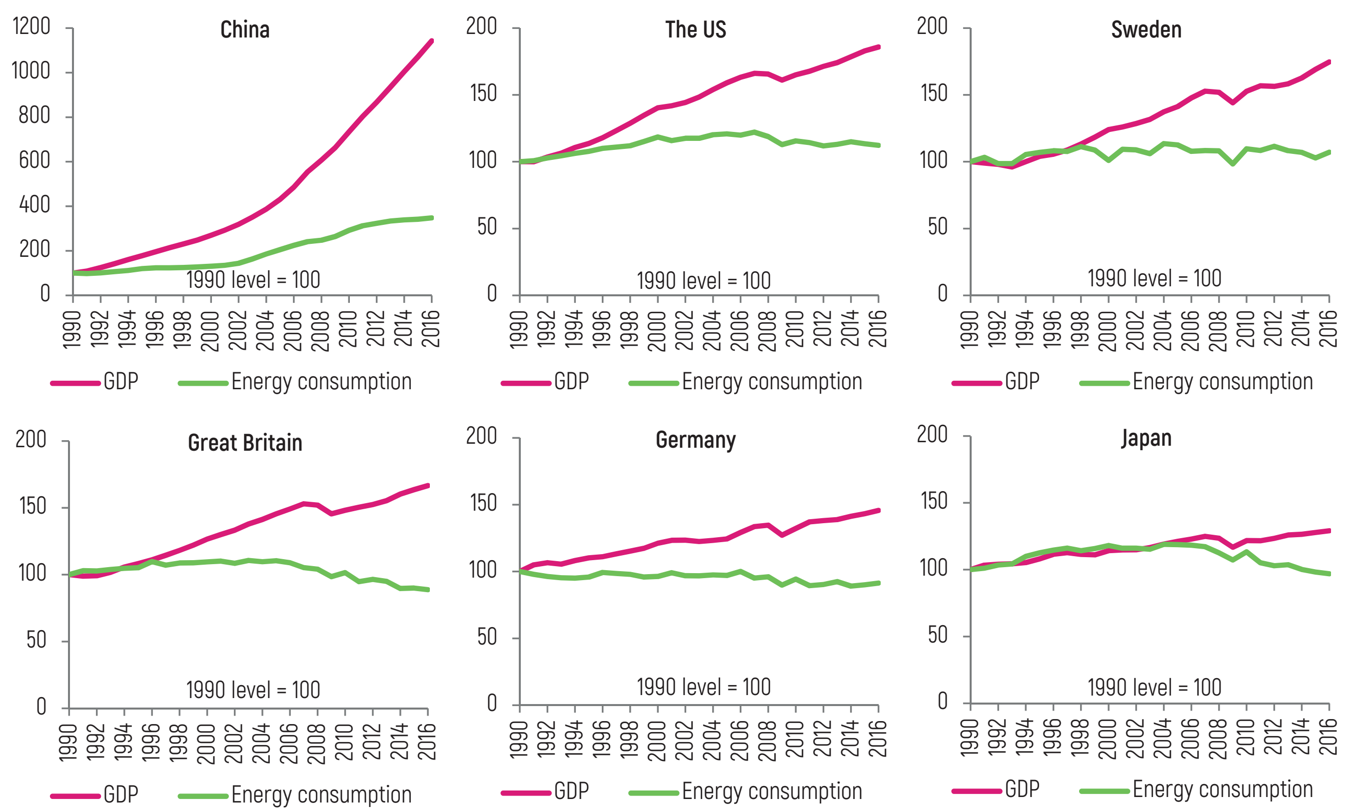
Sources: ERI RAS, SKOLKOVO Energy Centre

Despite the fact that no technological breakthroughs or, moreover, revolutions are expected to happen in relation to any of these technologies, cumulatively they produce a truly revolutionary effect, prompting world energy consumption to slow down significantly. Due to both structural change in the economy and progress in energy efficiency after many decades of continuous energy consumption growth, economic growth is for the first time becoming detached from energy consumption.

In many of the most economically and technologically developed countries, primary energy consumption has stabilized, while in some European countries, the United States and Japan there are signs of a gradual downward movement (Fig. 1.16).

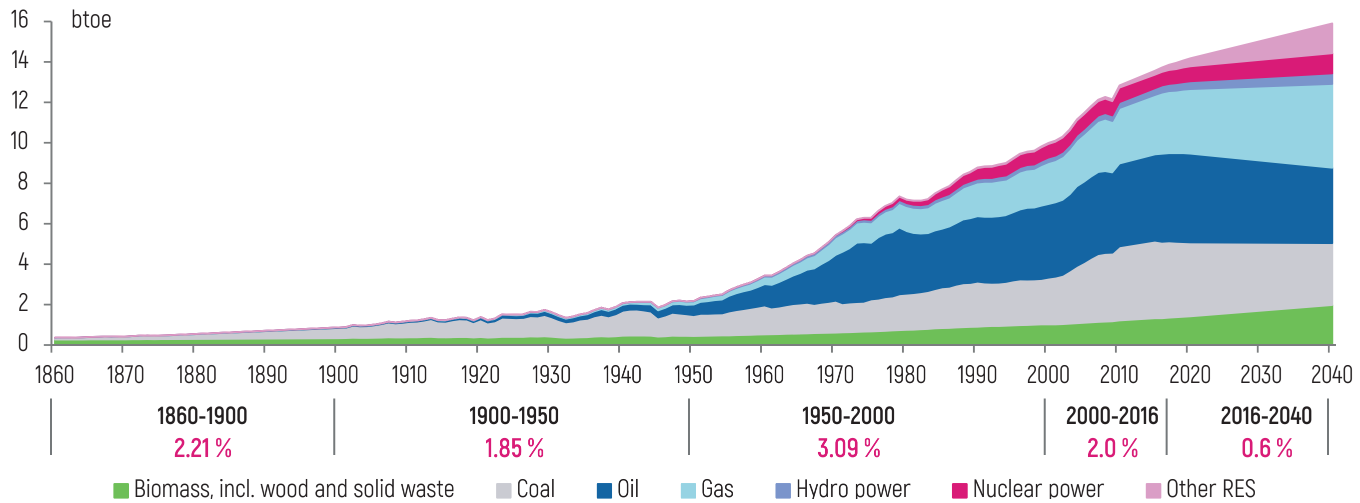
As a result of the introduction of the whole complex of energy-efficient technologies, there has been a slowdown in energy consumption across the world - from 3.1% in the period 1950-2000 to 2% in 2000-2016 (Fig. 1.17). Due to scientific and technological progress in energy conversion technology and growing energy efficiency of consumers, in the period up to 2040 the world will have an opportunity to stabilise primary energy consumption.

Figure 1.16 – GDP and energy consumption dynamic in selected countries in 1990-2016




Source: ERI RAS based on IEA data

Figure 1.17 – World energy consumption by type of fuel and energy consumption annual average growth rates




Source: ERI RAS based on IEA, IMF data

## 2. Electrification

Accelerated restructuring of energy consumption has been occurring over the past decades – a transition from direct fuel use to electricity, the most universal and efficient energy carrier – and one that has no alternatives in some processes. Active electrification[13] of consumption sectors is underway.

From 1990 to the present day, the level of electrification of primary energy consumption in the world rose from 31% to 36%, a trend that will continue in the future. In particular, in recent years, active development of electric car transport has been widely publicised. All global car manufacturers already have electric cars in their model lines, and some are planning a full transition to electric drive vehicles.

Electrification is a long-term trend across the world, meaning a gradual transition to a more universal, convenient and effective energy carrier in all end-use sectors.

**Figure 1.18 – Key directions of electrification by electricity consumption sector**

**Transport sector**

Increasing deployment of electric vehicles (EV) (their share in total vehicle felt has reached 1.5% of total number of vehicles), partial electrification (hybridization) of motor transport, electrification of power units in motor and railway transport

**Industry**

Electrification of industrial low- and medium-temperature processes (heat pumps for low-temperature processes in light industry - in particular, in food and beverage production, in pharmacology, textile, pulp and paper industry; electric arc furnaces for steel production and the use of electrolytic hydrogen for ammonia production)

**Residential and commercial sectors**

Electrification of domestic heating. Gaining access to distributed power generation and electrification of food preparation process in developing countries

Sources: ERI RAS, SKOLKOVO Energy Centre

13 The ratio of primary energy consumed in the power sector to total primary energy consumption.

## 3. Falling costs of electricity and heat produced from RES

Radically falling costs and rapid deployment of technologies for the production of electricity and heat from solar and wind power sources, biogas and other new renewable energy sources (NRES) is a key element of the Energy Transition. It is commercially efficient development of renewable energy sources and an increase in their efficiency that are to a large degree responsible for the current transformation of energy markets.

In 2000-2018 cumulative NRES capacities (solar, wind and biomass energy, excluding traditional hydro power) went up 21-fold from 56 GW in 2000 to 1179 GW in 2018. The share of NRES (excluding hydro power) in world final primary energy consumption more than tripled, their share in electricity generation grew from 3.4% in 2006 to 10.4% by the end of 2017. At the same time, over the past 15 years, actual NRES capacity additions were regularly above projections. Rapid NRES development is due to the combination of accelerated technological development which reduces production costs (including due to the ever-growing economies of scale) and the priority of this direction in the energy policy of many countries. Low cost of capital ensured by state energy policies is an important factor in the success of NRES. It is critical for this type of projects with high capital and low operating costs. However, the development of technologies and their falling costs, including large-scale technology transfer, have been decisive in the expansion of NRES. In particular, the most radical reduction in price was achieved in the period when mass manufacturing of basic equipment items started in China.

Positive dynamics in terms of technological development in the sector is demonstrated by the "Learning curve", which describes the decrease in the unit cost as the volume of industrial output accumulates.

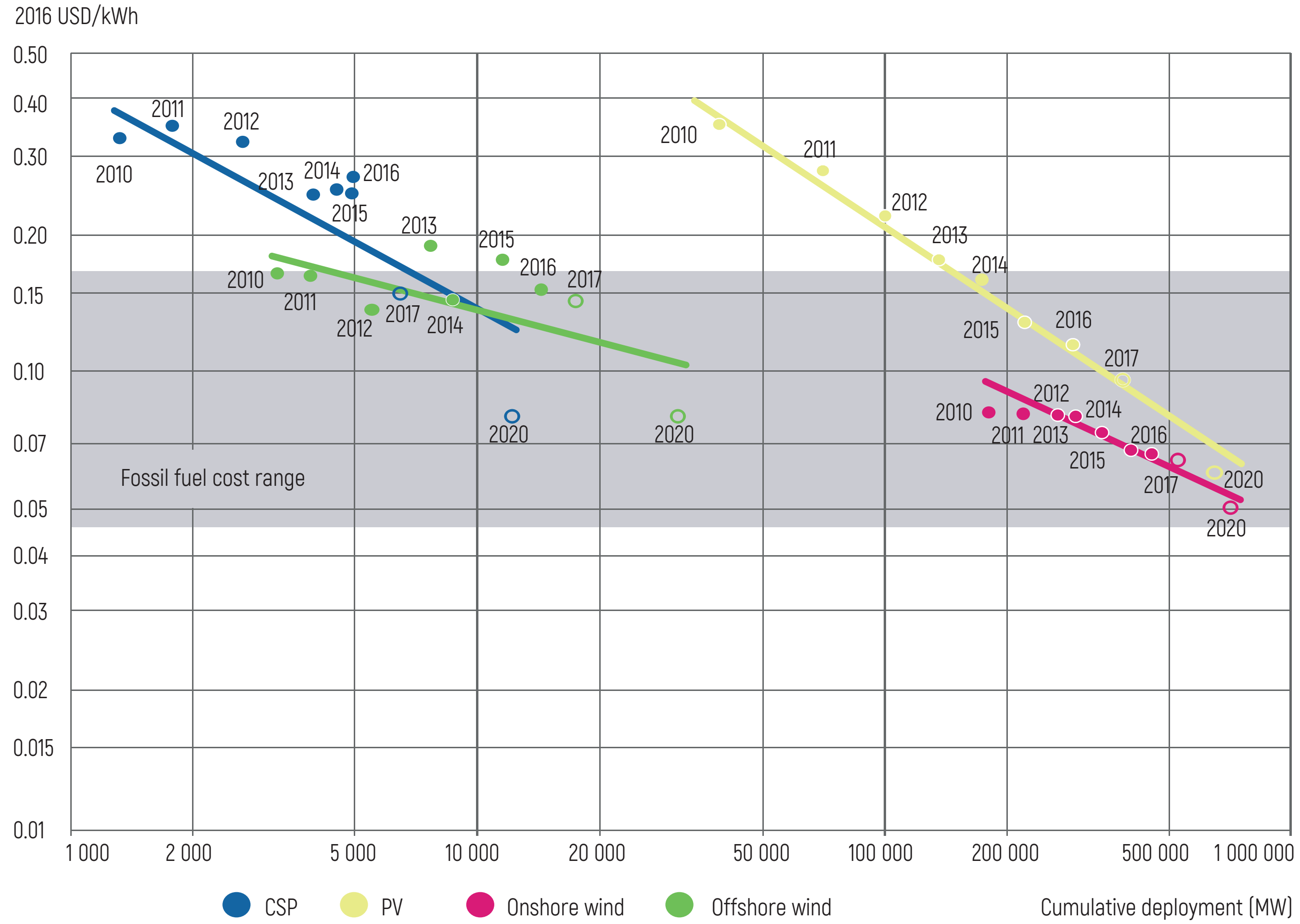
Figure 1.19 shows the learning curves for the most popular RES technologies from 2010 to 2020. The presented data demonstrates not only a marked reduction in LCOE, but also the point at which "grid parity"is reached. This is the start of fully-fledged economic competition of renewable energy with traditional sources under current regulation (without considering systemic impact).

The largest cost reduction was observed in the production of electricity from solar installations (PV, photovoltaic), where weighted average cost per 1 kWh went down over four-fold from the 2010 figure to 8.5 cents/kWh for new projects commissioned in 2018. There is also a significant improvement in wind generation technology, although per unit costs of wind generation did not fall as much (Fig. 1.20).

However, offshore wind power installations have significant potential for technological improvement. Technological development in the sector is mainly due to an increase in generation capacity of the plants with an increase in the diameter of the rotors; in some projects, the diameter of rotor blades has already exceeded 110 m.

Results of auctions held in 2017-2018 show the willingness of generating companies to provide further cost reductions. Thus, individual solar (PV) power projects in Dubai, Mexico, Peru, Chile and Saudi Arabia showed a result of 3 cents/kWh. The same level of prices is demonstrated by the best wind farms being built in Canada, Germany, India, Mexico and Morocco. However, by 2020 weighted average cost per unit of the most mainstream technologies–onshore wind farms and solar (PV) installations – is estimated at 4 cents/kWh, and for offshore wind farms and CSP installations – at 8-15 cents/kWh (Fig. 1.21). In any case, this is the price range within which NRES energy sources without special subsidies become economically attractive compared to traditional fossil-based electricity generation. And this is the beginning of a large-scale Energy Transition.

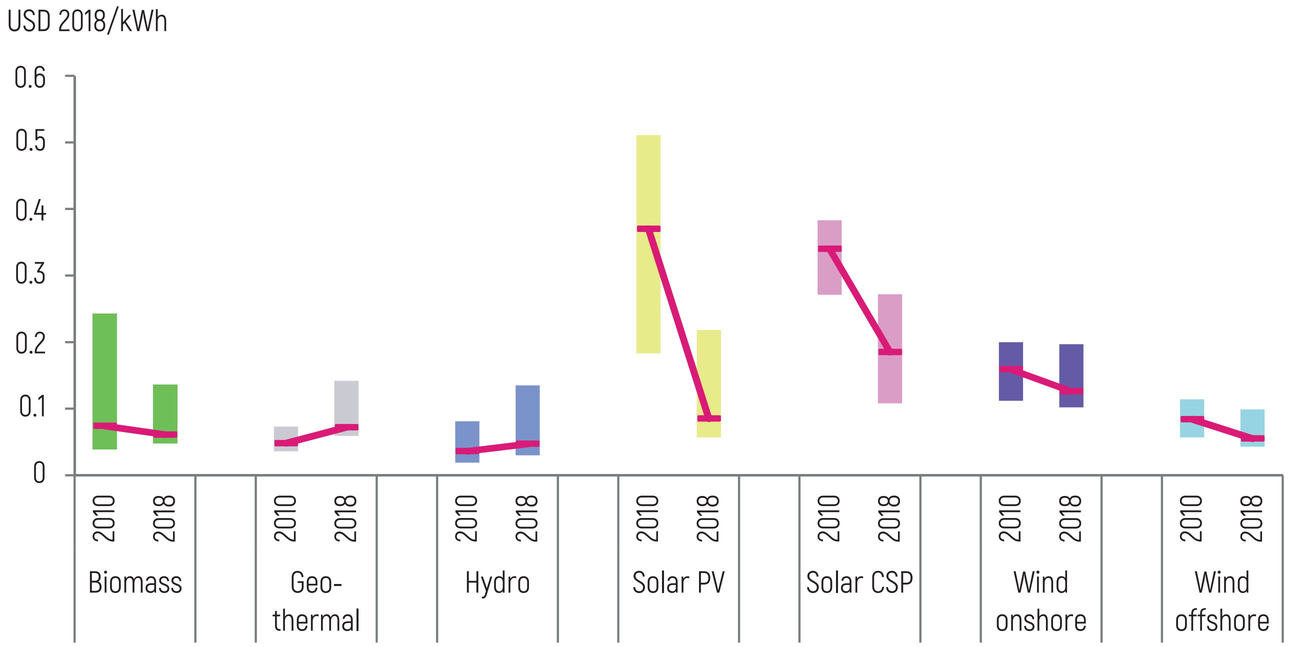
**Figure 1.19 – Learning curves for the global weighted average levelized cost of electricity from CSP, solar PV and onshore and offshore wind, 2010-2020**




Source: ERI RAS based on IRENA data

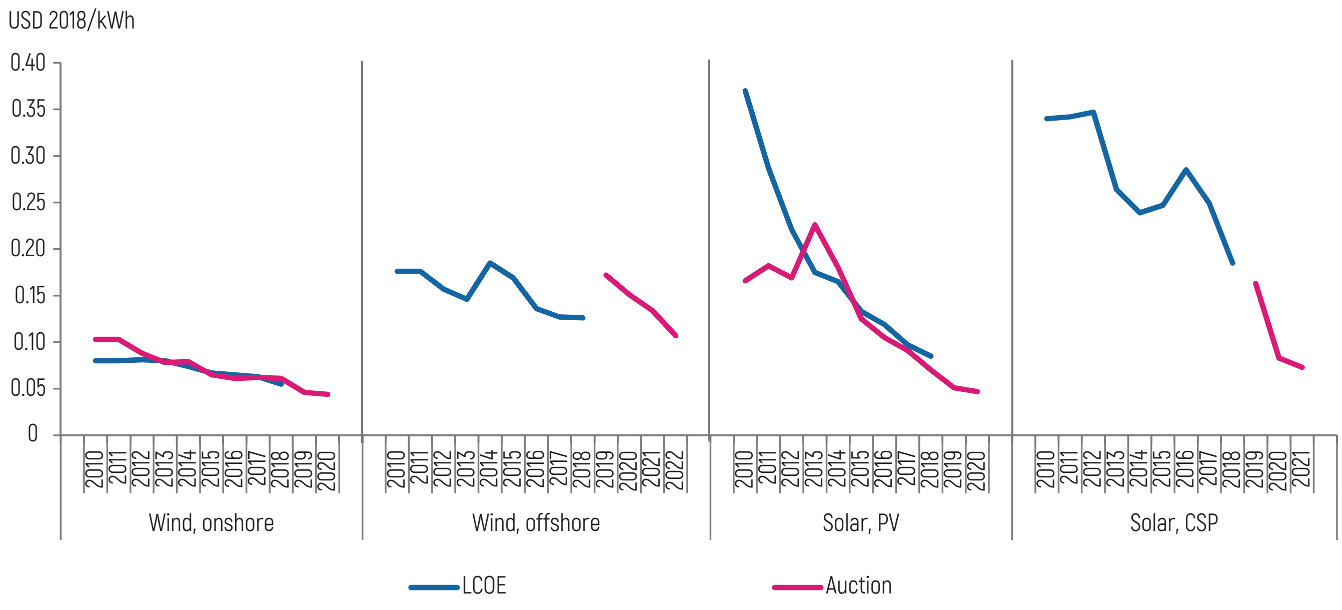
The main outcome of the development and falling costs of NRES technologies is a change in the structure of energy consumption, the start of the Energy Transition from the currently dominant hydrocarbons to non-fossil sources of energy.

Figure 1.20 – Dynamics of LCOE and selected RES technologies in World, 2010-2020, dollars (2018)/kWh




Source: ERI RAS based on IRENA data

Figure 1.21 – Dynamics of LCOE and results of RES power auctions, selected RES technologies, 2010-2020, dollars (2018)/kWh




Source: ERI RAS based on IRENA data

The potential for reductions in the cost of renewable energy is far from exhausted. Further enhancement of the efficiency and commercial attractiveness of RES will most likely follow the following technological directions:

- Improving the efficiency and reducing the cost of solar generation, achieved, among other means, via the production of silicon-free photovoltaic cells of various types, cascade cells with high efficiency and increased resource; thermal installations that convert solar energy into heat;
- Increasing the efficiency and reduce the cost of wind generation;
- Improving the efficiency of geothermal installations, including commissioning of binary cycle geothermal power plants;
- Development of small hydropower;
- Development of technologies for the production of electricity and heat from bio-fuels and waste.

"Outlook-2019" assumes a further reduction of LCOE from renewable energy sources by 20-50%, depending on the type of RES and the scenario.

**Issues of pricing and renewable energy integration**

In the technological sphere, the main issues of increasing the share of renewable energy sources are associated with the growing difficulties of integrating large volumes of sources distributed across the grid, into the power system. Many of these sources have an unregulated mode of operation (wind, solar).

A multi-fold increase in renewable generation requires intensive restructuring of the trunk power and distribution grid facilities, as well as the presence of a significant reserve of heat capacity or storage devices, which remain underutilized most of the time. Therefore, currently the conflict between new technologies and the previous organization of the power system is lessened solely through extensive measures - investment in electricity networks and capacity reserves. However, as NRES capacities grow, this becomes increasingly difficult.

In the market, the issues associated with the development of renewable energy sources are primarily related to the fact that RES based electricity entering the spot market in ever increasing volumes (with almost zero variable costs) leads to fundamental changes in market equilibrium. These take form of increasing periods of extremely low, zero or even negative prices.

This leads to a steady decline in electricity prices, without creating sustainable market signals for investment. To date, however, a whole range of innovations has accumulated both in the power sector itself and in related areas. None of these is revolutionary on its own, but their cumulative implementation can resolve this conflict and lead to a complete change of the traditional look of the power systems and the electricity market. Although the new architecture of the electricity sector is not yet quite clear, it is already evident that this new trend will be the result of the synergy of the forthcoming technological breakthroughs.

# 4. Technologies of energy accumulation and storage

The development of technologies of energy accumulation and a reduction in the costs of energy storage (industrial and distributed energy storage, as well as batteries) is another important component of the Energy Transition. It will ensure deeper electrification and the expansion of NRES. Storage is an intermediary link between different sources and ways of using energy. Accumulators enable to solve a number of tasks:

- To provide controlled power output from NRES with intermittent generation (wind and solar power plants) taking into account the needs of the power system, in particular, peak demand, which enables to optimize the load of generating and grid assets in the power system, as well as reduce the new necessary capacity additions and the need for reserve power generation;
- Expand the zones of distributed generation;
- Empower consumers in relation to price-dependent demand response (demand response) on the consumer side, allowing them to actively influence price equilibrium in the electricity market;
- improve the quality of the power system and services delivered by service providers (can stabilize voltage and frequency, act as emergency generators, network damper controls, etc.)

Expected technological advancement in the field of energy storage can drastically reduce restrictions on the way to effective development of RES and their integration in the system. In the future, it can radically change not only the market conditions in electricity markets, but also the very principles of operating electric power systems, providing them with greater flexibility and adaptability.

Currently, various methods of energy storage are used - these can be divided into five groups: mechanical storage, thermal, chemical, electrochemical and electrical (Table 1.2). Today, mechanical systems are the most common method of industrial storage of electricity, primarily pumped hydroelectric storage systems. They account for 99% of global storage capacity (160.3 GW)[14]. However, alternative energy storage systems are starting to be used more actively - in 2018, almost 2 GW of PSPP and more than 3 GW of energy storage systems of "alternative" technologies were implemented globally.[15] It can be said with confidence that over the past few years, companies have moved from assessing the applicability of various energy storage technologies to developing optimal methods for integrating energy storage into energy systems and developing specific business models for using energy storage systems.

Photo by mohamed Abdelgaffar from Pexels

[14] 2019 Hydropower Status Report. International Hydropower Associationю 2019.

[15] IEA. Energy storage. Tracking Clean Energy Progress 2019. https://www.iea.org/tcep/energyintegration/energystorage/

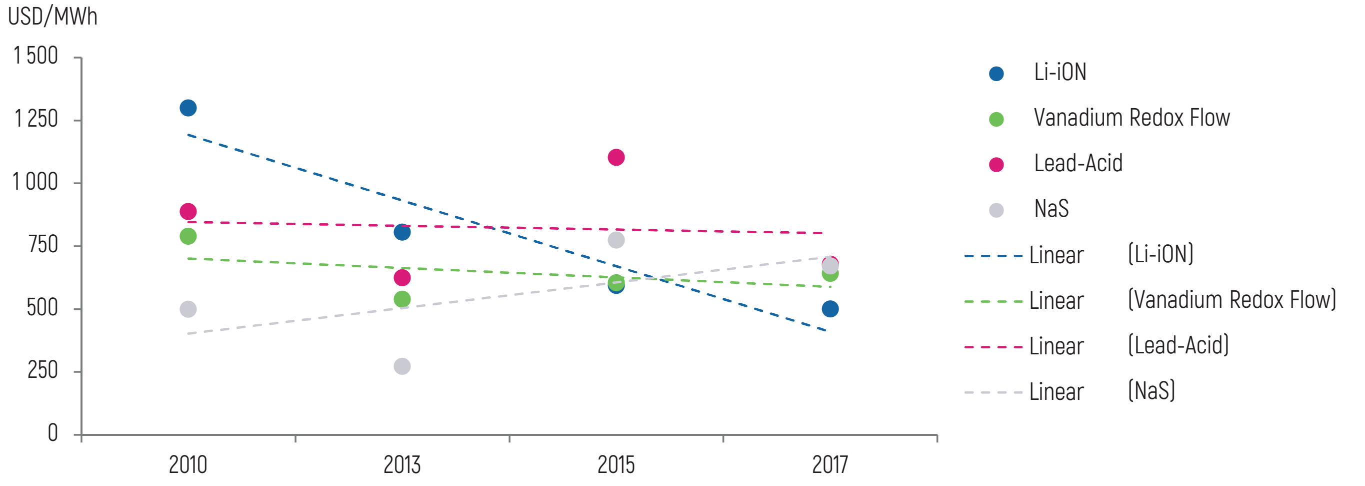
**Table 1.2 - Electricity storage systems**

| Electricity storage systems | | | | |
|---|---|---|---|---|
| **Mechanical/pneumatic** | **Thermal** | **Chemical** | **Electrochemical** | **Electric** |
| Pumped hydroelectric energy storage (pumped storage)<br>Compressed air energy storage (CAES)<br>Liquid air energy storage (LAES)<br>Inertia energy storage systems (flywheel) | Thermochemical energy storage<br>Sensible thermal energy storage<br>Latent thermal energy storage | Hydrogen fuel cells, Conversion of methane into methane-syngas (SNG) | Li-ion Ni-Cd NaS LeadAcid<br>Redox batteries<br>etc. | Supercapacitors and Superconducting magnetic energy storage (SMES) systems |

At the same time, there is not one single prioritised technology - different technological solutions are suitable for various applications and tasks. Thus, super-flywheels and super-capacitors are well suited to regulate frequency in the power system; lithium-ion (Li-ion) accumulators work well for smoothing fluctuations over the course of a day and peak shaving, while flow batteries are good for storing a relatively large amount of energy (if the discharge time is a few hours).

A multi-fold reduction in the cost of electricity and heat storage technologies is one of the most important drivers of the Energy Transition. Li-ion batteries (an "alternative" energy storage technology dominating today) have already fallen in price more than four-fold since 2010 (Fig. 1.22). Vanadium redox flow batteries also saw a more than threefold reduction in price. However, there was no significant reduction in the cost of lead-acid batteries, for example. This can be explained by the fact that this is an old and well-developed technology, which can only undergo minor improvements.

**Figure 1.22 – Levelized cost of electricity storage for selected technologies (fully integrated systems)**



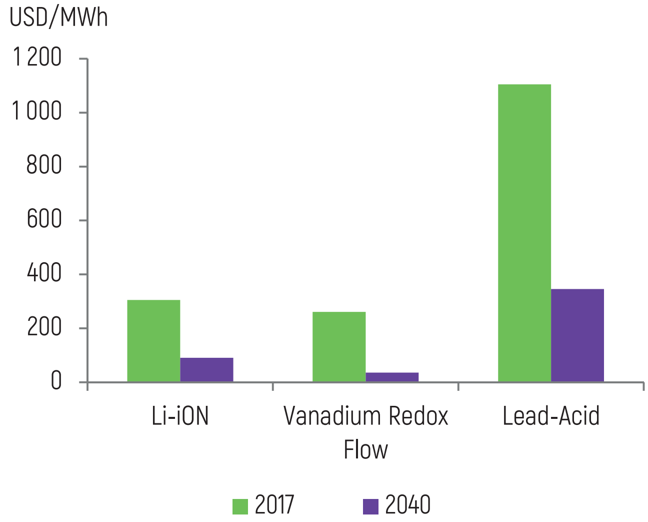

Sources: EPRI, DOE, Lazard

Similarly, it is not possible to observe a significant reduction in the cost of sodium-sulfur energy storage systems, which are among the first electro-chemical energy storage systems that have entered use for the needs of power systems. It should be noted that the disparate estimates of energy storage systems costs, the absence of a standard methodology and reference characteristics of systems that are being compared, make it difficult to compare price parameters specified in various studies. It is also important to understand what exactly we are talking about when comparing price parameters - the cost of cells, the battery or the entire energy storage system.

Future dynamics of energy storage costs is one of the key uncertainties of the Energy Transition. There are two main metrics for comparing the cost of electricity storage: specific investment cost (SIC) and levelized cost of storage (LCOS). SIC cost of li-ion batteries is projected to fall from USD 187/kWh of capacity in 2018 to USD 73/kWh by 2030[16] , flow redox batteries -from USD 315-1680/kWh in 2016[17] to USD 108-576 kWh by 2030, sodium-sulfur – from USD 263-735/kWh in 2016 to USD 120-330/kWh in 2030 and lead acid batteries – from USD 105-475/kWh in 2016 to USD 50-240/kWh in 2030. When comparing SIC prices of installed capacity of energy storage systems, it is important to bear in mind that they do not take into account the number of cycles and the battery life cycle, as well as the level of internal losses and self-discharge in the system, which are usually taken into account in the metric of levelized energy storage cost (LCOS). Therefore, capital costs can be used to assess the potential for price reduction within a single technology[18] (and those without taking into account improvements in technical characteristics). However, capital costs are not well suited for a comparison between various technologies.

As to the LCOS forecast of the main energy storage technologies for the period up to 2040, it takes into account a reduction in the capital cost of installing energy storage systems, as well as projected technical parameters, such as the number of cycles, depth of discharge (DOD) and electrical efficiency of the energy storage system. The forecast of capital costs is adopted in accordance with the learning curves for the respective technologies (Fig. 1.23). As can be seen, in the period up to 2040 we can expect a reduction in LCOS of energy storage based on lithium-ion batteries to arounnd USD 91/MWh, vanadium flow batteries - to USD 36/MWh, lead-acid batteries - to USD 346/MWh. Of course, achieving such cost parameters requires large scale production volumes and installation of storage systems.

**Figure 1.23 – Projected reduction in LCOS of electricity to 2040 for various selected technologies, USD/MWh**




Sources: IRENA, Imperial College London

> In the considered forecast scenarios, total storage unit costs are projected to fall from USD 100-700/MWh to USD 30-250/MWh, depending on the scenario.

[16] Bloomberg New Energy Finance, Lithium-ion Battery Costs and Markets.

[17] IRENA, Electricity Storage and Renewables: Costs and Markets to 2030

[18] The future cost of electrical energy storage based on experience rates; O. Schmidt, A. Hawkes, A. Gabhir, I.Staffell; Imperial College London, 2017.

Electrification of the transport sector plays a crucial role in the improvement of batteries. Since the start of the 2010s, scientific and technological progress was boosted in this segment with large-scale state support, with the aim of creating fully electric cars. As a result, electric cars began to gain increasing popularity with the general consumer due to their growing economic attractiveness, environmental friendliness and efficiency.

A lead-acid rechargeable battery is the one used most often in traditional cars with internal combustion engines. In addition to lead-acid batteries, nickel-cadmium and nickel-metal-hybrid batteries are widely used. All of them are characterized by their relatively large size and weight, which means less specific energy per unit surface and per unit mass compared to lithium, lithium-ion and lithium-polymer batteries. A llithium-ion battery is most often used in electric vehicles (battery-electric, BEV), but there are also cars that have other types of batteries installed, for example, lead-acid gel batteries or lithium-iron phosphate batteries.  Lithium-ion batteries are preferable because of their faster charge and higher capacity. Currently, the automotive sector occupies 31% of the lithium-ion battery market.

Hybrid cars (HEV) use a hybrid power unit that combines an internal combustion engine and an electric motor. Such a unit saves fuel and reduces exhaust emissions. Unlike electric vehicles, traditional hybrid cars do not require charging from the plug - batteries are charged from the internal combustion engine, as well as during braking and coasting.

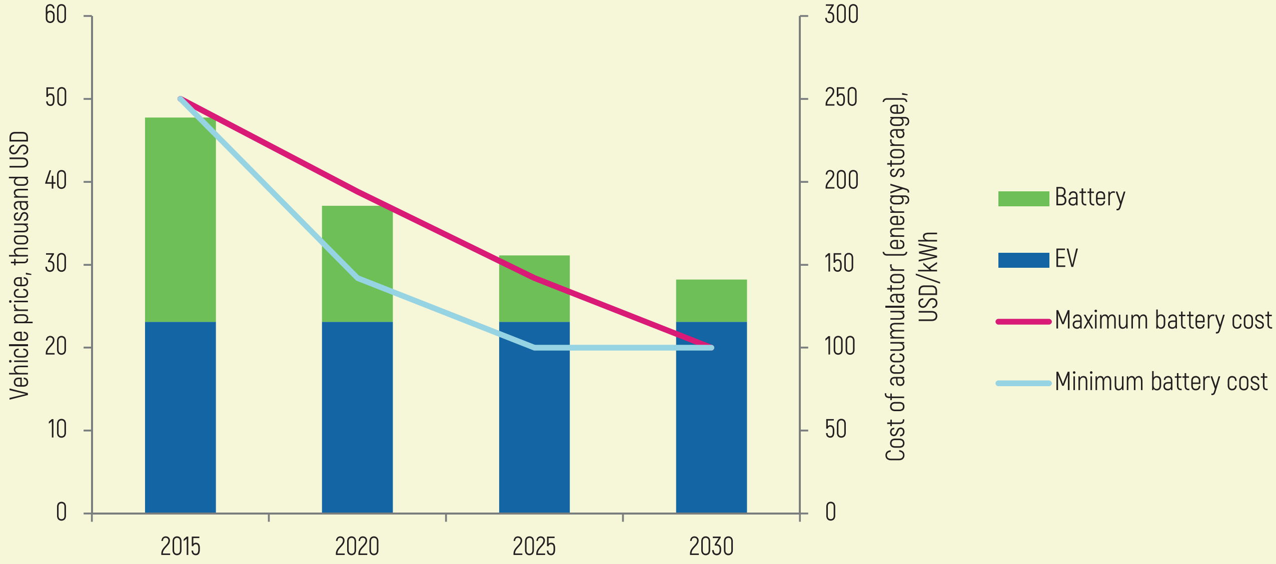
Plug-in hybrid vehicles (PHEV) are also appearing now.  Such cars travel a considerable distance - over 50 km - using an electric motor (while traditional hybrids can only travel 3-5 km).  The engine mainly recharges the battery, but it can significantly increase the power reserve of the car.

The efficiency of hybrid cars depends directly on the capacity of the batteries installed. Currently, nickel-metal hydrid batteries (for units with a sequential hybrid scheme requiring significant reserves of energy), lithium-ion and lithium-polymer batteries (for "moderately hybrid" cars) are most often used.The target indicator for achieving full economic competitiveness is a 1.5–2 fold reduction in the cost of a car battery (Fig. 1.25). By 2016 accumulated advancement in battery technologies made it possible to reduce per unit energy storage costs in electric vehicles to USD 250/kW by 2016, but the full potential for reduction has not yet been reached.  According to the statements of the largest car manufacturers, in the coming years, cost of energy storage may drop by 35-40%.  Falling cost of the cathode element should become the key source of reducing production costs. This would be achieved primarily due to a reduction in the use of expensive and rare cobalt in the production of cathodes. In addition, scaling up battery production and the creation of vertically integrated production chains from the supply of metals to the production of drivetrains should contribute to cost reduction. Depending on the scenario, the reduction in the cost of producing batteries to the target of USD 140/kW is expected in the next 2-7 years (Fig. 1.24)

Finally, the location of the storage system within the power grid also deserves attention. The closer to the energy consumer is such a system installed, the more functions it can typically perform.  Energy storage systems installed "off-meter" - that is, on the end-consumer side - are gaining more widespread application, aided by increasing utilization of rooftop solar panels and other types of generation installed directly by the consumer of electricity. In combination with the consumer's own generation, distributed energy storage systems enable to maximize the consumption of power generated by the consumer, and to transfer this consumption to periods when the load increases and there is a shortage of consumer's own generation. Taken together, such systems can reduce the transmission requirements of the electrical network to which the consumer is connected, and, accordingly, reduce the cost of its maintenance.

As a result, distributed energy storage systems which have a higher per unit cost than larger centralized storage systems may deliver bigger benefits to the consumer and have more attractive economic characteristics of their use.

**Figure 1.24 – Cost structure of a pre-tax price of an EV in the US and projected manufacturing costs of batteries**




Source: ERI RAS based on Bloomberg, IEA data

Image by Karolina Grabowska from Pixabay

# 5. Hydrogen economy

Hydrogen is an essential element for meeting the obligations of states, individual regions and companies on decarbonization. Renewable energy sources can reduce carbon emissions in the electric power sector, while the energy supply of buildings, the transportation sector, and the industry are largely left "outside" decarbonization if a new universal energy carrier cannot be found.

Hydrogen claims to be a solution. Hydrogen is also notable for its relative convenience of long-term large-scale storage and transportation over any distance, including via the existing infrastructure used for natural gas (including LNG). In practice hydrogen can be used in nearly all sectors of energy conversion and consumption (Fig. 1.25).

Hydrogen can be used as follows:

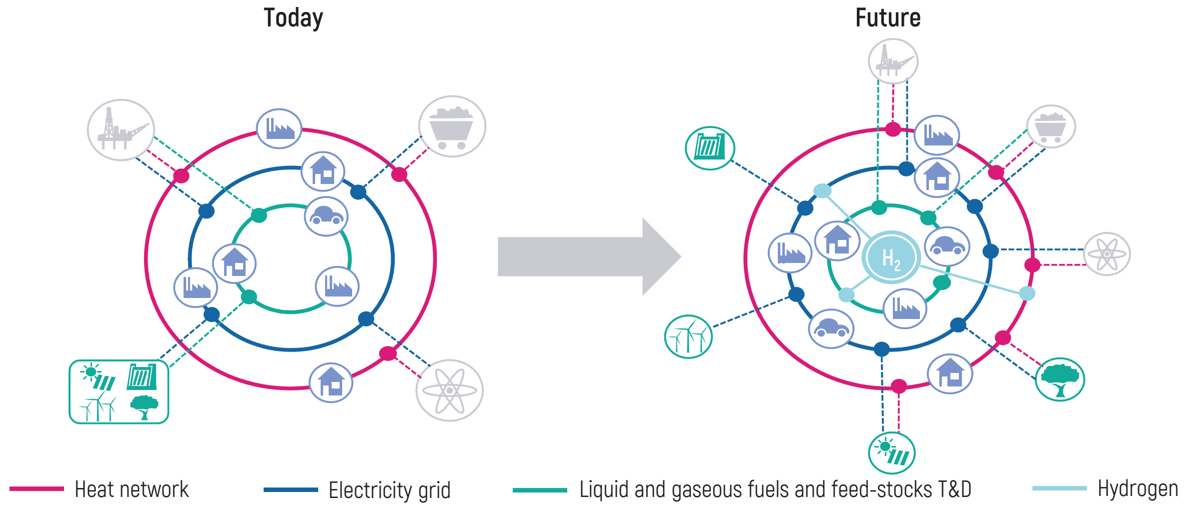
- in the electric power industry, in heavy industry (at the same time it will replace natural gas and oil products),
- in transport (replacing petroleum products);
- in the construction sector (for heating and electricity, including autonomous, replacing natural gas or petroleum products);
- in industry - as feedstock and a substitute for traditional hydrocarbons.
- hydrogen is one of the most effective methods to create long term energy storage facilities.

An important advantage of hydrogen in the conditions of the Energy Transition is the possibility of using surplus RES-based generation for hydrogen production by electrolysis and its subsequent storage or use in various processes.

The systemic effect is also complemented by new opportunities for economic development – hydrogen technologies are science- and technology-intensive, are at the very beginning of the "learning curve" and have great potential to increase efficiency and reduce costs. For example, electrolyzer capital costs are expected to fall 1.5-4-fold by 2030, depending on the technology. According to the Hydrogen Council, the nearly double disparity in the cost of owning a FCEV compared to an ICE powered car can be minimised to 10% between 2025 and 2030.

Such a drastic fall in cost (80%) can be achieved due to the economies of scale – both in the manufacturing of cars and in the infrastructure. It is projected that the cost of

Figure 1.25 - Energy system today and in the future




Source: IEA Hydrogen and Fuel Cells Technology Roadmap, 2015

Activity in the field of hydrogen use increased following the adoption of the Paris Agreement:

- Japan's Strategic Roadmap for Hydrogen and Fuel Cells was launched in the summer of 2014.
- 2017 saw the launch of an all-European initiative Fuel Cells and Hydrogen Joint Undertaking (FCH JU). As of May 2018 it already numbered 89 regions and cities in 22 European countries among its members.
- California, Australia and South Korea announced their hydrogen strategies in 2018 and the beginning of 2019.
- The Hydrogen Council is the most well-known association in the field of hydrogen technologies at the corporate level. The organisation, founded in 2017 in Davos, brought the number of its members up to 53 corporations from 11 countries with the total number of employees of 3.8 million and annual earnings of 1.8 trillion Euros by the end of 2018.
- The first meeting of energy ministers took place for the first time in October 2018 in Tokyo. Hydrogen Energy Ministerial Meeting was attended by representatives of 19 countries, as well as the European Union and the International Energy Agency.

hydrogen at a filling station will fall from the current 10 to 3 USD/kg by 2030.

From the point of view of projected production and consumption of hydrogen, the analysis is complicated by the fact that up until now hydrogen has not been reflected in international energy statistics - even those that are already being produced today.

If Conservative estimates of IRENA, Shell, ARENA are nearing the lower end of the range - around 500-2000 TWh of hydrogen in 2050 globally - then the Hydrogen Council orientates towards a much greater figure - 16100 TWh, or 18% of world energy consumption. The more complex country and regional estimates made by the DOE in 2016, the UK Committee on Climate Change in 2018 and Navigant in 2019 show that by 2050 its share would be in the range of 12-19% of final energy consumption in the US, UK and EU respectively within their scenarios of maximum use of hydrogen energy. This means that in the long term, the role of hydrogen in the global energy system may become comparable to the role that gas or coal are currently playing.

Total hydrogen production in the world is currently estimated by various sources at 55-65 million tonnes, with cumulative average annual growth rates over the past 20 years being low – about 1.6%. Over 90% of hydrogen is produced at the point of consumption (as the so-called captive product), and less than 10% is supplied by specialized companies operating in the industrial gas market (Air Liquide, Linde, Praxair Inc., etc.). Today, hydrocarbons dominate as feedstock for hydrogen production. Over 68% of hydrogen is currently produced from natural gas, 16% from oil, 11% from coal and 5% from water using electrolysis. This is explained by comparatively cheap costs of production from hydrocarbons. However, in recent years hydrogen production by electrolysis is gathering momentum. According to the IEA, in the last seven years, around 10 MW of electrolyzers were put into operation in the world on average annually. In 2018, 20 MW were brought online, and by the end of 2020, another 100 MW are expected to be commissioned. Investments in electrolysers are growing – total installed capacity of units could almost triple in the next 2-3 years[19], reaching 150 MW. In the transportation sector: annual supplies of hydrogen fuel cell cars increased from 20 in 2013 to 11,000 in 2018. In the energy sector - new prototypes of gas turbines operating fully on hydrogen appeared in 2018 (in 2018, Kawasaki reached 100% share of hydrogen in powering a gas turbine powered HPP in Japan).

19 https://www.iea.org/tcep/energyintegration/hydrogen

## 6. Increasing manageability– implementation of digital and AI systems in the electricity sector

The term "Internet of Things" or IoT appeared in 1999, and it we could speak of the physical appearance of the Internet of Things from 2008-2009[19], when the number of devices connected to the Internet (smartphones, smart TVs, refrigerators, light bulbs and other devices) exceeded the planet population. Digitalization of the energy sector is part of a global trend, in which fast-growing digital technologies are penetrating all sectors of the economy. This creates new opportunities for the energy sector - after all, managing energy systems with a large share of decentralization or RES penetration is becoming increasingly difficult. Digitalization opens new possibilities for managing distributed generation in conjunction with other types of distributed energy resources. Automation of equipment, the ability to monitor the state of equipment and manage it through the Internet of things, proliferation of energy storage devices and new business models for their use[20] are gradually transforming consumers into active full participants in the power system.

Proliferation of IoT and the digitalization process are prompting an unbelievable increase in the use of information and communication technologies in the economy, which has become possible thanks to technical progress and rapid price reductions in three components:

- **Data: digital information.** An explosive growth in the volume of available data due to a radical reduction in the cost of sensors (more than 95% since 2008) - as a result, according to IBM, 90% of the data in the world was created in the last two years.
- **Analytics: using data to get useful information and new knowledge. F**alling costs of computing capacity (processors, memory and data storage systems), the development of "cloud" technologies and big data make flexible data storage and data analysis systems available, despite a constant increase in the amount of information received. Rapid progress in advanced analytics, including machine learning, opens up incredible opportunities for identifying patterns and trends.
- **Connectivity: the exchange of data between people, devices, and machines (including machine-to-machine interaction (M2M) via digital networks.** Rapidly growing numbers of connected devices, multi-fold reductions in their prices and cheaper data transmission with increasing speed. By 2017, there were around 28 billion connected devices, an this figure continues to grow. It has become possible to not only remotely control production and household processes, but also build M2M networks thanks to the development of the technical ability to install data transmission and data processing modules in data transmitters, sensors and small devices, as well as to analyse the information received (including using "cloud" and so called "foggy" computing centers), and then connecting up controllers for process control in the real world. This set of technologies has a huge commercial potential, and both the consumer goods market and the business have taken advantage of it.

However, the development of IoT is associated not only with new technologies, but also with the creation of a technological ecosystem and the development of several proposals for collecting, transmitting and aggregating data and a platform that could process this data and use it to implement "smart solutions". The development of IoT in the fuel and energy complex, leads to the emergence of a whole layer of technologies and solutions that significantly increase efficiency and opens up opportunities for a structural transformation of the industries.

19 According to the estimates by Cisco Internet Business Solutions Group (IBSG)

20 For example, the cloud storage service for electricity storage of Deutsche Energieversorgung GmbH (SENEC), see http://renen.ru/storage-of-electricity-in-the-cloud

The main directions of digitalisation in the fuel and energy complex:

**«Smart devices-energy consumers».** This technology involves the ability of consumer- equipment to optimize the modes of electricity selection depending on the system load (tariff scale) and the final requirements for the operation of equipment. Additionally, it becomes possible for consumers to not only receive electricity, but also contribute it to the network. This can happen via the use of storage devices by the consumer and via local sources of electricity production - typically RES -based. Storage systems on the side of the consumer enable to receive energy at a low tariff and sell it back to the grid at a high one, even if their original purpose is different. Thus consumers have an opportunity to earn money. In many respects, the prospects for integrating the end system equipment into the system and operating it depend on the grid itself.

**«Smart grids»** are a key element of the system and enable to integrate and ensure the effective functioning of all its elements (electricity producers, consumers, storage, grid infrastructure), while taking into account new technological capabilities in real time. Reliability of operation and guaranteed self-recovery of the grid in case of failures are one of the key requirements for smart grids. At the same time, the smart grid should ensure participation of prosumers and storage hubs in its operation and flexibly synchronize and control the load.

Sustainable operation of smart networks and interaction at the level of the Internet of Things requires large-scale digitization of supply chain elements and the use of technologies to work with large amounts of data in real time.

Making the system more complex inevitably leads to increased risks of failures, for example, in the course of updating software which contains errors within disparate elements of the system. Therefore, **digital twins** - virtual images of the physical grids - are increasingly being created. They will make it possible not only to test the reliability of new software and equipment, but also model various emergency situations and test response mechanisms.

All these technologies provide enhanced flexibility and adaptability of the power system, smoothing the peak load, reducing losses, expanding the possibilities for distributed generation and increasing the acceptable share of renewable energy in the energy mix. Most importantly, they ensure a transition to the new principles of grid management and organization of market operations based on new information technologies. A dramatic increase in the productivity of computer technologies, systems of information transmission, storage and processing which are integrated in the Internet, smart meters, etc., combined with artificial intelligence technologies, enables to radically improve controllability of all elements of the power system (down to individual household appliances).

The appearance of a new type of consumer, the so-called prosumer, is setting a new format of interaction with the energy system. from passive one-sided towards active bilateral interaction thanks to the consumers' capabilities in decentralized power generation and demand response (demand response). Consumer's new technological capabilities are supported by a new information environment, which makes it possible to automate collection of data on system loading. It then enables to make quick decisions to adjust the load based on automatic control systems, including those using AI. Adjustments are made taking into account the balance in the power system and market prices. The development of technologies of virtual power plants and aggregators of demand response is the next step in this technological direction. These provide centralized control over the modes of operation of various sources of distributed generation or dispatchable loads of different consumer types.

Currently a whole number of projects are being implemented to test virtual aggregation technologies for distributed generation and controlled demand resources. In a number of countries and markets, each of these resources has already become a prominent component of the energy system. So, as part of the power auctions in the PJM pool[22] capacity additions of 50-80% will be provided within the next four years by demand management resources.

Intensive development of distributed generation centers and active consumption will require changes in the structure and operating modes of distributed energy grid - and with the increase in the volume of "new energy" - the main power grid as well.

A change in the technological paradigm of energy supply will also be accompanied by a qualitative change in the market environment. New technologies of distributed generation, controlled consumption, virtual aggregation of resources create new conditions for the development of a highly competitive retail market, based on highly automated local trading platforms for electricity trading, systemic and more complex energy-information services. Prosumers and virtual resource aggregators will be the main participants in this market. They will make for increasingly powerful competition with traditional energy generation.

The development of radically new payment technologies (for example, blockchain solutions and automatic "smart contracts" that enable making multiple deals with minimal transaction costs) creates the basis for servicing a virtually unlimited number of small transactions between individual participants in the electricity markets, including those made in an automatic mode.

The formation of basic premises for effective competition is the main outcome of all these changes. These premises include the emergence of a large number of participants, each of whom separately does not have market power and the appearance of free access to and exit from the markets. At the same time, thanks to distributed trading platforms, competition between participants is complemented by the competition between the markets. Conditions for forming the classic balance of elastic supply curves and demand (which is practically absent now) are being created in each of the markets.

Such a fundamental change in the entire power supply paradigm eliminates conflicts between the new energy sector and the existing technological and market environment:

- There are new opportunities in the electricity sector for load profile smoothing and more intensive use of assets instead of their continuous extensive development, which makes it possible to reduce required installed generation capacity and saves capital and operating costs;
- these savings should be translated into reducing the cost of energy supply to consumers, providing savings in their accounts via new market competitive mechanisms,
- due to the new adaptive capabilities of the power system, these savings will be complemented by reducing consumer losses (caused by unreliability and inadequate quality of electricity supply) and the fact that network operation will also be optimized overall.
- saving energy costs for consumers increases their competitiveness and produces the multiplier effect at the level of the entire economy.

22 Base Residual Auction Results PJM (2012–2014).

The key requirements here are as follows: flexibility and speed of change in operating modes, expansion of technical capabilities for grid adaptability to changes in the composition of generating sources and consumers. It is these requirements that are specified when national Smart Grid strategies are being developed.

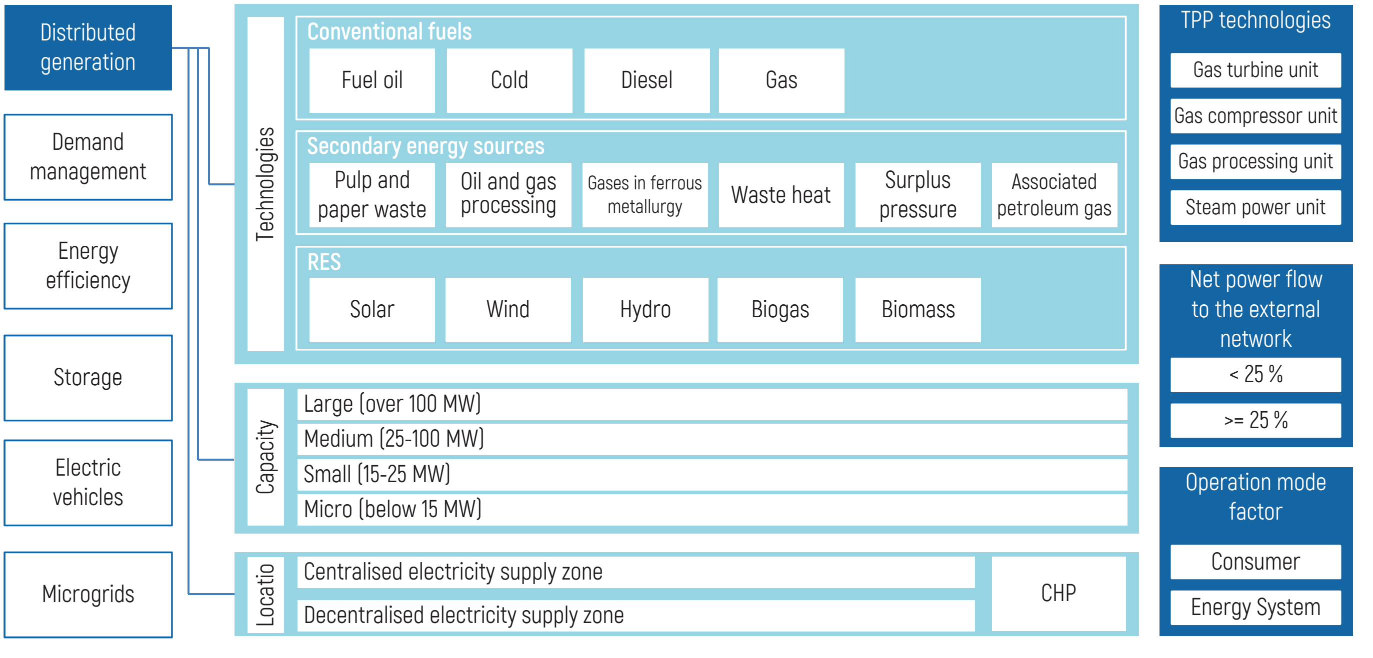
Implementation of these strategies in 2030–2035 will create a new type of energy infrastructure appropriate for the emerging energy industry and the needs of active consumers.

# 7. Decentralisation

Decentralization is the third most important driver of the Energy Transition and comprises the development of distributed energy. New solutions in the field of electricity generation and storage coupled with the simultaneous development of smart grids make it possible to connect more and more distributed devices which deliver electricity up to the system. Proximity to energy consumer is the basic characteristic of all these technologies. In global practice, distributed energy technologies traditionally include the following (Fig. 1.26)[23]:

- Distributed Generation;
- Demand Response;
- Management of energy efficiency;
- Micro grids;
- Distributed electricity storage systems;
- Electric vehicles.

**Figure 1.26 - Types of distributed energy and the matrix of criteria for distributed generation**




Source: SKOLKOVO Energy Centre

23 See, for example, Navigant Research. Global DER Deployment Forecast Database, 4Q 2017.

**Distributed generation (DG)** is a set of generating stations located close to the place of energy consumption and connected either directly to to the end users of power or to the distribution and transmission grid (in the case when there are several consumers). It does not matter what type of primary energy source is used by the station (fuel or renewable energy), or who it is owned by - a consumer, a generating / grid company, or a third party. In foreign practice, there is a tendency to cap the capacity of DG power plants with an upper limit, depending on the technology used. For example, Navigant Research uses the 500 kW limit for wind, 1 MW - solar, 250 kW - gas turbines, 6 MW - for free piston gas engines and diesel power stations. The EU-DEEP European Distributed Energy Partnership Project used[24] similar boundaries: thermal power plants (steam, gas turbines, free piston engines) - up to 10 MW, micro turbines - up to 500 kW, wind power stations - 6 MW and solar - 5 MW. In terms of the criteria for the classification of DR types, it is also possible to distinguish them by type of fuel (from gas to secondary energy resources, for example, blast furnace gas, associated petroleum and coke oven gases), by generation technology (from steam power plants to wind generators), by location, by consumer, mode factor, voltage level of connection to grids, etc. The types of distributed energy are shown in Fig. 1.27.

**Demand response -** changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized[25]. For the purposes of this study, it is important that demand response can reduce peak loads in the power system and, accordingly, the system needs for installed power capacity both in the short-term (day, week), medium-term (1 year) and long-term (for example, when conducting capacity selection for 4 years ahead). The "Demand Management rationalization program" launched in the USA in the 1970s is a classic example. The programme aimed at saving electricity by encouraging consumers to reduce energy consumption during peak demand periods or to shift energy consumption to off-peak demand periods. Demand management resources are already actively competing with the supply of new generating capacity in competitive markets. According to Navigant Research estimates, the volume of power included in demand management programmes will increase from 39 GW in 2016 to 144 GW by 2025.

**Micro Grid** is a group of interconnected loads and DERs within a clearly defined electrical and geographical boundaries which acts as a single controllable entity with respect to the main grid[26].

**Distributed energy storage systems (accumulators)** are a set of storage systems installed at end users and at distribution network facilities. Industrial-scale accumulators (for example, pumped storage hydroelectric plants ) do not belong to distributed storage systems.

**Electric cars** are considered as one of the types of distributed energy resources, as they do not only act as energy consumers, but also offer storage capabilities (vehicle-to-grid technology).

24 EU-DEEP (EUropean Distributed EnErgy Partnership) – a European project that united 42 partners from 6 countries, aimed at facilitating large-scale integration of distributed energy resources in Europe.

25 Siano P. Demand response and smart grids—A survey. / Renewable and Sustainable Energy Reviews, Volume 30, February 2014.

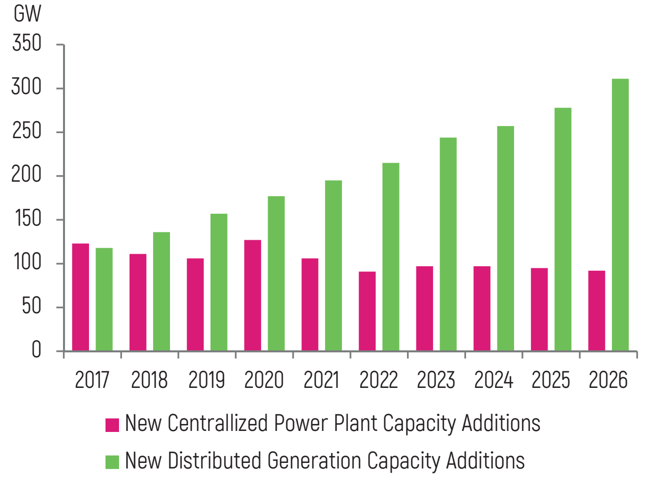
26 Yoldaşa Y. et al. Enhancing smart grid with microgrids: Challenges and opportunities. / Renewable and Sustainable Energy Reviews, Volume 72, May 2017.

Distributed generation became a catalyst for change. The appearance in the 1970s – 1980s of new technologies for the production of electricity - gas turbine and gas piston, based primarily on the use of new materials and technologies for manufacturing of equipment, made it possible to overcome the effect of scale and make small power stations from tens of kW to tens of MW competitive with large plants. This immediately led to an increase in DR capacity additions, and its average annual growth rates significantly exceeded the average annual electricity consumption growth. In other words, DG was developing faster than overall global generation.

By 2026, Navigant Research forecasts the commissioning of three times more DG capacities than centralised generation (Fig. 1.27). According to Bloomberg New Energy Finance estimates, by 2040 in countries such as Germany or Brazil the share of distributed generation in total installed capacity of power grids could exceed 30%, while in Australia it will reach 45%.

The main consequences of the distributed energy sector development is a change in the structure of the energy sector itself, i.e the ratio of centralized and decentralized part of energy systems ("flat energy"). The development

**Figure 1.27 - Annual Installed Centralized vs. Distributed Power Capacity, World Markets: 2017-2026**




Source: Navigant Research

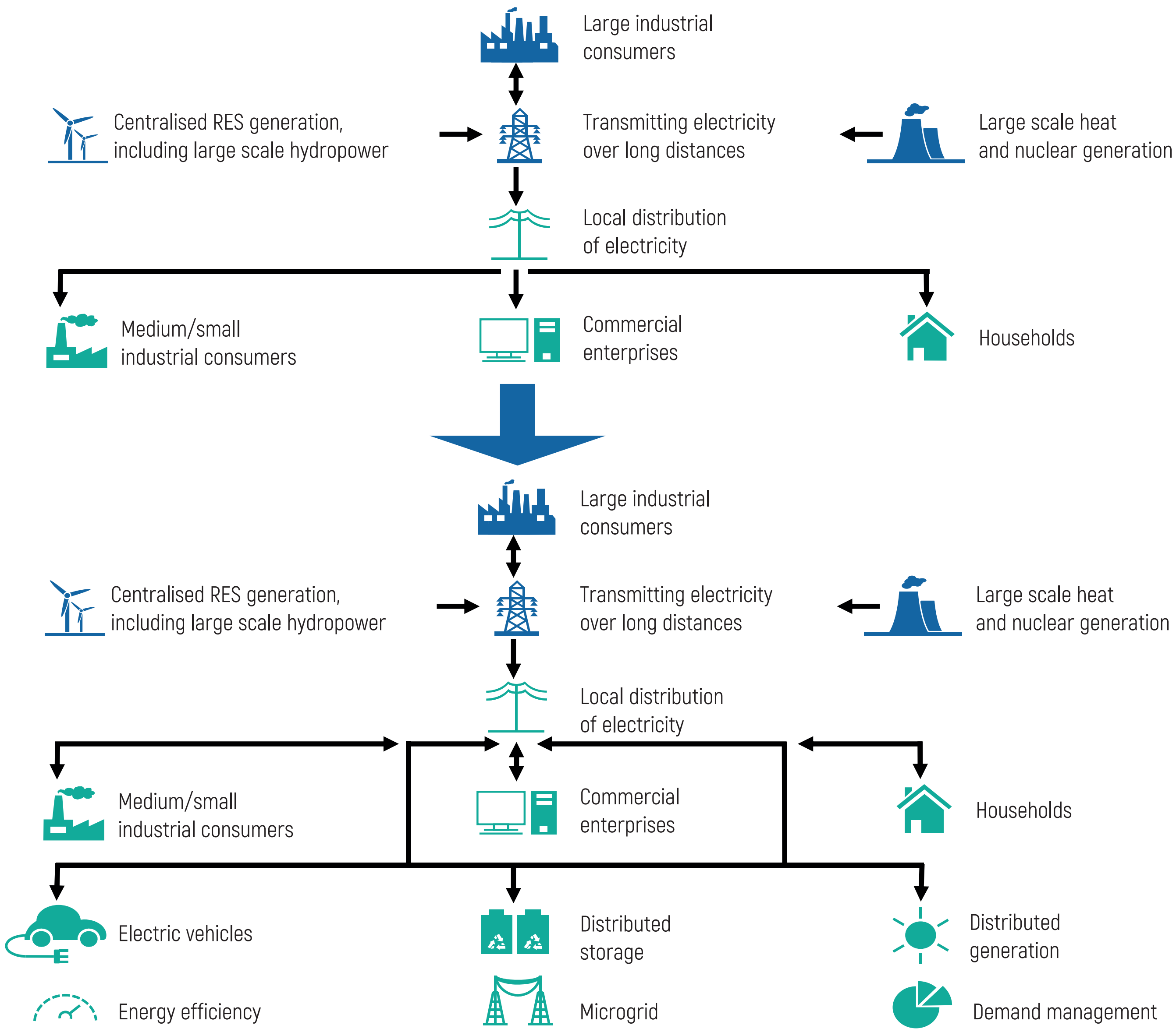
of small distributed generation has initiated the so called "democratization" of electric power grid. Prior to this, the architecture of power systems remained largely unchanged for many decades. Centralized power systems provided consumers with electricity successfully, reliably and at a reasonable price But as a result of technological advancements, the consumer has moved from a situation of a determined power supply from a centralized energy source to a possibility of choosing from a wide range of alternative solutions. These can be used in an optimal mix based on individual priorities of cost, reliability and quality of power supply.

The appearance of many new small generators has complicated the processes of their integration in a single energy system, as well as control and regulation processes[27]. This called for new technologies of flexible grid construction and intelligent control, which later became known as the Smart Grid[28]. Electricity consumers begin to play a growing role in the energy system, starting to generate and store electricity. The freedom of consumer choice is greatly increasing. At the same time, there are ample opportunities to manage demand and energy efficiency both at the level of a specific household and at the level of the economy as a whole. In order to realize these opportunities, governments are changing the models of electricity and capacity markets towards their liberalization. The development of distributed energy technologies and their penetration in the energy system prompts governments to actively discuss approaches to changing the tariff systems.

It can be said without exaggeration that with the development of distributed energy, the necessary foundation is being built for creating a truly competitive environment at the retail level.

Therefore, distributed energy has already become one of the most important elements of the transformation of energy systems across the world (Fig. 1.28), and these processes are just increasing.

Figure 1.28 - Transformation of the energy system: from a centralized model (top) to a decentralized model (at the bottom)




Source: SKOLKOVO Energy Centre

# THE ENERGY TRANSITION: CONSEQUENCES

## Increasing inter-fuel competition in all sectors

Competition between various types of fuel has been associated with the entire development of human made energy in the last century and a half, while the interchangeability of energy resources significantly differed by consumption sectors. Technological advancements in the 20th century created a number of unique areas of application for some energy resources. There was practically no affordable competitive replacement alternative in these sectors – for example, in the use of petroleum motor fuels in the mobile power industry, petroleum products and gas in the chemical industry, etc. However, the Energy Transition and the development of a whole range of related technologies are radically changinge this system, opening previously unavailable segments up to competition.

In the transport sector, where only petroleum products have dominated until now, the process of electrification is happening rapidly - the use of electric cars is growing exponentially as their cost is falling drastically. There is already state level support in many countries for the development of electric vehicles, with their owners being subsidized directly or via tax benefits.

Fuel cell cars powered by hydrogen or fuels containing hydrogen are increasingly being used.

Although natural gas (compressed, liquefied, synthetic liquid fuel derived from gas) still has a relatively small share in the transportation sector, this share is constantly growing. The use of bio-fuel is also being actively promoted, especially in North and South America.

As such, scientific and technological progress is gradually destroying the monopoly of petroleum products in the transportation sector, replacing them with other diverse sources which are used in other consumption sectors and binding the entire energy sector with uniform conditions of competition.

Although oil will continue to dominate in the transport sector until 2040, in terms of consumption growth, petroleum products will be significantly limited by alternative energy resources. This which will make liquid fuels demand more price responsive.

In industry, the continuing trend in favour of low-energy processes, a result of many years of investment in the energy efficiency of industrial equipment and processes, as well as a shift towards the production of less energy-intensive products reduce the role of this sector in global energy consumption.

The structure of industrial energy consumption is overall quite diversified, some technological processes continue to depend heavily on certain energy carriers. At the same time, almost all industries increasingly use electricity - the most universal energy carrier, which consistently growing its share and replacing all other types of fuel due to its simplicity and ease of use. It is through the electric power sector that inter-fuel competition is strengthening its role in industry and reducing the exclusivity of some energy carriers in certain technological processes.

The main trend of growing inter-fuel competition is also occurring in the residential and commercial sectors, as use of electricity is increasing for all processes, (consumers prefer to have one most convenient source of energy for all needs). Electricity consumption in this sector is growing at a high rate due to displacement of other sources. The use of renewable sources is also actively growing - primarily, of photovoltaic cells and heat pumps (instead of firewood and waste that are traditionally used for heating and food preparation in developing countries).

It is the residential and commercial sectors that are most active in the use of decentralized sources of electricity and heat. By placing these units directly at home, consumers can achieve extremely efficient fuel use - up to 90% of potential energy. Many of these technologies allow consumers to not only supply themselves with electricity, hot water and heat, but also to sell surplus electricity to the grid. The development of "smart grids" and electricity storage devices can provide additional impetus to the development of renewable energy in this sector in the long term.

The electric power sector, the largest consumption sector, is the main field for competition between nearly all of the energy carriers used. To a large extent, it determines the dominating source of fuel at the current stage of the electric power sector development. Deep decarbonisation and a transfer to RES will be most prominent in this sector during the Energy Transition.

Global energy consumption structure will become increasingly diversified. Accelerated development of RES will be the main driver of this process.


Photo by Randy Fath on Unsplash

# Intensification of scientific and technological progress in conventional energy

The development of "new energy" technologies will stimulate scientific and technological development and the search for more efficient solutions in conventional energy. The global energy system strives to balance itself via inter-fuel competition mechanisms. Therefore as the costs of renewable energy sources and storage systems fall, greater efforts will be made to improve the efficiency and environmental friendliness of gas and coal generation, cut the cost of fossil fuel production, accelerate technological development and adaptation of the entire fuel and energy complex to the new realities.

The development of "new energy" technologies will stimulate scientific and technological development and the search for more efficient solutions in conventional energy.

This mechanism is clearly seen in the example of the crude oil market: an increase in the number of electric vehicles will limit oil demand growth and reduce its prices. In turn, low oil prices make traditional ICE noticeably more attractive, which leads to another cycle of inter-fuel competition and stimulates scientific and technological progress. Under pressure from the market, oil and gas companies are forced to launch serious internal adaptation processes in terms of technological innovations. These aim to increase the availability of hydrocarbons (reducing production costs) and expand the mineral resource base. The modern global fossil fuel industry primarily carries out scientific and technical developments in the following areas (see Table 1.3).

All these technologies are reflected in our model calculations of the Outlook-2019, either by reducing production costs (break-even prices), or in the dynamics of changes in these costs (their escalation), as well as in the adjustment of production capabilities.

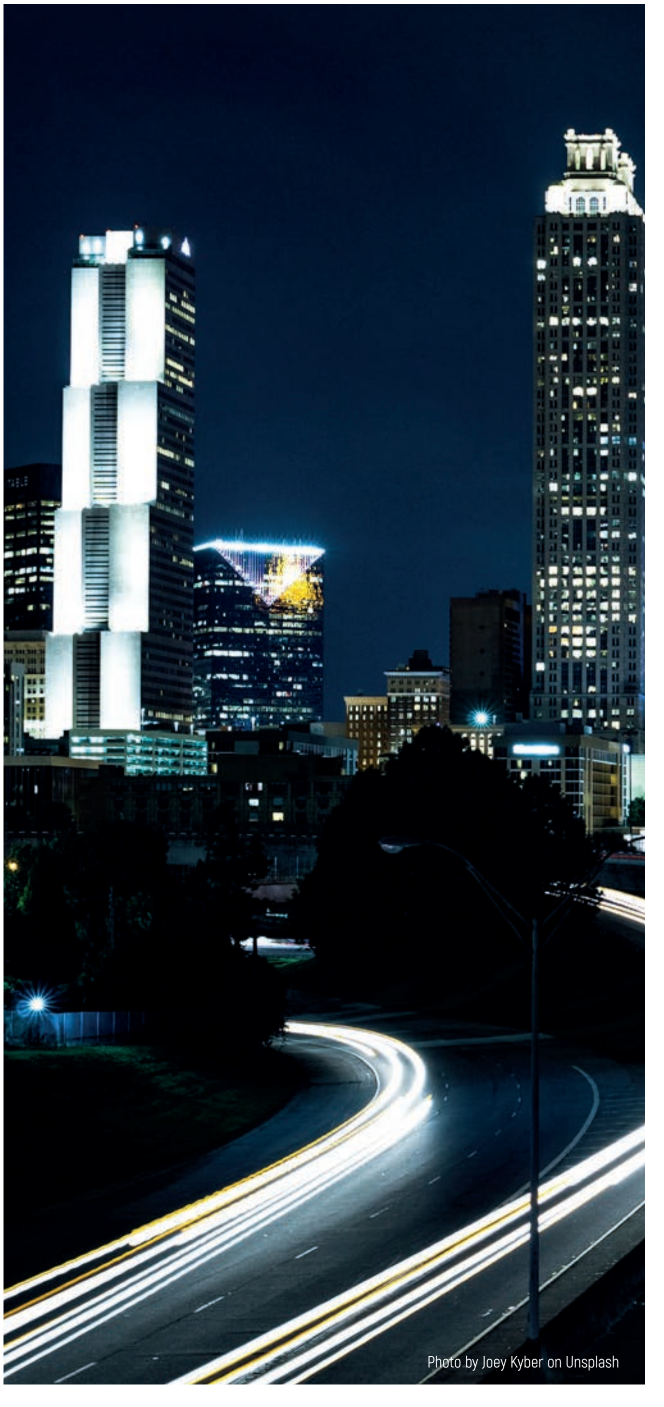


Photo by Joey Kyber on Unsplash

**Table 1.3 - Key technological directions and their impact on the energy system**

| Technological direction | Impact |
|---|---|
| Technologies for enhancing oil recovery in traditional fields (tertiary methods of enhanced oil recovery: miscible flooding, the use of chemical surfactants, thermal injection). | Ensures expansion of the resource base of conventional oil, however this is done by increasing the break-even price of production. |
| Technologies for developing deep-water production, including mobile floating drilling rigs and borehole drilling equipment of low capacity. | Expanded supply curve and cost reduction on individual projects. |
| Technologies for the extraction of oil and gas from low-permeability reservoirs (improvement of computer modelling and control of drilling and hydraulic fracturing, geological exploration; increasing the number of pad in one well; creating mobile drilling complexes; reducing the cost of service infrastructure; increasing lateral lengths; computer near wellbore modeling, well and surface network modelling in order to determine the most effective sites for hydraulic fracturing, reductions in the cost of propane). | Expansion of the world supply curve in its various parts due to the inclusion of shale plays and other low-permeable formations in exploitation. |
| Technologies for the development of extra heavy crude oil and kerogen. | Expansion of the world supply curve on the right-hand side of the curve, the commissioning of "closing" resources |
| Digitilization of upstream operations ("smart fields", "smart wells", automation of systems for control of crude oil delivery and acceptance). | Enables to optimize production chains, simplify supply logistics, reduce risks and ensure reserves growth. |
| In prospecting and exploration of coal deposits, computer multivariate modeling technologies are starting to play an important role. They provide a more accurate assessment of the structure of the reserves. In addition, work is underway to improve direct coal seam mapping by using geophysical and geochemical surveys. In coal mining, continuous and cyclical surface mining technologies are being actively introduced; new types of high-performance equipment (tunnelling equipment, control systems, electric drives, mining and transport systems, etc.); systems of mathematical modeling to assess underground workings; remote sensing technology and systems for monitoring the mining process and reservoir conditions; systems for methane and dust removal, warning and protection systems; robotized complexes. | Implementation of these technologies will ensure a long-term resource base for the coal industry. |
| LNG production and transportation technologies (improvement of LNG production equipment; development of low-tonnage LNG technologies; floating LNG production plants; floating LNG-to-power facilities) | Expanded supply curve and cost reduction on individual projects. |
| Improving the efficiency of heat and electricity generation from fossil sources (the use of co-generation plants; improving the environmental characteristics of coal and gas power plants to reduce harmful emissions; the use of carbon dioxide and flue gas transportation and disposal technologies; the use of supercritical & ultra-supercritical technology, steam coal turbines with intracyclic coal gasification; the use of advanced combined-cycle and gas turbine units, the use of nuclear power reactors on fast neutrons, new generation nuclear power plants based on water-cooled reactors, fast breeder reactor technology development; the introduction of the nuclear fuel cycle technologies for fast breeder reactors and thermal reactors. | Lower specific fuel consumption, greater maneuverability of thermal generation. |

Source: ERI RAS

## Impact on the main stakeholders

The Energy Transition is a complex and painful process for many market participants, associated with the depreciation of existing assets, increasing risks of immense investments already made going "dead", as new ones are becoming less attractive in contracting markets and given a downward price spiral on expectations of lower fossil fuel demand.  A number of players are losing global influence (primarily this includes countries-exporters of hydrocarbons) and, on the contrary, manufacturers and suppliers of equipment are gaining positions (primarily China).

The Energy Transition will mean a transformation of the entire energy business. The development of prosumers and distributed generation will challenge existing models of electric power markets.  New players will appear - primarily in the transportation sector, as it undergoes digitilization. Fossil fuel producers will have to adapt to the new realities and diversify their business. At the same time, large-scale development of new energy will at a certain stage require a new category of large investors.

These investors are likely to be more risk-averse, which raises the issue of greater predictability of return on investment. Government support will be require to back the flow of investment in many areas.  New market mechanisms (including pricing for new types of services) and the emergence of new regulatory measures are likely to be required. Developing countries will clearly demand large-scale international support to finance projects in the new energy sector. In the energy markets, new forms of competition will develop, and this sector will increasingly be joining the "virtual economy". A shift in consumer preferences towards low carbon sources will dictate conditions to manufacturers. Inevitably, production chains themselves will begin to transform.

Another side of decarbonization - corporate - also directly affects the future of fossil fuels, primarily coal. For example, European energy companies aim for carbon-free solutions and assets in their corporate strategy. In 2016 E.ON separated its thermal power plants and international energy trade into a separate company Uniper. E.ON then focused on renewable energy, the electricity grid business and new consumer services - distributed energy, energy efficiency, energy storage technologies. Equinor (formerly Statoil) re-branded in 2018 and revised its plans to meet the "goals of a financially efficient low-carbon strategy". In the same year, EDF adopted the CAP-2030 strategy, the key aspects of which were to double RES capacity, extend the life cycle of existing nuclear power plants and to strengthen its activities in carbon-free generation, consumer services and engineering in the international markets. In 2016, Enel announced the Open Power strategy, which envision, among other things, making new energy technologies available (in particular, renewable energy and smart grids), discovering new ways to manage energy efficiency (through smart metering, digitalization), and new application of electricity - primarily in electric transport. In February 2018, ENGIE announced a new strategy, specifying a gradual exit from coal generation and a focus on low-carbon energy. Vattenfall, a European energy company, has announced plans to achieve zero climate impact by 2050, which involves a gradual withdrawal of coal-fired power plants from the company's portfolio.

In 2015-2018 33 large banks around the world announced restrictions on the financing of projects and companies in coal mining and coal generation – ranging from partial restrictions with some exceptions to a total ban on taking part in financing around the world. Barclays, Credit Suisse, Goldman Sachs, HSBC and Morgan Stanley were among these banks. In October 2018 the World Bank announced the refusal to finance a coal-fired thermal power plant project in Kosovo - the last project in coal generation in its portfolio. It also stated that it would not finance any future oil projects in the future. The largest insurance companies are coming up with similar initiatives - for example, in May 2018, the international insurer Allianz announced that it would stop insuring new coal assets and gradually withdraw from the existing ones by 2040. Thus, decarbonization is becoming mainstream in the strategies of leading international companies.

Image by Free-Photos from Pixabay

The Energy Transition places several forks in the road in front of humanity, to which there are yet no clear answers:

- Will energy intensity continue to fall on the demand side (to ensure a reduction in $CO_2$ emissions), or will our civilization still prefer to ensure economic growth primarily by increasing energy consumption?
- Will there be advanced electrification of all consumption sectors (for the most rapid transition to carbon-free sources which can only be integrated only via the electric power sector electricity), is a combination of clean electricity and carbon-free gases (for example, hydrogen) possible instead of traditional fossil fuels in the long term?
- How quickly will the share of RES grow, what will be the fate of carbon-free nuclear energy (which, nevertheless, is increasingly being seen as environmentally unacceptable). And, linked to this, how fast will the share of fossil fuels shrink? There is also the key issue - is the ultimate goal of the Energy Transition a switch to entirely carbon-free energy sources or a combination of renewable energy sources with more efficient fossil fuel technologies?
- How will large volumes of renewable energy be integrated in the power grid and who (and at whose expense) will ensure its reliability and sustainability?
- What should the optimal ratio of centralized and decentralized parts of energy systems be?
- What exactly should be the main decision-making criterion - the aim of decarbonization at any cost or the principle of technological neutrality with moderate emission requirements, which would provide a niche for all fuels and technologies based solely on inter-fuel competition without additional government intervention?

So far, the answers to these questions have not been formulated yet. The discussion has only just started and many economic, geopolitical and market consequences of the Energy Transition remain unanswered. Nevertheless, despite all these complications and the ambivalent reaction of many countries to this new paradigm (including such global energy leaders as the US, Russia, the OPEC countries), the process of the Energy Transition is already gathering speed and should not be ignored.

# SECTION 2

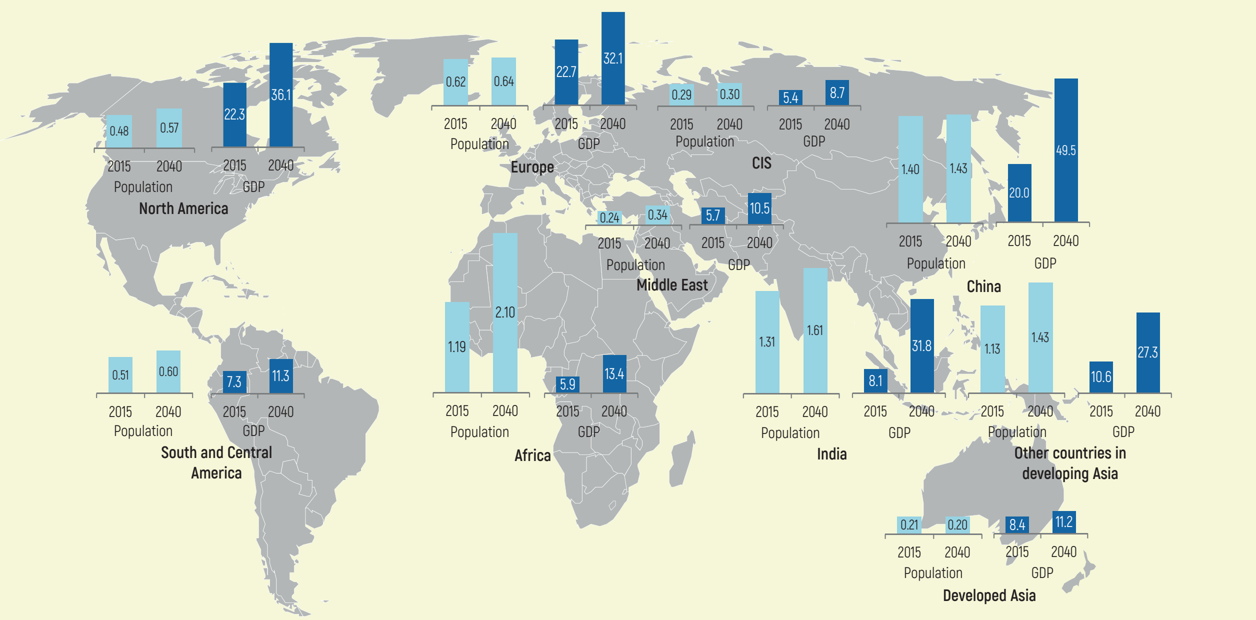
## THE WORLD AT THE CROSSROADS

# SCENARIO ASSUMPTIONS

The "Outlook-2019" is overall close to "Outlook-2016" by demographic and macroeconomic parameters, taking into account the changes which took place in 2015-2018 and were reflected in the statistics (Appendix 1)

The average UN forecast was adopted as a forecast for the world's population. According to it, by 2040 the world population will reach 9.2 billion people, population growth is expected to slow down in 2015-2040 and total 0.9% compared to 1.3% in 1990-2015. (Fig. 2.1). Most of the population growth will occur in the least developed countries in Asia and Africa, where the issue of energy availability remains unresolved.

**Figure 2.1 – Population growth (bln people) and GDP (trln USD) by regions of the world in 2015-2040**




Sources: ERI RAS, the UN (UN Population Division World Population Prospects: The 2017 Revision)

The World Economic Outlook is based on short-term 5-year IMF projections and our own long-term projections to 2040. In the forecast period of 2015–2040, world GDP growth will drop to 2.8% compared to 3.5% in 1990–2015, with an average growth rate of developed economies projected at 1.6% compared to 2.2% in 1990–2015, and in developing economies - just 3.6% compared to 5.2% in 1990-2015. A slowdown in economic growth will be observed in all regions, but it will be most noticeable in developing Asia (4.2% compared to 7.3%). Developing countries will continue to increase their share in the structure of world GDP, primarily due to Asian countries, in particular China and India, whose contribution to world GDP will grow from 17% and 7% in 2015 to 21% and 14% in 2040 respectively. Therefore by 2040 the developing countries of Asia will produce almost half of world GDP.

Three global scenarios are considered in the Outlook-2019. These vary in terms of the speed of technological development and regulatory change:

**The Conservative scenario** describes the prospects for world energy in the framework of current technological and regulatory trends. There are no technological revolutions. It envisions that only those technologies that are already being tested will be implemented. For the technologies already used, a gradual increase in their economic efficiency is expected, while the established trend of declining global energy intensity is expected to continue. Moderate investments in creating a green economy without attempts to move away entirely from energy dependence are foreseen in developed countries. At the same time, transfer of technologies to the developing countries is difficult (the average technology transfer time remains at around 10-12 years).

**The Innovative scenario** is based on the premise of accelerated development of new technologies and their transfer from the developed to the developing countries at a rate twice as fast as now. At the same time, technological progress is expected in all sectors of the fuel and energy complex, leading to increasing inter-fuel competition: any technological breakthrough in one of the competing industries will be opposed by a similar advancement in another. From a regulatory point of view, this scenario assumes strengthening of the already adopted national priorities in promoting renewable energy sources, supporting electric transport and boosting energy efficiency. However, only the developed countries and China will support decarbonization policy, while the others will primarily focus on combating energy poverty and local emissions.

**The Energy Transition scenario** envisions that in addition to rapid development of new technologies and their falling costs, there will also be extensive governmental support in the form of direct financial subsidies, standards for producers, ambitious targets, etc. This support will aim to enhance energy saving, introduction of new production and energy conversion technologies and other measures aimed at reducing the share of fossil fuels, as decarbonization policy takes priority for most countries of the world. In this scenario, it is assumed that although limitations on technology transfer restrictions do not entirely disappear, transfer opportunities grow thanks to the programmes tackling energy poverty, intergovernmental investment in cutting emissions and other initiatives. Unlike the Innovative scenario, the Energy Transition scenario projects that priority will always be given to zero or low-carbon technologies.

**Table 2.1 – Outlook-2019 development scenarios**

| Indicator | Conservative | Innovative | Energy Transition |
|---|---|---|---|
| World population by 20140, bln | | 9.2 | |
| Average annual GDP growth, 2015-2040, % | | 2.8% | |
| State energy policy | The current state policy remains unchanged. | The already adopted national priorities in the promotion of RES, electric transport and energy efficiency. Only the developed countries and China pursue decarbonization policy. | All national energy policies focus on decarbonisation. |
| Technological development | Technology development and transfer continues at the same rate. | Accelerated technological development and localisation, limitations on technology transfer remain. | Global technological competition leads to accelerated technological development in several world hubs and ensures technological transfer available to all countries. |

Sources: ERI RAS, SKOLKOVO Energy Centre

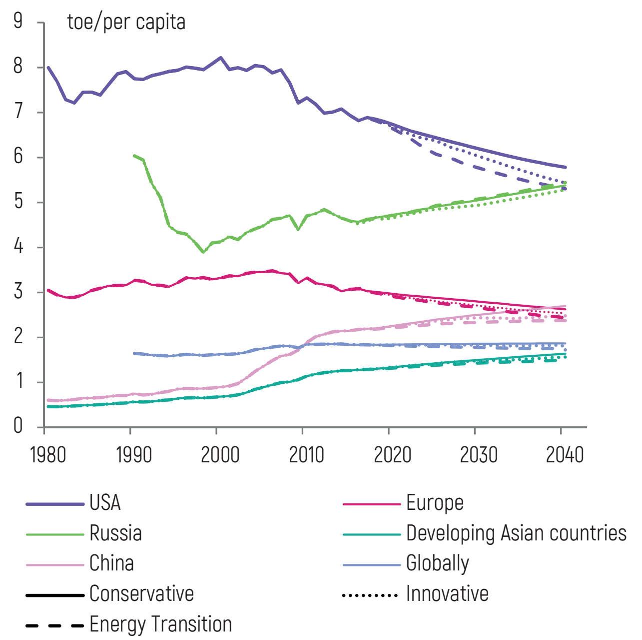
# PRIMARY ENERGY CONSUMPTION

## Changes in per capita energy consumption and GDP energy intensity

Energy consumption per capita and energy intensity of the countries at different stages of development. While the OECD countries have already passed peak per capita consumption, per capita consumption will still grow in the developing countries following increasing prosperity of the population. (Fig. 2.2).

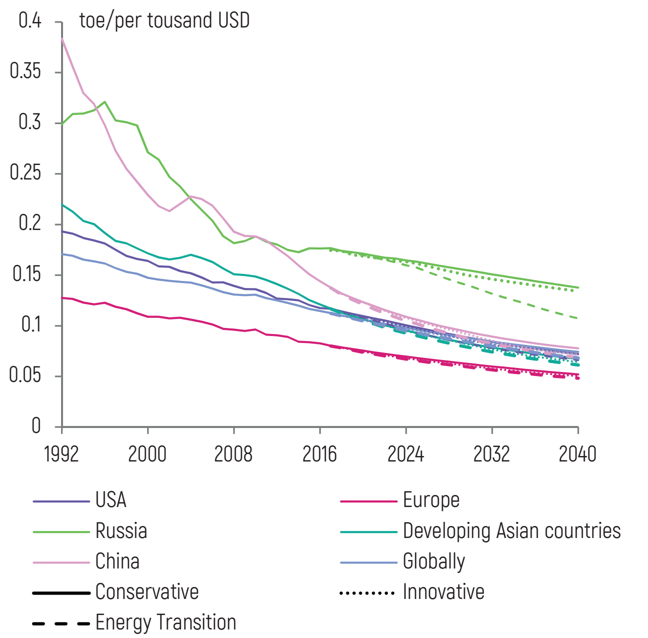
Similarly, the rate at which GDP energy intensity is declining in some countries depends on many factors: changes in the product and sector structure of GDP (growth of the service sector clearly leads to a decline in energy intensity), opportunities for the transfer of energy saving technologies and the availability of investment resources for their implementation, etc. (Fig. 2.3)

### Figure 2.2 – Per capita energy consumption by country, by scenario




Source: ERI RAS

### Figure 2.3 – GDP energy intensity by country, by scenario




Source: ERI RAS

## Primary energy consumption by region

Global primary energy consumption could increase by 17–27% by 2040, taking into account the difference in assumptions depending on the scenario (Appendix 1). This is noticeably lower than in the previous forecast. Nevertheless, by 2040 the world will still need more energy than today to meet the demand from a growing population. This will be the case despite advancements in energy efficiency and a noticeable slowdown in primary energy consumption growth (from 2% in 2000-2016 to 0.3-0.9% in 2016-2040 depending on the scenario). Most of energy consumption growth will occur in developing Asia - by 36-49% depending on the scenario (Fig. 2.4).

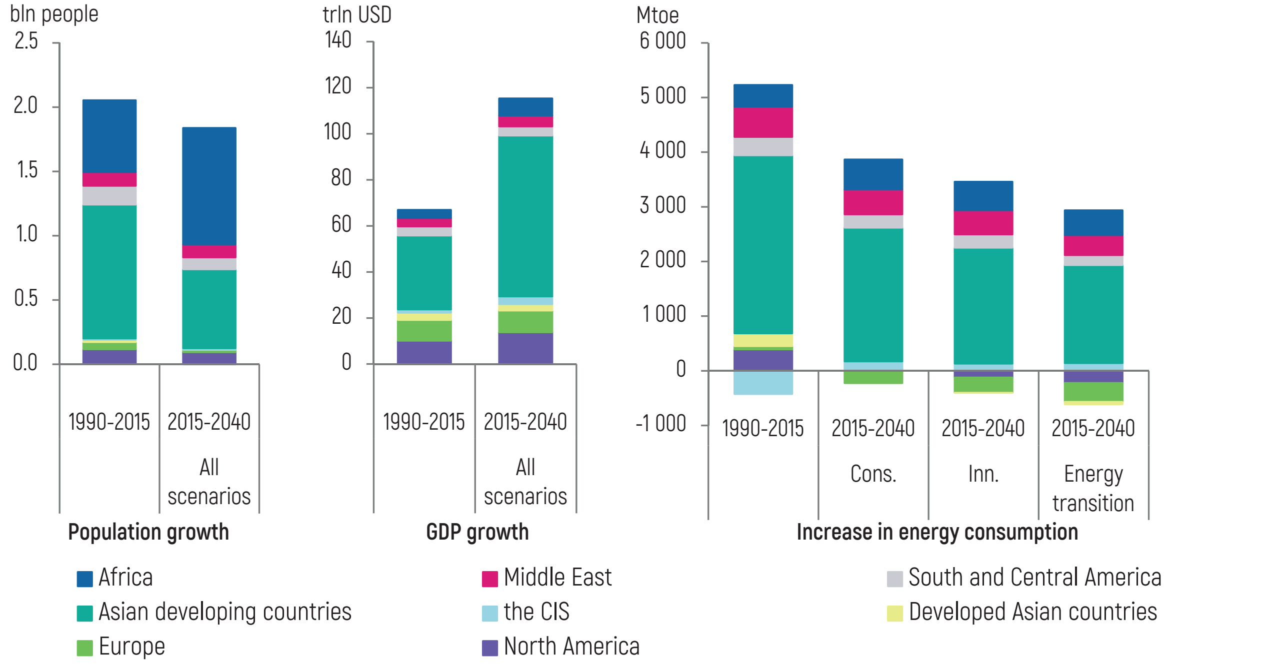
Energy consumption will decline in Europe, the US and developed Asia within all scenarios except for the Conservative one (which shows stagnation of energy consumption).

Energy consumption growth in South and Central America, the Middle East and developing Asia will slow down substantially compared to 1990-2015. A moderate growth in primary energy consumption is expected in the CIS. Energy consumption will grow most rapidly in the Middle East (by 1.5-1.8% per year) and in Africa (by 1.8-2.1% per year) (Fig. 2.5, Table 2.2.).

The energy mix of the regions will become increasingly diversified. Most of energy consumption growth in OECD countries will be attributable to RES; in developing Asia – to RES and gas, while in South and Central America, the CIS and the Middle East – primarily to gas. African countries will substantially increase bio-energy use (mainly – traditional biomass) – (Fig. 2.6).

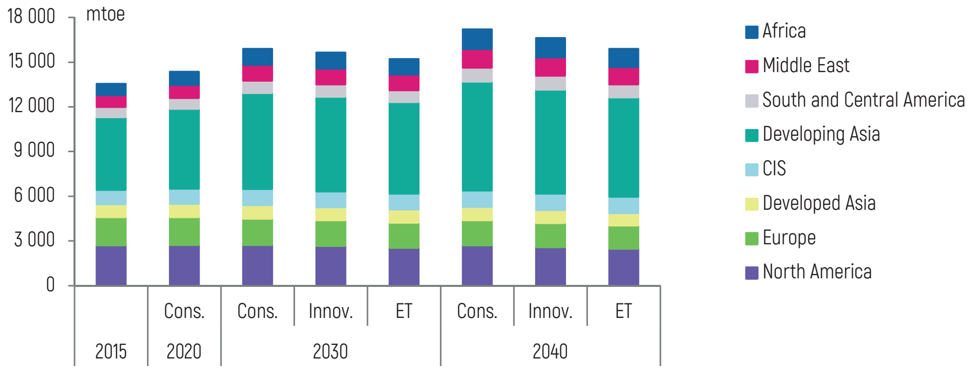
Within the Energy Transition scenario, the developing African countries and some states in South Eastern Asia will skip a stage which everyone has been following, directly entering low carbon future.

**Figure 2.4 – Scenario forecast of growth in world population, GDP and global world energy consumption**




Source: ERI RAS

## Figure 2.5 – Scenario forecast of primary energy consumption by region



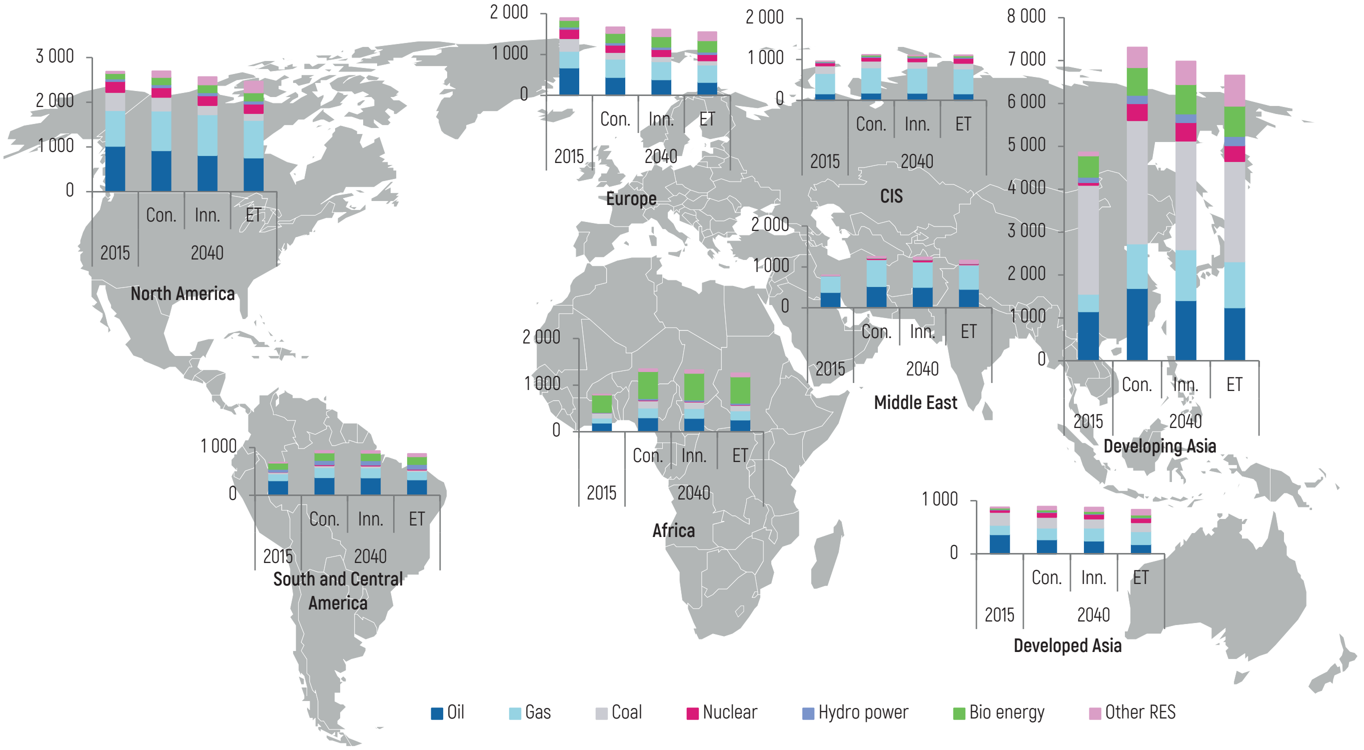

Source: ERI RAS

## Table 2.2 – Scenario forecast of primary energy consumption by region, mtoe

| | 2015 | 2020 | 2030 | | | 2040 | | | Growth in 2015-2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy ransition | Conservative | Innovative | Energy Transition |
| **North America** | **2687** | **2716** | **2711** | **2652** | **2530** | **2697** | **2566** | **2466** | **0.0%** | **-0.2%** | **-0.3%** |
| USA | 2219 | 2231 | 2196 | 2137 | 2045 | 2162 | 2032 | 1984 | -0.1% | -0.4% | -0.4% |
| **South and Central America** | **688** | **722** | **826** | **825** | **799** | **931** | **930** | **870** | **1.2%** | **1.2%** | **0.9%** |
| Brazil | 301 | 314 | 363 | 361 | 345 | 416 | 413 | 383 | 1.3% | 1.3% | 1.0% |
| **Europe** | **1897** | **1863** | **1773** | **1716** | **1686** | **1670** | **1616** | **1552** | **-0.5%** | **-0.6%** | **-0.8%** |
| EU-28 | 1672 | 1624 | 1510 | 1463 | 1435 | 1390 | 1352 | 1292 | -0.7% | -0.8% | -1.0% |
| **CIS** | **958** | **1002** | **1075** | **1056** | **1071** | **1117** | **1100** | **1109** | **0.6%** | **0.5%** | **0.6%** |
| Russia | 660 | 699 | 748 | 732 | 752 | 785 | 771 | 795 | 0.7% | 0.5% | 0.8% |
| **Developed countries in Asia** | **879** | **906** | **905** | **879** | **883** | **892** | **874** | **833** | **0.1%** | **0.0%** | **-0.2%** |
| Japan | 441 | 433 | 407 | 394 | 418 | 381 | 384 | 388 | -0.6% | -0.5% | -0.5% |
| **Developing countries in Asia** | **4862** | **5373** | **6448** | **6364** | **6139** | **7309** | **6982** | **6656** | **1.6%** | **1.5%** | **1.3%** |
| China | 3019 | 3231 | 3632 | 3532 | 3383 | 3847 | 3537 | 3384 | 1.0% | 0.6% | 0.5% |
| India | 857 | 1046 | 1479 | 1493 | 1407 | 1888 | 1865 | 1694 | 3.2% | 3.2% | 2.8% |
| **Middle East** | **795** | **881** | **1066** | **1053** | **1042** | **1254** | **1239** | **1163** | **1.8%** | **1.8%** | **1.5%** |
| Iran | 243 | 270 | 341 | 339 | 330 | 415 | 410 | 387 | 2.2% | 2.1% | 1.9% |
| **Africa** | **800** | **897** | **1109** | **1102** | **1074** | **1347** | **1323** | **1257** | **2.1%** | **2.0%** | **1.8%** |
| **World** | **13566** | **14360** | **15914** | **15647** | **15223** | **17218** | **16631** | **15904** | **1.0%** | **0.8%** | **0.6%** |
| OECD | 5424 | 5448 | 5352 | 5211 | 5063 | 5222 | 5019 | 4811 | -0.2% | -0.3% | -0.5% |
| Non-OECD | 8142 | 8912 | 10562 | 10436 | 10160 | 11996 | 11613 | 11093 | 1.6% | 1.4% | 1.2% |

Source: ERI RAS

### Figure 2.6 – Primary energy consumption by region, fuel type and scenario, mtoe



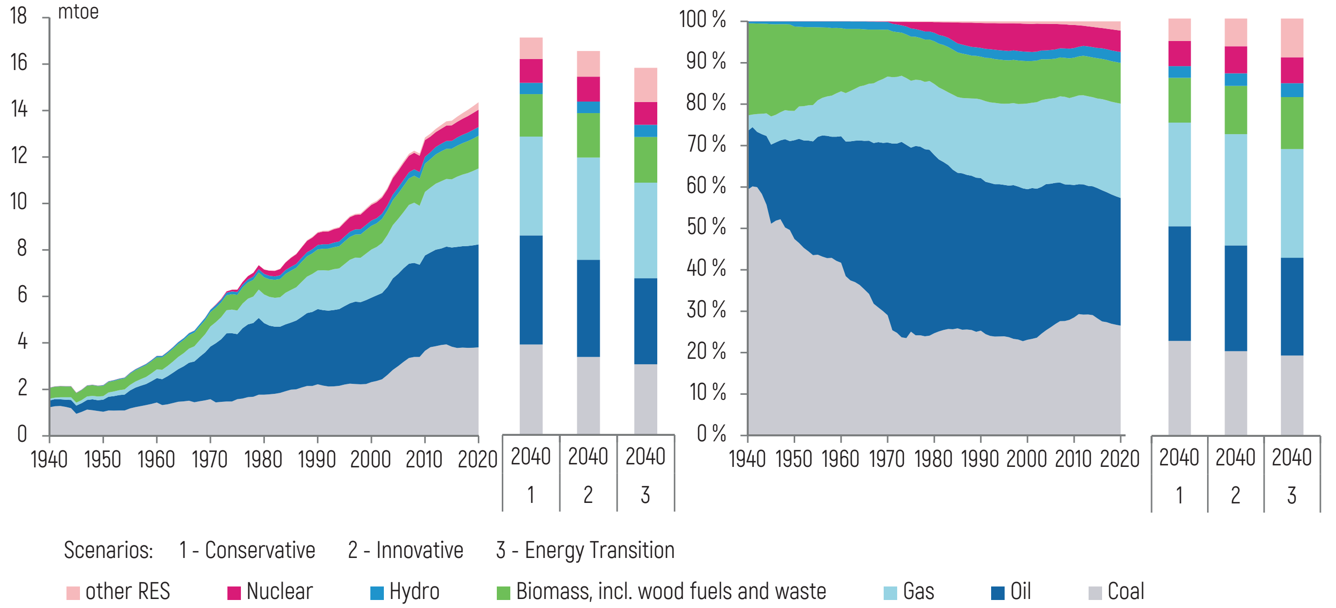

Source: ERI RAS

## Primary energy consumption by fuel type

World energy mix will continue to diversify (Fig. 2.7), at the same time the start of the 4th Energy Transition becomes apparent within all scenarios. However, the speed of its onset varies.

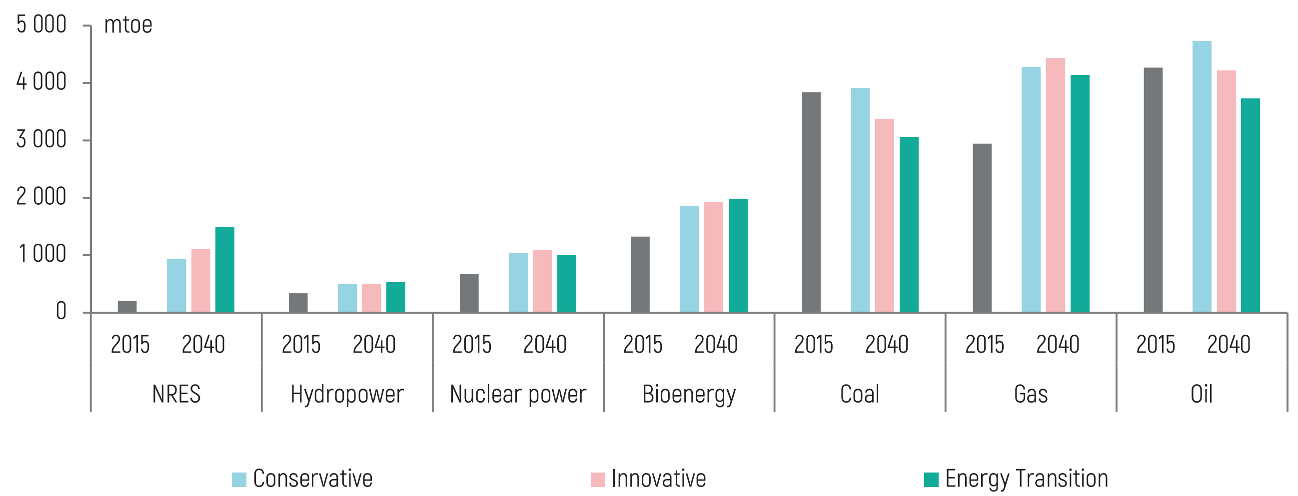
In terms of energy consumption by fuel, in the period to 2040 NRES will account for most of consumption growth, while coal usage will see the biggest decrease (Fig. 2.8).

**Figure 2.7 – World primary energy consumption and changes in the energy mix by fuel from 1940 to 2040 under the three scenarios**




Source: ERI RAS

**Figure 2.8 – Primary energy consumption by fuel (2015 and growth to 2040) by scenario**

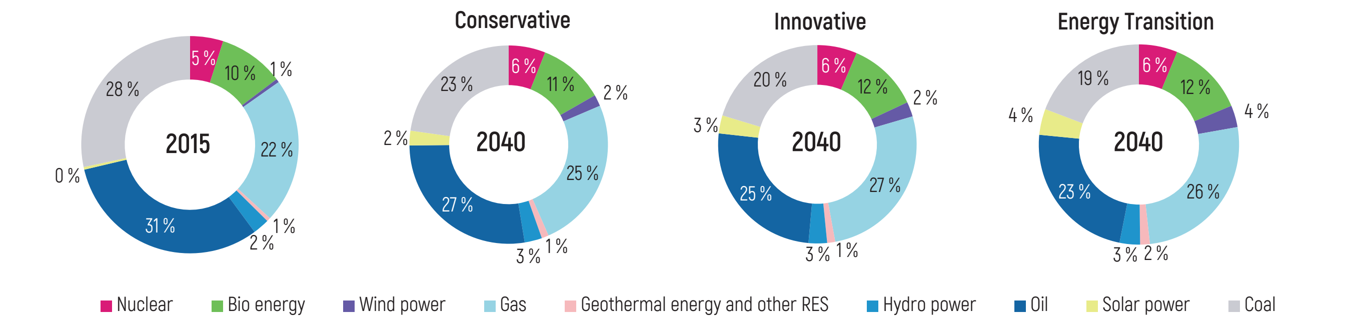



Source: ERI RAS

As a result, by 2040 the structure of world primary energy consumption will change: the share of renewable energy sources (solar, wind, geothermal energy and other RES) will increase substantially, and the overall contribution of non-fuel (carbon-free) energy sources will grow from 19% in 2015 to 25-31% by 2040, depending on the scenario (Fig. 2.9). Therefore, overall world energy consumption by fuel will become the most diversified in the entire history of statistically recorded development of energy consumption. Nevertheless, fossil fuels will remain predominant in the structure of world energy consumption until the end of the forecast period, although this dominance could already be lost in 2050-2060 (Fig. 2.10).

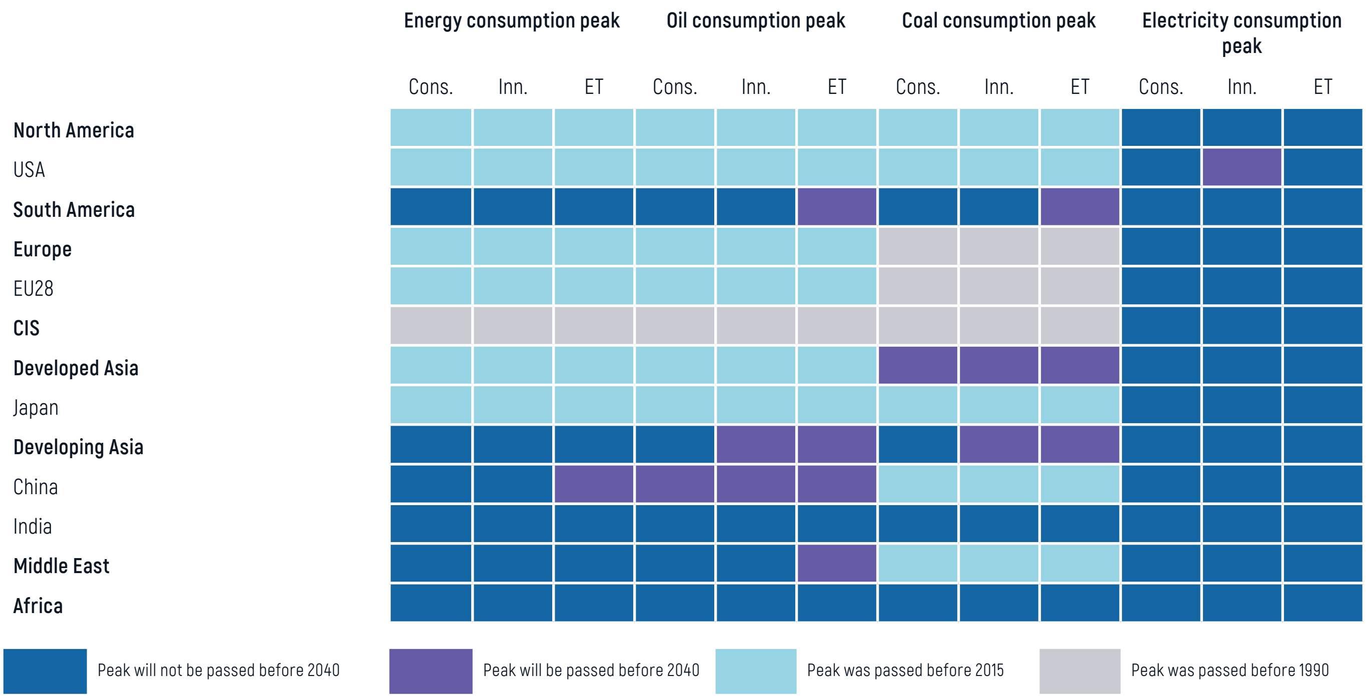
The world energy mix will continue to diversify and the start of the Energy Transition to RES is apparent in all scenarios. However, the speed of its onset varies. The share of all non-fuel energy sources will increase from 19% in 2015 to 25-31% in 2040.

### Figure 2.9 – World primary energy consumption structure - by fuel in 2015 and 2040 by scenario




Source: ERI RAS

### Figure 2.10 – Energy consumption peaks by scenario



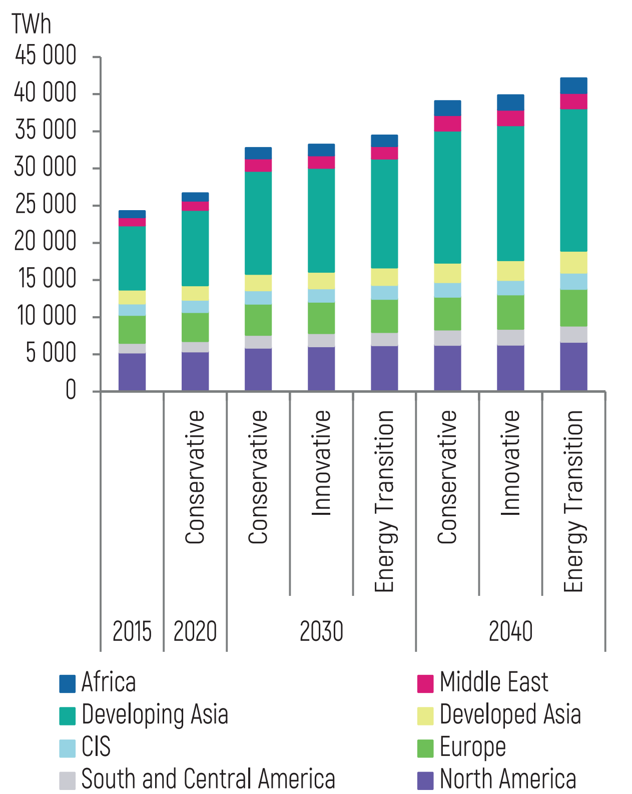
# ELECTRIC POWER SECTOR

## Electricity consumption

Increasing electrification of all sectors will stimulate accelerated electricity demand in all regions within all scenarios. The share of electricity in world final energy consumption will grow in all regions, even in those OECD countries where primary energy consumption is expected to decline (Fig. 2.11). While in 1990 -2015 consumption rose 2.04 fold, growth in 2015-2040 is projected to be slightly lower - by a factor of 1.62-1.74, depending on the scenario. At the same time, most of the growth in electricity consumption will be concentrated in developing Asia, the Middle East and Africa, where consumption will double in the forecast period. In absolute terms, most of the increase in 2015–2040 will be attributable to developing Asia (as was the case in 1990-2015).

Increasing electrification of all sectors will stimulate accelerated electricity demand in all regions. By 2040 electricity demand will grow by a factor of 1.62-1.74.

Figure 2.11 – Projected electricity consumption by region, TWh, by scenario




Source: ERI RAS

# Electricity production by fuel type

In the period from 2015 to 2040, electricity production/generation (the two terms are used synonymously) from all types of fuel (with the exception of petroleum products) is projected to increase in the Conservative scenario. In addition, electricity production from coal will also decline within the Energy Transition scenario (Fig. 2.12). The biggest growth in 2015-2040 is expected from solar and wind generation - both in the Conservative and in the Energy Transition scenario. In general, all types of renewable energy will demonstrate the largest increase both in percentage and in volume terms.

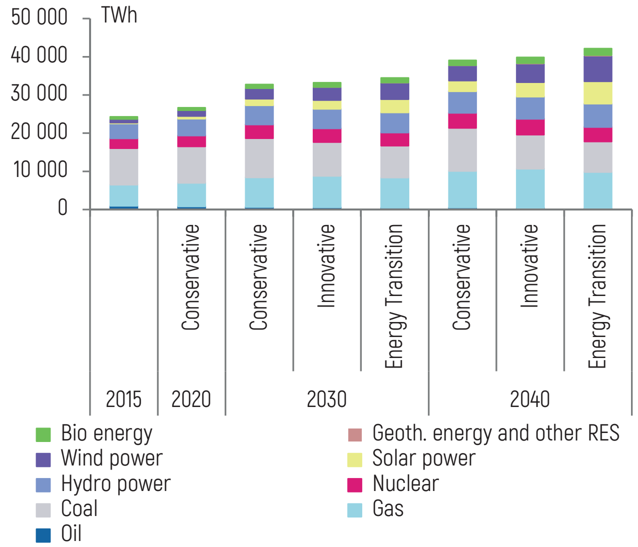
Prospects are good for electricity production from natural gas, which is projected to grow by 4028 TWh (by a factor of 1.7) in the Conservative scenario, by 4768 TWh (by a factor of 1.9) in the Innovative scenario, and by 4074 TWh (by a factor of 1.7) in the Energy Transition scenario.

In the coming years, the electric power sector will become the focus of transformations taking place in the global energy sector. The most radical changes will occur in the structure of global generation. The role of coal will dwindle drastically: by 2040, its share will drop from 39% to 29% - in the Conservative scenario. Thus, although coal will still be one of the most important energy sources, it will be rapidly surrendering its position. The share of natural gas will grow from 23% in 2015 to 23-26% by 2040.

However, most changes will be related to RES. A multifold increase in RES-based electricity generation was already recorded in 1990 -2015 when it grew 10-fold (mainly due

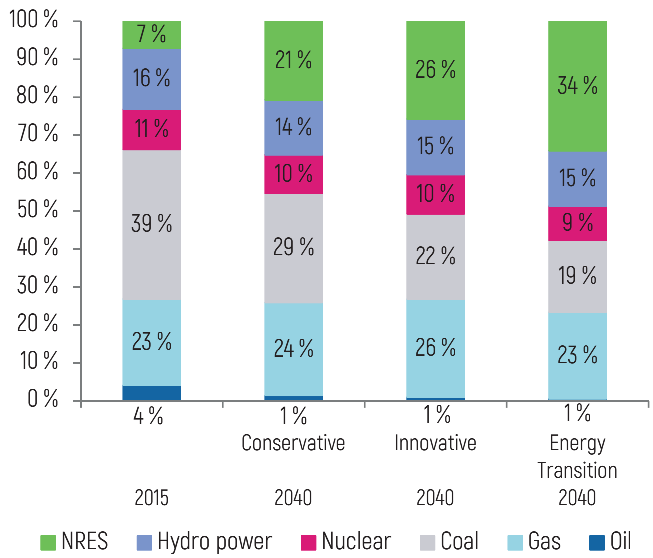
Coal will see the largest decline in its share of generation by 2040 – from 39% in 2015 to 29% in the Conservative scenario and to 22% in the Energy Transition scenario.The share of natural gas will increase slightly from 23% in 2015 to 25-27% by 2040. However, the most significant changes will be related to RES, with their contribution growing from 7% in 2015 to 21-26% by 2040. This is the most important feature of the current global energy transition.

**Figure 2.12 – Projected worldwide production of electricity by fuel type under the three scenarios, TWh**




Source: ERI RAS

**Figure 2.13 – Changes in worldwide electricity production by fuel type, %**



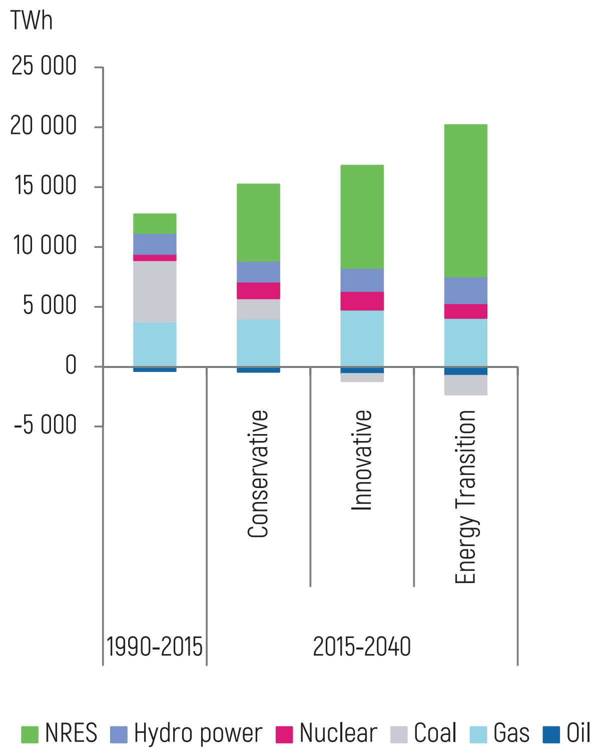

Source: ERI RAS

to the increasing solar and wind generation). However, this growth was recorded from a very low base, and the overall share of RES reached just 15% by 2015. In 2015- 2040 NRES will increase their share to 21-34%, transforming themselves from a marginal source of electricity into one of the main ones (Fig. 2.13). This is the most important feature of the current global energy transition.

It was coal-based generation that showed the largest growth in absolute terms in the last quarter of the century (1990–2015) (Fig. 2.14). However, this is expected to change in the forecast period. In all scenarios, RES will be the clear leader in terms of production growth in absolute terms. There will also be other major structural changes.

The use of oil in the electric power sector will decline in the forecast period under all scenarios. A decline in electricity generation from nuclear fuels in OECD countries will be more than offset by an increase in NPP generation in the developing countries, within all scenarios. The picture is even more complicated with coal-fired generation: in the Conservative scenario, a reduction in coal-fired generation in OECD countries will be more than offset by growing production from this type of fuel in developing countries. However, in the Innovative and the Energy Transition scenarios, the reduction in coal-based generation in developed countries will already exceed its growth in developing countries.

**Figure 2.14 – Growth in electricity generation by fuel type, TWh**




**Source: ERI RAS**

Coal-based generation showed the largest growth in absolute terms In the last quarter of the century (1990–2015). However, this is expected to change in the forecast period. In all scenarios, RES will be the clear leader in terms of production growth in absolute terms.

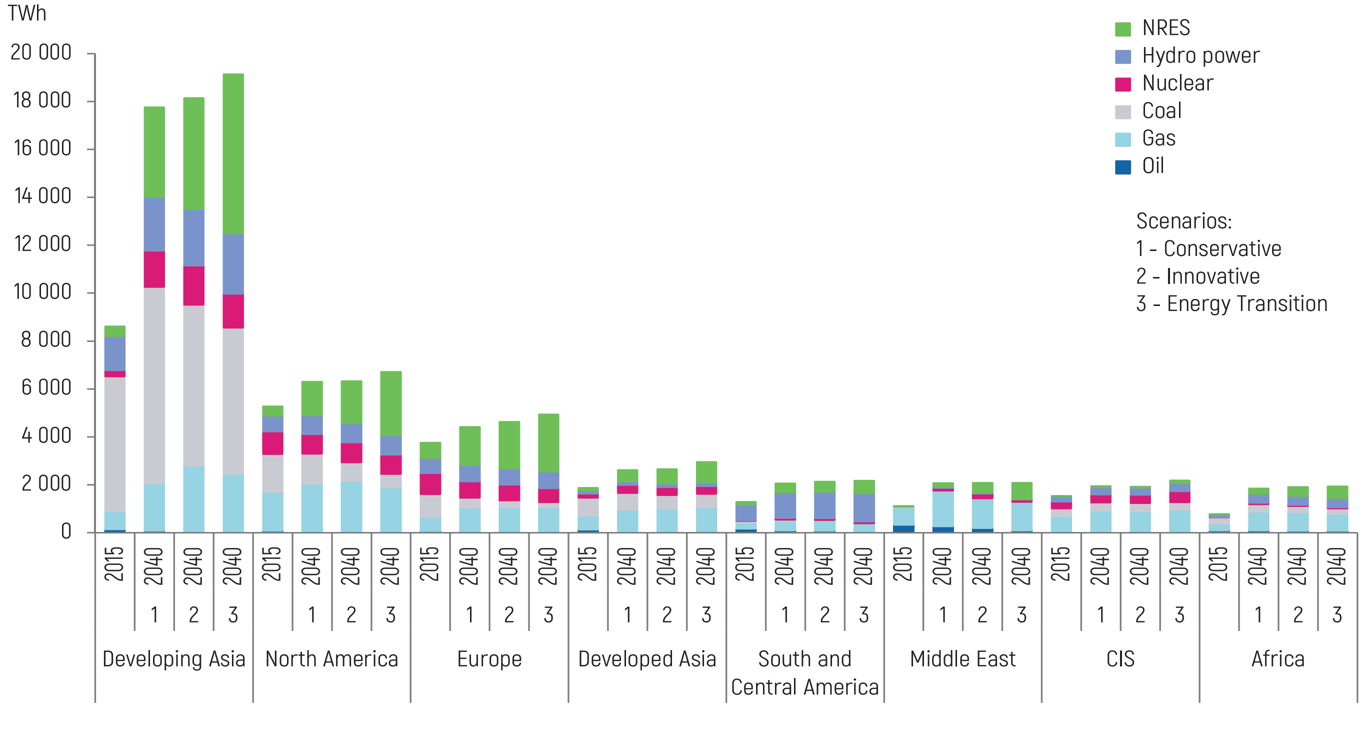
Photo by Paweł Czerwiński on Unsplash

# Electricity production by region

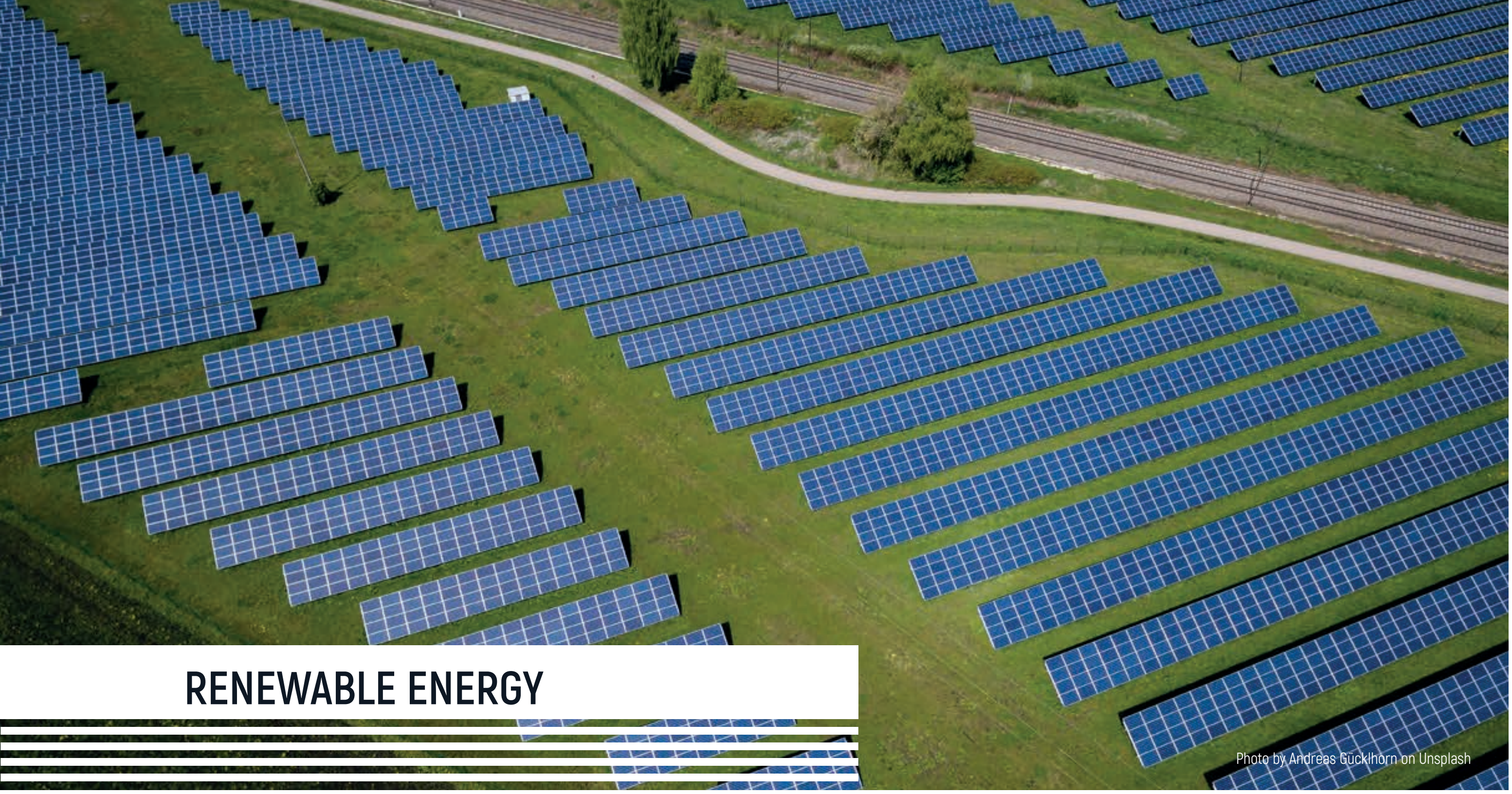
The development of the electric power sector in the regional context will be very heterogeneous. In the forecast period to 2040 (Fig. 2.15):

- The largest electricity production volumes across all regions will be demonstrated by developing Asia in 2040 as well as in 2015. Although coal will remain the dominant fuel for power plants, renewables are forecast to provide most of electricity generation growth.
- Gas fired generation will continue to lead In North America; however, the entire increase in output will be attributable to renewable energy resources.
- Coal-based generation in Europe will be actively reduced against faster growth of NRES.
- Coal-based generation will be displaced by gas-fired generation in developed Asia - this will also be accompanied by the rapid development of renewable energy sources.
- Hydroelectric electricity generation will maintain its first place in South and Central America
- Gas-based generation will continue to have the largest share in electricity production in the Middle East, in the CIS and in Africa.

**Figure 2.15 – Electricity production by region and fuel type in 2015 and 2040, TWh**



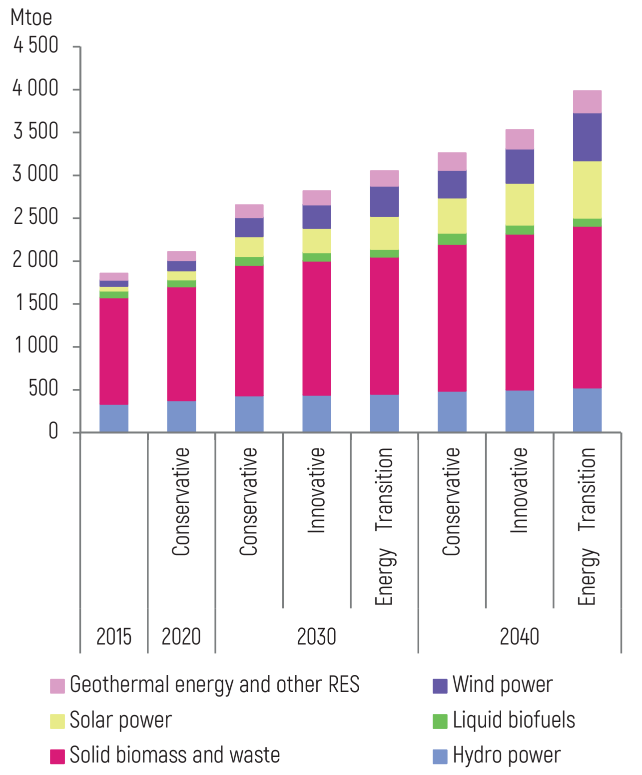

**Source: ERI RAS**




# RENEWABLE ENERGY

Cumulatively renewable energy sources provide around 15% of world primary energy consumption[29] of which 13% is attributable to hydro power and traditional biomass.  The share of new types of RES (NRES – solar power, wind power, tidal, geothermal, wave power etc.) is just 2%.  However, over the recent decade NRES have shown impressive development. In 2008 -2018 wind power capacity increased 6-fold, and solar energy – 8-fold. In the period to 2040, NRES will demonstrate the highest growth among all the energy resources considered - 6.3-8.3% per year, depending on the scenario - and the most important shifts in the global energy system will be linked to the further development of NRES.  In the period to 2040 consumption of all renewable energy will increase by 76-115% (Fig. 2.16), with NRES expected to develop most rapidly in all scenarios. In absolute terms, the largest increase is projected in the consumption of solid biomass and waste - they remain, as it was hundreds of years ago, the main source of energy supply in the regions of energy poverty (Fig. 2.16).

**Figure 2.16 – Projected RES energy consumption by type, mtoe**




Source: ERI RAS

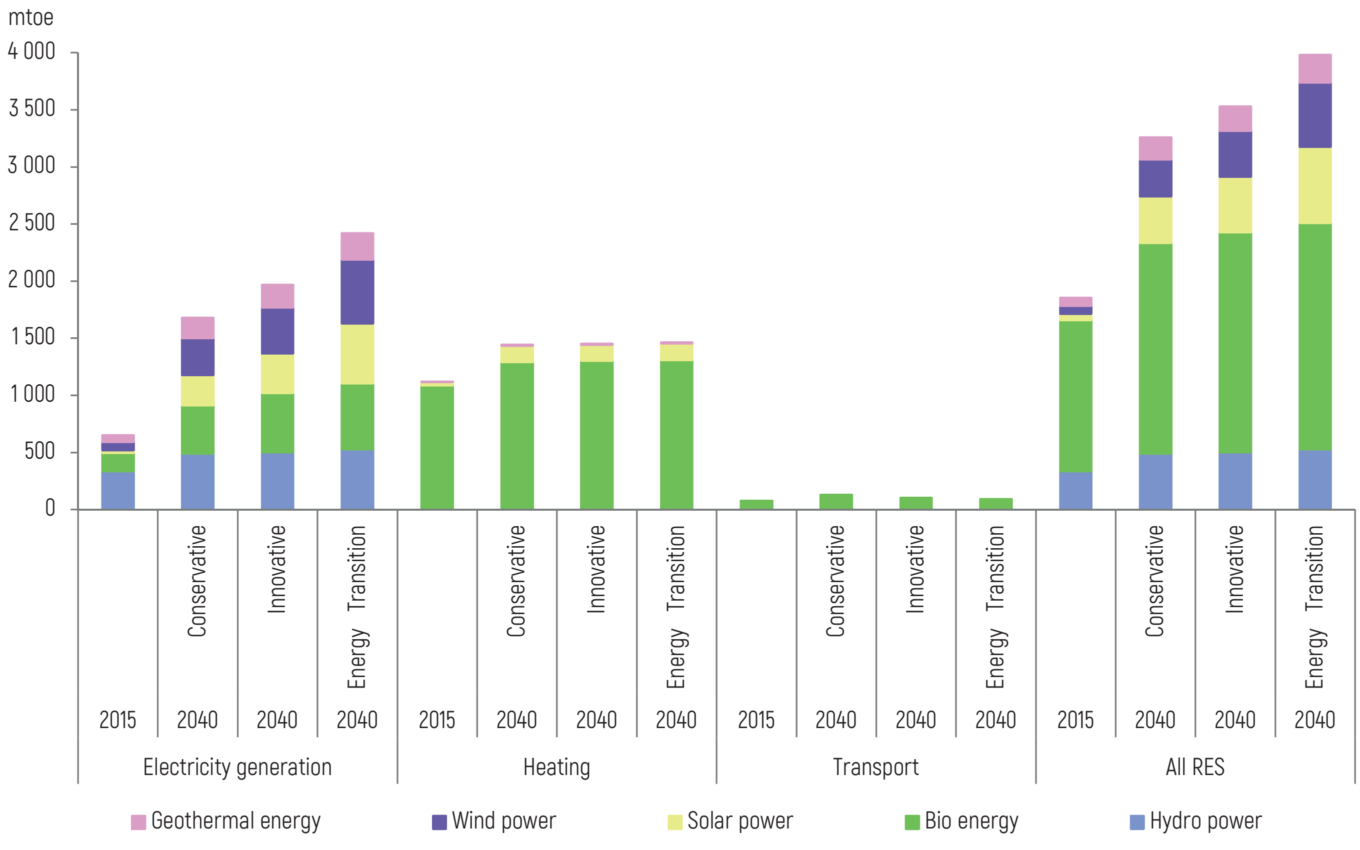
29 In this study, renewable energy sources include bioenergy (liquid biofuels, woodfuels, *pellets, waste, biogas), hydropower, landfill gas, solar, wind, tidal, geothermal, wave

Currently, most RES energy is consumed for heating and cooking (mostly biomass). However, by 2040, rapid development of NRES will push the use of RES for electricity generation into the first place under all scenarios (Fig. 2.17). An impressive 2.5-3.7 - fold increase in RES-based electricity production is projected in 2015–2040 - as solar and wind power capacity grows substantially. The share of bio energy, which in 2015 accounted for 97% in overall consumption of RES, will decline In the heating and cooking sector, as the use of solar power grows. Direct consumption of renewable energy (biofuels) in transport will be even lower in the Energy Transition scenario than in the Conservative one, as it is displaced by electric vehicles. However, actual use of renewable energy in the transport sector will of course be higher in the Energy Transition scenario if we take into account the sources of electricity production.

In the period until 2040, RES will become the fastest growing source of energy in all scenarios, consumption of renewable energy will increase by 76-115%.

The volume of renewable energy for electricity production will increase 2.5-3.7 fold by 2040, primarily due to a multi-fold increase in solar and wind generation capacity.

**Figure 2.17 – Projected world RES world energy consumption by fuel type and consumption sector in 2015, 2040, mtoe**



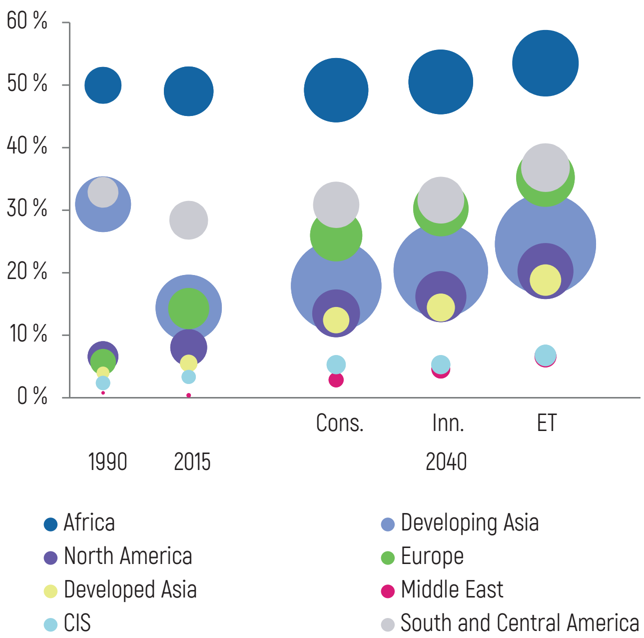

Source: ERI RAS

In the regional context, currently the largest share of RES in energy consumption is observed in Africa, where they account for half of all consumed energy. Mostly this is energy generated from traditional biomass. This situation will remain unchanged in the period to 2040 (Fig. 2.18 ). The share and the use of renewable energy is projected to increase significantly in Europe. As a result, by 2040 Europe, as well as South and Central America, will be meeting around a third of its energy needs through renewable energy. Asian countries and North America will boost the share of RES up to nearly 20%.

Only the CIS and the Middle East which have vast hydrocarbon resources will remain on the periphery of this process.

RES energy consumption will grow in all regions within all scenarios. While the biggest increase in consumption in 1990-2015 took place in Europe, in the period to 2040 consumption there is expected to go up only

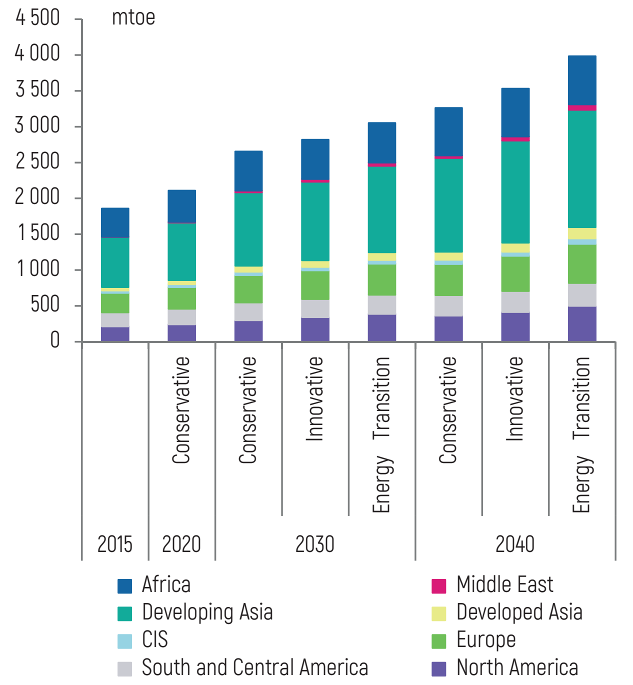
**Figure 2.18 – Share of RES in primary energy consumption by region (the left scale) and volumes of RES energy consumption (size of circle), mtoe**




Source: ERI RAS

1.6-1.8 fold, as the starting base for growth is larger this time. The biggest increase (11.5-17.4 fold) is expected in the Middle East. However, even in this region growing RES are gradually beginning to displace hydrocarbons (Fig. 2.19).

**Figure 2.19 – Projected RES energy consumption by region, mtoe**

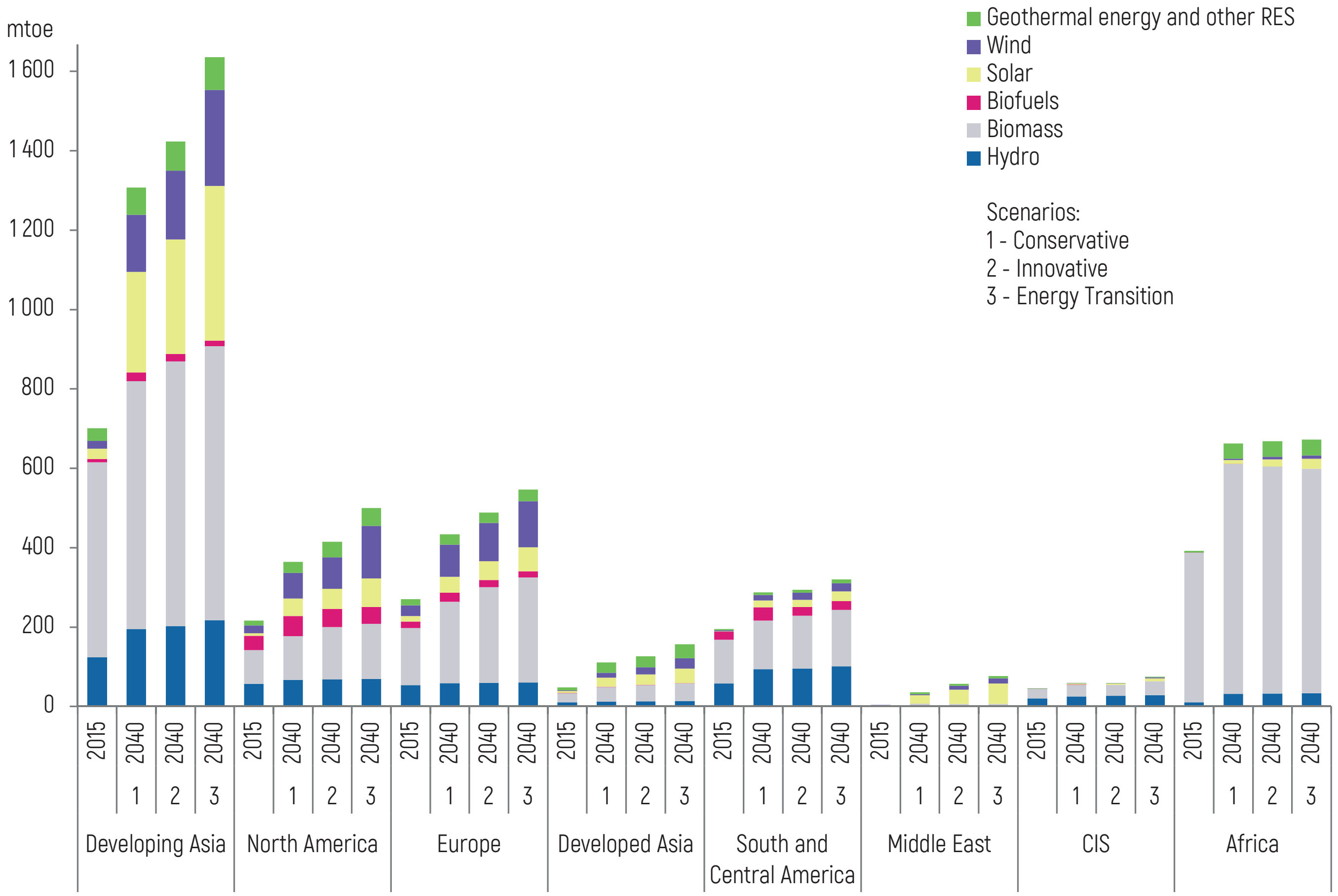



Source: ERI RAS

The most significant increase in the use of renewable energy in 2015- 2040 will be observed in developing Asia, mainly in China and India, and to a large extent this will be due to NRES use (Fig. 2.20). The use of solid biomass and waste in the region will also markedly grow. Not only centralised but also distributed RES will be playing an increasingly important role both in developing Asia and in Africa.

By 2040, the use of renewable energy in the production of electricity and heat in all regions will increase substantially, while consumption of liquid and solid biofuels will be growing at a slower pace.

**Figure 2.20 – Dominant types of RES by region and consumption growth indicators, mtoe**




Source: ERI RAS

Image by adege from Pixabey

# NUCLEAR POWER

During the initial development of the nuclear power industry, many experts supposed that it would become a key source of energy worldwide. However, these hopes were not justified, and as of 2015, the share of nuclear energy in global electricity production only reached 10.6%. Given changing market conditions with continuing uncertainty around demand and parameters of inter-fuel competition, including energy prices, many players are in no hurry to invest in complex expensive projects with long payback periods, with nuclear energy projects among those.

There is also still a level of concern about nuclear power safety in a number of countries. All of these factors lead to the development plans for the nuclear power sector being revised.

In the period to 2040 growth in nuclear power generation will lag behind electricity consumption growth and by 2040 the share of nuclear power generation will decline to around 10%. The share of NPPs in electricity production is expected to fall from 18% in 2015 to 12.6–13.4% by 2040, depending on the scenario.

The main increase in NPP capacity in the period to 2040 is expected in developing countries, where nuclear power is still being viewed as one of the attractive options against rapid energy consumption growth. Another important factor influencing the decision of some countries to use nuclear energy is their desire to get the relevant technologies and develop their own scientific knowledge and production expertise. Their centralised regulatory systems which enable to finance nuclear power projects which would have been too complicated in purely market conditions.

In context face of market uncertainty, declining fossil fuel prices, technological advancements and cost reduction in renewable energy, many market participants are in no hurry to invest in large expensive nuclear projects with long payback periods. These are difficult to place in a stagnating market. It is also challenging for these projects to pay for themselves within the majority of existing market models.

As of June 2019, 54 nuclear power reactors are under construction in 18 countries with cumulative installed capacity of 55 GW. 44% of these are being built in developing Aisa (Fig. 2.21), of which 18 reactors are located in China and India.

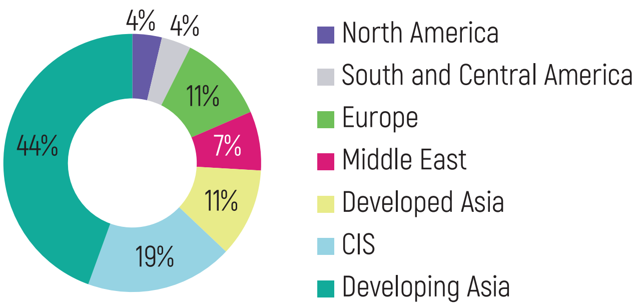
The lifecycle of nuclear power reactors is on average 40 years, and many countries which actively built NPPs in the last century are facing the issue of decommissioning nuclear power reactors. Of 451 operational reactors worldwide, 91 have already been in operation for over 40 years (Fig. 2.22). As a result, decisions to extend operating life of an increasing number of reactors to 60 years. There are plans in the USA to introduce applications for 80-year licenses. However, despite the decisions on extensions, by 2040 over half of operational nuclear power capacities will still have to be decommissioned. Not in all regions will this be offset by the commissioning of new capacities.

A whole number of countries are deciding to move away from the development of nuclear power, cancelling expensive construction projects or deferring putting reactors in operation. Reasons vary: economic slowdown and unacceptably high costs of NPP construction projects, changes in government, lack of sufficient electricity demand, availability of cheaper sources - gas and coal, etc. And the desire to optimize costs, combined with technological progress and upgrading capabilities, makes it possible to extend licenses for the operation of nuclear power plants. As a result, in 2017–2018 there were significant adjustments in the programmes of various countries in the field of nuclear power. The number of countries planning to reduce the role of nuclear energy has gone up substantially, but there are still many who want to start using nuclear power in their territories (Fig. 2.23).

Given these trends, by 2040 the world's cumulative installed nuclear power capacity is expected to increase by 45–51% compared to 2015, primarily due to growth in developing countries.

By as early as 2035, electricity production at nuclear power plants in developing countries will exceed nuclear generation in OECD countries (Fig. 2.24), according to the calculations. Stabilization and reduction in NPP installed

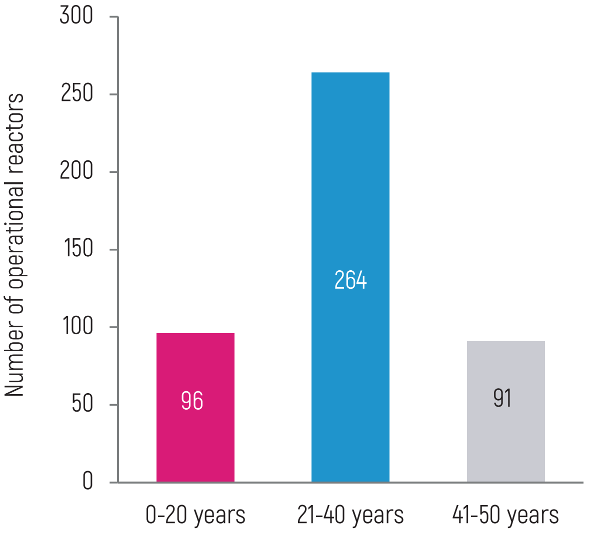
**Figure 2.21 – Nuclear power reactors under construction, regional distribution as of June 2019**




Source: PRIS database, June 2019

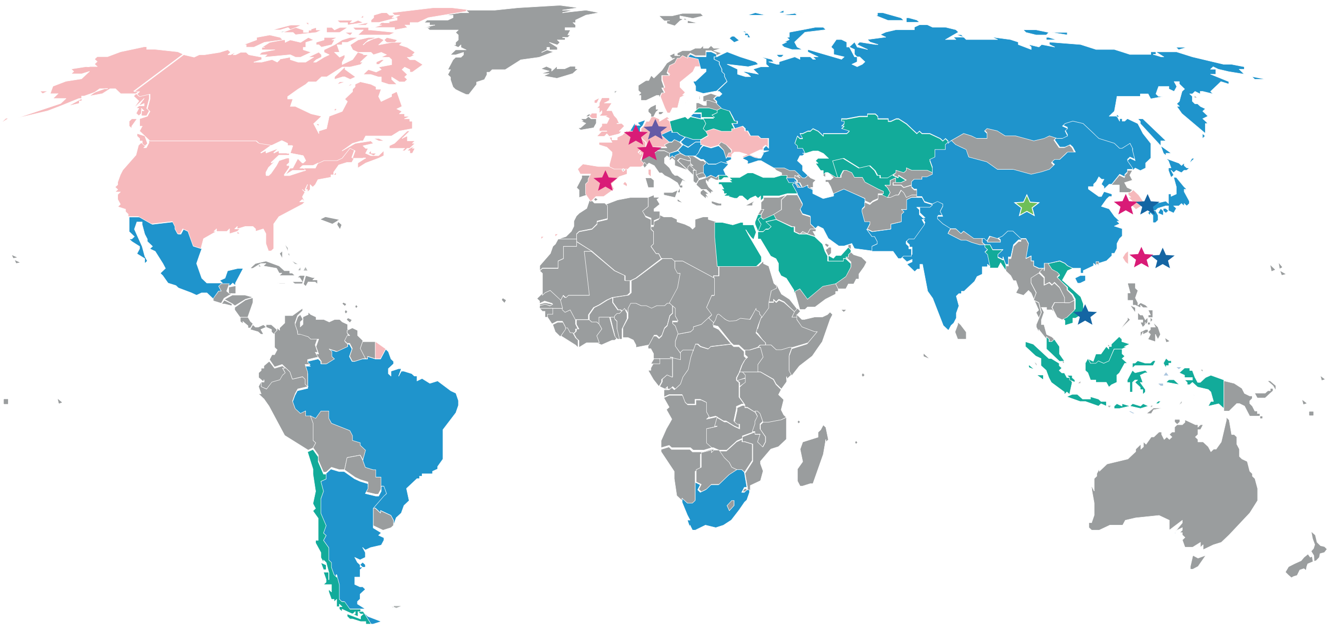
In the recent years, national strategies have undergone substantial revisions in relation to nuclear power development. The number of countries planning to reduce the number of nuclear reactors and nuclear power generation. However, there remain some countries interested in commissioning new NPPs in their territories.

**Figure 2.22 – Operational reactors worldwide, by age, as of June 2019**




Source: ERI RAS based on PRIS data, June 2019

**Figure 2.23 – Decisions on the use of nuclear power capacity and adjustments to capacity, by country**



★ NPP to be shut down prior to the end of the 40 year life cycle

★ A gradual phase out of NPPs (there are NPPs in the country, the country is moving away from building new nuclear reactors, existing ones are being shut down without lifetime extension)

★ A revision of previous plans and assessments in 2016-2018 and a downward adjustment to the use of nuclear power

★ A revision of previous plans and assessments in 2016-2018 and an upward adjustment to the use of nuclear power

A reduction in operational nuclear power capacity

An increase in operational nuclear power capacity

Commissioning of the first NPPs in the countries where there were none as of 01.01.2019

**Source: ERI RAS**

By 2035 electricity production at NPPs in developing countries will exceed output in developed countries.

capacity in OECD countries will be partly offset by increasing operating efficiency of equipment in operating reactors and optimizing the operating modes in the grid. With the exception of North America and Europe, the rest of the regions show an increase in nuclear energy production.

A substantial increase in power generation at nuclear power plants is expected in developing Asia and the Middle East. At the same time, development of renewable energy poses new challenges for the nuclear power industry.

Previously, baseload mode was standard for NPPs, since fossil fuel based generation made it possible to cover all changes in load. However, as RES based generation grows, the issue of maneuverability of NPPs is becoming increasingly important.

The use of external electricity storage technologies is the safest but fairly expensive way to resolve this. An alternative solution is changing the load factor of nuclear power reactors. This is possible in practice and in several

**Figure 2.24 – Production of nuclear electricity at NPPs by region**

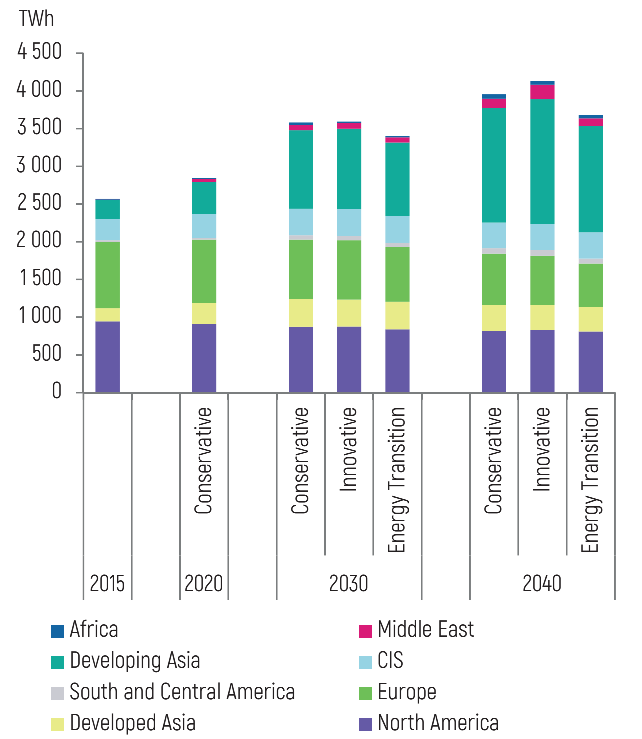
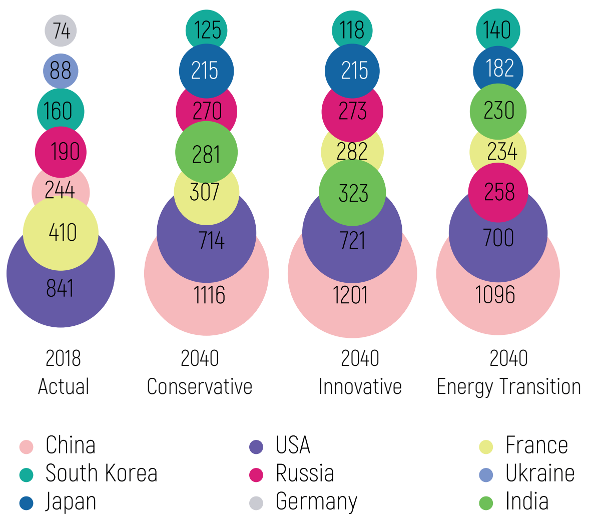



**Figure 2.25 – Largest nuclear electricity producing countries, NPP in 2018 and in 2040 under the three scenarios, output in TWh (size of circle)**




**Source: Fig.2.24 and Fig.2.25: Source: ERI RAS**

ways, but presents additional challenges in terms of safety, length of operational life and economic viability.

Revisions of national energy policies and company plans lead to a change in positions among the leading countries (Fig. 2.25). In particular, South Korea and France are significantly reducing the use of nuclear power. By 2040 China is projected to lead in electricity generation at NPPs.

The largest increase in installed NPP capacity is expected in China and India.

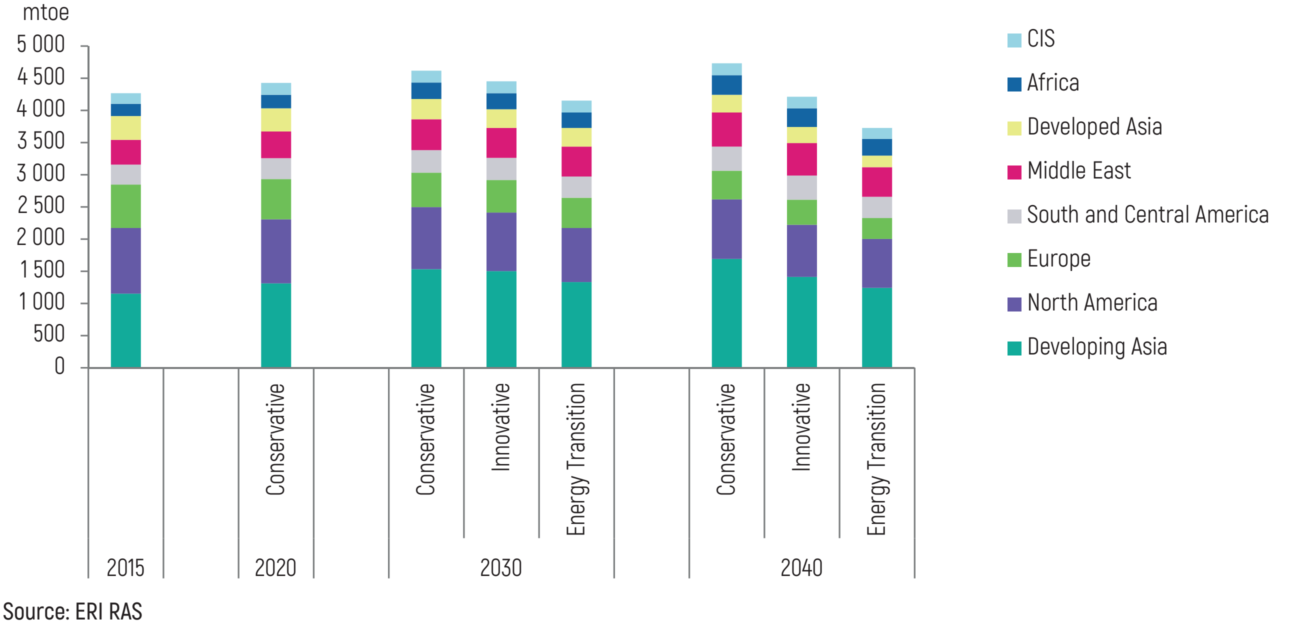
# LIQUID FUEL MARKET

## Demand for liquid fuels

Prospective demand for liquid fuels (which include bio fuels, coal-to-liquids (CTL) and gas-to-liquids (GTL) in addition to petroleum products) is one of the most most controversial aspects of the future development of world energy. This indicator is extremely sensitive to scenario conditions.

By 2040 demand for liquid fuels will increase by 11% compared to 2018 in the Conservative scenario. In contrast, the "peak of demand" for liquid fuels will come as early as 2026 and 2021, respectively, and by 2040, demand will decrease by 2% and 13% from current values in the Innovative and Energy Transition scenarios (Fig. 2.26).

**Figure 2.26 – Projected demand for liquid fuels by region, mtoe**

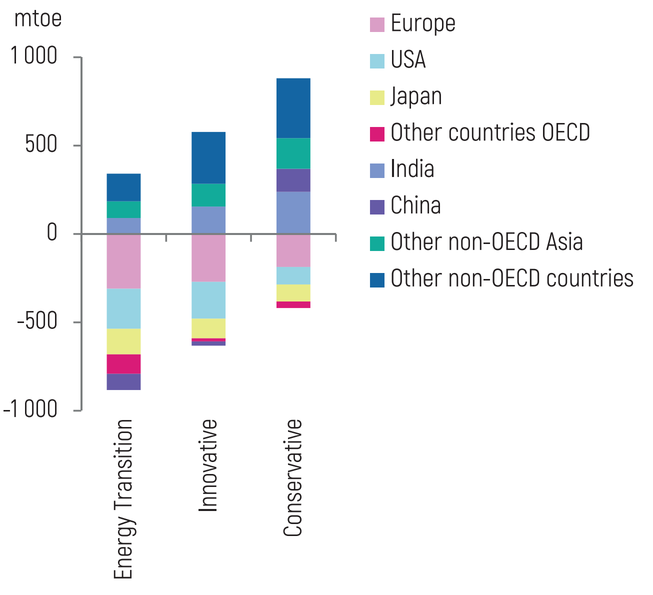



Source: ERI RAS

In the period to 2040, an increase in global liquid fuels demand is expected in non-OECD markets, primarily in Africa, the Middle East, South America and Asia in all scenarios. It is important to note that only in the Conservative scenario will non-OECD growth in demand in countries exceed demand decline in OECD countries, which will lead to an overall increase in world consumption. A decline in liquid fuel demand becomes inevitable within the Energy Transition scenario (Fig. 2.27). In all of the scenarios, developing Asian countries are expected to provide most of the growth in global liquid fuels demand.

However, in the Innovative scenario some of them, including China, pass through the "peak of demand" and by 2040 reduce consumption compared to 2018 levels. As a result, demand in the region is projected to increase by 47% in the Conservative scenario, and by just 8% in the Energy Transition scenario. Such a significant difference between the scenarios is primarily due to different assumptions in relation to the speed of transfer of technologies aimed at improving energy efficiency of the transport sector and in relation to locating electric vehicles production directly in these countries (the latter is further stimulated by decarbonisation policy) (Table 2.3).

**Figure 2.27 - Changes in demand for liquid fuels - largest countries and regions, under the three scenarios**




Source: ERI RAS

Developing economies provide growth in global demand in the Conservative scenario. However,, that is no longer sufficient to offset falling consumption in the developed economies in the Innovative scenario, while the parameters in the Energy Transition scenario produce a projected decline in demand for liquid fuels.

The time frame for the world to pass the "peak demand" for liquid hydrocarbons is determined by three factors:

- the speed of scientific and technological progress, which manifests both in increasing the efficiency of petroleum product consumption (primarily in reducing the average specific fuel consumption in transport) and in expanding application of alternatives not only in transport, but also in other consumption sectors (the chemical industry, power sector and the household sector);
- the speed of transfer of the most effective Innovative solutions across countries;
- the priorities of national energy policies, including the strategic choice of individual countries between oil and alternative fuels.

### Table 2.3 – Demand for liquid fuels by country and region, mtoe

| | 2015 | 2020 | 2030 | | | 2040 | | |
|---|---|---|---|---|---|---|---|---|
| | | Conservative | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| **North America** | **1021** | **1009** | **964** | **915** | **840** | **923** | **813** | **761** |
| Canada | 95 | 95 | 89 | 88 | 85 | 89 | 86 | 71 |
| Mexico | 95 | 97 | 100 | 105 | 90 | 103 | 105 | 86 |
| USA | 830 | 818 | 775 | 722 | 665 | 731 | 622 | 603 |
| **South and Central America** | **310** | **323** | **350** | **346** | **331** | **376** | **370** | **329** |
| Brazil | 125 | 129 | 136 | 134 | 125 | 140 | 137 | 119 |
| Venezuela | 34 | 36 | 40 | 39 | 39 | 50 | 48 | 43 |
| **Europe** | **678** | **631** | **539** | **504** | **470** | **448** | **391** | **325** |
| EU-28 | 604 | 557 | 469 | 440 | 411 | 384 | 336 | 274 |
| **CIS** | **168** | **184** | **187** | **185** | **184** | **184** | **181** | **169** |
| Kazakhstan | 16 | 15 | 15 | 14 | 13 | 14 | 13 | 10 |
| Russia | 115 | 131 | 134 | 134 | 132 | 140 | 138 | 128 |
| **Developed Asia** | **367** | **360** | **316** | **292** | **290** | **272** | **248** | **181** |
| Japan | 195 | 179 | 136 | 117 | 126 | 100 | 85 | 52 |
| **Developing Asia** | **1149** | **1290** | **1530** | **1499** | **1330** | **1691** | **1409** | **1242** |
| China | 569 | 644 | 714 | 712 | 609 | 700 | 545 | 477 |
| India | 212 | 244 | 341 | 317 | 275 | 450 | 367 | 302 |
| **Middle East** | **385** | **422** | **477** | **470** | **464** | **530** | **508** | **461** |
| **Africa** | **190** | **212** | **254** | **251** | **241** | **305** | **292** | **257** |
| **Worldwide** | **4268** | **4331** | **4617** | **4462** | **4150** | **4729** | **4212** | **3725** |

Source: ERI RAS

Photo by Marc-Olivier Jodoin on Unsplash

# Energy consumption in transport

The transport sector, which accounted for 60% of global demand for liquid fuels in 2016, will continue to dominate by 2040 in terms of demand for liquid fuels by sector (69-73% of the total, depending on the scenario). The share of petrochemical industry in total oil demand for will also grow from 12% in 2016 to 16-19% by 2040 (depending on the scenario). However, demand in this sector will be dampened by both political restrictions on the use of plastics and inter-fuel competition, primarily from gas chemical enterprises. In other sectors, oil is losing inter-fuel competition: by 2040, the share of these sectors in total demand for oil and petroleum products will decline. Consumption of liquid fuels in these sectors is also projected to shrink.

Growing demand for transport primarily from the developing countries will ensure an increase in energy demand in the transport sector (in the current technological parameters) by 1.5 btoe. At the same time, increasing vehicle energy efficiency, stimulated by the introduction of new fuel standards around the world and achieved through the large-scale introduction of modern internal combustion engines, composite materials and digital systems, will reduce potential demand in the Conservative scenario by 600 mtoe[30]. Inter-fuel competition, primarily with increasingly popular electric cars, will displace another 270 mtoe of liquid fuels.

In the Innovative scenario, which envisions accelerated transfer of electric and hybrid transport production technologies and accelerated progress in reducing the cost of batteries, the increase in fuel efficiency ensures displacement of another 300 mtoe of energy demand in the transport sector, compared to the Conservative scenario. Interfuel switching reduces potential demand for liquid fuels by another 360 mtoe, which brings total petroleum consumption in the transport sector to a figure below the 2015 levels.

The Energy Transition scenario assumes tougher requirements of the state energy policy in relation to decarbonization, including in developing countries, in addition to the technological progress of the Innovative scenario. Within the Energy Transition scenario, demand for liquid fuels in the transport sector is reduced by another 295 mtoe. Total demand for petroleum products is down by almost 350 mtoe compared to 2015 (Fig. 2.28)

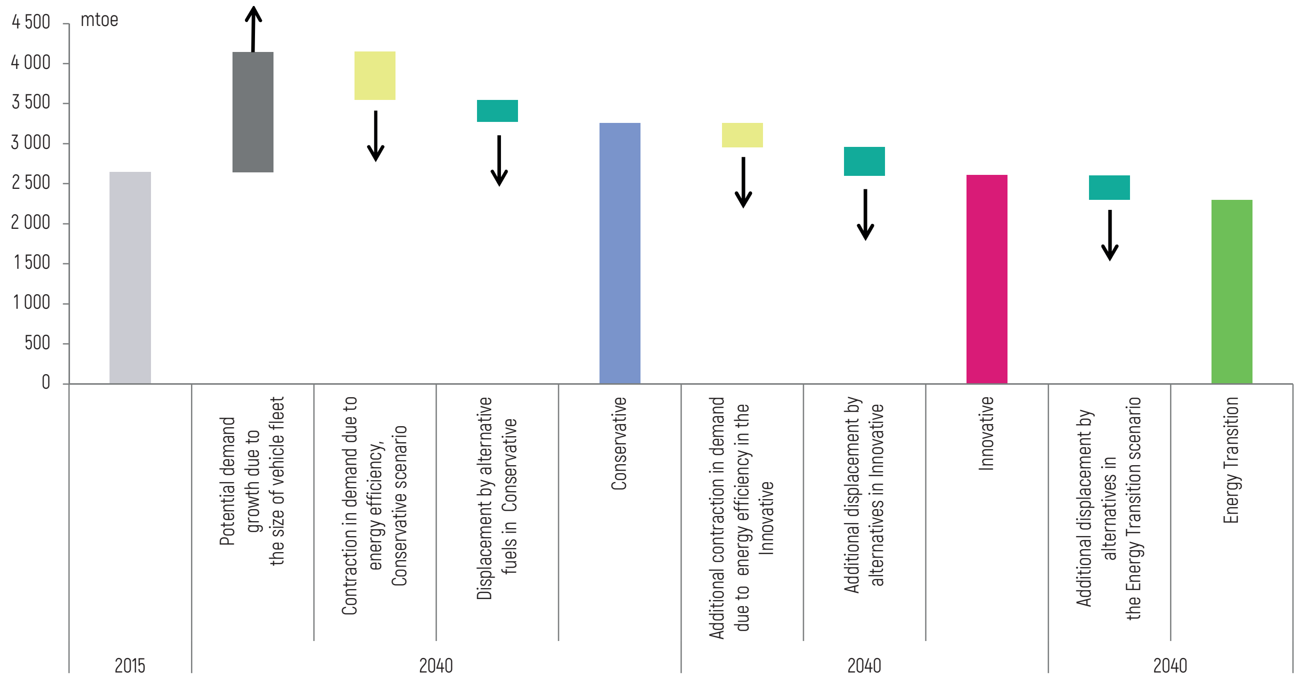
Competition of electric vehicles with traditional ICE transport is becoming one of the key factors in the formation of the fuel basket in the road transport sector, largely determining the entire future development of the global crude oil and refined products markets. Electric vehicles are more environmentally friendly than ICE vehicles and give better acceleration for a smooth ride. This attracts the general consumer to purchasing this type of vehicle.

In the Conservative scenario, by 2040 growing vehicle energy efficiency ensures a reduction in liquid fuel demand in the transport sector by 600 mtoe compared to current trends, which is commensurate with current oil output in Saudi Arabia. In the Innovative scenario, this impact of energy efficiency increases 1.5 fold to 900 mtoe. On top of that, by 2040 a transition to alternative fuels ensures the displacement of another 300-925 mtoe of oil, depending on the scenario.

As a rule, the cost of electric charging is significantly lower than the prices of petroleum products. At the same time, service and charging infrastructure is actively being developed, and the EV is becoming cheap and affordable to maintain. However, of course, all of this would not be enough if EV were many times more expensive than their gasoline counterparts. By 2019, due to accumulated progress in reducing the cost of batteries and large-scale subsidies for purchases of electric vehicles, average annual cost

30 Electric transport in this paper refers to fully charged cars or chargedhybrids, as well as vehicles that use the energy of hydrogen fuel cells to drive electric motors. At the same time, hybridization of the vehicle fleet, that does not include charging the battery from external electric power sources (due to the fact that it does not cancel out, but only reduces consumption of petroleum products or other liquid fuels), is considered as one of the mechanisms of increasing fuel efficiency of the ICE.

**Figure 2.28 – The process of formation of liquid fuels demand in the transport sector**




Source: ERI RAS

of ownership for an electric vehicle in the US and Europe is already slightly below that for an ICE car, encouraging consumers to switch to this type of transport. But the real revolution has happened in China. Full localization of EV manufacturing in the country, combined with the cancellation of the registration fee for electric vehicles, which often doubles the cost of purchasing a traditional car for a Chinese resident, have led to the cost of owning an EV now being almost half of that for an ICE vehicle.

A key question in relation to further growth in the number of EV is how quickly parity in the cost of ownership will be achieved in developing Asia. India can be taken as an example. As of 2018, there was no large-scale localized production of EV in India, however, cheap ICE cars were being produced domestically. Transfer of technologies for the production of electric transport to such countries does not occur as part of scenario assumptions in the Conservation scenario, and imported vehicles are not able to compete with cheap local gasoline and diesel cars in the mass segment. In the Innovative scenario, technology transfer is limited, and by 2040, production in these countries does not have time to scale up sufficiently to allow full scale competition with traditional cars. Only the Energy Transition scenario envisions fully fledged rapid localization of EV production occurring in India and other developing countries of Asia (Fig. 2.29).

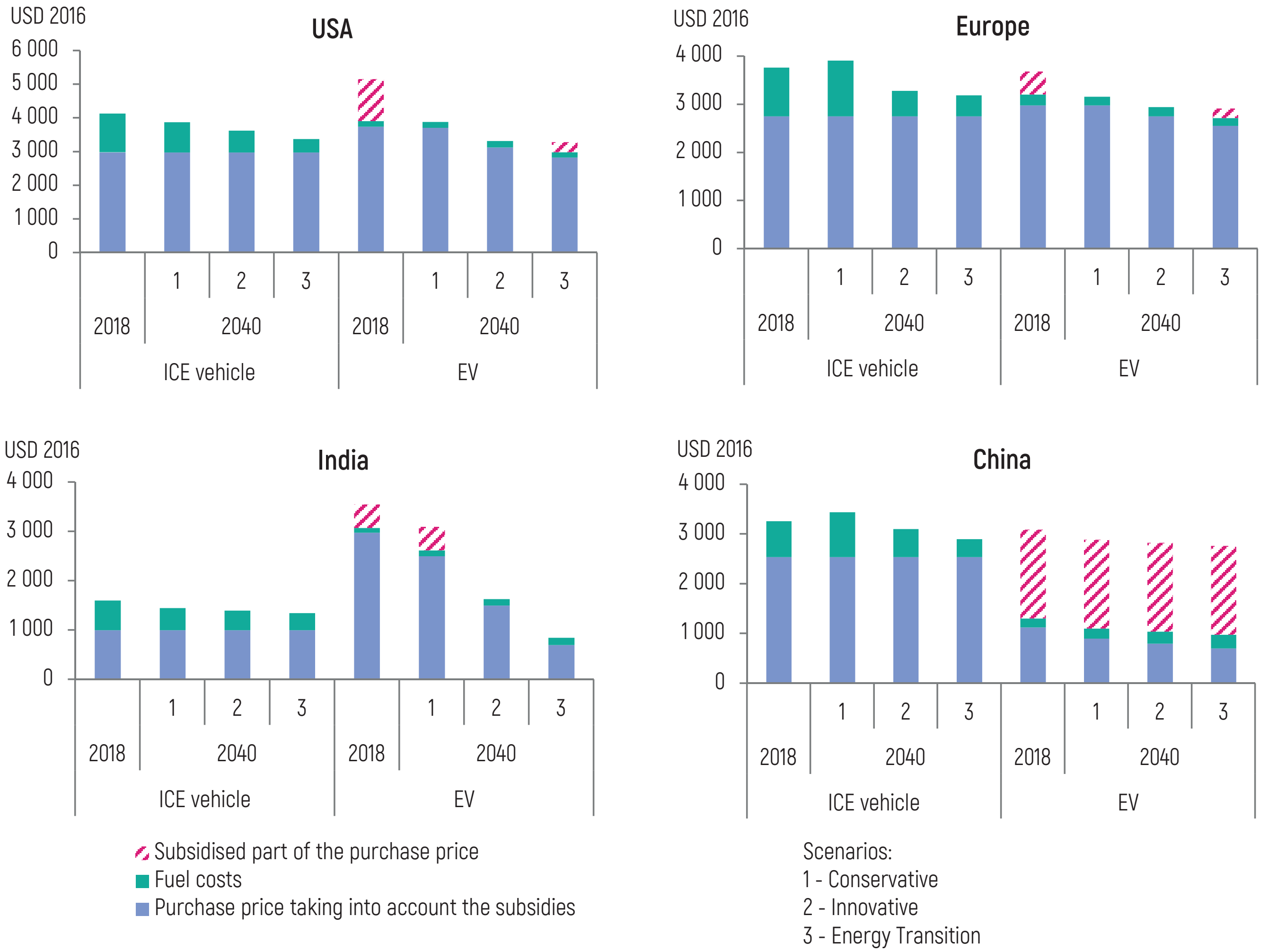
A reduction in costs and localization of electric vehicle production technologies specified in the forecast lead to the fact that in the Conservative scenario, by 2040 the size of EV global fleet (including electric buses) reaches 250 million units (12% of the global automotive market). In the Innovative and the Energy Transition scenarios, the number of electric vehicles reaches 410-600 million by 2040, or 21-32% of the global fleet (Section 1, Fig. 1.2), depending on the scenario.

It is important to realise that electric transport is not limited to just four-wheeled cars. A quiet electric revolution has already occurred in the segment of two-and three-wheeled light-motor transport.

This type of transport occupies a significant share of energy consumption in the transport sector (23% and 11%, respectively) in some Asian countries, for example, in China and India. Here, electric vehicles have become fully competitive with traditional mopeds and motorcycles at purchase cost, without any subsidies. While the number of new electric cars sold in 2018 barely reached the mark of 2 million worldwide, which is about 2.5% of total car sales, the number of electric scooters sold back in 2017 exceeded 30 million, amounting to 30% of the number of new two- and three-wheeled vehicles sold worldwide. Of course, specific

Today, reduced average annual ownership cost for an EV in the US, Europe and China is already lower than that for an ICE car, which is encouraging consumers to switch to this type of transport. In future, the speed of proliferation of electric vehicles will primarily depend on the speed of transfer of EV production technologies and the achievement of cost parity in the cost of ownership in the developing countries of Asia.

**Figure 2.29 – Average quoted ownership costs for different types of vehicles**




Source: ERI RAS

energy consumption of each individual motorcycle is up to 10 times less than that of an average electric car.

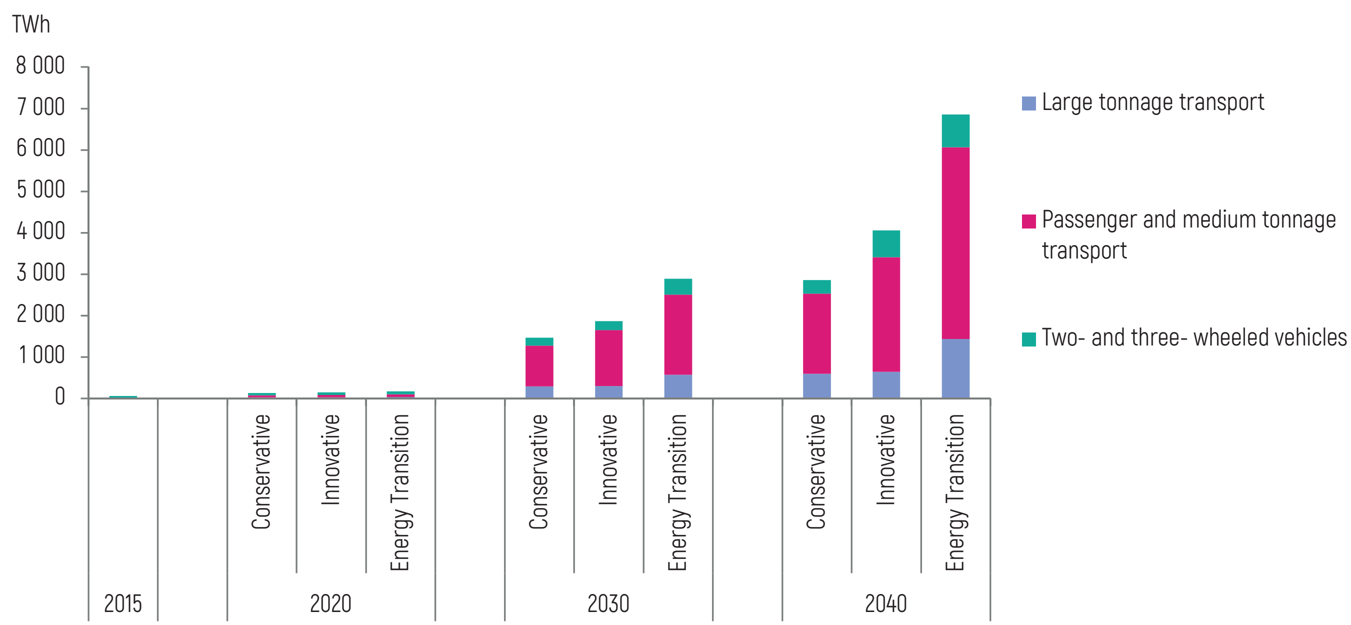
However, given their huge number, especially in the countries of developing Asia, they account for a very significant share in total electricity consumption in transport (Fig. 2.30).

Growth in competitiveness of electric transport, and, as a result, of its share in the total vehicle fleet affects not only petroleum products consumption but also the prospects for consumption of other alternative fuels. For example, in the period to 2040, global consumption of gas natural fuels (in the form of compressed and liquefied gas) is projected to moderately increase. This is despite the fact that at the current stage of technological development this type of fuel is already fully competitive with traditional oil fuel in terms of car ownership costs, in most regions of the world.

Limited expensive gas filling infrastructure, which does not pay for itself, is one of the reasons for this moderate growth. Thus, average costs of building a gas filling station are estimated at 500-800 thousand US Dollars, a petrol station - 50-150 thousand US Dollars, while DC-fast charging stations cost 8.5-50 thousand US Dollars. Future market volume for such fuels is in fact determined mainly by the level of state policy and state support mechanisms. The countries that are willing to co-finance the setup of infrastructure for gas transport and provide mechanisms to support production, will be able to ensure the development of this sector. However, the prospects for

As of 2019, two- and three- wheeled electric vehicles are already fully competitive with traditional scooters and motorcycles in terms of purchase costs. Over 30% of new global sales of two- and three-wheeled transport is attributable to the electric vehicle segment.

**Figure 2.30 – Structure of electric energy consumption by type of transport, by scenario**




Source: ERI RAS

increasing the use of natural gas fuels are limited in the countries where the development of electric transport is the main priority and where natural gas fuels are not given state support. In those countries prospective growth in the use of natural gas fuels is concentrated mainly in the large-tonnage segment.

Gas-based fuels can play a significant role in the segment of international shipping sector and maritime cabotage. The implementation of the environmental initiative of the International Maritime Organization (IMO) beyond the boundaries of the European seas and the West Coast of the United States will act as the key driver in this segment. This markedly increases the attractiveness of LNG as a fuel for maritime transport and ensures displacement of additional volumes of oil-based fuels (about 164 mtoe from the Conservative scenario indicators to the Energy Transition scenario as of 2040). In addition, the Energy Transition scenario assumes that emissions restrictions are included in the IMO initiative. Without this, LNG as a fuel for LNG bunkering would not receive a meaningful advantage over low-sulfur diesel fuel, given high costs of refitting power plants and port infrastructure.

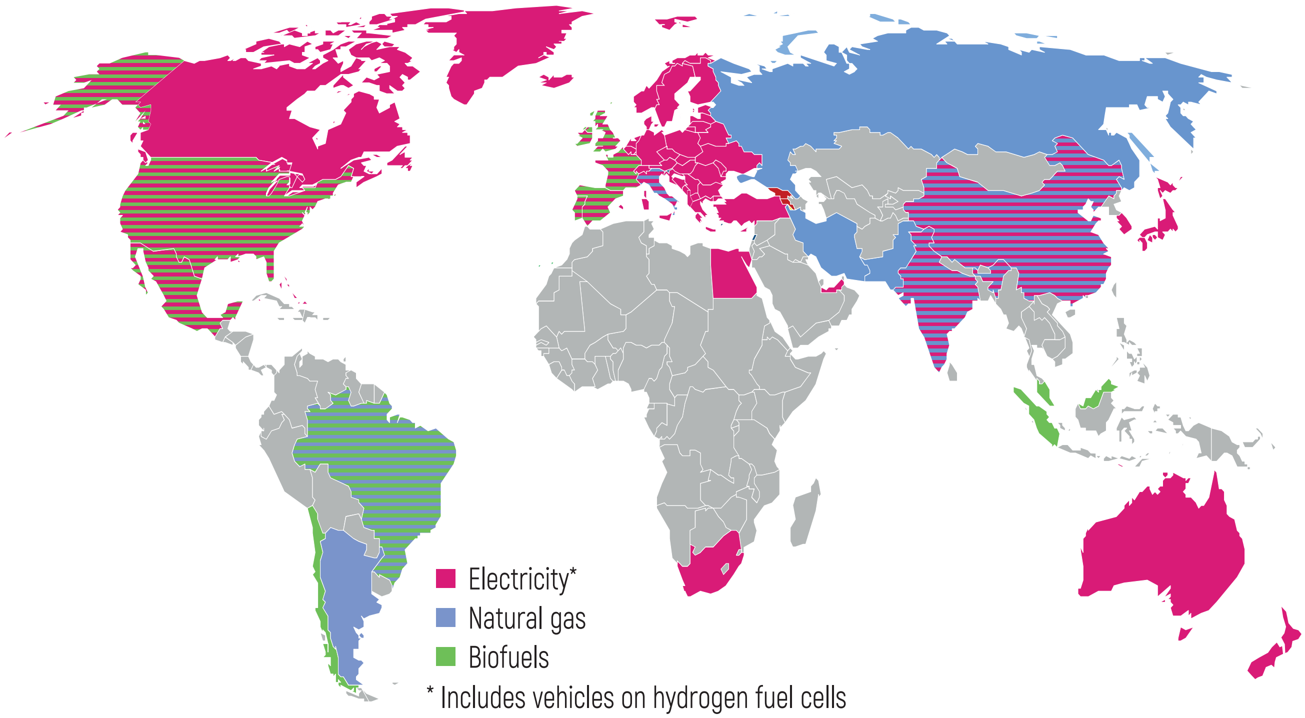
Image by Marilyn Murphy from Pixabay

The development of electric transport also has a significant impact on direct substitutes for petroleum products - synthetic fuels made from gas, coal and biomass, whose competitiveness is falling against the backdrop of low world prices. In fact, the growing electric vehicle fleet partially replaces potential volumes of synthetic fuels. Even bio-fuels - the cheapest direct substitute for petroleum products - become competitive only when the crude oil price is around 70-95 dollars per barrel. In the conditions of low prices (due to low demand for oil when oil-based fuels are replaced with electricity), the possibilities for developing synthetic fuels production are also reduced. By 2040, in the Conservative scenario synthetic fuels will account for just 130 mtoe of liquid fuels demand (comapred to 70 mtoe in 2016). and nearly all of these volumes will be attributable to bio-fuels, the cheapest of synthetic fuels. In the Energy Transition scenario, if growing proliferation of electric vehicles were to continue, demand for liquid synthetic fuels would amount to as little as 105 mtoe by 2040 (Fig. 2.31).

Overall, by 2040 the fuel basket of the transport sector will change substantially: petroleum products will reduce their share from the current 93% to 85-73%, depending on the scenario. The share of electricity (including that produced by fuel cells) will reach 11% in the Conservative scenario, 21% in the Innovative and 32% in the Energy Transition scenario. Synthetic liquid fuels (mainly bio-fuels) will account for around 2-3% in total fuel consumption in the transport sector (Fig. 2.32).

Growing competitiveness of electric vehicles, and, as a consequence, their share in the total fleet, affects not only consumption of petroleum products, but also the prospects for consumption of other fuel alternatives in the transport sector.

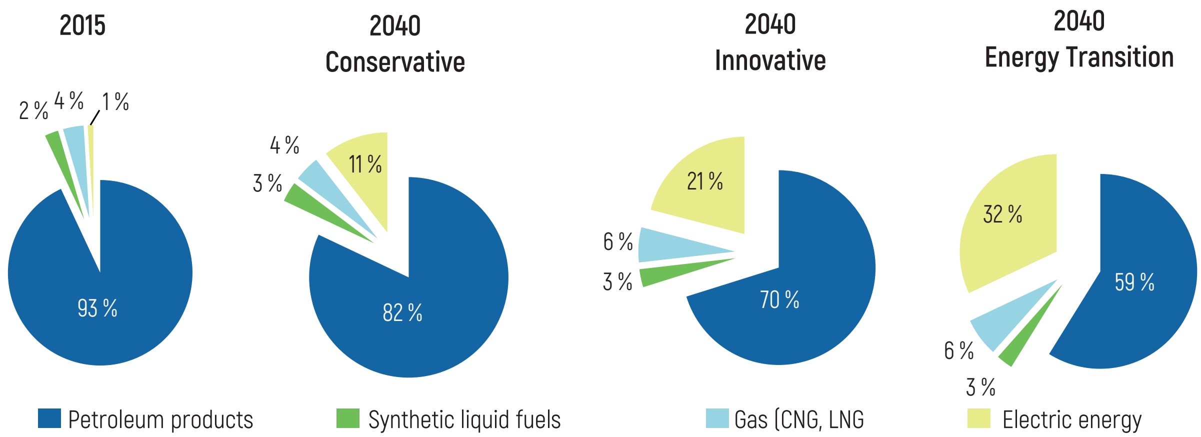
### Figure 2.31 - A map of key alternatives for petroleum products in different regions




Source: ERI RAS

Even the parameters of the Energy Transition scenario do not envision that petroleum products would be completely displaced from the transport sector in the long term until 2040. Moreover, oil-based fuels continue to dominate in the segment. However, in absolute terms liquid fuels consumption in the transport sector is down by 2040 in all scenarios except the Conservative one.

### Figure 2.32 – Structure of energy demand in the transport sector by fuel types




Source: ERI RAS

## Consumption of petroleum products

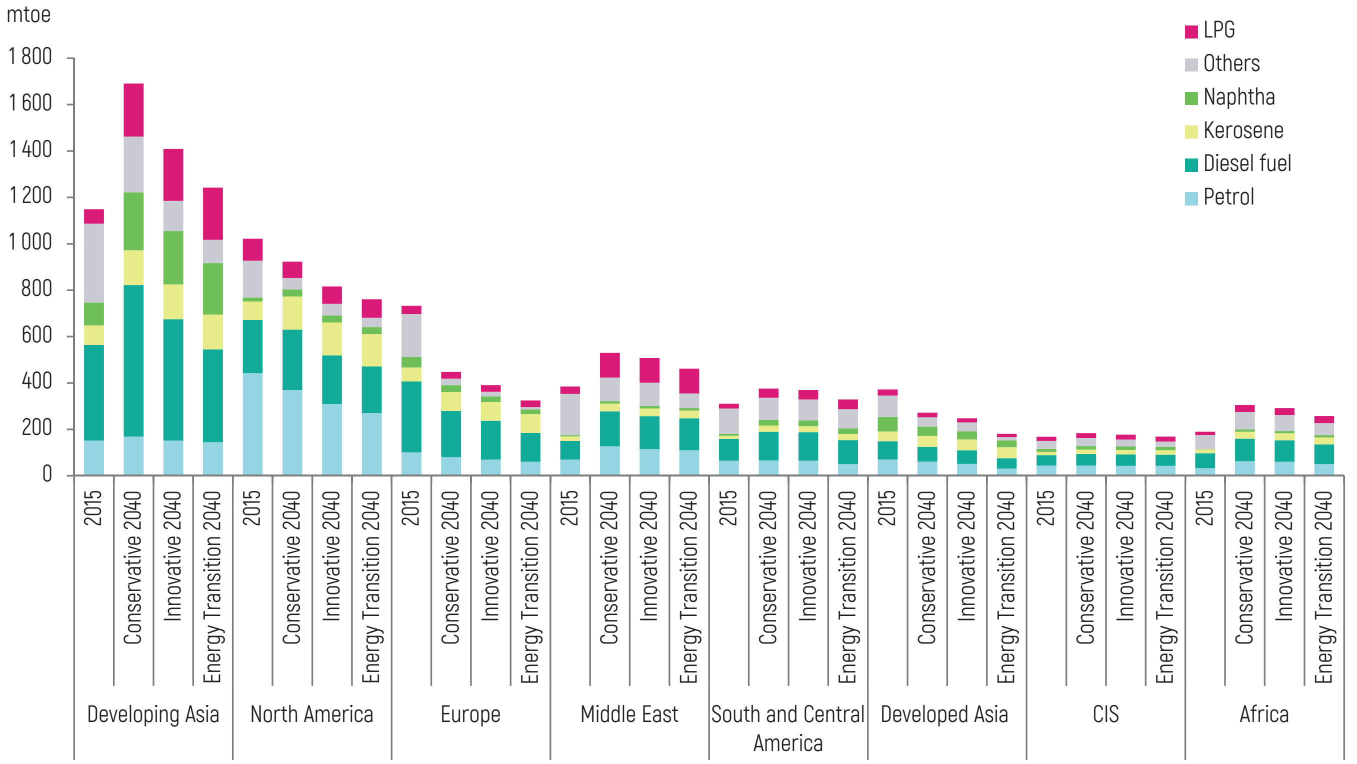
In the period to 2040, the structure of demand for petroleum products is noticeably changing - this is influenced by consumption growth in the transport sector with a simultaneous decrease in demand for petroleum products in the residential, commercial and electric power sectors, as well as changes in the chemical industry. In the forecast period, an increase in demand for motor fuels (gasoline, diesel and jet fuel) is expected, while their share in total demand for petroleum products will increase from 63% at present to 70-75% by 2040, depending on the scenario. At the same time, the share of heavy petroleum and other products in consumption will fall from the current 24% to 8-12% by 2040, due to a reduction in the consumption of fuel oil in the fleet, as well due to decommissioning of petroleum-fired (fuel oil) generation capacities.

A decline in global demand for heavy petroleum products is expected in all scenarios, requiring a certain adaptation from the refining industry.

The regional picture as a whole will not change much. In the North American market, gasoline will remain the dominant fuel among oil-based products against the backdrop of a general decline in demand for petroleum products, This is backed by both the historical commitment of Americans to this type of motor fuel and the expected increase in the price spread between gasoline and diesel fuel due to the "washing out" of middle distillates from the pool of processed feedstock. In Europe, diesel fuel will remain the main motor fuel, while a significant decrease in demand for heavy petroleum and other products is projected. This decline would be due to almost complete decommissioning of petroleum-fired (fuel oil) generation capacities and restrictions on the use of heavy petroleum products for the fleet. Demand will also contract, and, accordingly, the share of petrochemical feedstock in total consumption of petroleum products will fall.

The structure of consumption of petroleum motor fuels is expected to change considerably in developing Asia due to the support given to diesel-powered passenger car and truck fleet. If two and three-wheeled vehicles were to switch rapidly from gasoline to electricity, the proportion of gasoline and diesel fuel in the basket of petroleum fuels consumed would change substantially (Fig. 2.33).

**Figure 2.33 - Scenario forecast of the structure of petroleum product demand by region, mln tonnes**




Source: ERI RAS

# Oil production

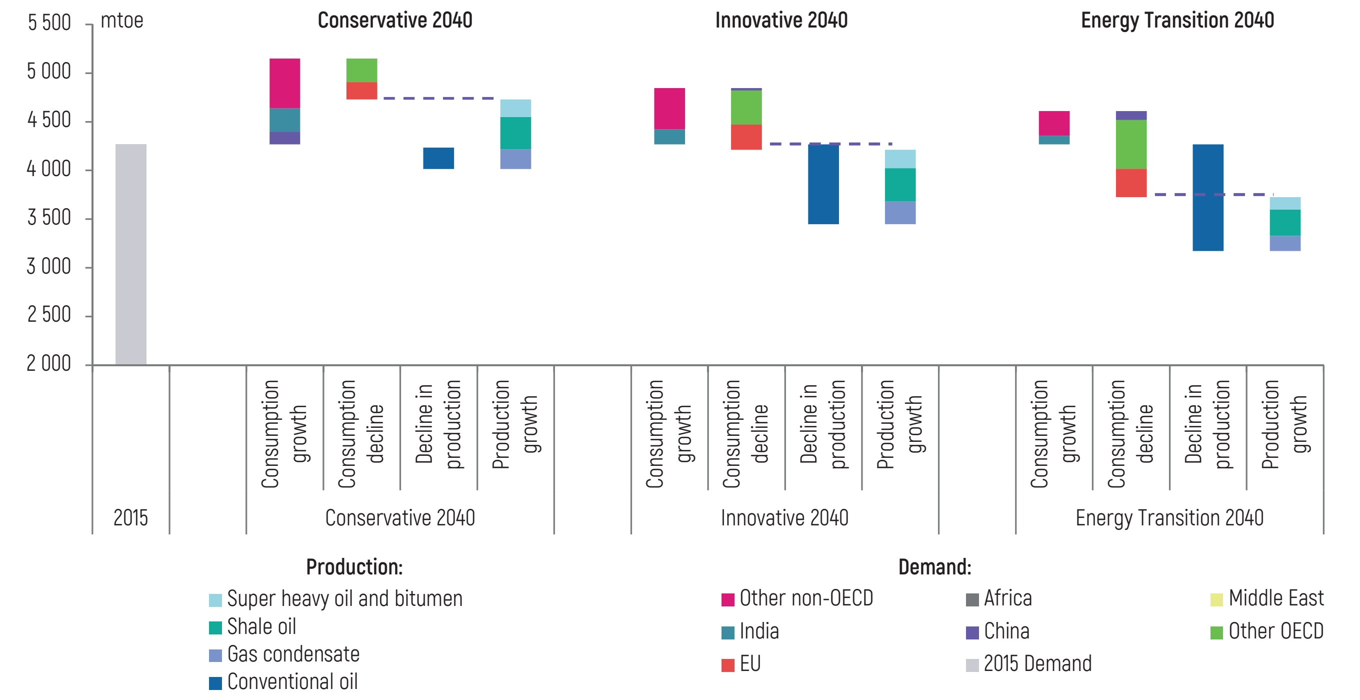
Despite the fact that conventional oil will remain the main source of supply in the market in all scenarios, the share of non-conventional production will double and reach 20-22% (Fig. 2.34). Shale oil (also known as tight oil) will continue to have a particularly large impact on the market. This type of oil has already ensured rapid growth in production in the US. This is due not only to a reduction in the range of "break-even prices" for similar projects down to 35-70 USD 2017/bbl in recent years, but also to the fact that shale oil development projects are unique as a business model. The payback period is significantly shorter (1-2 years) than in conventional projects and this attracts institutional investors, since shale oil projects allow them to hedge price risks for the entire development period. Banks are extremely willing to finance such low-risk projects.

Against this backdrop and given remaining negative expectations in relation to future demand and prices in the oil markets, development of a traditional field with a payback period of 10–15 years looks less attractive as an investment asset.

In the period to 2040 shale oil projects win against traditional projects not only due to their competitiveness in terms of costs, but also due to short payback periods. This is attractive for investors, given serious long-term risks present in the industry and associated with the development of oil demand.

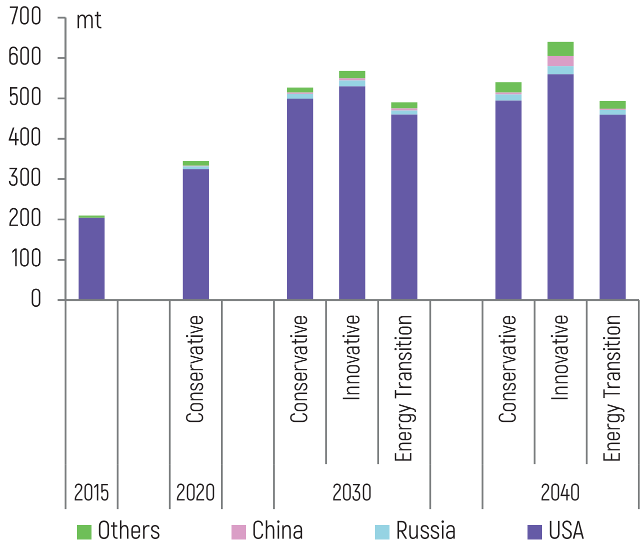
If this situation remains the same in the forecast period, the US will be able to demonstrate high shale oil output in the Conservative scenario even without any significant technological advancements.

**Figure 2.34 – Supply/demand balance in the oil market by scenario**




Source: ERI RAS

Figure 2.35 - World shale oil production, by scenario




Source: ERI RAS

At the same time American companies would be able to keep some reserve to further optimise production processes and reduce costs. (Fig. 2.35).

The potential for reducing shale oil production costs is realized in the Innovative scenario, boosting production of this type of oil in the US. At the same time, development of commercially efficient oil production technologies for tight reservoirs in China and Russia is expected in the Innovative scenario. In the Energy Transition scenario, shale oil output decreases due to a significant contraction in global oil demand. However, it is not projected to decline as rapidly as, for example, conventional oil production. Heavy oils and natural bitumen are characterized by relatively high development costs and will remain in the closing part of the supply curve. According to scenario calculations, in the forecast period, Canada will remain the world centre for the production of this type of feedstock, with output increasing in all scenarios, despite high costs. Paradoxically, growth in shale oil output in the neighboring US is the reason for this. Despite modern global technological development making it possible to involve feedstock of any quality in processing, increasing production of non-conventional

> Heavy oils and ultra-light shale oil mutually complement each other at the refining stage, their combined use enables to restore refinery feedstock balance in terms of the volume of middle distillates. This leads to a paradox: heavy oils do not compete with shale oil but rather turn out to be mutually complementary goods. Combined, they compete with traditional producers.

oils leads to the "washing out" of middle distillates out of fractional composition of oils from the feedstock pool. This leads to heavy oils competing with light oils at the stage of processing by component goods. Blending them prior to primary distillation enables to restore the average indicators of density and viscosity to conventional types of oil.

In the Conservative scenario, by 2040 global production of heavy crude oil and bitumen is estimated to reach 335 mtoe. In the Innovative scenario, output is projected to reach 355 mtoe, due to large shale oil output, which stimulates demand for heavy crude oil for blending with super-light oil. The Energy Transition scenario envisions the figure of 290 mtoe. (Fig. 2.36).

Technological and economic changes that determine the structure of production of oil feedstock by type, in many respects also form the geographic structure of oil production (Fig. 2.37). The dynamics of oil production in North America is largely determined by innovations in the development of non conventional oils. US production increases from 565 mtoe in 2017 to 620–640 mtoe by 2020 (depending on the scenario), and then declines by 2040 to the current levels in the Energy Transition scenario and to the level of 600-620 mtoe in the Innovative and Conservative scenarios, due to an accelerated decline in conventional production against the backdrop of growing shale oil production. By 2040 production in Canada, second largest producer in the region, is much lower in the Energy

Transition scenario than in the Conservative scenario (190 mtoe compared to 270 mtoe and 150 mtoe in 2017). This is linked to falling demand for middle distillates in the region, and as a result, a decline in demand for heavy crude oil for mixing with US light oil.

Oil production in South America in the Conservative scenario will increase to 450 mtoe by 2025 solely due to the active development of deep-water deposits in Brazil, and further high global demand for crude oil will require deployment of expensive equipment. The level of production in the region will reach 550 mtoe. In the Energy Transition scenario, Venezuelan projects will not be in sufficient demand in the period to 2040, since in 2020 their volume will be 450 mtoe compared to 390 mtoe in 2017.

Production decline in Europe at the beginning of the forecast period will be somewhat held back by the activity which has started in the oil bearing zones in the North Sea. However, the reserves being brought online will not be enough to ensure sustainable production to 2040.

Output is also expected to fall in the Asian region following depletion of the deposits of key producers - Malaysia, Indonesia, China and India. Production is projected to reach 307 mtoe in the Conservative scenario and 280 mtoe in the Energy Transition scenario, compared to the current level of nearly 400 mtoe. The difference between the last two scenarios is primarily determined by production in China, where low prices of the Energy Transition scenario do not make it possible to commission expensive domestic projects, and Chinese companies prefer to meet domestic demand with oil produced in other regions. Neither does this scenario envision the commissioning of costly projects to increase deep-sea oil production in Malaysia and Indonesia.

The Middle East will continue to remain the largest world producer in terms of oil output, its share in global oil production will remain above 30% in the period to 2040 (Table 2.4).

**Figure 2.36- World oil production by type, by scenario**

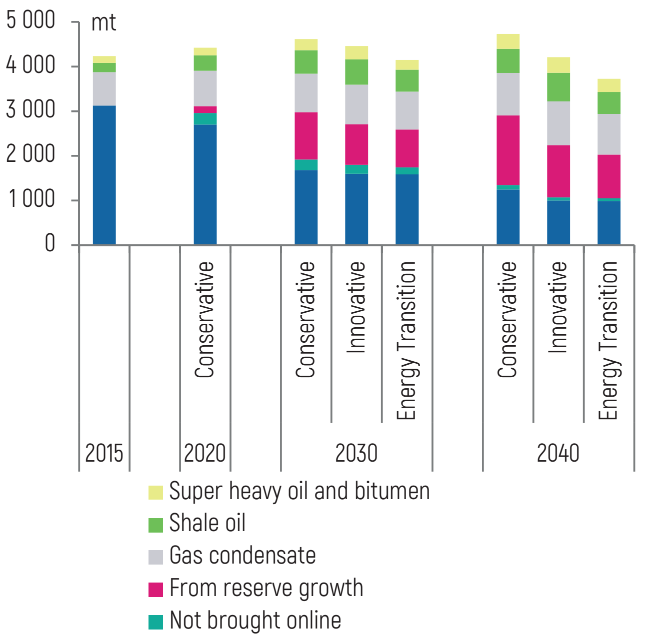
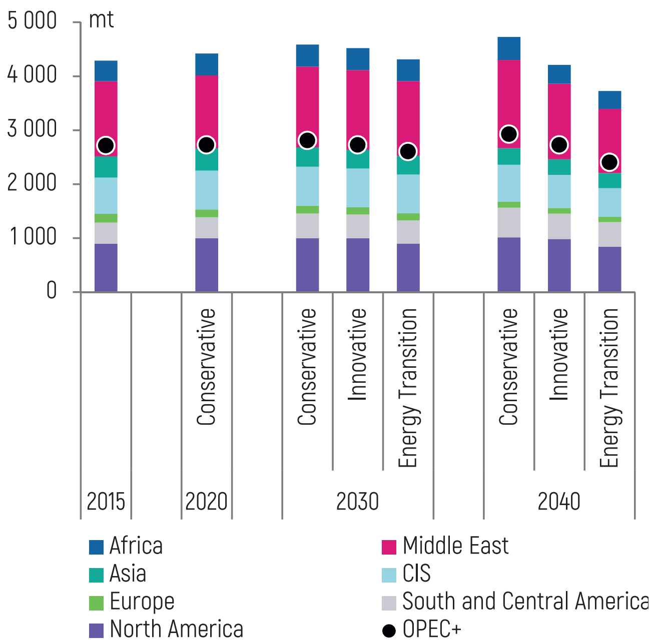



**Figure 2.37- World oil production by region, by scenario**




Sources - Fig.2.36 and Fig 2.37 - ERI RAS

**Table 2.4 – Crude oil production by key country and region, million tonnes**

| | 2015 | 2020 | 2030 | | | 2040 | | |
|---|---|---|---|---|---|---|---|---|
| | | Conservative | Conservative | nnovative | Energy Transition | Conservative | nnovative | Energy Transition |
| **North America** | **895** | **999** | **998** | **998** | **898** | **1013** | **982** | **843** |
| Canada | 213 | 249 | 260 | 250 | 236 | 303 | 272 | 192 |
| Mexico | 152 | 130 | 118 | 108 | 92 | 110 | 90 | 89 |
| USA | 557 | 620 | 620 | 640 | 570 | 600 | 620 | 562 |
| **South and Central America** | **392** | **391** | **459** | **440** | **430** | **552** | **472** | **452** |
| Brazil | 120 | 153 | 233 | 227 | 200 | 263 | 257 | 215 |
| Venezuela | 133 | 91 | 109 | 95 | 69 | 115 | 100 | 96 |
| **Europe** | **162** | **141** | **143** | **131** | **131** | **108** | **105** | **99** |
| **CIS** | **673** | **723** | **741** | **710** | **630** | **686** | **613** | **530** |
| Kazakhstan | 79 | 78 | 120 | 110 | 92 | 133 | 95 | 87 |
| Russia | 534 | 562 | 543 | 524 | 498 | 485 | 457 | 412 |
| **Asia Pacific Region** | **395** | **415** | **358** | **345** | **345** | **307** | **288** | **280** |
| China | 211 | 221 | 166 | 165 | 150 | 126 | 123 | 121 |
| India | 40 | 46 | 45 | 44 | 40 | 41 | 38 | 35 |
| Malaysia | 32 | 31 | 26 | 25 | 25 | 24 | 20 | 20 |
| Indonesia | 39 | 35 | 30 | 29 | 28 | 24 | 20 | 19 |
| **Middle East** | **1391** | **1354** | **1498** | **1480** | **1385** | **1634** | **1403** | **1191** |
| Iran | 177 | 175 | 196 | 179 | 149 | 210 | 196 | 173 |
| Iraq | 192 | 215 | 321 | 247 | 242 | 310 | 261 | 250 |
| Saudi Arabia | 560 | 571 | 581 | 568 | 530 | 643 | 580 | 555 |
| **Africa** | **381** | **409** | **421** | **358** | **331** | **430** | **349** | **330** |
| Libya | 20 | 41 | 52 | 44 | 35 | 66 | 50 | 25 |
| Angola | 86 | 83 | 73 | 70 | 65 | 60 | 55 | 48 |
| Nigeria | 103 | 114 | 121 | 124 | 110 | 139 | 140 | 90 |
| **Worldwide** | **4289** | **4432** | **4618** | **4468** | **4149** | **4730** | **4212** | **3725** |

Source: ERI RAS

## Oil refining

Key trends in the development of the global oil refining industry largely depend on scenario parameters. In the forecast period up to 2040, the global refining industry as a whole will function according to the trends of the previous years in the Conservative and the Innovative scenarios. An increase in primary processing capacity is expected in the Asian region, primarily due to the commissioning of new refineries in China and India to meet growing internal demand at their own high-margin (due to relatively low labor and operating costs) capacities. Some increase in primary refining is expected in African countries; here, growth in domestic demand for petroleum products will also be the key driver. At the same time, it would be cheaper and more reasonable for African countries to build low-complexity refineries in their own territory rather than organize import of high-quality petroleum products from other regions. Towards the end of the forecast period, additional processing capacity will be required in South America and the Middle East. In Europe and North America, there will be a decline in primary refining due to low margins. This downward trend for primary refining will also be seen in the CIS countries.

The situation looks much more tense for oil refiners if the demand parameters of the Energy Transition scenario are implemented; under this scenario oil producing regions will have to face fierce competition. As many of the major CIS refineries are located quite far away from the key sales markets, primary refining is expected to go down to 300 mln tonnes by 2040. Significantly fewer new capacity additions than in the Conservative scenario are expected in the Middle East, Asia and Africa. In Europe and North America, the rate of decline in primary processing is also expected to accelerate.

At the same time, large-scale changes will affect secondary refining processes. The development of major technological trends will be determined by structural changes in the demand for petroleum products by region (Fig. 2.33).

In the forecast period, the global oil refining industry will have to resolve a challenging issue: significantly increasing light product yield while reducing primary refining volumes. At the same time, refineries in America and Europe will have to focus on the implementation of destructive crude oil processing, while African and Asian manufacturers will have to focus on conversion units.

For North America, the expanding share of super-light and extra-heavy oils in the feedstock pool of the refining industry will act as the key driver for developing refining. This leads to the "washing out" of middle distillate fractions obtained at the crude oil distillation units (CDUs). Although it is possible to achieve physical parameters comparable to the conventional oils to which the American refining is adapted by mixing heterogeneous hydrocarbon mixtures, their fractional composition can only be changed during destructive crude oil processing. Considering growing demand for middle distillates (kerosene and diesel fuel) both in North America itself and in Europe and South America, the main markets for the producers in the region and given the traditional focus of oil refining in the region on maximizing production of motor gasoline, the industry will have to undergo a large-scale adaptation to changing conditions. This will occur primarily due to the active expansion of capacity for destructive crude oil processing (hydrocracking, hydroconversion of heavy residues).

In South and Central America, construction of capacities for hydrotreating and destructive crude oil processing for the refining of own resources of medium high-sulfur crude oil (Fig. 2.38) will be the main task for the refining industry in terms of organizing secondary processes while primary refining output grows.

In the European region, the structure of the secondary refining capacity should not undergo significant changes. Hydro processes will continue to occupy a large share in the structure of secondary refining capacity. These are used to maximize the output of diesel fuel and improve the environmental friendliness of petroleum products with a general decrease in the absolute volumes of both primary and secondary capacity, primarily used for the production of high-oxidized gasoline components.

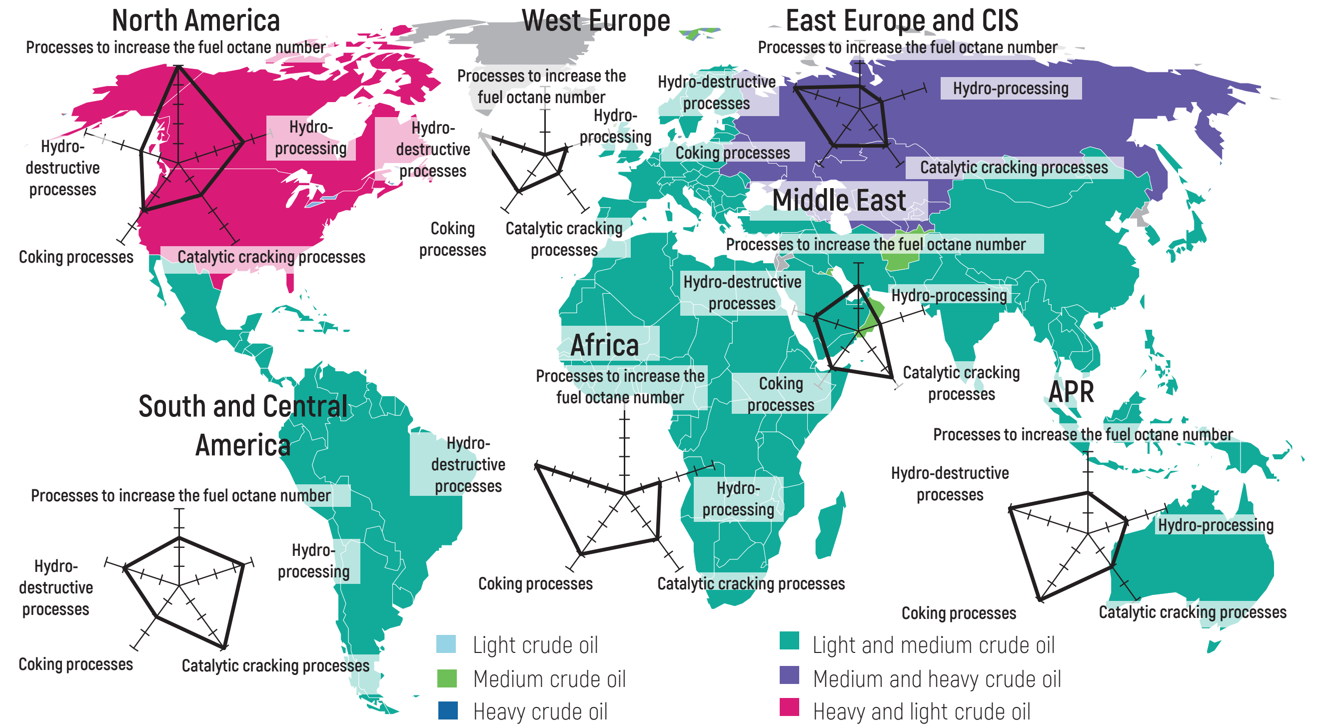
In the forecast period, the Middle East in all scenarios expects an expansion in demand for petroleum products with a parallel tightening of requirements for their quality.

Linked to this, we can expect primarily the development of conversion processes: hydroprocessing and synthesis of high-octane fuel components. The expansion of capacity for catalytic cracking and coking processes will also be relevant, especially in view of the growing demand for feedstock for petrochemical industry in the region.

The situation is similar in African countries. However, as feedstock here is lighter than in the Middle East, it will be possible to focus on hydroprocessing and refining processes for upgrading light hydrocarbon feedstocks, while the more expensive destructive crude oil processing will develop at a relatively slow rate.

Following expanding demand in the Asia-Pacific region, the oil refining segment will also be developing actively. One should expect development in all technological areas of secondary processes, but destructive crude oil processing will become the focus. At the same time, growing demand for naphtha, the main petrochemical feedstock in the region, means that the production of straight-run naphtha will become more attractive than the production of high-octane gasoline.

**Figure 2.38 - Priorities in the development of technologies for refining and dominant types of feedstock by region**

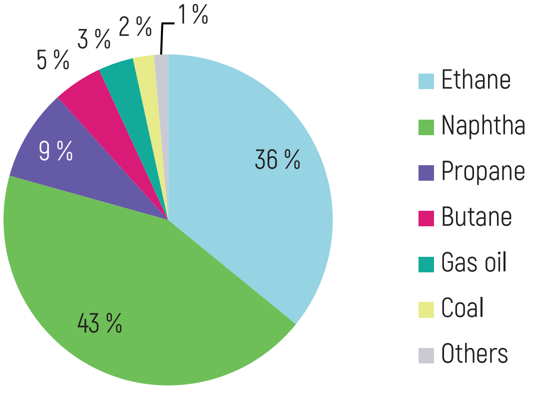



Source: ERI RAS

## The petrochemical industry

In recent years, the chemical sector has become one of the fastest growing sectors in terms of demand for liquid fuels; by 2017, it was consuming around 535 million tonnes of liquid hydrocarbons, and by 2040 consumption will reach 835-875 mtoe. Nevertheless, it would be wrong to assume that all of this increase in demand will be met exclusively with fuels made from crude oil. Ethane and naphtha, which currently dominate in the commodity basket with a combined share of 80% (Fig. 2.39), as well as propane, butane and even gas oil can either be refined products or be produced at gas processing plants via treatment of rich gas, or even in the field during its preparation for transportation. It is important that the end product- ethylene does not differ in its product characteristics, regardless of whether the feedstock for its production was obtained from oil or gas. This makes the traditionally accepted division of the chemical industry into petrochemicals and gas processing rather notional.

**Figure 2.39 - Feedstock for global ethylene production in 2017**




Source: The Kaiteki Company Sustainability Report 7th March 2017

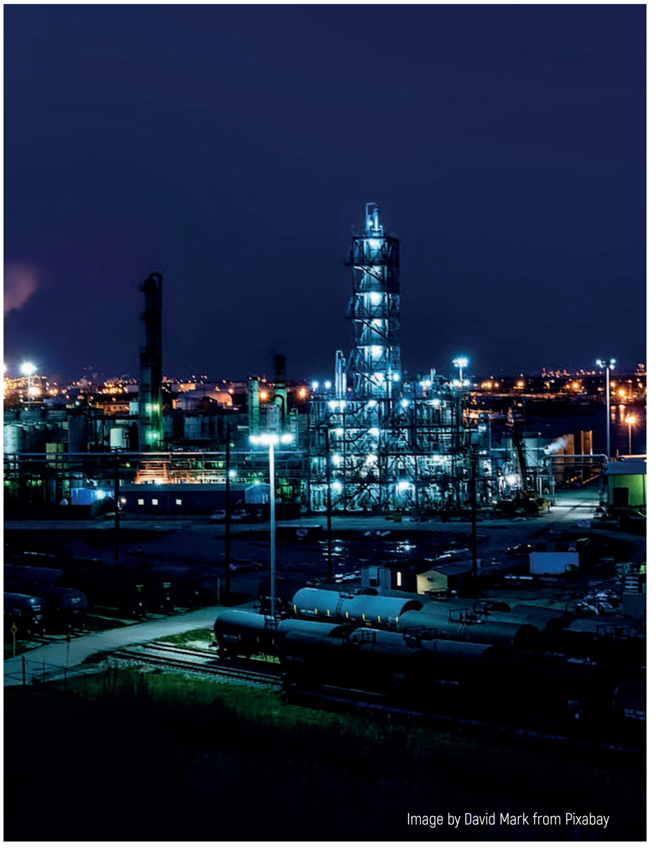


Image by David Mark from Pixabay

The issue of whether oil or natural gas will be the primary feedstock for the production of LPG, ethane and naphtha is important for the prospective development of global markets for liquid and gaseous fuels. From a technical and economic point of view, ethane is the preferred feedstock for the production of ethylene, due to high yield of the target product and lower prices of feedstock. Ethane is a byproduct of the gas industry and, in theory, can be considered a feedstock with a negative cost, since its content in the commercial gas is strictly regulated and de-ethanization is a mandatory process. At the same time, it should be noted that transportation of ethane over long distances does not seem economically feasible due to technological limitations and relatively small volumes of its production. Thus, ethane is "locked up" in the regional markets of gas producers, which is the main barrier for its use outside these markets, limits the volume of global ethane trade and, as a result, widespread ethanoic chemicals. The logic is similar for the countries using LPG as a primary feedstock for petrochemical production.

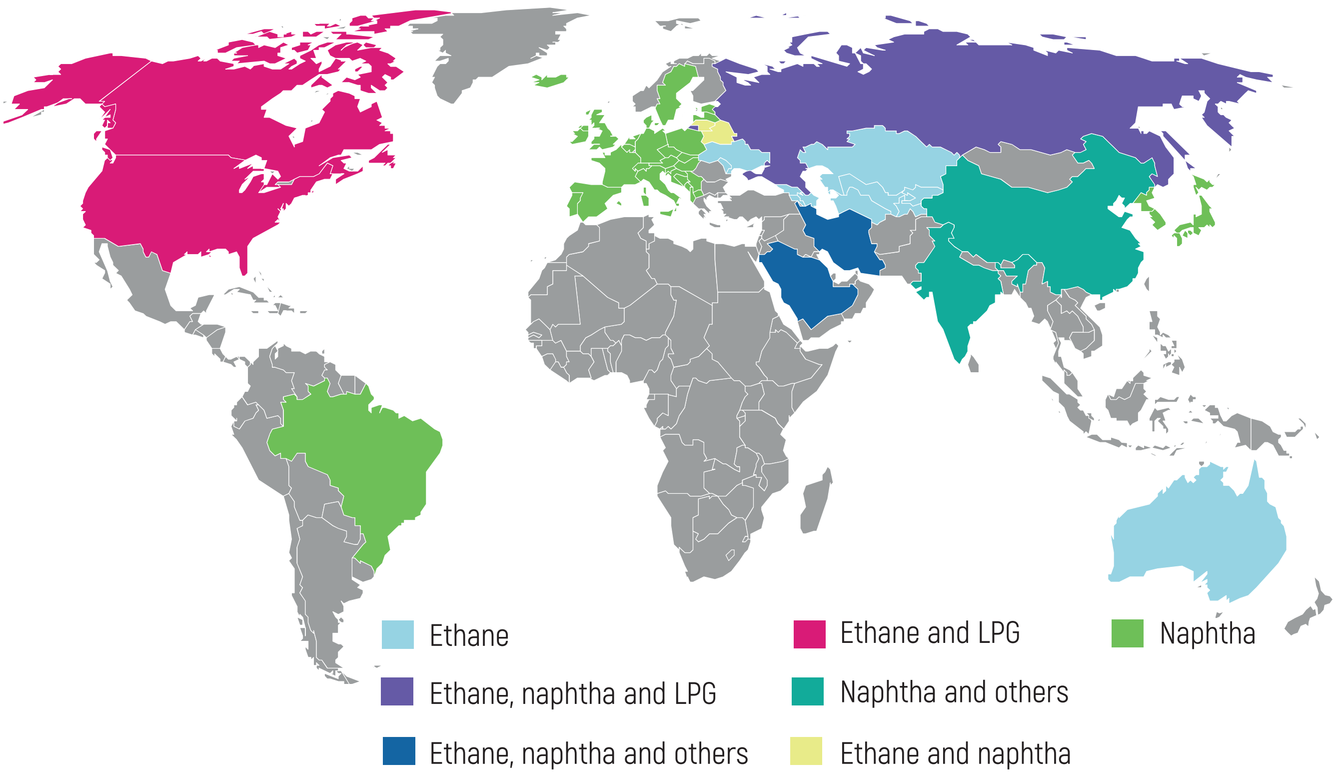
At the same time, naphtha has significant advantages over ethane and LPG as a commodity for inter-country trade, as it is easy to transport (or produce on-site from crude oil). A wide range of valuable by-products can be obtained from processing naphtha, including propylene and butylene. For example, China managed to become one of the world top producers of propylene due to large-scale use of liquid feedstocks.

Considering these characteristics of ethane and naphtha as feedstocks for the chemical industry, the composition of the range of feedstocks for individual regions will continue to be determined primarily by the availability of surplus volumes of natural gas that can be used for ethane production. (Fig. 2.40).

Until recently, the situation in the United States was unique in many ways. The world's largest producer of petrochemicals based its production on ethane, while having a shortage of its own natural gas. Vast demand for motor gasoline in the domestic market still limits the production of naphtha by refineries, while gas imports from neighbouring Canada and large capacity of crude oil destructive processing at local refineries make it possible to cover this deficit.

In the forecast period, the composition of the range of feedstock for the petrochemical industry will continue to be determined by the availability of surplus volumes of directly extracted rich natural gas that can be used for ethane production.

**Figure 2.40 - Feedstock for ethylene production in 2040**




Source: ERI RAS

The start of the "shale revolution" in the US and rapid growth of shale gas production have led to lower prices of ethane and natural gas liquids (NGL), encouraging American investors to develop the natural gas chemical sector near gas fields in their own territory. This trend is expected to continue in the future, given substantial projected production of rich gas.

Europe will continue to base its petrochemical production on imported naphtha (primarily from the Middle East and the CIS countries) . The volume of chemicals production capacity in the region will decline in the forecast period – under the impact of competitive pressure from monomer manufacturers in the US and the Middle East. European production based on imported feedstock is less cost-effective due to a number of environmental restrictions for chemical plants.

In the Middle East the chemical industry has experienced a period of rapid growth starting in the 1990s, backed by an excess of local feedstocks.

Gasification of the utilities and the industrial sectors, which began in this region in the 2000s, pulled substantial volumes of domestically produced gas from the chemical complex, and therefore ambitious plans of the countries in the region to develop the chemical industry with natural gas as the main feedstock have come under question. In the period to 2040, most countries in the region will gradually re-orientate their chemical industry from gas to oil as a feedstock for production. This will happen against the backdrop of substantial plans for the construction of primary oil refining capacity, which will be able to produce sufficient quantities of naphtha.

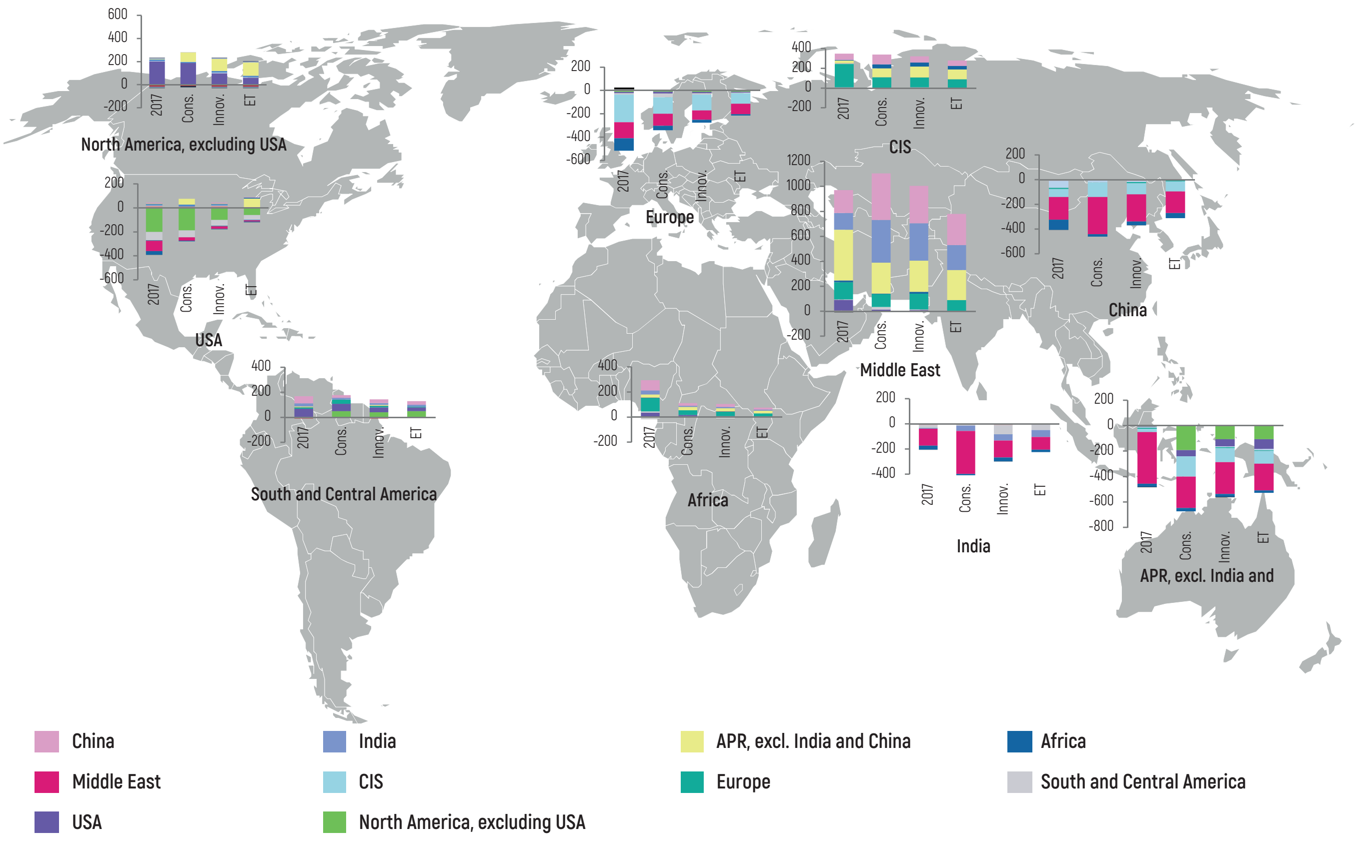
China is already one of the current world leaders in the chemical industry, and by 2040, in all scenarios, it is expected to take a leading position in terms of capacity, overtaking the US. China's limited internal gas resources predetermined the feedstock structure of petrochemicals in the country with a predominance of imported naphtha and coal gasification products. In the forecast period, it is expected that China will continue to diversify the feedstock range of the chemical complex, remaining the world leader in terms of total chemical production capacity.

# International trade

The prospects for international trade in the oil market are highly dependent on the scenario. No revolutionary changes are expected in the Conservative scenario. In the period to 2040, the US will remain a net oil importer, despite an increase in shale production and a decline in absolute petroleum product demand. At the same time, there will be a significant reduction in imports into the country - from 395 to 280 mln tonnes, primarily due to the displacement of suppliers from Africa and the Middle East from the pool. Imports will be represented mainly by Canadian heavy crude oil (it currently makes up 43% of imports to the US). By 2040 this figure will increase to 62%, while supplies to the US from Canada will remain largely the same in absolute terms.

In general, in the first half of the 2020s North America will become a net exporter of crude oil due to growth in Canadian exports to the APR countries and exports of light crude oil from the United States to European countries. in the Innovative scenario, the US reduces import further, bringing it down to 100 mln. tonnes, due to a contraction of petroleum product demand and growing domestic production. The parameters of the Energy Transition scenario lead to a decrease in net imports to the United

**Figure 2.41 – Export (positive values) and import (negative values) of crude oil by key countries and regions by scenario, mtoe**




Source: ERI RAS

> The prospects for international trade in the oil market are very sensitive to scenario assumptions. In the Conservative and Innovative scenarios only the countries in the Middle East will be able to grow crude oil exports by 2040, mainly by supplying developing Asia's markets. However, in the Energy Transition scenario, they will be forced to significantly cut crude oil exports compared to the current volumes.

States nearly down to zero by 2040, and unused surplus volumes of Mexican and Canadian crude oils go primarily to Asia (Fig. 2.41).

In the Conservative and Innovative scenarios only the countries in the Middle East will be able to grow crude oil exports by 2040, mainly thanks to deliveries to developing Asia's markets. However, in the Energy Transition scenario, they will be forced to significantly cut crude oil exports compared to the current volumes.

The CIS countries will face the inevitable transition to hard-to-recover, expensive reserves as the current resource base gets depleted.

Consequently, they will see a decrease in cost competitiveness in the world market, which coupled with a decline in the need for imports in both America and Europe will lead to a tough fight for the Asian consumer in the Conservative scenario. Another important change is that crude oil exports from the African continent will decline in all scenarios, due to a significant boost in the region's own demand for refining products and active construction of low-complexity refineries. These refineries are capable of producing low-quality fuel that is not required in the rest of the world. At the same time, the development of the African continent as a new exporter of petroleum products is quite possible. If the political and military situation in several countries in the region were to stabilise, European

Image by Pexels from Pixabay

and American companies could very well relocate their plants there.  These capacities are currently becoming unprofitable due to high environmental standards.

Europe will reduce import volumes in all scenarios; from 500 mln tonnes in 2017 to 220-340 mln tonnes by 2040, depending on the scenario. The supply structure will remain diversified by regions of origin. Suppliers from North America, the CIS, the Middle East, Africa and South America will be represented in the European market.  An increase in demand for oil imports compared to current levels should only be expected in the Asia Pacific Region and developing Asia (except for China). Intense competition is expected in relation to these very markets.  Those suppliers who have already ensured that they have a supply infrastructure and built long-term economic relations with Asian partners will hold the strongest positions in this competitive struggle. These are primarily the CIS countries and the Middle East.

The Asia Pacific region will become the most import-dependent region in the forecast period, in all scenarios. The share of net crude oil import in total consumption will reach 80-85%, depending on the scenario. For most countries of the APR, even a contraction of demand in the Energy Transition scenario will not be able to offset a faster decline in production.  The latter is caused by the absence of a competitive advantage of the region's own producers vs. Middle Eastern suppliers and the CIS oil exporters, considering low crude oil prices. At the same time, the two key economies in the region will almost completely depend on imports - China by 75-82%, India by 88-91% (Table 2.5).

**Table 2.5 - The share of net crude oil import in total consumption in the key countries and importing regions, by scenario**

| | 2015 | 2030 | | | 2040 | | |
|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| **North America** | 12% | 0% | 0% | 0% | 0% | 0% | 0% |
| USA | 33% | 20% | 11% | 14% | 15% | 5% | 2% |
| **Europe** | 76% | 73% | 74% | 70% | 76% | 73% | 70% |
| **APR countries** | 73% | 81% | 81% | 79% | 84% | 83% | 80% |
| China | 61% | 77% | 77% | 75% | 82% | 77% | 75% |
| India | 90% | 87% | 86% | 86% | 91% | 90% | 88% |

Source: ERI RAS

# Oil prices

Oil prices showed high volatility in 2013-2017, with fluctuations reaching 50% of the price. In many respects, the ground for this had been laid earlier, when the basis for overproduction was created due to high prices and hopes for robust demand, and the mechanism for regulating the market in the face of OPEC virtually stopped working.

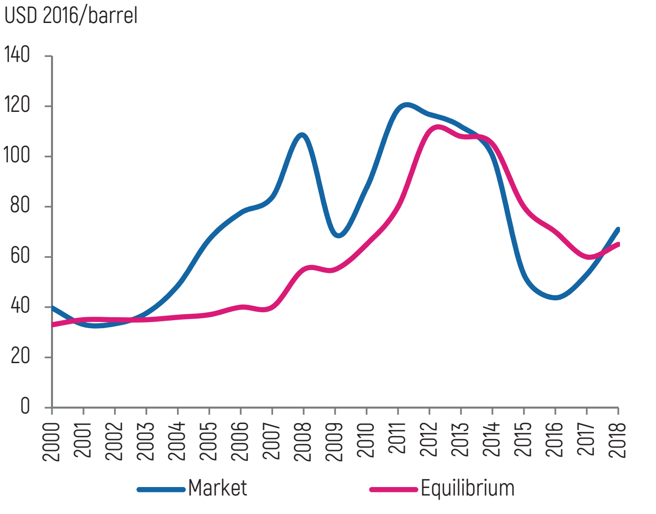
An analysis of the market dynamics and equilibrium prices (prices determined on the basis of fundamental factors - the supply/demand ratio) is a rather good reflection of the situation (Fig. 2.42). Prior to 2011, rapid demand growth encouraged the formation of prices above equilibrium and the appearance of additional supply in the market. And even the crisis of 2009 only led to a convergence of market and equilibrium prices, but not to the convergence of the curves. Subsequently, the slowdown in economic growth and the implementation of many new projects, especially non-conventional ones, formed a glut, and market prices were below equilibrium prices. Only by mid-2018 was it possible to speak of some rebalancing.

However, even this recovery is artificial to an extent, due to OPEC+ agreements. In the coming years, geopolitical factors and the fate of the OPEC+ agreement will have a decisive impact on the price situation in the oil market. The following scenarios are quite probable:

- OPEC+ is maintained and acts as a working mechanism for market management over the next few years. Key producers keep prices in a comfortable corridor of USD 60-80/bbl by means of quota mechanisms and restrictions. In this case, momentary price jumps of up to USD 90/bbl are possible, as a reaction to instances of geopolitical tensions;
- The actual disintegration of OPEC+, non-compliance with the agreement by any large member state (Saudi Arabia, Russia, Iran, Iraq), or a whole group of countries. At the same time, the agreement can remain on paper.

As a result, the new world order in the oil market could turn into a natural "war of all against all", in Thomas Hobbes's description. Breaking the agreement at any time may force the participants to start dumping oil into the markets, instead of a consolidated policy on upward pressure on oil prices. This would fill the import markets with the least expensive oil in order in a desire to retain market niches and capture new ones, which will lead to a price collapse at USD 40-50/bbl with possible short-term drops to USD 30/bbl.

**Figure 2.42 - Market oil prices vs. theoretical equilibrium oil prices[31] in 2000-2017**




Source: ERI RAS

[31] Theoretical "equilibrium prices" are estimated production prices at the "closing" fields (in terms of costs) that have to be commissioned to fully meet global demand.

## What is happening to oil prices?

The situation in 2014 became largely indicative of the market. Markedly reduced costs of shale oil extraction in the United States enabled to deliver large volumes of relatively cheap oil to the market, which intensified competition for consumers. At the same time, Canada and Iraq, which was recovering after military action, significantly increased their output. While previously, in the event of a glut, OPEC used to consider the situation and make a decision on the potential reduction in production quotas, in 2014 the cartel participants followed independent policies. In particular, Saudi Arabia began flooding the markets in order to maintain its own market niche. Global physical demand growth was not sufficient to absorb excess supply, while falling prices were a good incentive to fill up reserves. Thus, buying oil and petroleum products that were not claimed by the real sector of the economy led to overfilling of strategic oil reserves of the OECD countries and a rapid growth in oil and petroleum products reserves. These reserves have historically been a market indicator for stock market players when making decisions regarding supply/demand ratio, and this prompted further downward pressure on the prices.

Contrary to many expectations, lower prices did not lead to a decrease in oil output from the major traditional producers (Russia, Canada, Brazil, the Middle East, etc.). All of them managed to adapt to new market conditions, reducing their total production costs by 30-50%. In Russia's case, this was possible due to the devaluation of national currency, Canada, Kazakhstan, Colombia and Iraq introduced tax concessions, and Norway, Brazil, Angola coped by implementing technological innovations.

Not only oil companies but also the national budgets of many exporting countries managed to adjust to low oil prices. So, in just four years (2014 - 2017) all major oil producers - Kuwait, Russia, Qatar, the United Arab Emirates, Qatar, Saudi Arabia, Iraq, Iran and Nigeria - announced a reduction in their budget break-even oil price (that is, oil prices, at which the national budget does not suffer a deficit) (Fig. 2.43). Only two countries - the main oil producers - Venezuela and Iran - are not showing a lower budget break-even oil price, which is largely due to the general situation in these economies and restrictions on oil export volumes.

In the normal course of events, such an adaptation of the market (a reduction in production costs, following a decline in oil prices via the inflationary spiral) could last at least until the early 2020s, if not until the time that relatively cheap technically recoverable reserves of conventional and non-conventional oil have been depleted. Nevertheless, since 2017, oil prices have been showing an upward movement. A radical change in the institutional conditions of the market is the reason for this.

As 11 producing countries led by Russia joined the OPEC oil cartel, this fundamentally changed the rules of the game in the oil market. While in the 2000s OPEC controlled about 40% of global production, the new players joining the production quotas agreement made it possible to expand the overall share of players complying with the agreement to 60% and substantially increase the total market power of oil powers. It should be noted that the 2016 agreement to curtail oil production was one of the few that was fulfilled 100% and turned out to be unprecedented both in terms of its accuracy and the deadlines for meeting the obligations in the entire history of the existence of OPEC and the production quota mechanism. The expansion of the cartel in combination with the commitment of the countries participating in the deal led to a recovery of market prices. Thus, the formation of a new oil cartel led to an increase in the "market power" of the OPEC+ countries. While in 2013 the "market power" of OPEC, according to ERI RAS calculations, ranged from USD 2 to USD 6/2013, by 2018 similar estimates made by Oxford Energy Insight[32] for the new Agreement (with the participation of Russia and other countries) were already 10-15 USD 2016/bbl. (around USD 10/bbl according to new estimates by ERI RAS). At the same time, it is important to realise that, despite gaining the opportunity to influence world prices, the new OPEC cartel + has to sacrifice controlled market volumes, which fell from 60% to 43% in the period from 2018 to mid-2019 in 2018 alone. This means that further control over the market situation will demand increasingly greater output cuts which will be replaced primarily with American shale production.

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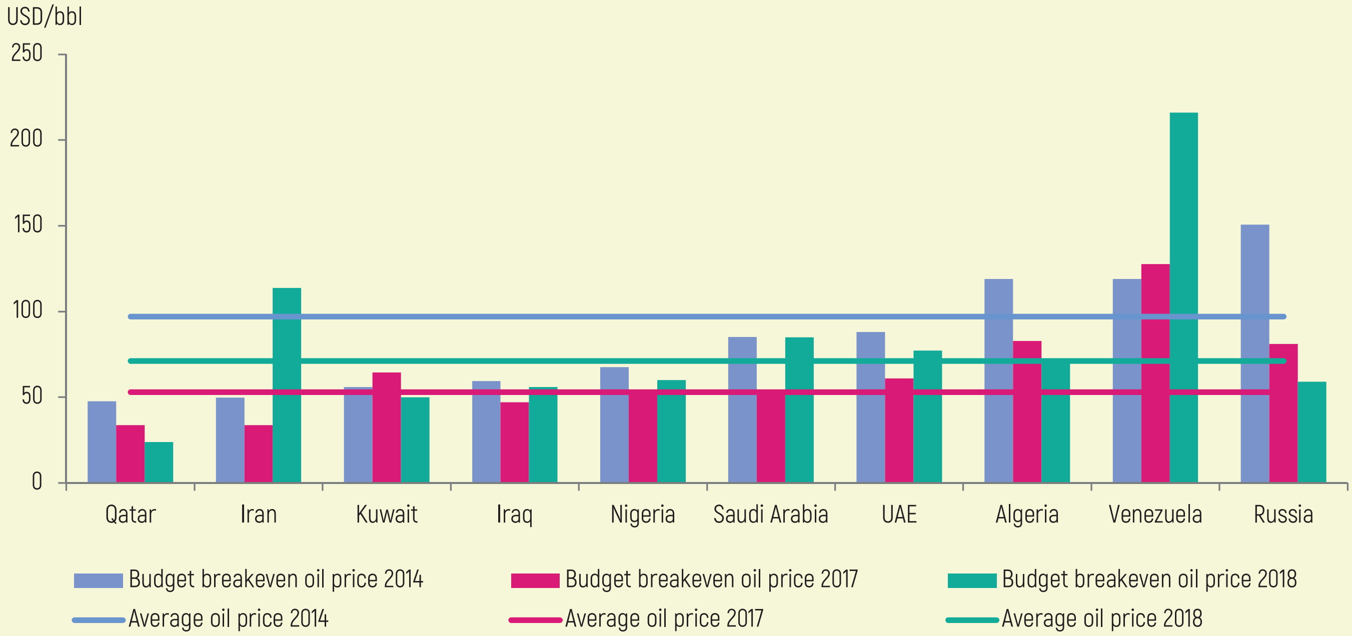
32 (B. Fattouh, A. Economu, "OPEC at the Crossroads", Oxford Energy Insight: 37 June 2018, The Oxford Institute for energy studies, https://www.oxfordenergy.org/wpcms/wp-content/uploads/2018/06/OPEC-at-the-Crossroads-Insight-37.pdf (access time 15.02.2018))

Figure 2.43 - Budget break-even oil price in oil producing countries in 2014, 2017 and 2018




Sources: ERI RAS based on IMF External Breakeven 2019, S&P Global Platts 2019, FRED Economic data "Breakeven Fiscal oil Price"


Image by skeeze from Pixabay

Despite obvious medium-term financial losses for exporters in the event of the termination of the OPEC+ agreement, it is necessary to realise the negative long-term consequences of keeping prices above equilibrium:

- Increased production costs in the countries whose budgets and GDP are heavily dependent on oil revenues, due to the inflationary spiral and the strengthening of currencies (exchange rate differences). The inflationary spiral described above – rising prices of energy carriers, including oil, leading to higher costs and prices for products of energy-intensive industries – leads to higher costs for the oil companies, which consume goods of the energy-intensive industries. Given an upward movement of oil prices, the inflationary spiral causes production and refining costs to go up. For Russia in particular, the inflationary spiral coupled with a simultaneous strengthening of the national currency makes domestically produced oil less cost competitive in the global market. At the same time, no similar effect caused by exchange rate differences that would apply to the US shale producers, for instance.
- Growing incentives to improve energy efficiency and energy saving standards in the oil importer countries and intensify actions to find alternative fuels will lower growth in demand for oil and petroleum products in the long term. Consequently, this will spur competition for consumers in the oil market and push oil prices down.

The OPEC+ agreement is a good instrument for maintaining a favourable level of oil prices in the market in the medium term. However, in the long term it could lead to a deterioration in the functioning of oil exporters.

Given the current market situation where oil prices are primarily dependent on political decisions, the prices in the period to 2025 are set as a scenario prerequisite in this forecast. After this period they are determined based on the calculations of the equilibrium oil price. By 2040, oil prices in the Conservative scenario reach USD 110 2017/bbl, and this, according to the calculations, can be reasonably seen as the upper optimistic limit of projected potential market oil prices for exporting countries. The parameters of the Innovative scenario bring the equilibrium prices to the level of USD 76 2017/bbl, and in the Energy Transition scenario, the balancing point in the world oil market drops to USD 60 2017/bbl. Moreover, market prices in this scenario can turn out to be noticeably lower than the equilibrium ones, since the global market will almost always be in the conditions of a surplus of supply over demand until 2040 (Fig. 2.44).

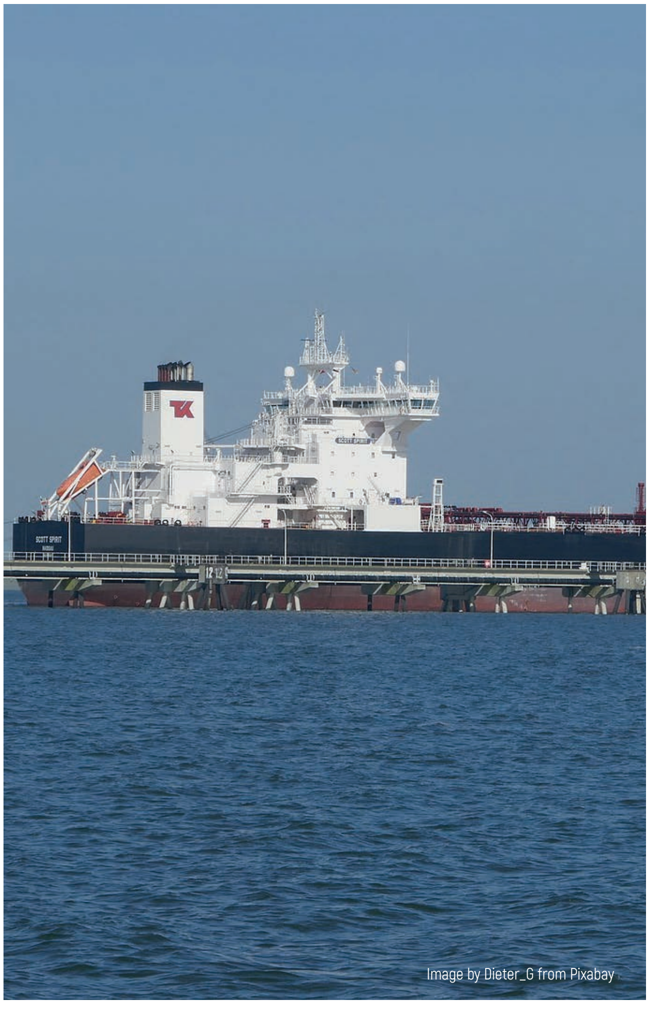


Image by Dieter_G from Pixabay

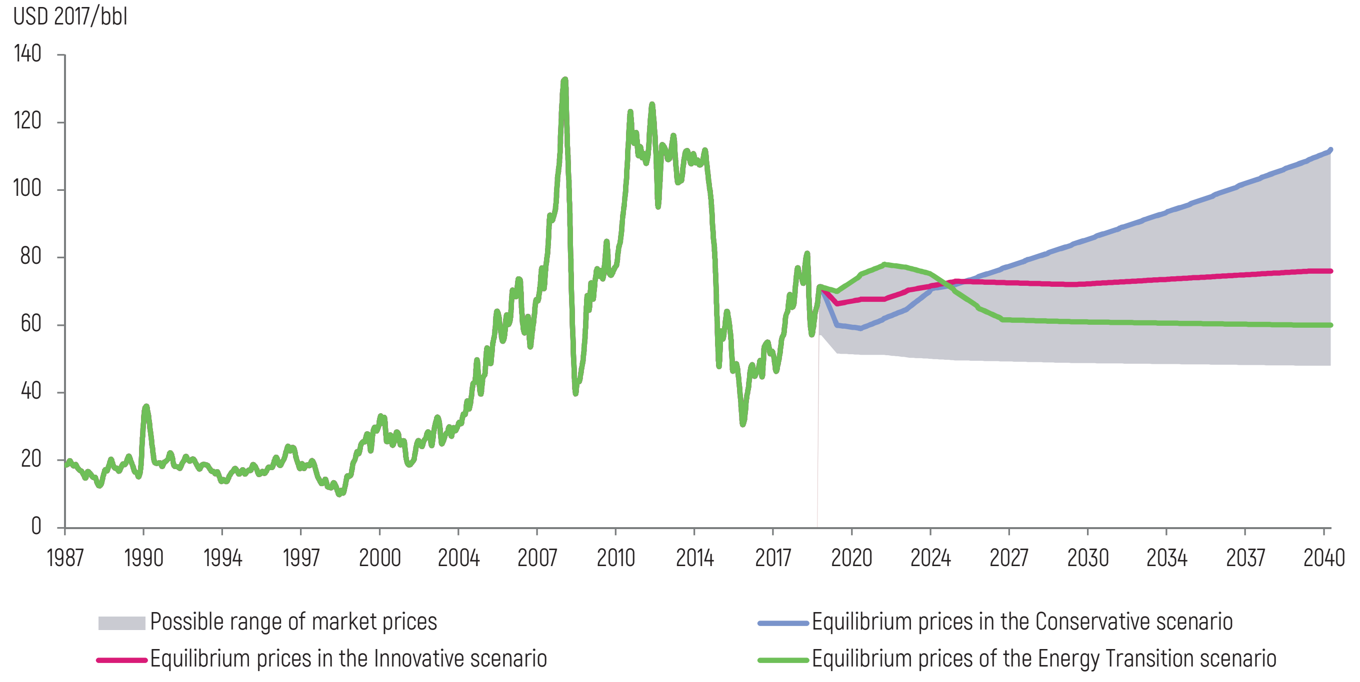
Oil prices in Outlook-2019 are fairly low against those projected by international organisations (Table 2.6). However, the parameters of market transformation show that there is virtually no potential for long-term price increases above USD 100 2017.

**Table 2.6 – Equilibrium oil prices in Outlook-2019 compared to other forecasts**

| | 2018 | 2025 | 2030 | 2040 |
|---|---|---|---|---|
| ERI RAS - SKOLKOVO Conservative | | 72 | 84 | 109 |
| ERI RAS - SKOLKOVO Innovative | | 73 | 72 | 76 |
| ERI RAS - SKOLKOVO Energy Transition | | 62 | 61 | 60 |
| IEA WEO 2018 New Policies | | 88 | | 112 |
| IEA WEO 2018 Current Policies | | 101 | | 137 |
| IEA WEO 2018 Sustainable Development | | 74 | | 64 |
| EIA AEO 2019 Reference case | | 82 | 93 | 105 |
| EIA AEO 2019 Low macroeconomic growth | | 82 | 92 | 103 |
| EIA AEO 2019 High oil price | | 156 | 176 | 197 |
| EIA AEO 2019 Low oil price | | 44 | 45 | 47 |
| EIA AEO 2019 High macroeconomic growth | 70 | 83 | 94 | 107 |

Sources: ERI RAS, IEA WEO 2018, EIA AEO 2019

**Figure 2.44 – Equilibrium oil prices by scenario, possible range of market prices by scenario**




Source: ERI RAS

# NATURAL GAS MARKET

## Gas demand

The share of natural gas in the structure of world energy consumption has been growing continuously for the last few decades. In 2018, it was around 22%, and, according to our calculations, this figure will reach 25-27% by as early as 2040, depending on the scenario. Compared to other fossil fuels, natural gas will become the undisputed leader in terms of annual consumption growth - 1.3-1.6% in 2015-2040, which is significantly higher than average annual growth in oil and coal consumption (in the Innovative and the Energy Transition scenarios, in general, reductions will be observed in oil and coal consumption). Nevertheless, this increase will be significantly lower compared to gas consumption growth in previous years (2.3% on average in 1990–2015). Gas demand will grow in all regions, however, some of the OECD countries will pass consumption peak.

Gas is the only fossil fuel that will increase its share in global energy consumption from the current 22% to 25-27% by 2040. But growth in its consumption will slow down significantly compared to the previous decades.

Gas will be most in demand in the electric power industry. In the Innovative scenario and, especially, in the Energy Transition scenario, the growth in demand for electricity will lead to the appearance of additional niches in the area of electricity generation. However, competition for both these niches and the entire volume of demand will increase significantly. Moreover, this will be competition with a whole range of technologies and solutions, primarily in the field of renewable energy.

Given expanding renewable energy use, the operating conditions of electric power systems will also change. In addition to traditional variability in the system on the demand side, the variability of generation from renewable energy sources is added. At the same time, this variability acquires a clear seasonal and climatic character. As a result, the role of fuels which balance the power grid is increasing.

Gas is becoming one of these fuels, given reduced use of coal. However, competitiveness of gas as one of the key balancing fuels can significantly compromise the development of energy storage solutions- both industrial and on the consumption side - with the parallel development of smart grids that allow decentralized electricity supply to the grid. There is potential to increase the role of gas In industry and households, as coal consumption decreases, but after that, the share of gas will also decline, giving way to electricity, which is a more universal energy source.

The development of electric transportation technologies In the transport sector will reduce the potential of the gas fuel market. On the one hand, gas acquires additional opportunities to compete with petroleum products. On the other hand, electricity will partially occupy the niche that gas could have had in the road transport market. At the same time, gas gains new opportunities for its use in maritime transport. However, the realization of these opportunities will strongly depend on the rate of geographical implementation of requirements for marine fuels within the framework of MARPOL and the content of these requirements, in particular, the inclusion of $CO_2$ emissions restrictions in them.

Gas is one of the most controversial components of the transformation of the energy system. This is a fossil fuel, but with the lowest $CO_2$ emissions. The increase in electricity consumption, including as part of the conquest of electricity in the transport market, creates good conditions for gas demand growth. In parallel, emission reduction initiatives are helping to substitute gas for coal. The consequence of this is an increase in the use of gas, as can be seen in the example of the Innovative scenario. However, active development of renewable energy sources with appropriate state support and new solutions in the field of load balancing will markedly intensify the struggle in the electricity market and could hold back gas consumption. As a result, in the Conservative scenario, global gas demand in 2040 will reach 5.15 trillion cm (an absolute increase of more than 1.5 trillion cm), in the Innovation scenario, gas consumption by 2040 will exceed 5.34 trillion cm, and in the Energy Transition scenario it will only reach 4.99 trillion cm.

Growth in gas demand in the forecast period is expected in all scenarios in all regions with the exception of the EU. In the past few years, gas consumption in Europe increased largely due to a sharp decline in prices, which allowed gas to partially restore its share in the fuel mix. However, further opportunities are limited due to the stabilization of total energy consumption and the expansion of renewable energy. At the same time, the potential for coal substitution is gradually being exhausted. As a result, after a slight increase, gas consumption in Europe will begin to decline and by 2040 it will reach the level of 2016.

Most of the growth in demand for natural gas will come from the non-OECD economies, where absolute consumption will more than double, increasing by 64-77% between 2016 and 2040, depending on the scenario. Economic growth and environmental friendliness of gas will be the main drivers behind demand growth, although the latter factor will not be decisive due to large-scale plans to expand renewable energy use (and given the fact that at the same time gas will be significantly higher in price compared to cheap local coal).

Gas consumption in the Middle East will grow by nearly 300 bcm in the Conservative scenario, with half of that increase attributable to Iran. Absolute consumption growth in the region will total less than 230 bcm in the Energy Transition scenario due to the use of more energy efficient technologies and renewable energy, primarily solar power.

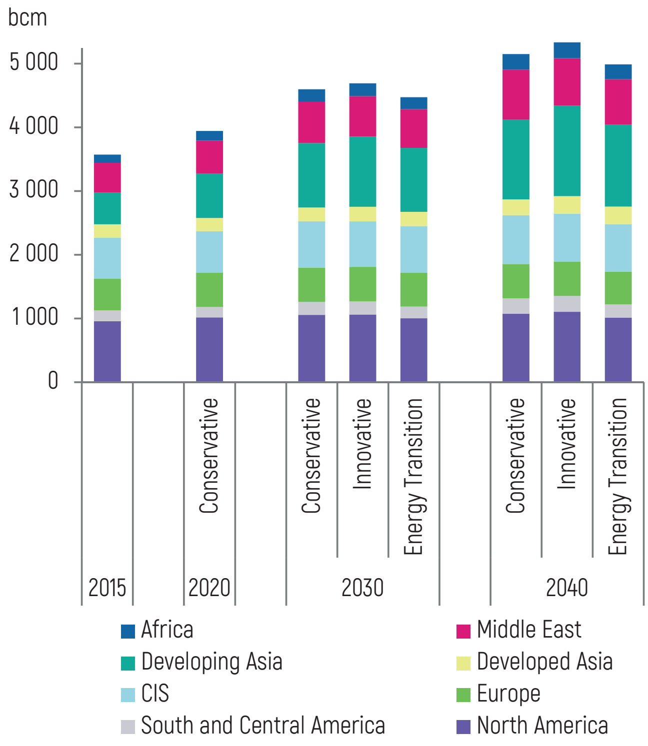
Solar power has good development potential in this region thanks to a high degree of insolation and virtually no cloud

The scenarios clearly demonstrate the growing uncertainty for the gas market. On the one hand, rising demand for electricity, supported, among other factors, by the development of electric transport, creates conditions for increasing gas consumption. Gas, largely due to its environmental characteristics, directly or indirectly displaces oil and coal, as can be seen from the example of the Innovative scenario, where gas demand has increased compared to the Conservative scenario. On the other hand, a whole set of promising technologies and solutions, primarily in the field of renewable energy and electricity storage, toughen competition in the electric power industry, which leads to a decline in gas consumption by 2040 in the Energy Transition scenario relative to the two other scenarios.

cover. Also, peaks of the demand for air conditioning coincide with the maximum possibilities for producing solar based electricity. At the same time, fossil fuels within the region (which are cheaper for producing countries) can be exported to premium foreign markets. The increase in gas consumption in the region will be driven by the needs of the developing economies and population growth, while gas will continue to actively replace petroleum products in all sectors, primarily in the power industry, and will be widely used in the chemical industry for air conditioning and water desalination.

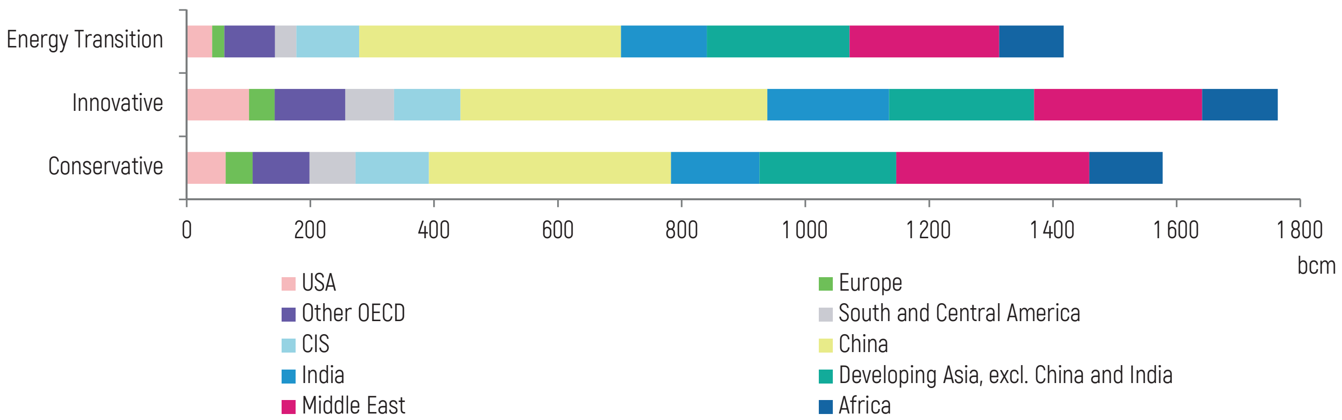
Gas consumption in Africa will nearly double to 250 bcm linked to economic needs and initiatives to develop the domestic gas market, including in Tanzania, Mozambique, Nigeria, Algeria and Egypt. Gas consumption will increase by 1.5-fold In South and Central America, approaching 250 bcm in the Conservative and the Innovative scenario. Growth will be limited to 32% in the Energy Transition scenario. At the same time, gas will hold back growth in the use of bio-energy and will start gradually replacing bio-energy sources. In contrast, in the CIS countries, which are characterized by high gas consumption, consumption growth will begin to slow down starting in the 2030s, and the increase in 2016–2040 will be limited to 10-16% (fig. 2.45, fig. 2.46, table 2.7).

**Figure 2.45 - Scenario forecast of natural gas demand by region, bcm**




Source: ERI RAS

**Figure 2.46 - Scenario forecast of natural gas demand growth in 2015 - 2040 by region and largest country, bcm**




Source: ERI RAS

## Table 2.7 – Gas consumption by region and major country, bcm

| | 2015 | 2020 | 2030 | | | 2040 | | | Growth rates in 2015-2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| **North America** | **958** | **1018** | **1057** | **1064** | **1003** | **1074** | **1107** | **1016** | **0.5%** | **0.6%** | **0.2%** |
| Canada | 102 | 121 | 147 | 146 | 137 | 145 | 147 | 127 | 1.4% | 1.4% | 0.9% |
| Mexico | 78 | 79 | 82 | 78 | 72 | 87 | 81 | 69 | 0.5% | 0.2% | -0.4% |
| US | 778 | 818 | 828 | 840 | 793 | 841 | 879 | 819 | 0.3% | 0.5% | 0.2% |
| **South and Central America** | **170** | **164** | **205** | **207** | **184** | **244** | **248** | **205** | **1.5%** | **1.5%** | **0.8%** |
| Brazil | 40 | 38 | 61 | 59 | 47 | 83 | 82 | 59 | 3.0% | 2.9% | 1.6% |
| **Europe** | **495** | **536** | **536** | **540** | **532** | **539** | **536** | **515** | **0.3%** | **0.3%** | **0.2%** |
| EU-28 | 435 | 466 | 450 | 457 | 447 | 435 | 440 | 420 | 0.0% | 0.0% | -0.1% |
| Great Britain | 72 | 79 | 72 | 70 | 72 | 65 | 62 | 61 | -0.4% | -0.6% | -0.6% |
| Germany | 81 | 101 | 107 | 112 | 104 | 101 | 108 | 89 | 0.9% | 1.1% | 0.4% |
| Italy | 68 | 63 | 55 | 57 | 58 | 45 | 48 | 51 | -1.6% | -1.3% | -1.1% |
| France | 39 | 41 | 34 | 34 | 33 | 53 | 51 | 52 | 1.2% | 1.0% | 1.2% |
| Turkey | 48 | 57 | 70 | 66 | 65 | 85 | 78 | 75 | 2.3% | 2.0% | 1.8% |
| **CIS** | **645** | **652** | **729** | **713** | **732** | **764** | **752** | **746** | **0.7%** | **0.6%** | **0.6%** |
| Russia | 444 | 475 | 533 | 516 | 543 | 559 | 545 | 549 | 1.0% | 0.9% | 0.9% |
| **Developed Asia** | **211** | **209** | **216** | **230** | **223** | **250** | **278** | **276** | **0.7%** | **1.1%** | **1.1%** |
| Japan | 124 | 105 | 93 | 104 | 110 | 105 | 131 | 149 | -0.7% | 0.2% | 0.7% |
| South Korea | 44 | 52 | 68 | 70 | 68 | 90 | 90 | 89 | 2.9% | 3.0% | 2.9% |
| **Developing Asia** | **494** | **694** | **1009** | **1101** | **1002** | **1249** | **1422** | **1287** | **3.8%** | **4.3%** | **3.9%** |
| China | 193 | 324 | 502 | 560 | 485 | 585 | 690 | 617 | 4.5% | 5.2% | 4.7% |
| India | 50 | 74 | 120 | 143 | 120 | 192 | 246 | 188 | 5.6% | 6.6% | 5.5% |
| Indonesia | 45 | 57 | 78 | 77 | 75 | 92 | 88 | 84 | 2.9% | 2.7% | 2.6% |
| Malaysia | 42 | 51 | 62 | 61 | 61 | 64 | 62 | 62 | 1.7% | 1.6% | 1.6% |
| **Middle East** | **470** | **518** | **647** | **636** | **609** | **782** | **741** | **712** | **2.1%** | **1.8%** | **1.7%** |
| Iran | 183 | 199 | 264 | 259 | 251 | 337 | 328 | 310 | 2.5% | 2.4% | 2.1% |
| Saudi Arabia | 90 | 105 | 123 | 115 | 100 | 147 | 113 | 105 | 2.0% | 0.9% | 0.6% |
| **Africa** | **128** | **153** | **197** | **199** | **186** | **246** | **250** | **232** | **2.7%** | **2.7%** | **2.4%** |
| **Worldwide** | **3571** | **3943** | **4597** | **4690** | **4472** | **5149** | **5335** | **4989** | **1.5%** | **1.6%** | **1.3%** |
| OECD | 1654 | 1754 | 1806 | 1827 | 1749 | 1863 | 1916 | 1798 | 0.5% | 0.6% | 0.3% |
| Non-OECD | 1917 | 2189 | 2791 | 2863 | 2723 | 3286 | 3418 | 3190 | 2.2% | 2.3% | 2.1% |

Source: ERI RAS

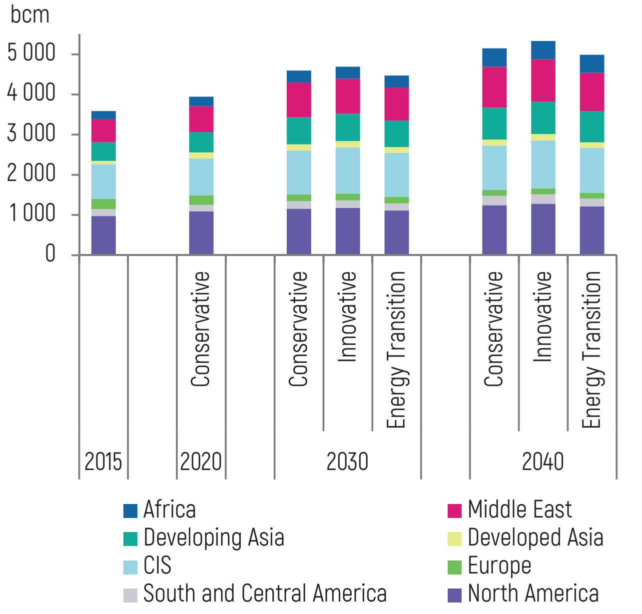
In terms of individual countries, the most significant increase in gas consumption will be attributable to China and India. China - the world leader in gas demand growth - will account for 25-30% of total additional global demand. Having reached the values of 585-690 bcm by 2040 in terms of gas demand, China will surpass the European region with its consumption volume of under 540 bcm. Taking into account rising gas demand in India (more than threefold compared to 2016), the increase in consumption in these two Asian countries will exceed total demand growth in large natural gas producing regions - North America and the Middle East. OECD demand in 2015-2040 will slow down to 9-16% compared to 60% in the previous 25 years, while the slowdown in non-OECD countries will be more restrained - to the level of 66-78% compared to 88% earlier.


Image by David Mark from Pixabay

# Natural gas supply

At the end of 2018, the world's total proven natural gas reserves totalled over 200 trillion cm, meaning that supply of natural gas would last over 50 years at current production levels. At the same time, the annual increase in reserves, as a rule, exceeds production volumes. In response to dynamic growth in demand, gas production will continue to rise - according to the calculations, global gas production will increase by 39-48% to 4.9-5.3 trillion cm in 2016 - 2040 The most robust growth in natural gas production is expected in the Middle East, North America, the CIS (Russia) and developing Asia, while the United States, Russia and Iran will remain the largest producers over the entire forecast period. (Fig. 2.47, Fig. 2.48, Table 2.8). By 2040, North America and the CIS will exceed the level of 1 trillion cm in all scenarios, while the Middle East will reach this level in the Innovative and Conservative scenarios.

**Figure 2.47 - Scenario forecast of natural gas production by region, bcm**




Source: ERI RAS

> Global natural gas production will increase by 39-48% by 2040 in response to growing demand, reaching 4.9-5.3 trln. cm

Natural gas production in Europe will continue to decline. A forced reduction and later a complete cessation of production at the once-largest European field Groningen in the Netherlands is one of the reasons. This decision of the Dutch government is due to security concerns linked to an increasing number of earthquakes in the region. A decrease in gas production in Norway is also forecast due to the depletion of explored reserves, with significant under-exploration of new sources. As a result, by 2040 gas production in Europe will fall by over 40% compared to 2017.

Some growth until 2030, and then a slight decrease in production will be observed in Asia-OECD countries. At the same time, Australia - the only exporter of gas in the region and one of the largest LNG exporters in the world - will boost production by 15-35% by 2040.

In the Middle East, production will grow at an average annual rate of 2.1–2.4%. This increase will mainly be used to meet the needs of the domestic markets. As before, high uncertainties remain regarding the prospects of Iran, the country with the largest gas reserves in the region. Geopolitical conditions limit its access to technology and investment, which hinders the implementation of gas export projects and places the focus mainly on meeting growing domestic demand. Qatar, the largest regional exporter, will continue to boost gas exports after a pause taken in recent years, increasing production by 41-50% by 2040 compared to 2017.

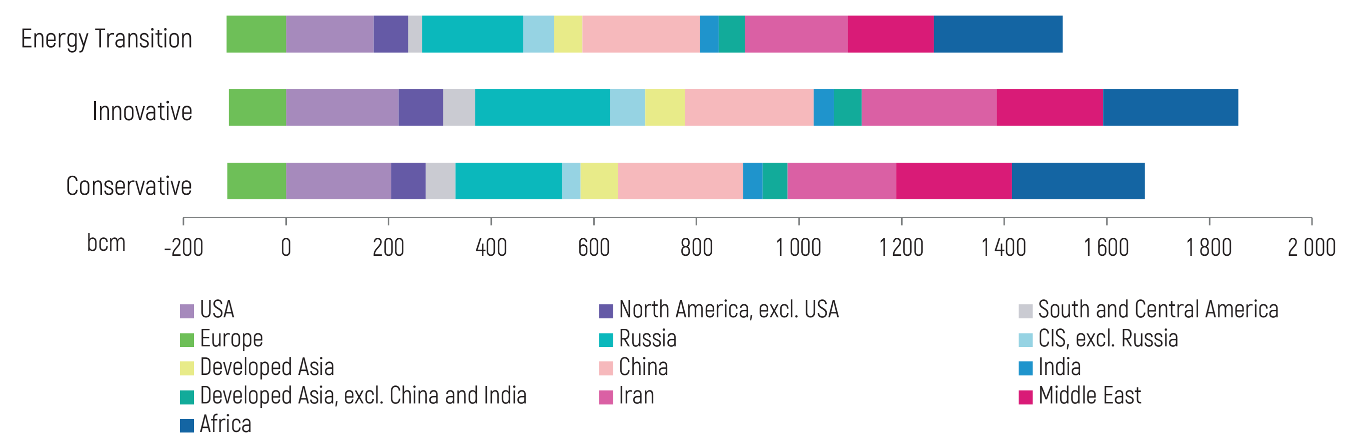
In developing Asia, the highest increase in production will be shown by China, where output will grow over 1.5-fold, including due to shale extraction, coal bed methane and bio-gas.

In the CIS, the main opportunities for production growth are associated with Russia, and output will be determined mainly by demand in the domestic and foreign markets. The countries of Central Asia and the Caspian basin (Turkmenistan, Azerbaijan, Kazakhstan, Uzbekistan) have the potential to increase production by 25-35% by 2029, but after that both production and export are expected to decline. Available resources could allow output of these four countries to be increased by another 120 billion cm by 2040, but sales prices need to be considerably higher for such projects to be more competitive than those in the considered scenarios. Output growth of 10-35% by 2040, depending on the scenario, is expected in South and Central America, mainly provided by Brazil and Argentina. In the Energy Transition scenario, despite technological advancements and access to technologies, shale gas production in Argentina is lower than in other scenarios due to high production costs and its poorer competitiveness in the gas market and in consumption segments, given accelerated proliferation of renewable energy.

Gas output in Africa will double compared to current levels. Unlike in the last few decades, this output growth will be attributable mainly not to North Africa, but to Central and Eastern Africa, including Mozambique. At the same time, an increase in domestic demand in the countries of North Africa will significantly limit their export opportunities.

The prospects for many gas production projects in the world depend on the situation with oil production, as gas is used to maintain pressure in oil reservoirs. They are also dependent on the often associated project economics in the process of simultaneous production of these two hydrocarbons, including associated petroleum gas. This situation is typical for gas production in North America. At the same time, in all scenarios, by 2040 the region manages to reach a record output of 1.2 trillion cm, mainly due to continued growth of gas production in the United States. In Canada, gas output is expected to decline by 2030, followed by a recovery by 2040 (Fig. 2.48). The difference in demand in the scenarios is most clearly reflected in the production of the largest gas exporting countries. As a rule, local production opportunities in the centres of world consumption appear required in any conditions and do not vary greatly across the scenarios. Changes in demand growth primarily affect the volume of cross-country trade and the players that participate in it.

**Figure 2.48 – Gas production growth by region in 2015-2040, bcm**



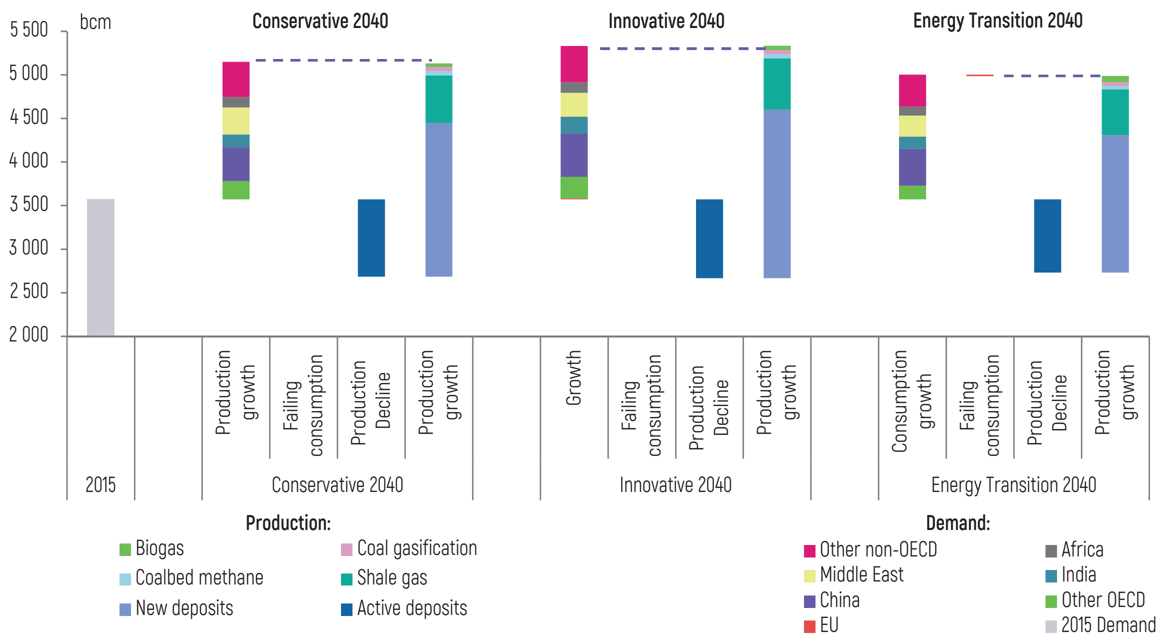

Source: ERI RAS

### Table 2.8 – Gas production by region and major country, bcm

| | 2015 | 2020 | 2030 | | | 2040 | | | Growth rates in 2015-2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| **North America** | **973** | **1091** | **1177** | **1191** | **1152** | **1245** | **1294** | **1229** | **1.0%** | **1.1%** | **0.9%** |
| Canada | 164 | 179 | 157 | 162 | 151 | 174 | 184 | 168 | 0.2% | 0.5% | 0.1% |
| Mexico | 42 | 37 | 34 | 34 | 33 | 55 | 62 | 55 | 1.1% | 1.6% | 1.1% |
| USA | 767 | 875 | 986 | 995 | 968 | 1016 | 1048 | 1006 | 1.1% | 1.3% | 1.1% |
| **South and Central America** | **172** | **169** | **188** | **192** | **175** | **231** | **237** | **199** | **1.2%** | **1.3%** | **0.6%** |
| Argentina | 40 | 44 | 47 | 48 | 43 | 53 | 59 | 46 | 1.1% | 1.6% | 0.6% |
| Brazil | 24 | 21 | 46 | 52 | 38 | 69 | 68 | 45 | 4.3% | 4.3% | 2.5% |
| **Europe** | **261** | **230** | **169** | **169** | **168** | **146** | **149** | **145** | **-2.3%** | **-2.2%** | **-2.3%** |
| Norway | 121 | 120 | 99 | 99 | 98 | 88 | 90 | 88 | -1.3% | -1.2% | -1.3% |
| **CIS** | **861** | **923** | **1072** | **1119** | **1052** | **1104** | **1176** | **1091** | **1.0%** | **1.3%** | **1.0%** |
| Russia | 636 | 699 | 805 | 838 | 813 | 854 | 900 | 833 | 1.2% | 1.4% | 1.1% |
| **Developed Asia** | **82** | **150** | **156** | **159** | **144** | **155** | **158** | **137** | **2.6%** | **2.7%** | **2.1%** |
| Australia | 74 | 144 | 150 | 152 | 138 | 149 | 152 | 131 | 2.8% | 2.9% | 2.3% |
| **Developing Asia** | **459** | **508** | **671** | **675** | **658** | **790** | **804** | **776** | **2.2%** | **2.3%** | **2.1%** |
| India | 31 | 31 | 51 | 50 | 50 | 69 | 71 | 68 | 3.3% | 3.4% | 3.2% |
| Indonesia | 75 | 74 | 105 | 105 | 104 | 114 | 120 | 113 | 1.7% | 1.9% | 1.7% |
| China | 135 | 180 | 267 | 273 | 259 | 379 | 386 | 364 | 4.2% | 4.3% | 4.0% |
| Malaysia | 69 | 75 | 73 | 72 | 69 | 69 | 70 | 67 | 0.0% | 0.1% | -0.1% |
| **Middle East** | **585** | **642** | **868** | **874** | **826** | **1022** | **1055** | **963** | **2.3%** | **2.4%** | **2.0%** |
| Iraq | 7 | 14 | 34 | 36 | 33 | 63 | 68 | 61 | 9.2% | 9.5% | 9.0% |
| Iran | 184 | 204 | 297 | 301 | 283 | 396 | 447 | 395 | 3.1% | 3.6% | 3.1% |
| Qatar | 164 | 182 | 247 | 252 | 243 | 250 | 255 | 240 | 1.7% | 1.8% | 1.5% |
| Saudi Arabia | 87 | 105 | 124 | 115 | 100 | 147 | 113 | 105 | 2.1% | 1.1% | 0.8% |
| **Africa** | **198** | **231** | **296** | **311** | **297** | **457** | **462** | **449** | **3.4%** | **3.4%** | **3.3%** |
| Algeria | 84 | 87 | 89 | 92 | 88 | 109 | 108 | 107 | 1.0% | 1.0% | 1.0% |
| Egypt | 38 | 57 | 66 | 65 | 66 | 57 | 58 | 56 | 1.6% | 1.7% | 1.6% |
| **Worldwide** | **3590** | **3943** | **4597** | **4690** | **4472** | **5149** | **5335** | **4989** | **1.5%** | **1.6%** | **1.3%** |

Source: compiled by ERI RAS

## Figure 2.49 - Gas Demand/supply balance in 2040

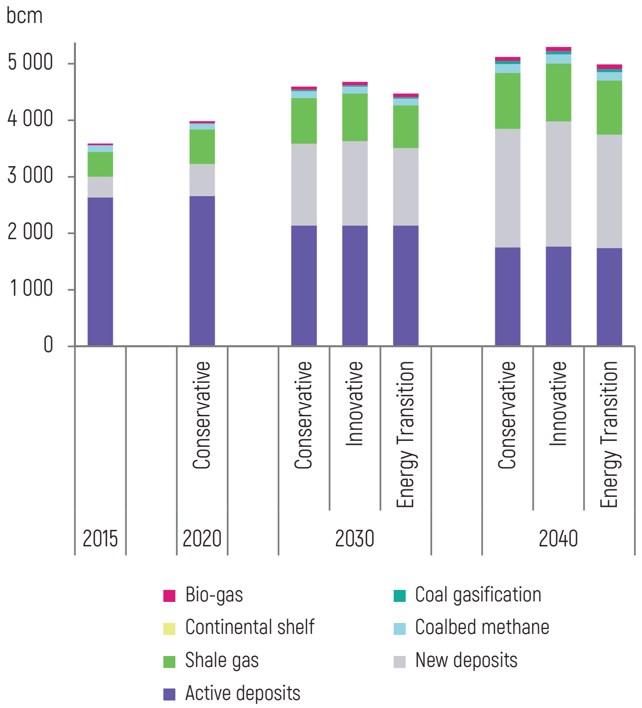



Natural gas fields in operation are gradually being depleted, and by 2040 they will be able to meet only about 50% of the demand. It is obvious that the remaining demand will need to be covered by the means of expanding the resource base and implementing new projects. Conventional das will still be the main source to meet growing demand, but the development and gradually falling costs of production technologies will contribute to an increase in the share of non-conventional gas from 16% in 2015 to 25% at the end of the forecast period. This includes 19% for shale gas, 3% for coalbed methane and 1% each for coal gasification and bio-gas (Fig. 2.49).

Despite the fact that the "shale revolution" has already lasted over a decade, development of non-conventional gas production continues to largely determine the state of the gas market and global gas trade (Fig. 2.52). The US will continue to be the undisputed leader in this field – managing to produce around 700 bcm of shale gas by 2040.

> The share of non-conventional gas, including shale gas and bio-gas, in the structure of gas production will steadily increase.

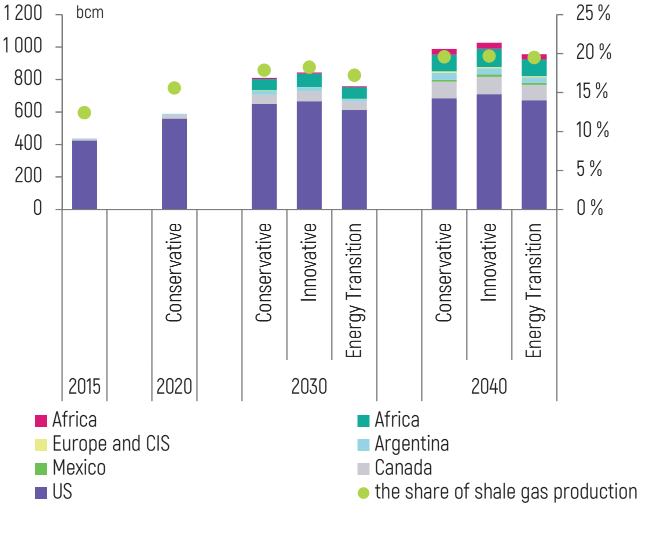
## Figure 2.50 - Scenario forecast of worldwide gas production by type of deposit, bcm




Source for Fig. 2.51 and 2.52: ERI RAS

Besides the US, Canada, Argentina and China produce shale gas, but none of these countries has succeeded in replicating the success of the US in developing shale reserves. According to the forecasts of the Ministry of Natural Resources of China, there are plans to increase shale gas production from 8 bcm in 2016 to nearly 30 bcm in 2020, and up to 80 - 100 bcm in 2030. However, the key uncertainty for Chinese shale gas, as well as for all such resources outside North America, lies in the quality of the resource base and the cost of its production (Fig. 2.51). The most rapid growth in shale gas production is expected in the period up to 2025. By this time, its global production will exceed 700 bcm, the vast majority of which will be produced in the United States. Then, US production growth will slow down noticeably, and global production of shale gas will expand due to other countries: Canada is expected to raise output to 100 bcm, Mexico and Argentina will add over 50 bcm to total production, Asian countries led by China - slightly over 100 bcm, and African countries will contribute around 40 bcm of gas. In Europe and the CIS, there is no expectation of breakthroughs in non-conventional gas production due to geological, economic and political constraints.

**Figure 2.51 - Scenario forecast of shale gas production by region and country, bcm**




**Source: ERI RAS**

# International gas trade

Unlike in the oil market, accelerated development of energy technologies combined with socio-economic trends does not lead to passing peak consumption and a reduction in demand in the gas market, but business practices will change. Competition in major gas markets is increasing, world gas trade will continue to gain momentum - by 2040 its volumes will increase 1.7-2 fold, reaching 1.4-1.5 trillion cm. At the same time, over the forecast period, nearly 85% of world net gas exports will be from the top ten countries, which will include Qatar, Australia and the US in addition to Russia. Exports of gas will also grow at an accelerated rate in African countries, primarily in Nigeria, Mozambique and Tanzania.

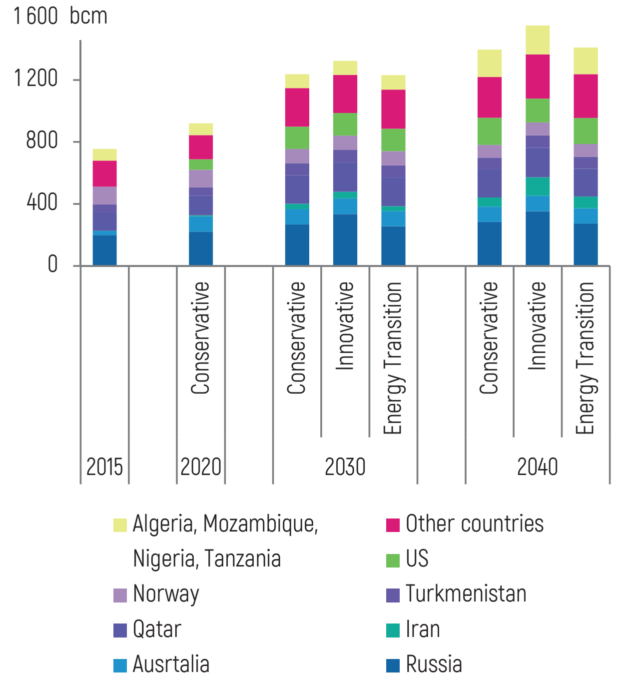
Iran will face the highest degree of uncertainty, as its prospects will depend heavily on access to investment, technologies and the presence of restrictions on foreign trade. (Fig. 2.52). A gradual lifting of international sanctions against Iran is envisioned in the Innovative and the Energy Transition scenarios. This will make it possible to increase gas exports from Iran to 118 bcm by 20140 in the Innovative scenario. However, demand for additional volumes will be smaller in the Energy Transition scenario, and export will not exceed 76 bcm.

Ten market players will control 85% of global natural gas exports.

On the import side, there is a gradual shift in trade flows from the countries of the Atlantic Basin to the Asia-Pacific region, mainly South and Southeast Asia. Despite the number of natural gas importers constantly growing, just 10 countries will account for around 70% of the traded volumes in 2040. Among them are the top five gas importers - China, India, Japan, Germany and South Korea, which account for half of the world's net gas imports.

Japan will cede the first place among natural gas importers to China and India, taking the third place. China is expected

**Figure 2.52 - Scenario forecast of global natural gas net exports by country, bcm**




Source: ERI RAS

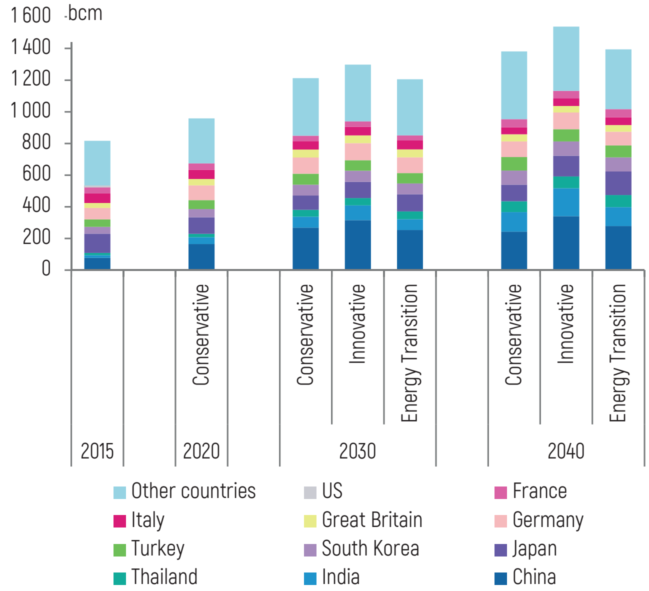
to increase imports 3-5-fold, and India will boost imports 7-9-fold, depending on the scenario. (Fig. 2.53).

European countries will continue to increase gas imports due to lower domestic production. However, growth rates will weaken as peak demand is passed and domestic production decline in absolute volumes slows down.

> China will increase gas imports 3-5 fold, India 7-9 fold, which will allow them to become the world's largest natural gas importers. However, after 2035, China will be close to passing the peak of import.

China's import dependency will largely determine the overall situation in the Asian gas market. Increasing domestic natural gas production while simultaneously slowing down its consumption will lead to China passing the peak of gas imports after 2035 in the Conservative and Energy Transition scenarios, and after 2040 - in the Innovative scenario. Linked to this, high uncertainty arises for gas projects which aim to deliver gas to China, the implementation of which is planned after 2035.

**Figure 2.53 - Scenario forecast of global net imports of natural gas by country, bcm.**




Source: ERI RAS

> LNG exports will accelerate, and by 2040 the share of LNG in international gas trade will reach 60-65%.

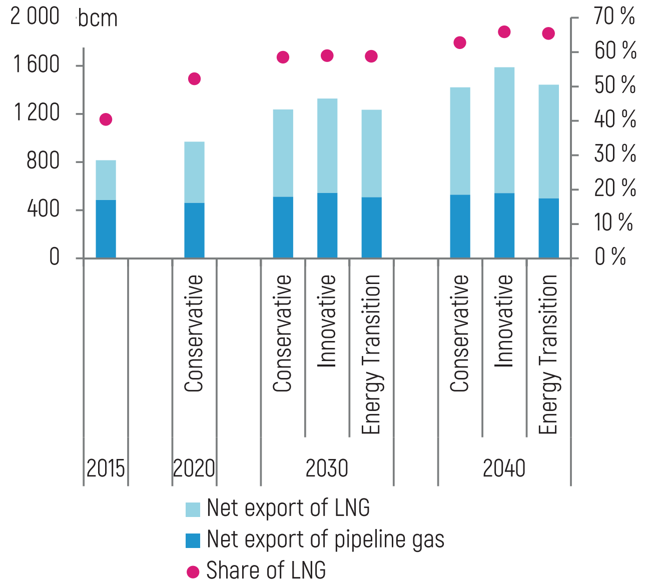
International pipeline gas deliveries will grow by 10% by 2040, with most of the growth determined by higher imports to China. At the same time global LNG deliveries will increase by nearly 70%, and their share in total global trade volume will rise to 65% (Fig. 2.54)

A growing number of LNG consumers and an expansion in the geography of supplies, especially to markets located far from the centres of gas production, will contribute to the growing importance of LNG in world gas trade. In response to rising demand, LNG supply is expanding rapidly, primarily in the US, Australia, Russia and Qatar. Iran could potentially become another major LNG supplier, however, due to geopolitical factors, prospects for increasing capacity in this country remain uncertain (Fig. 2.55).

In 2016 LNG trade reached 260 mln. tonnes, and 2017 saw a sharp rise by 14% to over 290 mln. tonnes, the second jump in trade in the history of the LNG industry. LNG trade will continue to grow, backed by a rapid increase in global LNG capacity additions. As of 1 June 2019, investment decisions have been made on new projects to introduce over 88 mln tonnes of new capacity. If these projects are successfully brought online, it would increase global capacity by another 21% by 2024.

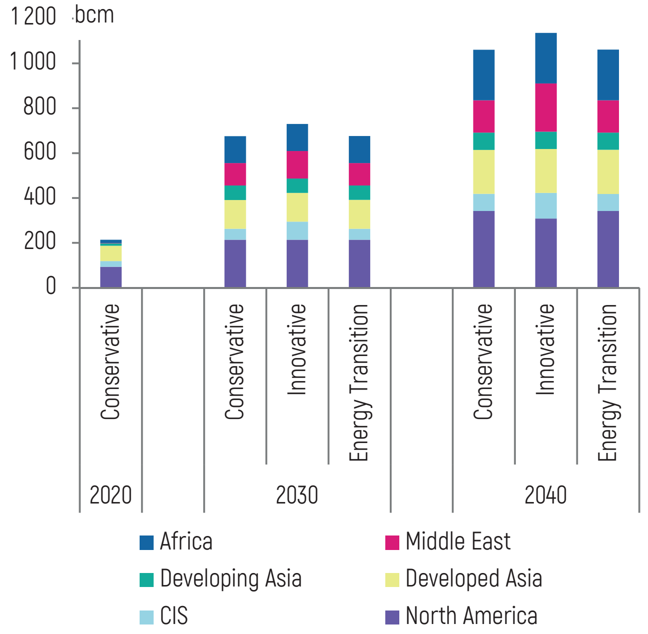
There are plans to consider new projects with cumulative capacity of another 102 mln tonnes. Regasification capacity is also growing rapidly – by 2019 it reached 868 mln tonnes, another 95 mln. tonnes of capacity are under construction (8 floating and 14 onshore units).


**Figure 2.54 – Scenario forecast of global net exports of pipeline natural gas and LNG, bcm**




Source: ERI RAS

**Figure 2.55 – Scenario forecast of aggregate liquefaction capacity additions by region**




Source: ERI RAS

## Natural gas prices

After a significant drop in gas prices in the European and Asian markets in 2014–2016, which largely repeated the dynamics of oil prices, prices started to rise in response to increasing gas demand and following the recovery of oil prices, which many of the gas contracts are still tied to. However, by the summer of 2019, gas prices in Europe and Asia once again started moving downward from the high levels of the autumn of 2018, losing around 50% and significantly overtaking the downward dynamics of oil prices. This was another signal that the gas market went its separate way, gradually losing its relationship with the oil market.

The price situation in the gas market is noticeably changing. On the one hand, the tie to oil prices (indexation) is lessening. On the other hand, the expansion of renewable energy is having an effect on gas prices.  Even today, renewable energy enables to almost completely eliminate the need for electricity on some summer days in some countries, while in the winter RES can sometimes show almost zero output.  As a result, traditional seasonal imbalances in gas demand increase. Moreover, the imbalances generated by the demand for electricity and heat and the variability of renewable energy generation differ significantly from the imbalances of more stable oil demand. Thus, conditions are created for the formation of distinct seasonal price levels. At the same time, with the expansion of renewable energy capacities, changes in daily gas demand, for example in Europe, may be multifold, which will inevitably affect the prices.

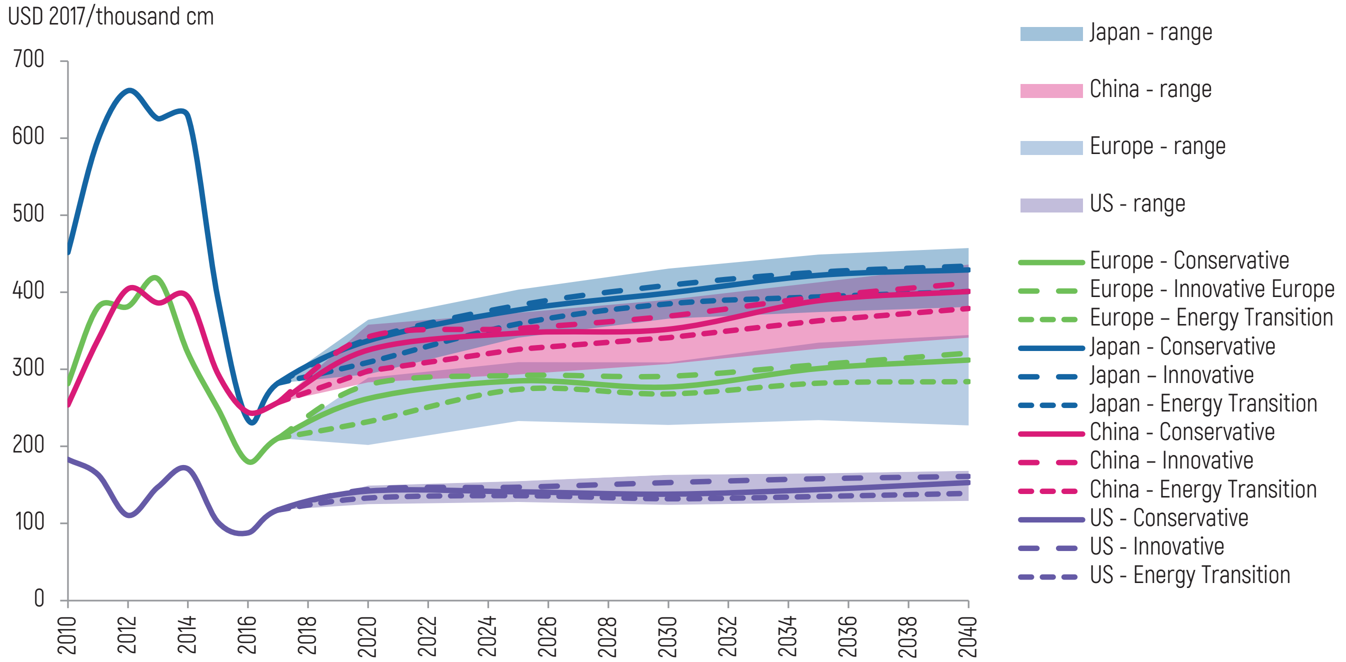
The price dependency of the gas market on the oil market is gradually lessening.  Gas consumption is becoming increasingly more variable because of a combination of seasonal demand for electricity and heating , as well as due to seasonal and daily fluctuations created by RES.  As a result, gas prices are becoming distinctly seasonal in nature and increasingly volatile.

In the period to 2040, price regionalization of gas markets is expected to continue alongside a gradual formation of a global trading space. The development of the LNG segment and the commissioning of new pipeline capacities will ensure fairly flexible cross-flows between regions, but a high proportion of transportation costs for long-distance deliveries will lead to price differentials between the markets, in particular, the North American, European and Asian markets. At the same time, calculations show a moderate increase in equilibrium gas prices in all regions, due to rising global gas demand, in particular in developing countries, and increasing extraction costs (Fig. 2.56)

Considering the availability of sufficiently large capacities of existing and potentially accessible mining and transportation projects, in the long term prices are not expected to return to the levels of 2012--2013 in either Europe or Asia. Given growing demand, most trade will be shifting to the Asian market. The price indices formed in this region will gradually become decisive for the entire world trade.

Considering the availability of sufficiently large capacities of existing and potentially accessible mining and transportation projects, in the long term prices are not expected to return to the levels of 2012--2013 in either Europe or Asia.

**Figure 2.56 - Projected weighted average gas prices in regional markets in three scenarios**




**Source: ERI RAS**

Image by skeeze from Pixabay


Photo by Nick Nice on Unsplash

# SOLID FUELS MARKET

## Demand for solid fuels

In 2015 solid fuels[33] accounted for 38% of world energy consumption, with the contribution of coal of 28.3%. Around 38% of the world's electricity is currently produced from coal. The coal market is perhaps showing the most complex and controversial dynamics in the process of the global transformation of the world energy system. For many decades coal has been one of the cheapest and most affordable sources of energy, and it remains as such in the period to 2040. It is coal that has been and remains the source of economic growth for countries that are not yet prepared to pay more for other resources, and for which environmental problems are less of a priority than economic development. However, under pressure from decarbonization policy and the impact of rapid development of new technologies (primarily, renewable energy sources, electricity storage, distributed energy resources, non-conventional methods of gas production, etc.) nearly all countries with developed economies and available technologies aim to gradually reduce the share of coal in the energy mix, mainly to cut harmful emissions into the atmosphere.

Environmental restrictions are becoming an increasingly important factor influencing the development of the coal industry.

For most countries, coal is a forced choice in the absence of other more economically and environmentally acceptable alternatives.

Tighter restrictions lead to rising cost of capital and operating costs in coal generation, due to higher environmental charges and costs for the implementation of measures for emission reduction and flue gas treatment. Cheaper alternative sources and the introduction of "carbon" charges can start to squeeze coal generation out economically, and the growing share of renewable energy also creates technical challenges – after all, coal generation should become more flexible and maneuverable as a result. In this situation, "clean coal" technologies could provide a compromise: modern coal-fired plants have very low gas-produced emissions, are very efficient and much more maneuverable. But the cost of these systems (membranes, etc.) negates the low cost of coal in comparison with other energy sources. And CCS - Carbon Capture and Storage technologies have not yet become widespread due to high transportation and injection costs, limited possibilities for their application and possible subsequent negative impacts - the dangers of gas emissions into the atmosphere and of potentially inducing seismic activity, etc.

33 Coal, solid biomass etc.

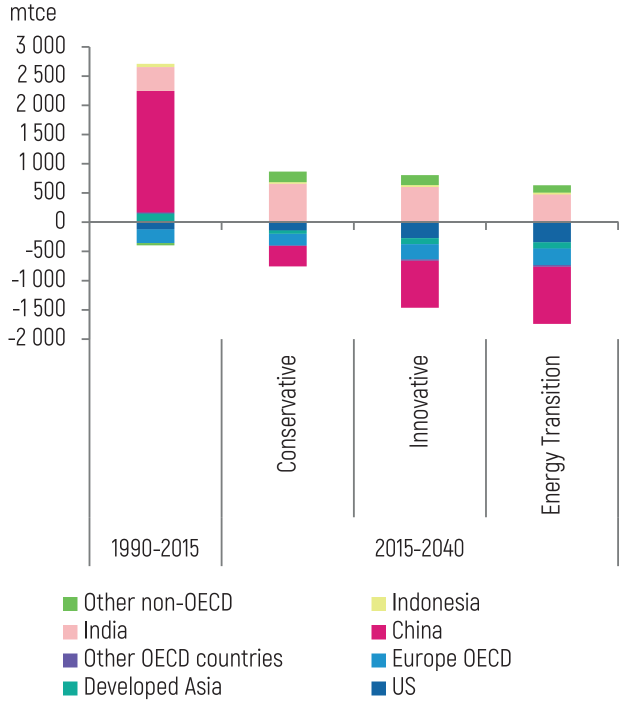
In many ways, the choice between all scenarios will be predetermined by China and India's position in relation to their domestic coal -based generation and coal production, since these two are the largest participants in the coal market. India is still giving contradictory signals about its plans for coal, and China is actively upgrading its coal-fired plants and has announced its intention to deal with environmental issues by further developing technologies, rather than rejecting coal generation altogether. In the forecast period, by 2040 demand for coal in absolute terms is expected to decrease by 6–9% compared to the current level in all scenarios. As a result, its share in the global energy mix is projected to decrease further, from 28% to 19-23% by 2040, depending on the scenario (Fig. 2.57).

A slump in coal consumption in the OECD countries will be an important driver of reducing global demand for coal. This is prompted by a general reduction in energy consumption, the effect of environmental policies and a gradual improvement of renewable energy generation technologies. In addition, growth in demand for solid fuels in developing countries will slow down significantly (nearly down to zero in the Energy Transition scenario), due to sharply falling coal consumption in China. Although China passed the "peak" of demand for this fuel type in 2013, it still accounted for 51% in world coal consumption in 2018.

In the period up to 2030 the world will pass the peak of coal consumption within all scenarios. At the same time, if in the Conservative scenario the world passes the peak of coal consumption only by the end of the period in question, in the Energy Transition scenario this will happen in the next few years.

The share of coal in the energy mix of China steadily increased from 51.6% in 1980 to 65.9% in 2015.

**Figure 2.57 - Consumption growth by country and region in 1990-2015 and 2015-2040 in the three scenarios**

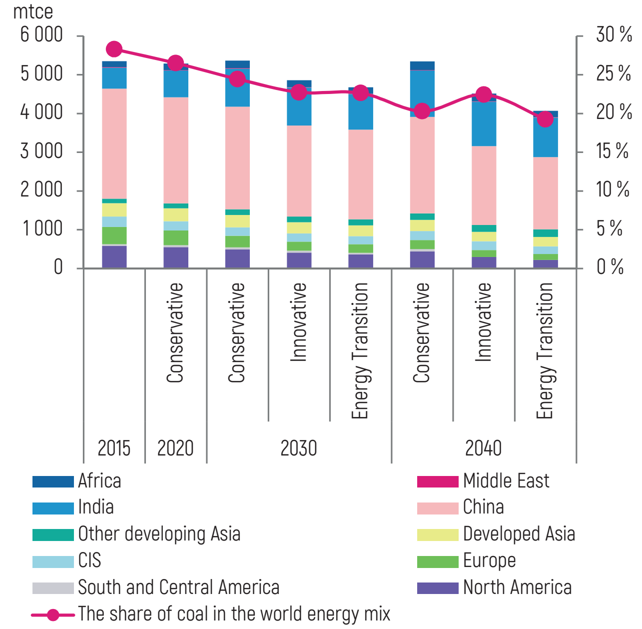



Source: ERI RAS

However, as a result of revised priorities of the national energy policy and the Blue Sky Energy Plan, by 2040, the share of coal will be reduced to 41-45%. India, which increased the share of coal during 35 years from 22% in 1980 to 44.2% in 2015, will slightly increase it further to 44.5% in the period to 2040 in the Conservative scenario. On the contrary, the Innovative and the Energy Transition scenarios envision that India will reduce it to 42-43%, despite an increase in absolute coal consumption. Other developing Asian countries - Vietnam, Indonesia, Malaysia, Pakistan, Bangladesh etc. will be increasing coal consumption, keeping its share in the energy mix approximately at the current level, 17–20% on average for this group of countries (Fig. 2.58, Table 2.9).

China will be reducing coal consumption, but other developing Asian countries will be increasing consumption in the period to 2040. The Asian market is solidifying its status as the world's centre of coal consumption.

**Figure 2.58 – Projected coal consumption by region for the three scenarios**




Source: ERI RAS

**Table 2.9 – Coal consumption by region and major country, mtce**

| | 2015 | 2020 | 2030 | | | 2040 | | | Growth rates in 2015-2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| **North America** | 580 | 551 | 492 | 409 | 363 | 440 | 297 | 221 | -1,1% | -2,6% | -3,8% |
| **South and Central America** | 48 | 51 | 55 | 48 | 43 | 58 | 49 | 39 | 0,8% | 0,0% | -0,8% |
| **Europe** | 446 | 379 | 297 | 234 | 221 | 236 | 177 | 150 | -2,5% | -3,6% | -4,3% |
| **CIS** | 266 | 238 | 222 | 216 | 207 | 234 | 227 | 199 | -0,5% | -0,6% | -1,2% |
| **Developed Asia** | 347 | 335 | 317 | 287 | 279 | 289 | 245 | 242 | -0,7% | -1,4% | -1,4% |
| **Developing Asia** | 3630 | 3706 | 3974 | 3677 | 3592 | 4104 | 3622 | 3341 | 0,5% | 0,0% | -0,3% |
| India | 541 | 695 | 987 | 977 | 917 | 1200 | 1145 | 1016 | 3,2% | 3,0% | 2,6% |
| China | 2841 | 2738 | 2647 | 2349 | 2313 | 2493 | 2035 | 1862 | -0,5% | -1,3% | -1,7% |
| **Middle East** | 14 | 12 | 12 | 12 | 12 | 11 | 10 | 10 | -1,1% | -1,3% | -1,3% |
| **Africa** | 153 | 166 | 192 | 183 | 165 | 224 | 200 | 171 | 1,5% | 1,1% | 0,5% |
| **Worldwide** | 5484 | 5439 | 5561 | 5066 | 4881 | 5595 | 4826 | 4374 | 0,1% | -0,5% | -0,9% |

Source: ERI RAS

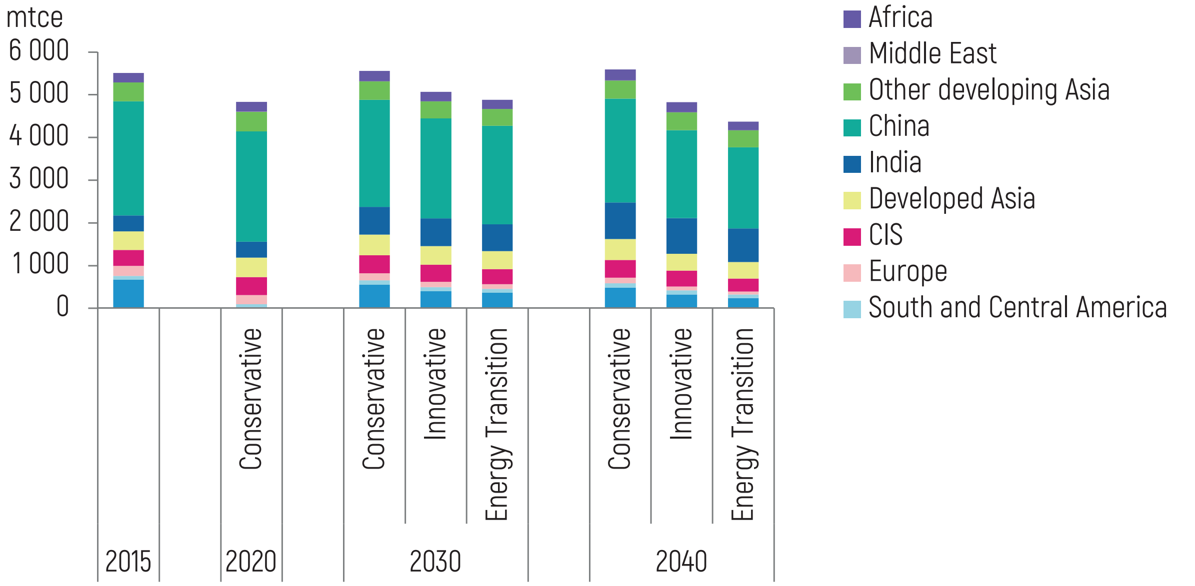
# Supply of solid fuels

There are an estimated 1.1 trillion tonnes of proven coal reserves worldwide, according to 2017 data, which will last over 130 years at current production levels. Three-quarters of these are concentrated in just five countries - the US (24%), Russia (16%), Australia (14%), China (13%) and India (9%). Currently, the main leaders in world production of tradable coal are China (46.4%), US (9.8%), India (7.8%), Indonesia (7.2%), Australia (7%). , 9%), South Africa, Colombia and Russia (5.5%).  In the period to 2040, the list of these countries will not change, but the distribution of shares between them could change substantially depending on the scenario.

By 2040 global coal production will only be able to remain at the current level in the Conservative scenario, falling by 13% and 21% in the Innovative and Energy Transition scenarios, respectively (Fig. 2.59). As a result, projected output volumes vary by over 1200 mtoe across the scenarios (5.595 mtoe in the Conservative scenario and 4.374 million tons of mtoe in the Energy Transition scenario), which roughly corresponds to the current aggregate consumption of the five regions- North America, South and Central America, Europe, the Middle East and Africa.

High uncertainty on the supply side will remain throughout the forecast period.  It is associated with the dependence of the entire market on the two key major players - China and India, which provide most of demand and determine the prices in the market.  China's political position, specified in the 13th Five-Year Development Plan, will encourage a decrease in demand and production, which will contribute to the closure of small coal mines and the modernization of large ones. Thus, in accordance with the 13th Five-Year Plan, China has already begun decommissioning 800 million tons of coal mining capacity that does not meet environmental and technical requirements, and this work is planned to continue. At the same time, 500 million tons of new upgraded production capacities are being brought online. The peak of coal production in China, which was previously expected in the period to 2025, came as early By 2040 coal

**Figure 2.59 – Projected global coal production by region for the three scenarios**




Source: ERI RAS

production in China will fall by 9-29% compared to 2018. At the same time opportunities for production will freely allow China to become a coal exporter in the Innovative and the Energy Transition scenarios.

By 2040 developing and developed Asia will provide up to 75% of production in the Conservative scenario and 79% in the Energy Transition scenario (Table 2.10)

Asian countries will provide over 70% of global coal production in all scenarios.

As demand rises in India, the ability to provide growth via its domestic production will be an important issue for the entire world trade. Given the absence of production restrictions and the desire to ensure energy security, India has an opportunity to increase output. However, there is the issue of its ability to bring online needed production capacity and the speed of development of the necessary infrastructure, in particular the railway network.


Image by Анатолий Стафичук from Pixabay

The US will cut production in all scenarios, while remaining a net exporter. Australia will increase output in the period to 2040 (by 19% in 2016–2040) in the Conservative scenario, directing export flows towards India and partially to China. On the contrary, Australia is projected to reduce production in the Energy Transition scenario.

**Table 2.10 – Projected coal production by region and major country, mtce**

| | 2015 | 2020 | 2030 | | | 2040 | | | Growth rates in 2015-2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| **North America** | 671 | 608 | 551 | 403 | 364 | 481 | 322 | 238 | -1.3% | -2.9% | -4.1% |
| **South and Central America** | 88 | 99 | 105 | 95 | 87 | 107 | 95 | 83 | 0.8% | 0.3% | -0.2% |
| **Europe** | 236 | 211 | 166 | 125 | 114 | 132 | 96 | 70 | -2.3% | -3.6% | -4.7% |
| **CIS** | 374 | 423 | 421 | 402 | 354 | 415 | 369 | 306 | 0.4% | -0.1% | -0.8% |
| **Developed Asia** | 430 | 453 | 483 | 433 | 422 | 490 | 395 | 386 | 0.5% | -0.3% | -0.4% |
| **Developing Asia** | 3489 | 3416 | 3591 | 3389 | 3326 | 3711 | 3314 | 3086 | 0.2% | -0.2% | -0.5% |
| India | 376 | 375 | 653 | 646 | 623 | 856 | 832 | 787 | 3.3% | 3.2% | 3.0% |
| China | 2669 | 2579 | 2503 | 2345 | 2313 | 2428 | 2058 | 1897 | -0.4% | -1.0% | -1.4% |
| **Middle East** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.2% | 0.2% | 0.2% |
| **Africa** | 221 | 227 | 243 | 218 | 212 | 259 | 233 | 203 | 0.6% | 0.2% | -0.3% |
| **Worldwide** | 5512 | 5439 | 5561 | 5066 | 4881 | 5595 | 4826 | 4374 | 0.1% | -0.5% | -0.9% |

Source: ERI RAS

## Cross-regional coal trade and coal prices

The inevitable decrease in consumption in OECD countries and the passing of peak demand or stabilization of demand in developing countries in the context of the speed of these changes create extreme uncertainty in relation to the prospects for the international coal market. In the period 2014-2017 trade grew rapidly- lower prices for coal, low prices for $CO_2$ emissions, China's decision to close coal mines - all this contributed to the expansion of world trade and the emergence of additional niches. However, in the long term, this situation could change dramatically. China has already completed its withdrawal from small coal mines specified within its programme, more efficient capacities are being introduced, and the country itself is at the peak of consumption, and therefore there is no need for import growth, while there are grounds for reducing it. Europe no longer relies on clean coal technologies as one of its development priorities and is systematically reducing the use of coal. There is still high uncertainty in India in relation to its ability to meet growing demand with its own production. In the US, D. Trump's administration has announced a review of the policy on withdrawal from coal mining, including for export. At the same time, it is unlikely that this would lead to a coal renaissance in the US, instead just slowing down the process of reducing its production and consumption.

Trade volume and prices in the market will primarily depend on the actions of two players – China and India. This makes the entire market very unstable and dependent on specific political decisions.

Trade volume and prices in the market will primarily depend on the actions of two players - India and China, which makes the entire market very unstable and dependent on specific political decisions. Future growth in coal imports is expected to be provided precisely by the countries of the Asia-Pacific region (primarily India and the countries of Southeast Asia, which will see a rise in demand for high quality coal).

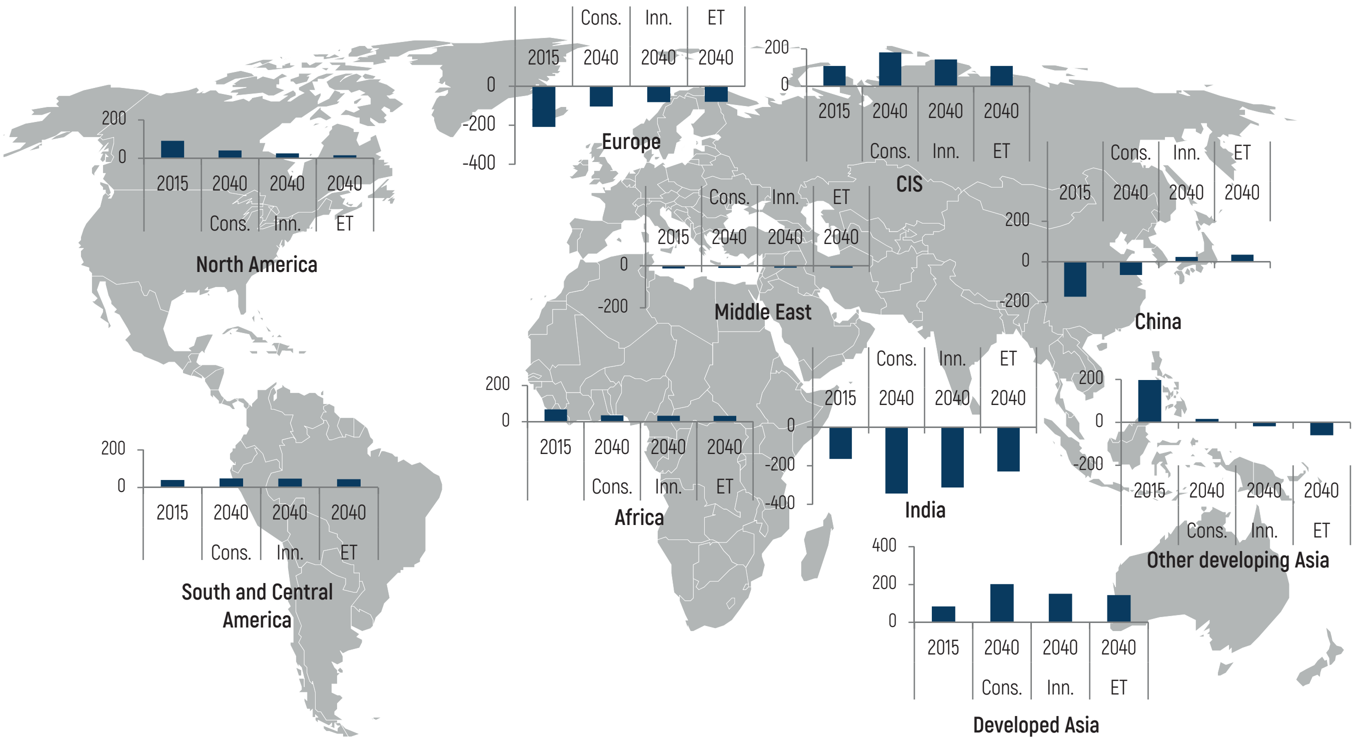
The Middle East and African countries will also increase their import of coal, while China and developed Asia (Japan, South Korea) will see stagnating or falling demand. A decline in demand for coal is inevitable in Europe. It is expected that by 2040 European import of coal will drop by 50-62% depending on the scenario, with a simultaneous decline in European coal production by 45-70%.

At the same time, a number of producers will further reduce their export volumes for various reasons: Columbia will deplete its main deposits by 2030, and Indonesia will be forced to redirect part its coal exports to meet domestic demand. Thus, real competition in the major growing markets - Southeast Asia, India, the Middle East, Africa - will unfold primarily between Australia and Russia.

Cross-regional trade volume will increase in the Conservative scenario compared to the current levels by 10% due to consumption growth in the countries which do not have their own coal reserves. However, trade volume falls by around 25% compared to 2018 in the Energy Transition scenario, which will inevitably lead to an increase in market concentration and tougher competition between suppliers for a narrowing export niche (Fig. 2.60).


Image by Erich Westendarp from Pixabay

**Figure 2.60 - Scenario forecast of international coal trade in 2040, mtce (positive values denote export, negative - import)**



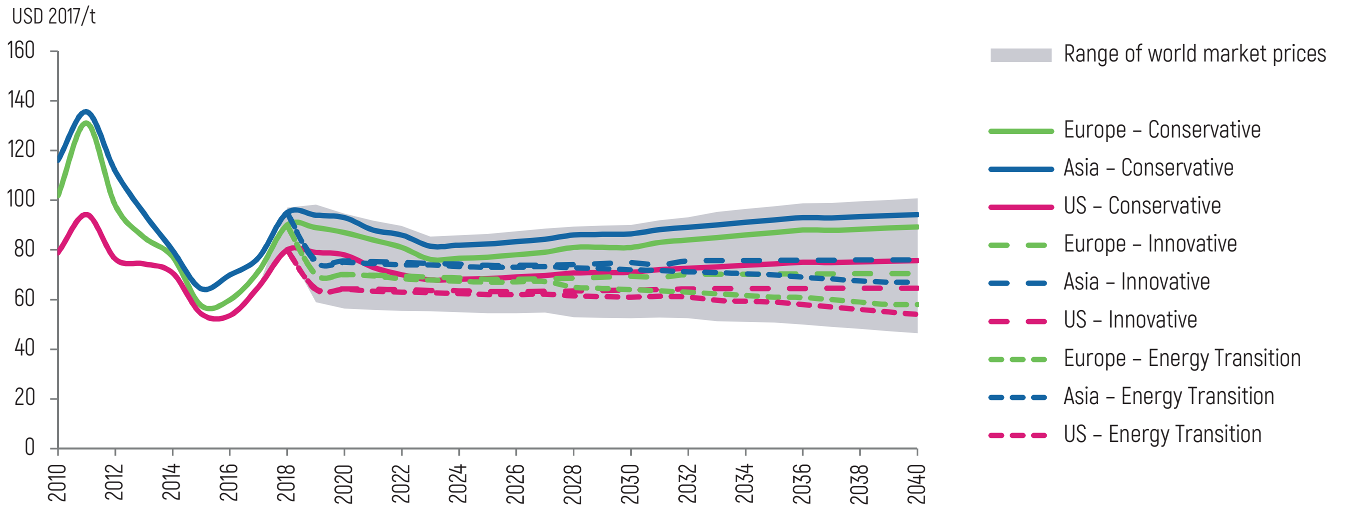

Source: ERI RAS

The changing nature of international trade and the specificity of balancing supply and demand in the coal market will largely determine both the general dynamics of global coal prices in the long term to 2040 and their differentiation across the regions. The Innovation and the Energy Transition scenarios imply a reduction in prices at the very start of the forecast period in the context of increased inter-fuel competition in generation and a recovery of coal production in China. In the Conservative scenario, these factors are more spread over time. The Conservative scenario foresees moderate price increases backed by an increase in imports by India and other developing countries of Asia (excluding China) and a natural escalation of production costs linked to the need to mine more complex deposits to meet slowly rising global demand.

The Energy Transition scenario shows that development of renewable energy sources and storage and accelerated growth in gas-fired generation would lead to a decrease in global demand for solid fuels, making the involvement of expensive new reserves, which was envisioned in the Conservative scenario, unnecessary. The combination of these factors leads to the fact that prices in the Energy Transition are lower than the values of the Conservative scenario, both for the Asian and the European markets (Fig. 2.61).

While coal prices are relatively stable in the Conservative scenario, a decline in coal prices becomes inevitable in the Energy Transition scenario, since world trade volume is maintained by new importers.

**Figure 2.61 - Retrospective and projected prices of coal in 2010 - 2040 for two scenarios**



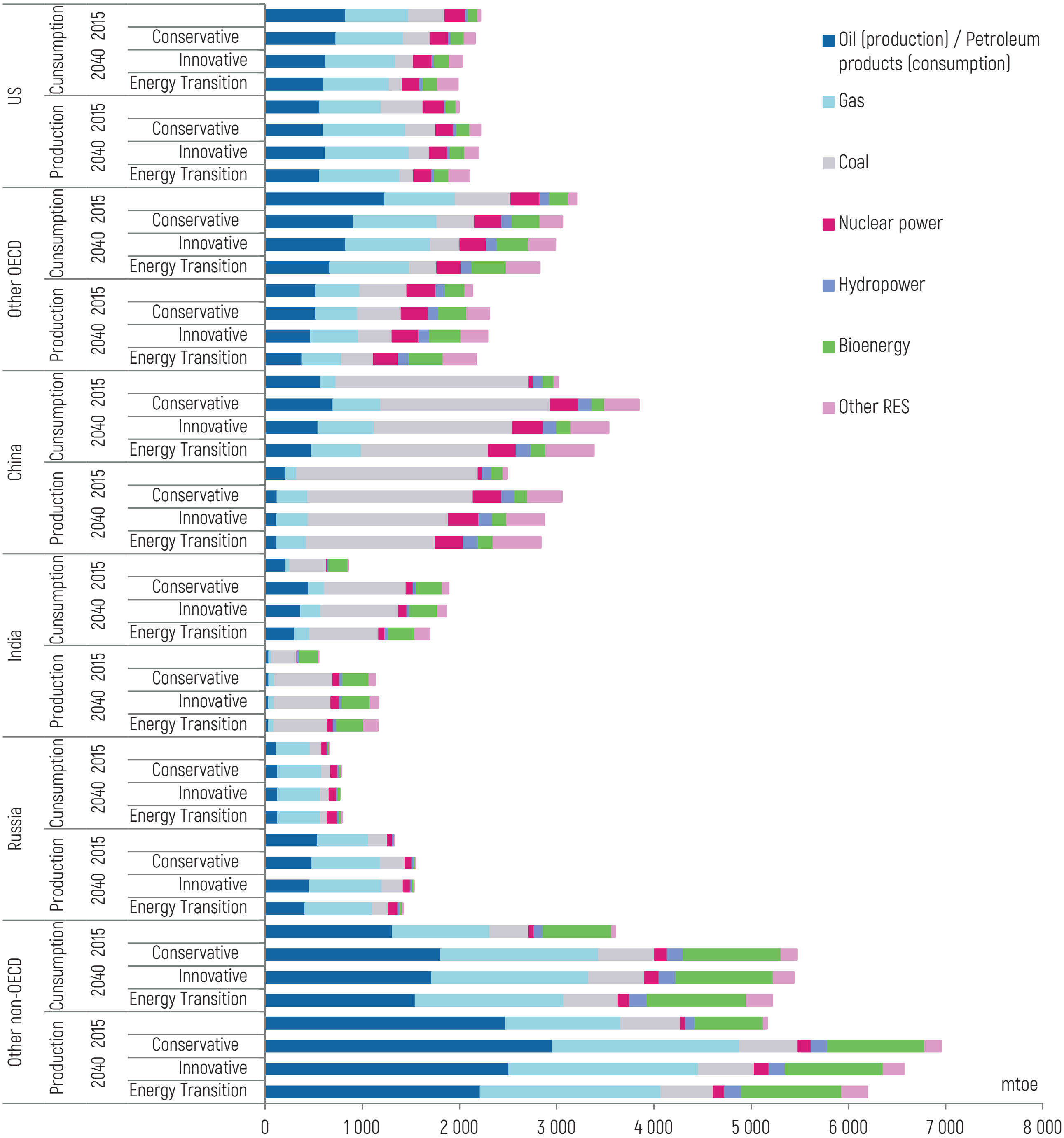

Source: ERI RAS

# THE POSITIONS OF THE KEY PLAYERS

Most of the growth in world total energy production will be provided by the non-OECD countries, their share will exceed 70% in all scenarios. Among fossil energy resources, natural gas production will grow the fastest, significantly exceeding the rates of growth in the production of oil and coal. However, overall hydrocarbon fuels will gradually cede their dominant position to fast-growing carbon free energy sources.

China will remain both the largest producer and consumer of energy resources in the world throughout the entire forecast period. It is followed by the US, who retain second place in terms of production and energy consumption. Russia will remain third in terms of production in all scenarios, while India will be the third largest consumer. It is India that will become the leader in terms of primary energy consumption growth (Fig. 2.62).

**Figure 2.62 - World energy production and consumption by fuel type in 2015 and 2040 within the three scenarios**




Source: ERI RAS

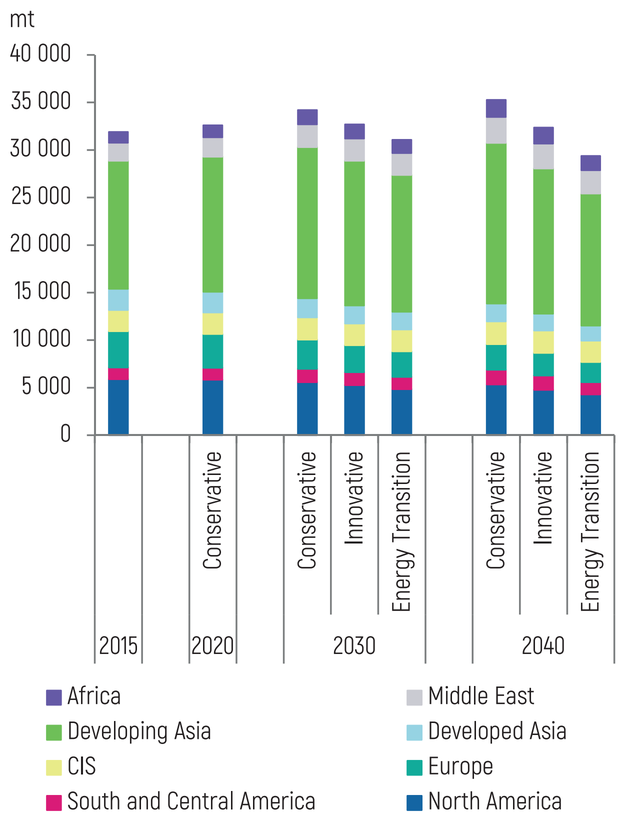
# $CO_2$ EMISSIONS

This forecast considers $CO_2$ emissions from burning fossil fuel (fuel combustion)[34]. These account for most of global carbon emissions (around 70%, according to the United Nations Environment Programme (UNEP)[35]).

The world passes the peak of manmade $CO_2$ energy-related emissions by 2040 in the Innovative and Energy Transition scenarios. In the Conservative scenario, emissions continue to rise throughout the forecast period - by 2040 they are projected to increase by 10% compared to current values. In the Innovative scenario, emissions return to nearly their current level by 2040 after passing the peak, and in the Energy Transition scenario there is a reduction of 9% by 2040 (Fig. 2.63).

> The world passes the peak of $CO_2$ man-made energy related emissions by 2040 in the Energy Transition scenario.

**Figure 2.63 – Dynamics of $CO_2$ emissions by region[36]**




Source: ERI RAS

[34] Calculated based on $CO_2$ Emissions from Fuel Combustion data by IEA, 2016.

[35] The Emissions Gap Report, UNEP, 2015.

[36] Here and thereafter only $CO_2$ emissions from fuel combustion are considered.


Image by Hans Benn from Pixabay

# SECTION 3

## SCENARIO FORECAST OF RUSSIAN ENERGY SECTOR DEVELOPMENT

# SCENARIO ASSUMPTIONS FOR RUSSIA

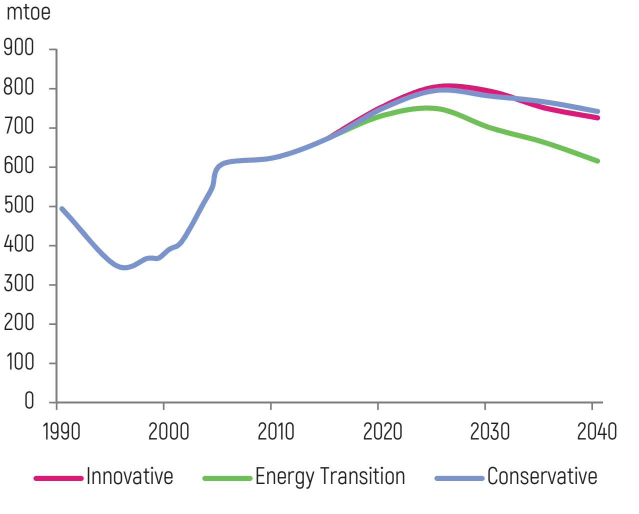
The aim of Outlook-2019 is not only to model the dynamics of world energy markets, but also to assess its implications for Russia. The presented scenario forecast of the development of world energy markets shows a greater likelihood of a negative impact of the changes in market conditions on Russia. Although Russia remains one of the key players in international trade within all scenarios, export revenues will stagnate or fall, which creates a threat to the stability of Russia's economic development.

In 2000–2007 Russia managed an unprecedented growth in energy exports – they increased by a record-breaking 62% (Fig. 3.1), exceeding cumulative energy exports from the USSR.

However, the following decade of 2008–2018 saw stagnant revenue growth, despite growing export volumes. In the period to 2040, export volumes will not be growing substantially, according to the calculations in all scenarios.

By 2040 Russian energy exports will be only 1% higher than currently in terms of volume and 45% higher in monetary

**Figure 3.1 – Total exports from the Russian Federation: retrospectively from 1991 and a scenario forecast to 2040**




Source: ERI RAS

Despite the fact that Russia produces only 3% of world GDP and has a population equivalent to 2% of the world population, it is the third largest producer and consumer of energy resources in the world after China and the US, providing 10% of world production and 5% of world energy consumption. Russia consistently ranks 1st in the world in gas exports, 2nd in oil exports and 3rd in coal exports. With energy production of about 1470 mtoe, Russia exports over half of the primary energy produced, providing 16% of the global cross-regional energy trade, which makes it the absolute world leader in energy exports.

terms even in the Conservative scenario, which is the most favourable one from the point of view of export conditions. The Energy Transition scenario shows a reduction in exports in terms of volume by 15% and in revenue - by 17% by 2040. All this will occur as production costs increase as a result of moving to more complex reserves. The levelling off and the decline in Russian energy exports is primarily caused by a reduction in oil exports and, to an even greater extent-petroleum product exports (Fig. 3.2). This is due to the simultaneous impact of both internal factors (levelling off and a subsequent decline in oil production) and external factors (lower demand for liquid hydrocarbons in the European market and increased competition in the Asian market).

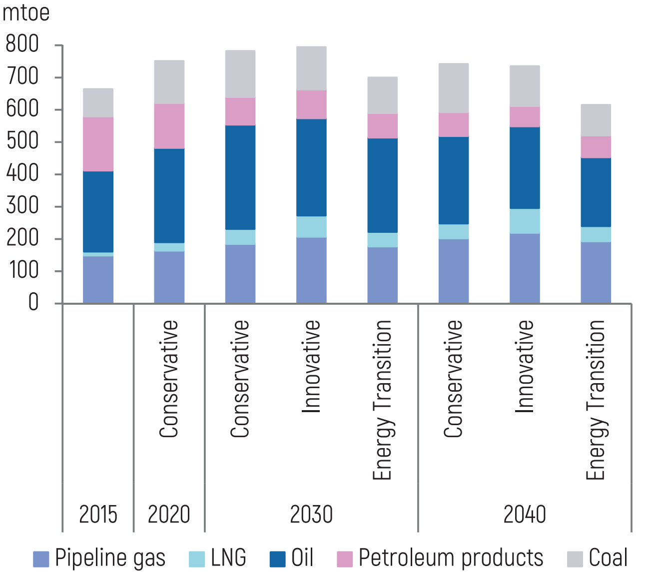
The falling share of oil exports in total supplies in absolute volumes will be offset by an increase in the share of gas exports from 27% in 2015 to 33–39% by 2040, depending on the scenario.

By 2040 gas exports will rise by 20–43% compared to now. Europe will remain the key sales market for Russian gas, as well as for all energy resources.

In the Innovative and especially in the Energy Transition scenarios, demand for gas in Europe is lower than in the Conservative scenario, but due to increasing demand in Asia, some suppliers are expected to reorient towards this market.

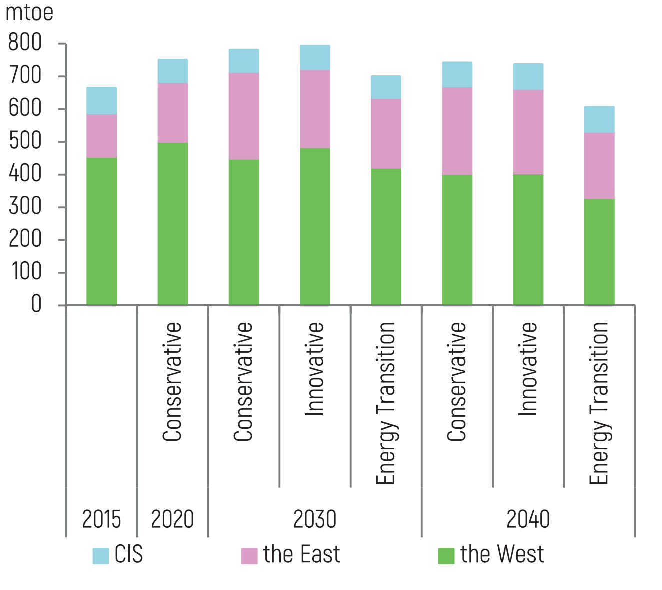
> By 2040 changing market conditions in Russia's main export markets will lead to a levelling off or a decrease in the absolute volumes of total energy exports compared to the current indicators in all scenarios. The Conservative and Innovative scenarios for the development of the world energy sector are more optimistic for Russia than the Energy Transition scenario – growing demand for natural gas and higher prices enable to partially offset losses from reduced oil exports. Nevertheless, this small additional potential is incomparable to the "export boom" at the beginning of the 21st century.

**Figure 3.2 – Exports from the Russian Federation by type of energy resource, scenario forecast to 2040, mtoe**




Source: ERI RAS

**Figure 3.3 – Exports from the Russian Federation by direction of trade, scenario forecast to 2040, mtoe**




Source: ERI RAS

This opens an additional small niche for Russia in Europe. It is quite reasonable to expect that, given the changes in the world's centres of energy consumption growth, the share of the Asia Pacific Region in Russian energy exports will rise from the current 20% to 32–36% by 2040. As shown in the previous section, primary energy consumption in Europe will steadily decrease. Reorientation of deliveries to Asian markets will occur for all energy resources: oil, natural gas and coal. As a result, the share of exports to Europe in total Russian energy exports will decrease from 73% in 2018 to 54–56% in 2040 in absolute terms. However, European markets will remain key for Russia in the coming period.

Export prices are a most important external factor for Russia besides volumes of energy exports, and, linked to this, there is the dynamics of export revenues.

As shown in section 2, export prices do not move up to the levels of 2007–2012, even in the Conservative scenario. They are significantly reduced in the Innovative and the Energy Transition scenarios, so we cannot count on a noticeable increase in export earnings in any of the scenarios. The Conservative scenario assumes that the old sanctions will remain in place and that new ones will be applied, including limiting Russian energy companies' access to borrowed capital, the latest technologies and sales markets. In this scenario, if the existing financial, price and tax policy in the energy sector were to remain the same, it would prolong stagnation of energy efficiency of the economy and maintain slow technological progress in the Russian energy sector.

In this scenario the Russian economy will demonstrate annual GDP growth of around 1.6%. The saving rate will be ≈ 20% of GDP, and the contribution of the fuel and energy sector to GDP will decrease from the current 23 to 17% in 2040.

The Innovative scenario for the development of the Russian energy industry, as well as in the global energy industry, assumes an acceleration of scientific and technological progress at all stages: from production to energy consumption - with optimistic expectations of an increase in the efficiency of a wide range of technologies. But, unlike in most developed countries, the implementation of technological advancements in Russia is hampered by the lack of a favourable business climate, which is able to ensure economic efficiency of the use of new technologies. At the same time, international trade volume and the prices of all fuel types decrease in the Innovative scenario of the world energy sector development, compared to the Conservative scenario. This will lead to a reduction in the size of Russian energy exports and generated revenues.

According to this scenario, scientific and technological progress in the Russian energy sector could compensate for these losses and ensure the same economic growth as in the Conservative scenario, but not beyond this.

The Conservative and Innovative scenarios for Russia are built entirely within the logic of global scenarios. However, the Energy Transition scenario requires further clarification. In fact, it has two versions: the first - under the condition that the current regulations remain the same, and the second - involves an adaptation to the new conditions. The first option creates a very significant threat to Russia with economic growth falling by half compared to the Conservative scenario. However, in addition to this "catastrophic" version, we see that the global energy transition creates potential for Russia to use global technological progress to offset risks and accelerate the development of the national economy – this is the Energy Transition scenario with adaptation.

It considers all losses linked to poorer export potential and involves potential opportunities located to a significant degree outside the energy sector, as reasonable hypotheses.

There are two conditions under which at least partially favourable conditions for scientific and technological

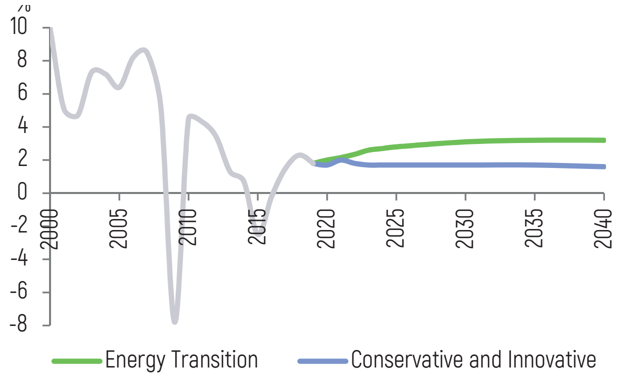
Although by 2040 revenues do not fall below the level of 2017 in any scenario, significant reductions to budget revenues are expected. This is dictated by to the need for a significant increase in financial (including tax) support for new complex mining and transportation projects, as well as with the expansion of fuel exports without export duties.

progress could be created in Russia in the second version of the Energy Transition scenario. These are: a reduction in the cost of capital and an increase in gas prices. We realise that it would be difficult to implement this version and that there is a lack of readiness among the government and the main stakeholders to make such a change in pricing and financial policies. However, it is only under these conditions that we see an opportunity to ensure the effectiveness of the use of advanced technological measures considered in the world. At least half of the world's measures could be implemented, as the price of gas, even if it achieves equal profitability in the domestic and foreign markets, will still be below prices in Europe and the APR, and the cost of capital is still almost double).

The Energy Transition option with adaptation, which implies the implementation of energy saving measures which are economically viable in the conditions of Russia, provides for the dynamics of domestic demand for primary energy close to the Conservative scenario, with significantly higher GDP growth. As our calculations show, it is possible to accelerate GDP growth from 1.7 to 2.7% per year on average for the period (Fig. 3.4) by developing domestic production and thanks to multiplicative effects in the related industries.

If the current policy were to remain unchanged, progress achieved in the world would prompt a slowdown in Russia's economic growth to 0.8–0.9% per year in the Energy Transition scenario without adaptation and the need to take special measures. If we transfer the logic and the consequences of global scenarios to Russia, the following national scenarios are formed (Table 3.1).

**Figure 3.4 – Scenario forecast of average annual growth in Russia's GDP in 2000-2040 for the three scenarios, %**




Source: ERI RAS

**Table 3.1 – National scenarios**

<table>
<tr><th>Scenario</th><th colspan="2">Prerequisites and conditions formed by world markets for Russia</th></tr>
<tr><td>Conservative</td><td colspan="2">
◆ Conservative scenario of world energy sector development<br>
◆ Russian energy exports increase in volume terms from 2016 to 2030 by 5% and then decline to nearly the current level by 2040. In monetary terms, by 2040, exports will grow by 15%<br>
◆ The existing financial policy with a high cost of capital remains unchanged.<br>
◆ The existing pricing policy with a freezing of domestic gas prices and their indexation for inflation.<br>
◆ The existing energy policy with a focus on traditional energy and maximum lifetime extension of existing energy assets.<br>
◆ Economic policy indicators and GDP growth rates are taken close to the Baseline scenario of socio-economic development of the Ministry of Economic Development of the Russian Federation.<br>
Average annual GDP growth – 1.7%</td></tr>
<tr><td>Innovative</td><td colspan="2">
◆ Innovative global energy scenario.<br>
◆ Russian energy exports increase in volume terms from 2016 by 15% to 2025 and then decline by 10% by 2040, with most of the decline attributable to exports of oil and petroleum products, while gas exports are growing. However, in monetary terms, by 2040 revenue from energy exports is reduced by 6%.<br>
◆ The existing financial policy with a high cost of capital remains unchanged.<br>
◆ The pricing policy implies a gradual increase in gas prices, but at a rate not exceeding the inflation rate of + 2%<br>
◆ State policy aimed at supporting scientific and technological progress.<br>
◆ A slightly faster scientific and technological progress in consumption helps Russia to compensate for the fall in export revenues compared to the Conservative scenario, and as a result, it provides for approximately the same dynamics of GDP.<br>
Average annual GDP growth 1.7%</td></tr>
<tr><td rowspan="4">Energy Transition</td><td colspan="2">
◆ World Energy Transition scenario.<br>
◆ A reduction in energy exports volumes (by 7% in 2018 - 2040) and revenues (by 15% in 2016 - 2040)</td></tr>
<tr><td>Without adaptation</td><td>With adaptation</td></tr>
<tr><td>◆ The existing financial, pricing and technological policies remain the same</td><td>
◆ By 2030, a gradual increase in domestic gas prices to the level of equal profitability (lower in this scenario), i.e., by a factor of 1.5–1.7, for all consumers except households.<br>
◆ A set of measures aimed at reducing the cost of capital (the yield of government bonds): from the current 8–9% to 6–7%.<br>
◆ Introduction of $CO_2$ emission charges (at around USD20 per tonne)</td></tr>
<tr><td>Average annual GDP growth – 0.6%</td><td>Average annual GDP growth – 2.7%</td></tr>
</table>

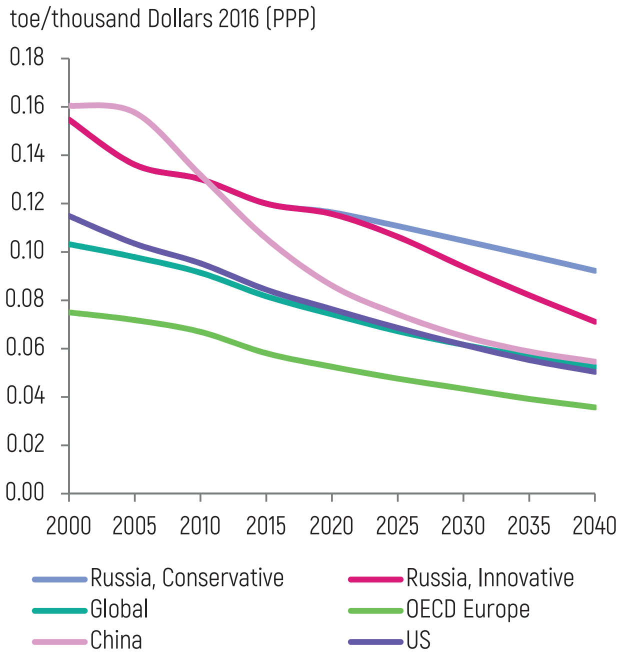
Without the implementation of adaptation measures, Russia's economic growth will inevitable slow down in all scenarios. We show the potential for mitigating these effects only in the Energy Transition scenario with adaptation (this is not a forecast, but only an assessment of the potential).

# GDP ENERGY INTENSITY AND NATURAL GAS PRICES

Some objective conditions in Russia doom it to worse energy efficiency indicators compared to other countries: a cold climate, larger distances, as well as a hypertrophied raw materials sector and a noticeable technological lag between Russia and the West determine high energy intensity of Russia's GDP. It is 1.5 times higher than the world average and America's GDP and twice the GDP intensity of leading European countries (Fig. 3.5). At the same time, an analysis of international and Russian reports showed the possibility of halving GDP energy intensity in 2015 – 2040, coupled with an optimistic assessment of the potential for using energy-efficient technologies and intensifying energy conservation measures. The experience of large countries (the US reduced GDP energy intensity by a factor of 1.4 within 15 years, and China - 1.5 fold within 10 years) shows it to be a realistic estimate.

Nevertheless, so far, visible success in energy efficiency in Russia was only achieved in the short historical period of 1999–2008, during a period of rapid economic growth and an increase in domestic fuel prices. In addition to objective natural factors and already inherited inefficient production assets and housing stock, the main obstacles for increasing energy efficiency in Russia are as follows:

**Figure 3.5 – GDP energy intensity in Russia compared to GDP energy intensity in the US, Europe and China and global energy intensity, mtoe/thousand Dollars PPP 2016**




Sources: IEA, ERI RAS

The objective conditions of Russia condemn it to poorer energy efficiency indicators compared to other countries. Nevertheless, our analysis shows the possibility of halving GDP energy intensity. The key factors for this are cheaper loans and higher gas prices.

- lack of available "long-term cheap finance" and loans for energy-efficient projects for medium and small market participants (they are the main investors in energy efficiency measures and not large state-owned companies, as is the case in the production of energy resources);
- administrative barriers;
- natural gas prices remaining low

High cost of capital constitutes the main barrier for scientific and technological progress in Russia. Prior to the introduction of US and EU sanctions against Russia in 2014, large exporters of goods, including the main energy companies, solved this by borrowing capital in foreign markets. This allowed them to modernize production on a large scale, using the world's best technologies in fuel extraction and processing. The rest of the national economy was modernizing with much more expensive borrowed capital. However, the sanctions limited the volumes of borrowing and worsened the conditions for raising capital for export companies, and the subsequent stagnation of the economy as a whole increased the cost of capital in Russia. The dynamics of the yield of federal loan bonds serves an indication: even with a discount for inflation it nearly doubled in 2014 and only decreased to 7–8% per year in 2017.

However, even given the yield of OFZ (federal loan bonds), borrowed capital cannot cost below 10–12%, while new energy production and consumption technologies are effective worldwide at a cost of capital of 3-5%. Thus, the essence of the current regulatory policy is that capital which is several times more expensive combined with fuel which is several times cheaper sharply reduces the attractiveness for Russia of any areas of scientific and technological development in the energy sector as a whole and compromises any measures aimed at improving energy efficiency in particular. Due to this, the country is cut off from the overall global trend of increasing efficiency.

The difficulty of reducing the cost of borrowed capital because of high national risks makes it especially relevant to incentivize technological advancements in the energy sector via pricing. Domestic prices of crude oil, exported petroleum products and coal in Russia are formed on the principle of equal profitability with prices in world markets. State regulation of natural gas prices remains as a non-market mechanism. Natural gas accounts for over half of primary energy consumption and up to 60% of fossil fuel consumption in Russia. A course of setting domestic gas prices on the principle of equal profitability with exports declared by the government 10 years ago was replaced by the strategy of increasing prices in line with inflation, then "Inflation minus" and finally "freezing" prices after a double devaluation of the Rouble in the period since 2014, with the aim to support households and energy intensive producers

Increasing natural gas prices would ensure:

1) an intensification of energy conservation in all types of economic activity, especially in the electricity sector, heating and public utilities sectors;

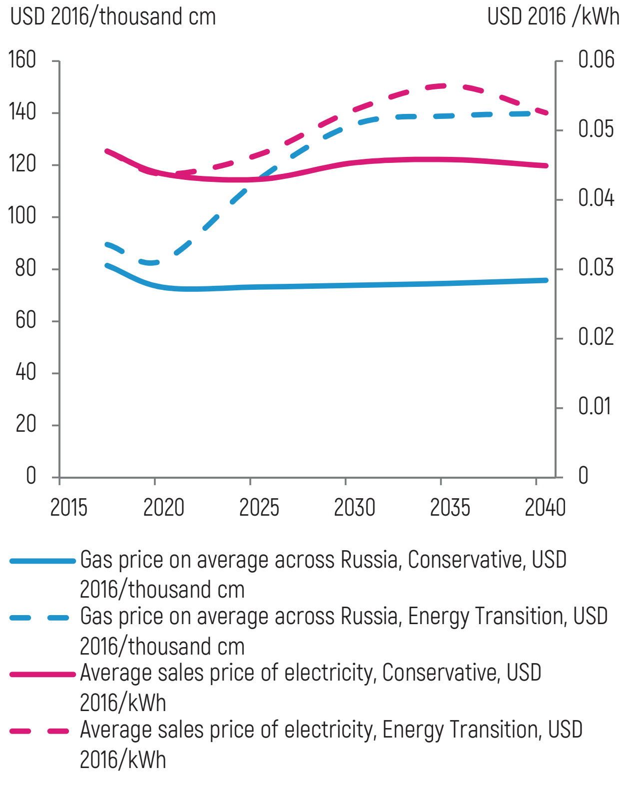
2) accelerated development and technological progress in the electricity and heating sectors, especially in the use of renewable energy sources for the production of electricity and heat;

3) a reduction in losses of natural gas and its expenditure for the industry's own needs;

4) normalization of market conditions in the Russian fuel and energy complex.

As a result, consumers of gas and competing energy resources have lost the incentive to increase energy efficiency and use low-carbon energy resources (including renewable energy). In the Conservative scenario, gas prices continue their current trajectory, supporting energy sustainability and contributing to rising energy consumption even in a slowly growing economy. However, increasing domestic natural gas prices starting in 2020 would be the condition for the implementation of the Energy Transition scenario. Natural gas prices would have to be raised to reach equal profitability with gas prices in world markets.(excluding prices for the household sector).

**Figure 3.6 - Scenario forecast of average Russian gas prices for industrial consumers (left axis), USD 2016/thousand cm, and corresponding average sales prices of electricity (right axis), USD 2016 /kWh**




Source: ERI RAS

This means that domestic gas prices would have to increase by 50-60% over 10 years, compared to 2016 (in US Dollars), given markedly lower world prices in this scenario. Later they would have to change synchroniously with the prices in world gas markets (Fig. 3.6). Such a rise in natural gas prices, the dominant fuel in Russia, will have a great impact on the prices of inter-fuel competition for coal in Eastern Siberia and the Far East. However, contrary to fears,calculations show that electricity prices change significantly less given incentives to replace equipment at power plants with more efficient equipment and reduce specific fuel consumption.

We should emphasize that even if domestic gas prices rise to the level of equal profitability, they will still be noticeably below those in the markets of Europe and the Asia-Pacific region, and the price of capital will still sometimes be higher than negative European rates, creating deliberately less powerful incentives for energy saving and scientific and technological progress in Russia and maintaining the lag in these parameters.

Therefore, higher energy intensity of the Russian economy compared to other countries will remain for the whole forecast period in all scenarios. However, while this is not so critical in the Conservative scenario, a reduction in energy intensity becomes a matter of survival of the entire national economy in the Innovative and especially in the Energy Transition scenarios. These threats are not the result of the Energy Transition - in this scenario they simply arise faster and more explicitly, which is a serious argument in favour of the Energy Transition scenario with adaptation. At the same time, as it will be shown later, this scenario creates multiplicative effects which outweigh the negative consequences of rising gas prices.

# PRIMARY ENERGY CONSUMPTION AND THE FUEL MIX

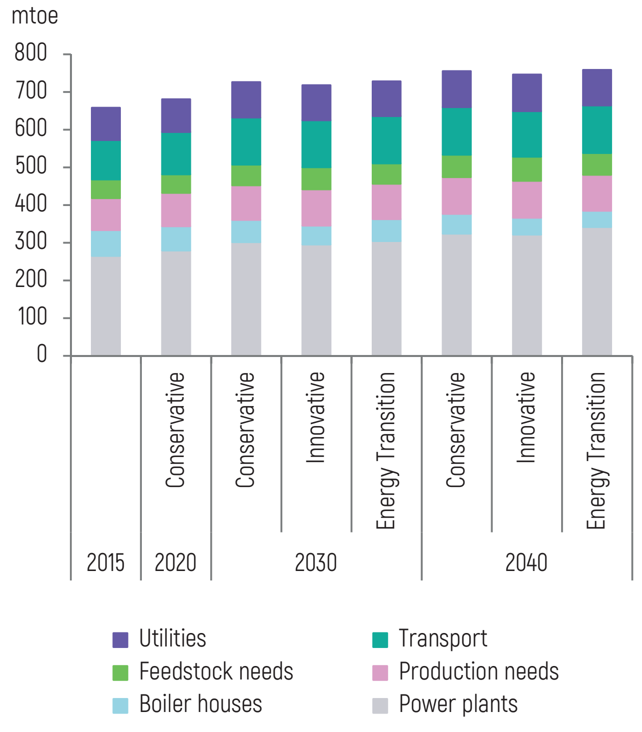
In the considered scenarios, Russia's overall demand for primary energy resources will increase by 12–13% from 2018 to 2040 (Fig. 3.7). However, at the same time, in the Energy Transition scenario, GDP growth rate will be almost twice as high as in the other two scenarios: the same amount of energy consumption can prompt the economy to grow twice as fast.

By 2040, half of primary energy will go to thermal power plants and boiler houses. The share of the transport sector, the second largest fuel consumer, will increase from 16% in 2015 to 17% by 2025. It will remain at this level due to the electrification of railway transportation and (from the middle of the period) automobile transport, as well as due to the availability of compressor drives at gas pipelines and the replacement of motor fuels in road and marine transportation with compressed and liquefied gas. Motor fuels can potentially be replaced with hydrogen produced from natural gas in large cities.

Further electrification will maintain the share of fuel used for production and household needs at around 13%, and the share of its use as a feedstock will grow from 7.6% in 2015 to 9% in 2040.

In the Energy Transition scenario, although primary energy consumption will be the same as in the Conservative scenario, its structure will change. Accelerated

**Figure 3.7 – Scenario forecast of primary energy consumption by sector**

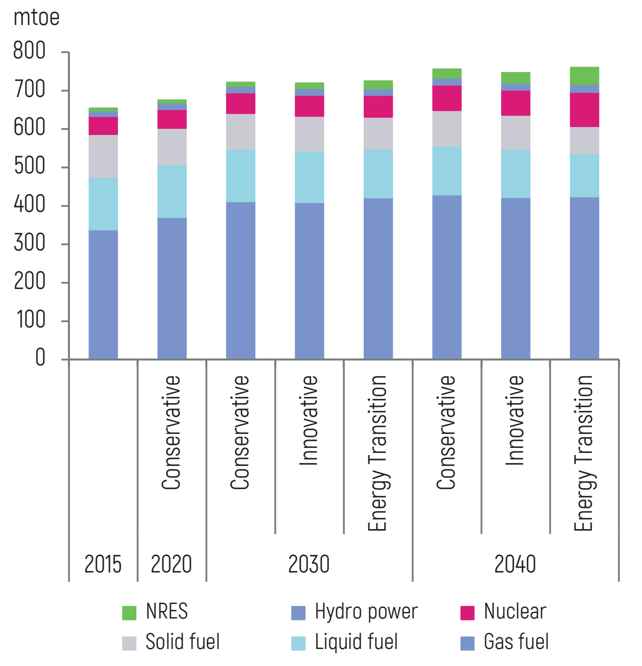



Source: ERI RAS

electrification of production, transport and household processes, will increase electricity consumption by 36% by 2040 (compared to an increase of 20% in the Conservative scenario, even with energy saving doubling.  The structure of the energy mix in Russia will not change much in all scenarios. Natural gas will remain the dominant energy resource, with its share growing further, from the current 54 to 57% of total primary energy consumption. (Fig. 3.8).

The share of liquid fuels will decrease from 21% in 2018 to 17% in 2040 in the Conservative scenario and to 15% in the Energy Transition scenario.  Solid fuel will reduce its share from 17 to 13% in the Conservative scenario and to 9% in the Energy Transition scenario, while low-carbon sources (renewable energy, hydro power and nuclear power), will, on the contrary, nearly double their share: from the current 10% up to 19% by 2040 in the Energy Transition scenario. This will be the main transformation in the energy mix. It is low-carbon generation that will account for 70% of additional electricity generation. Production at thermal power plants will grow by just 1-2%, mainly due to the accelerated development of distributed co-generation of electricity and heat. However, cumulatively low-carbon sources will increase their share slightly: from 10 to 13% in the Conservative scenario.

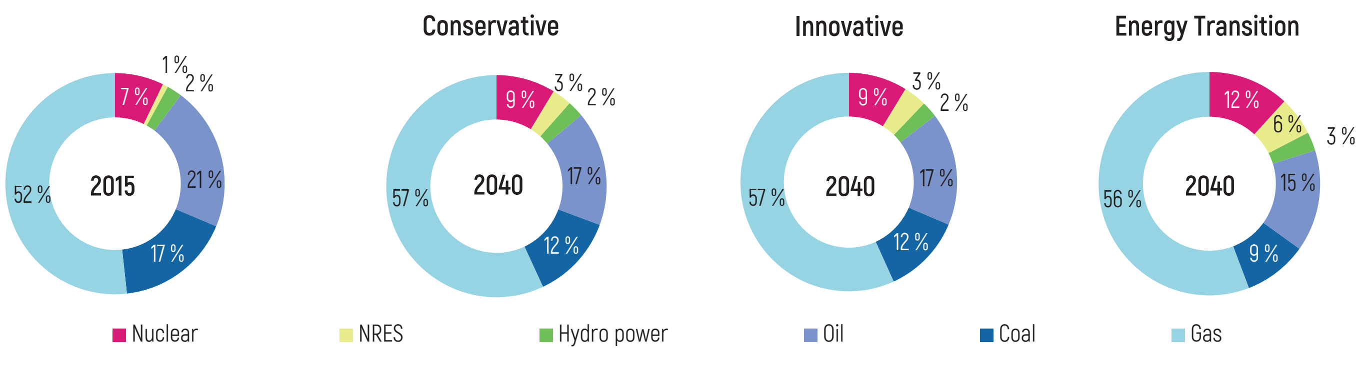
**Figure 3.8 – Scenario forecast of primary energy consumption by fuel type**




Source: ERI RAS

Natural gas will retain its dominant position in the Russian energy mix,  However, significant changes will take place in the Energy Transition scenario: by 2040 the share of solid fuel swill halve and the share of low carbon energy sources will nearly double.

**Figure 3.9 – Scenario forecast of primary energy consumption in Russia in 2015, 2040, %**




Source: ERI RAS

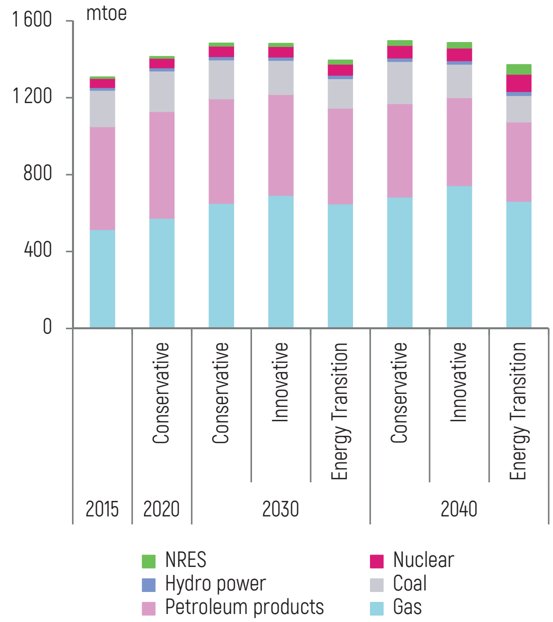
# ENERGY PRODUCTION

Energy production in Russia will increase by just 6% in the Conservative scenario, considering the dynamics of domestic demand and export described above. The Energy Transition scenario envisions that by 2040 energy production in Russia will fall by 3%, (Fig. 3.10) after a peak in the 2020s.

Gas and oil will retain their dominant position in primary energy production with virtually no change in their combined share (78–79%). A noticeable decline in the share of coal is expected in the Energy Transition scenario by the end of the period (from 15 to 10% of total energy production). This will be fully offset by an increase in the share of non-fossil energy resources - renewable energy, hydro and nuclear energy: from 5% in 2018 up to 11% by 2040.

By 2040, energy production in Russia will increase by just 6% in the Conservative scenario. The Energy Transition scenario envisions that by 2040 energy production in Russia will fall by 3%, after a peak in the 2020s. This will not only bring Russia closer to the developed economies, but also mark the transition of the energy sector to a new stage of development: from the prevalence of quantitative growth to qualitative improvement.

**Figure 3.10 -Scenario forecast of primary energy production by fuel, mtoe**




Source: ERI RAS

This will not only bring Russia closer to the developed economies, but also mark the transition of the energy sector to a new stage of development: from the prevalence of quantitative growth to qualitative improvement. The reason for this will not be depletion of resources but a nearly twofold slowdown in global growth in primary energy consumption in the Energy Transition scenario.

# ELECTRIC POWER SECTOR

Accelerated electrification of the economy is taking place in Russia as well as in the rest of the world. Electricity consumption will grow in all scenarios. By 2040 it will rise by 20% compared to 2018, while electrification rate will increase from 40.6 to 44%.

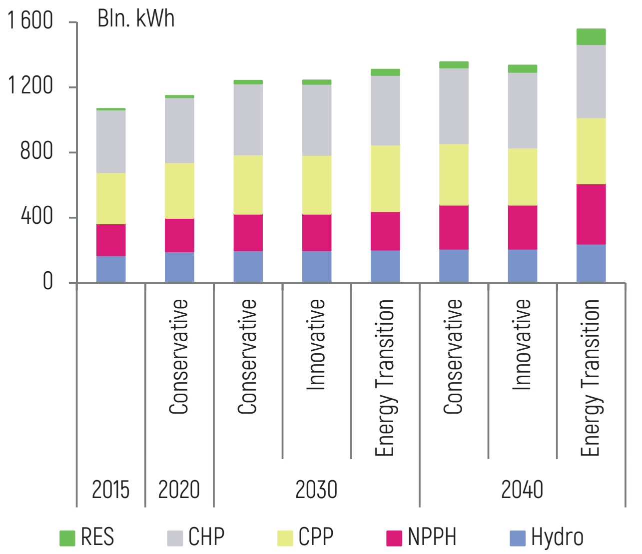
Nuclear power in Russia, unlike in most countries in the world, enjoys substantial support from the government, while remaining scientific and production potential combined with specific forms of financing its technological advancement could provide an increase in nuclear-based

> Accelerated electrification of the economy will be taking place in Russia as well as in the rest of the world. NRES will show most of the growth in power generation.

The share of electricity in overall energy consumption will increase to 47% while electricity consumption volumes will grow by 36% by 2040 in the Energy Transition scenario.

Thermal power plants will remain the basis of the Russian electric power industry (around 62% of total electricity generation in 2040 in the Conservative scenario and 55% in the Energy Transition scenario compared to 65% in 2018; Fig. 3.11.). The highest rate of growth in electricity generation will be shown by renewable energy sources (15% per year until 2040), and by 2040 their share in electricity production will increase from less than 1% to 2.5–6% depending on the scenario. The state has created mechanisms to stimulate the use of solar and wind energy in the electricity market, but climatic factors and the location of renewable energy resources combined with the presence of a relatively cheap competitor (gas) delay the point at which RES reach economic competitiveness until 2030–2035, given the dynamics of their cost reduction adopted in our global forecast.

**Figure 3.11 – Scenario forecast of power generation by the main types of power plants, bln. kWh**




Source: ERI RAS

electricity generation by 34-84% by 2040. Again, this depends on the scenario – on the cost of capital and $CO_2$ emission charges.

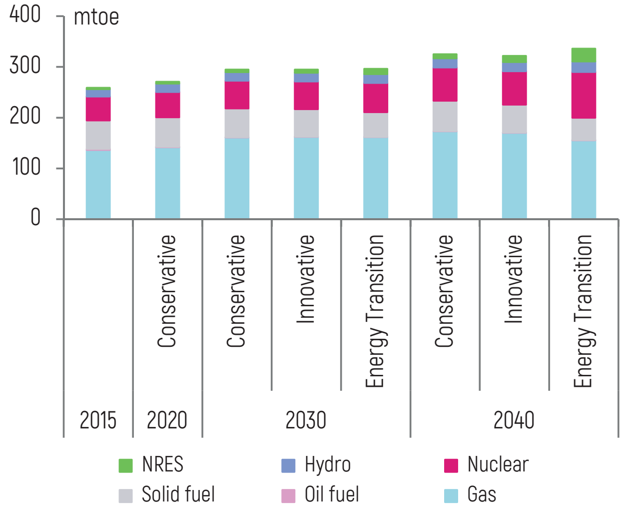
The characteristics of geography (long distances), climate (a long heating season with sharp temperature fluctuations) and the resource base (proximity to cheap hydrocarbon resources) determine the specific way in which electricity and heat supply systems develop in Russia. Given vast territories with low population density, if the cost of borrowed capital were to become cheaper, development of decentralized power, primarily distributed co-generation, would be able to intensify in the Energy Transition scenario. This would reduce the requirements for the development of distribution grids and the growth of centralized generating capacities, ensure their fuller use and reduce the existing imbalances in the cost of generation and grids, slowing down increases in the price of electricity for consumers.

As power plants cut specific fuel consumption, they will increase primary energy consumption by just 6%, while electricity generation at thermal power plants will grow by 18% in the Energy Transition scenario. The volumes of gas and fuel oil consumption in power plants obtained in the Conservative scenario will remain nearly the same, and the share of coal use by power plants will decrease from the current 23% to 18% in the Conservative scenario and 13% in the Energy Transition scenario by 2040 (Fig 3.12).

The main increase in generating capacities is attributed to carbon free and gas generation. In the Conservative scenario, by 2040 capacity increases by 22% (56 GW, of which RES account for a quarter). Taking into account accelerated electrification of the economy and the active promotion of renewable energy with a lower capacity utilization factor, it will be necessary to increase installed capacity by 55% in the Energy Transition scenario (133 GW, of which 43% - renewable energy sources) (Fig. 3.13).

Solar and wind power plants , as well as thermal power plants operating on biomass and waste have the most potential in Russia (Fig. 3.14). Small scale hydro power stations, which have been unfairly forgotten, could also make a noticeable contribution.

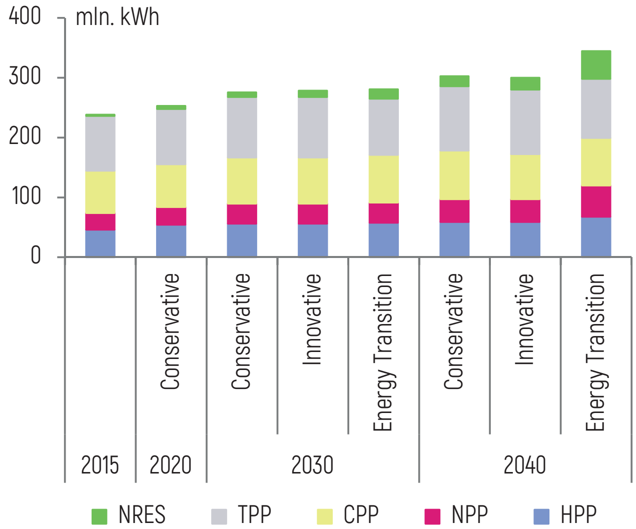
**Figure 3.12 – Scenario forecast of primary energy consumption at power plants, mtoe.**




Source: ERI RAS

Low carbon and gas-based generation will account for most of the growth in generation capacity.

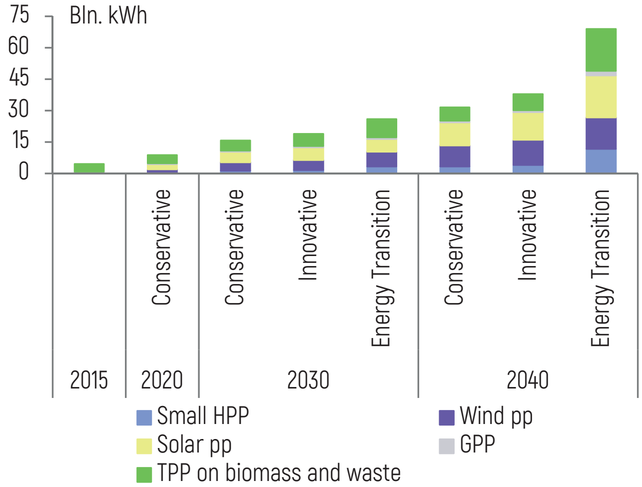
**Figure 3.13 – Scenario forecast of installed capacity of main types of power plants, mln. kWh**




Source: ERI RAS

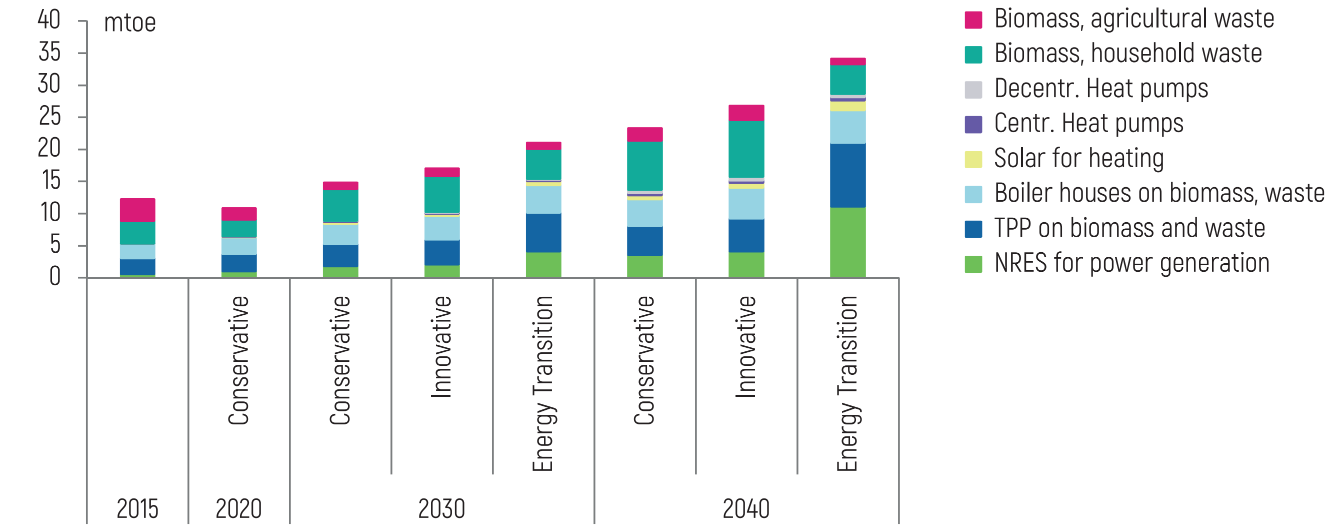
At the same time, biomass has the greatest potential among renewable energy sources in all consumption sectors in Russia. This is natural for Russia, as it is the first in the world in terms of forest area and wood reserves and generates large volumes of agricultural waste (Fig. 3.15).

### Figure 3.14 – Use of NRES in the power generation, bln. kWh




Source: ERI RAS

### Figure 3.15 – Dynamics and structure of NRES, mtoe




Source: ERI RAS

# OIL INDUSTRY

Image by David Mark from Pixabay

# Production

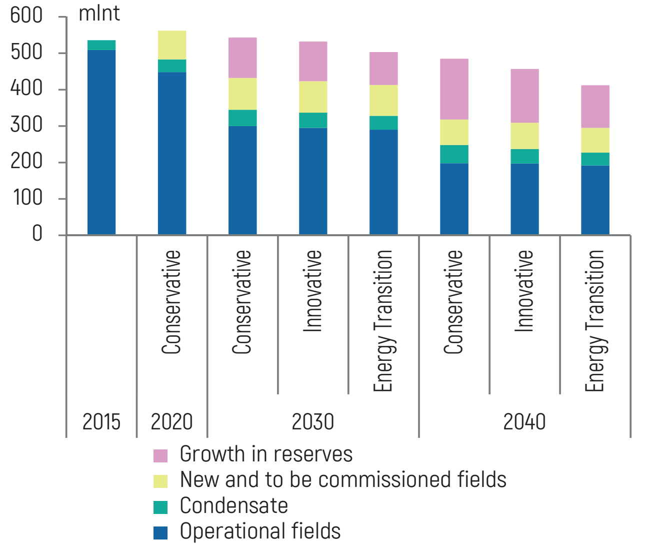
Despite the unfavourable pricing environment and difficulties with attracting foreign capital and technology, Russia will manage to increase oil output throughout the second decade of the 21st century. Such stable production performance indicators are largely due to both the presence of a significant resource base, mostly inherited from the Soviet Union, and a significant reduction in production costs caused by the devaluation of the national currency in 2014-2018, combined with import replacement measures in relation to foreign production equipment on a number of technological directions. All these factors have had a positive impact on the competitive ability of the Russian oil in the world market.

An analysis of the current resource base (operational fields, new fields and projects being prepared for commissioning) shows that it will be able to ensure stable high production until 2022–2024 even regardless of the global pricing environment: major investments have already been made, and companies will produce oil at these fields. After 2024, on the one hand, it will be necessary to actively expand the resource base and the use of new technologies needed to bring hard-to-recover reserves into operation, with the aim to maintain output. On the other hand, a limitation in external demand becomes apparent after 2024. This will happen under the influence of transformation in global markets, described in Section 2. After a peak of 565–570 million tonnes per year in the 2020s, output will begin to decline. By 2040 it will decrease to 410–485 million tonnes per year, depending on the scenario.

Currently around a third of output is subject to beneficial tax treatment (Fig. 3.16).

After a peak of 565–570 million tonnes per year in the 2020s, oil output in Russia will begin to decline and by 2040 it will decrease to 410–485 million tonnes per year, depending on the scenario.

**Figure 3.16 – Projected production of liquid hydrocarbons in Russia by type of reserves for the three scenarios**




Source: ERI RAS

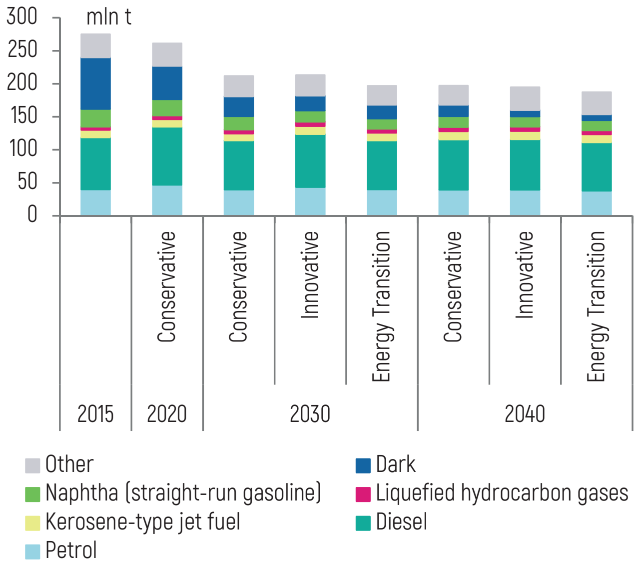
# Oil refining

As of now, specific price and regulatory conditions have formed for the development of domestic refining in Russia. On the one hand, these conditions have reversed the long-term tendency to form excess primary processing capacities with a general lack of secondary treatment processes for the production of high-quality petroleum products. On the other hand, these conditions have slashed the margins of even highly technological refineries.

A further reduction in both capacity and volume of primary oil refining is expected in the forecast period, dictated by an internal tax policy aimed at supporting extremely efficient refineries and limited demand for Russian petroleum products from external markets. A gross decline in primary oil refining in Russia will be due mainly due to decommissioning of independent oil refineries, which are not able to save on crude oil purchases by using tolling arrangements in vertically integrated oil companies, and due to decommissioning of capacities which have low efficiency, as they are not sufficiently equipped with secondary treatment processes. The forecast period will see the decommissioning of those plants which could not be fully modernized by 2018 in accordance with the quadripartite agreements made back in 2011 and other strategic guidelines for the fuel and energy complex. These refineries are not capable of producing sufficient volumes of Euro 5 environmental standard products.

At the same time, retirement of such capacities in combination with minimal efforts to modernize other refineries, and mainly aimed at increasing oil refining depth to reduce output of fuel oil (which will not find demand either in the generation segment or as marine fuel) will have a significant impact on the growth of the country's average oil refining depth from 81.3% in 2018 to 92–95% by 2040. Given such refining depth in the context of a slight increase in domestic demand (due to the slow economy in the Conservative and Innovative scenarios and replacement with alternatives in the Energy Transition scenario), even declining primary processing capacity will be enough to meet domestic demand for main motor fuels. (Fig. 3.17).

**Figure 3.17 – Projected production of petroleum products by Russian oil refineries for the three scenarios**




Source: ERI RAS

# Exports of oil and petroleum products

An increase in gross volumes of Russian exports of raw materials (crude oil and gas condensate) is expected in the forecast period until the mid-2020s in the Conservative and Innovative scenarios. This is achieved by boosting production. After 2020, oil output starts declining, but crude oil exports can be maintained at a relatively high level due to the fact that smaller volumes will begin to flow to the domestic market because of a decline in refining volumes. By 2040, Russian oil exports will stabilize at 250–270 million tonnes in these two scenarios. The Energy Transition scenario appears to be much more risky for Russian oil exports: a decrease in volumes from the current values happens as early as in the 2030s, and by 2040 the volume of crude oil deliveries to foreign markets will only stand at 215 million tonnes due to a contraction in global demand for oil and petroleum products.

A decrease in crude oil deliveries to the West is expected after 2020, primarily due to declining demand for petroleum products in Europe and increased competition from other crude oil suppliers. As a result, the Russian share in the European oil market will decrease from 33% in 2018 to 28-30% in 2040. In addition to lower demand in the European market, Russian companies will have to face fierce competition for European consumers with suppliers from the Middle East, Africa and even North and South America. The declining quality of oil delivered via the Druzhba trunk pipeline system, which European consumers have been complaining about for several years, can lower demand somewhat.

In addition, there is reputational risk linked to the incident in which organochlorine compounds got into Russian oil in 2019.

At the same time, Russia, thanks to its developed export infrastructure and production projects in Eastern Siberia and the Far East, will have prospects for growing exports to the Asia Pacific Region, primarily to China, where significant growth in oil refining capacities is expected. Russia's share in the total volume of Chinese imports could increase from 14% in 2018 to 20–22% by 2040. Thus, reorienting oil exports to the east is becoming the main way to curb the decline in volumes (Fig 3.18).

In addition to a reduction in crude oil exports, petroleum product exports are also expected to fall due to decommissioning of unprofitable primary processing refining, not equipped with secondary treatment processes. This could take place against the backdrop of increasing domestic demand for liquid fuels.

The signals from foreign markets are serve as a negative indication for export growth.

After the mid-2020s, gross oil export growth will halt. In the Conservative and Innovative scenarios, it will stabilize by 2040 at around 250–270 million tonnes. In the Energy Transition scenario starting in the 2030s, its volumes will begin to decline and by 2040 the volume of crude oil exports to foreign markets will total just 215 million tonnes due to reduced global demand for oil and petroleum products.

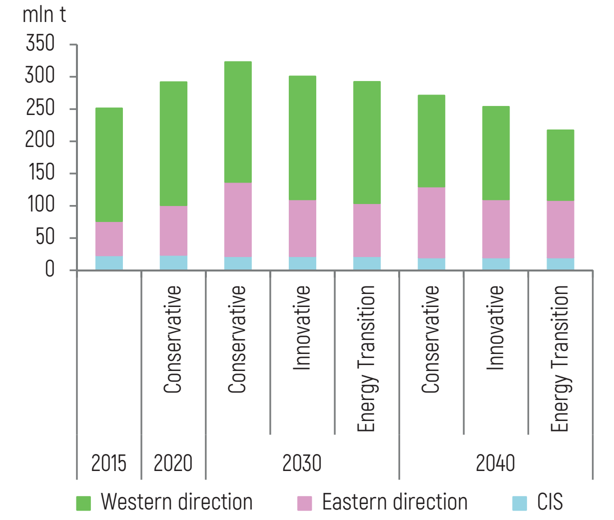
A key factor affecting the dynamics of Russian exports in Europe is a substantial reduction in demand for liquid fuels (including petroleum products), expected in the period to 2040.

Demand will slow in the context of an increase in the supply of relatively cheap petroleum products from the growing Middle East and Asian (Indian) refineries, which are displacing not only Russian, but also US refineries from the European product market. Tougher competition is also expected in the petroleum products markets of the Asia-Pacific region. Russian petroleum products will primarily have to compete with relatively cheap (including due to the absence of a transportation leg) products produced directly in the Asian countries. By 2040 aggregate export of liquid hydrocarbons from Russia (including crude oil, condensate and petroleum products) will decline 280–345 million tonnes compared to 420 million tonnes in 2015. At the same time crude oil exports will remain more profitable for companies than petroleum product exports (Fig.3.19) in the period to 2040.

Given substantial risks which the scientific and technological progress poses for the global liquid fuels market, Russia, being of the key global suppliers of oil and petroleum products, will need to carefully develop its long-term strategy for the development of the oil industry in the Conservative and Innovative scenarios, and even more so in the Energy Transition scenario. Formally, Russia retains its most important place in the oil market, and remains the second largest crude oil exporter in the world after Saudi Arabia, ranking third in the production of petroleum products after the US and India and the third in production volumes after the US and Saudi Arabia up to 2040 in all scenarios.

However, a significant adaptation of the Russian refining complex is critical, both in terms of increasing oil refining depth and boosting the production of motor fuels of higher environmental standards, and in terms of reducing the volume of low-efficiency capacities which are not equipped with secondary processes. This adaptation is necessary to maintain competitive ability and marginality

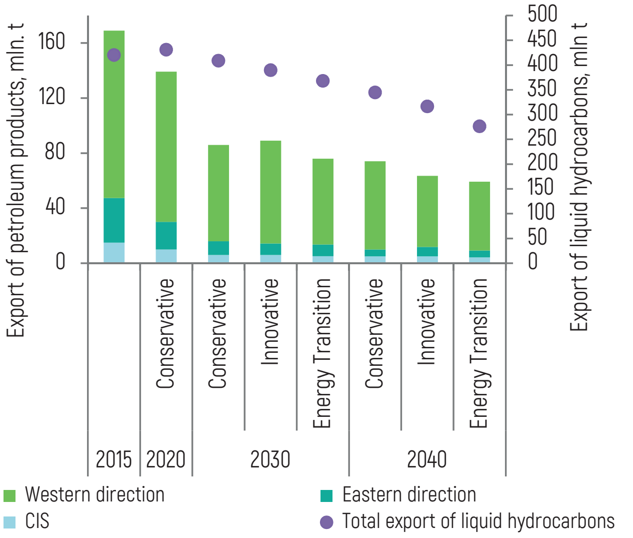
**Figure 3.18 – Export of crude oil and gas condensate by export direction**




Source: ERI RAS

A sharp fall in exports of petroleum products is expected both due to the decommissioning of low-efficiency, primary processing capacity not equipped with secondary processes. This will take place in the context of growing domestic demand for liquid fuels, and due to a decrease in production amid negative signals from the foreign markets.

**Figure 3.19 – Petroleum product export, by export direction for the three scenarios, total export of liquid hydrocarbons from Russia for the three scenarios**




Source: ERI RAS

of supplies, considering the need to improve the quality of oil products and change the structure of demand for various petroleum product groups. High-sulfur diesel, fuel oil and intermediate products, which are produced by such refineries will simply not find demand in the world or domestic markets and will only push high-value raw materials from the technologically complex refineries.

Within the context of adapting to changing international trade which will take the form of substantially increasing competition for the European consumers while demand in this region slows, it is advisable now to provide a production base and begin to prepare production capacities and transportation systems from traditional production regions in the east of Russia for expansion. This is necessary to ensure the most efficient export of liquid fuels in the Asian direction in the long term.

At the same time, given the emerging conditions, the main objective is to maintain the competitiveness of the industry in terms of costs, including through technological development, fiscal policy and the development of "short-term" projects with a quick payback period for attracting private and foreign investments.

# GAS INDUSTRY

# Domestic demand and export

In 2009, following many years of steady growth, the Russian gas industry faced a fall in all of production and export indicators and only managed to return to previous production levels by 2017.

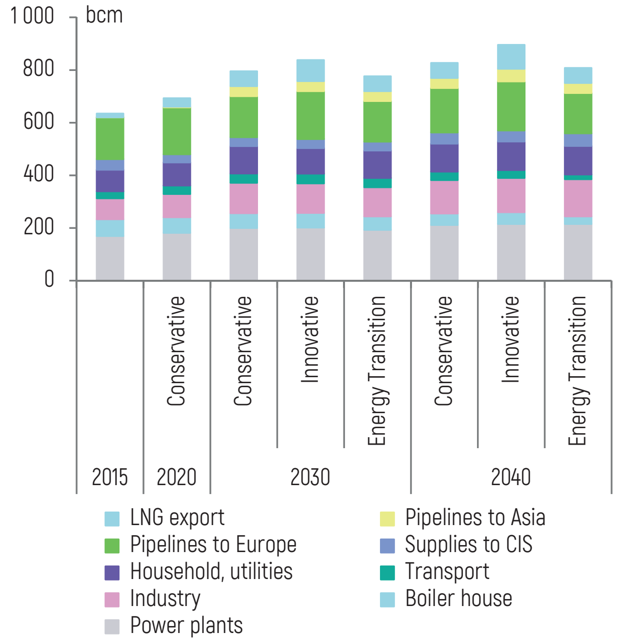
After a long period of continuous growth, when production was held back by production capabilities, gas producers were for the first time confronted with stagnant demand. The rather low projected growth rates of the Russian economy also determine moderate growth in domestic gas demand for the entire period up to 2040 - by 22–24% compared to 2018. At the same time, natural gas always remains the "number one choice" for the Russian economy in the face of tight budgetary constraints. Power plants will remain the main consumers of gas (40–41%) in all scenarios, and the share of its consumption by central boiler houses will nearly halve (Fig. 3.20).

Consumption of gas will increase in industry, especially as a chemical feedstock (from 20 to 24–25%), and the share of its use in households and utility sector will remain unchanged. An analysis of the development prospects for the global gas market, carried out in Section 2, shows that constraints in the foreign markets will remain to a considerable extent. Gas exports carried out under existing long-term contracts and via spot trading, can help maintain the volume of deliveries from Russia to the European market. However, given the geopolitical situation and moderate European demand, we cannot count on a significant increase in export volumes in this direction in the period to 2040 in the Conservative scenario. A reduction in export deliveries is inevitable in the Energy Transition scenario, and export growth for European consumers is only possible in the Innovative scenario.

The potential for growing supplies of Russian gas to the CIS will largely be linked to the situation in Ukraine and decisions on energy supply to Ukraine after the end of the operational life of existing nuclear power plants.

The main opportunities for Russia to boost supplies to the foreign markets depend on the growth in exports to the Asia-Pacific region (China, Japan, the Republic of Korea, etc.) and the development of global LNG trade. However,

**Figure 3.20 – Use of natural gas in domestic and foreign markets, bcm**




Source: ERI RAS

there is high uncertainty about the future prospects of these new markets and the competitiveness of Russian gas there. During the period under review, gas exports in this direction are expected to grow nearly 5–6 fold. However, this increase comes from a very low base, and in absolute terms, deliveries to Asia by 2040 will not equal even half of the current export volumes to Europe, even in the Innovation scenario.

Great hopes are pinned on the development of a flexible and adaptive LNG industry in Russia, which, depending on the scenario, can provide a significant increase in the export of liquefied natural gas. However, again in absolute terms, by 2040 export volumes in all directions will reach 42% of current deliveries to Europe even if the most favorable scenario for LNG production growth is realized. Therefore, the European pipeline gas market will continue to account for 52–55% of Russian exports in 2040.

## Production

In the period to 2040, production of natural and associated gas in Russia will increase by 18–30%, depending on the scenario. In principle, the state of the resource base and the scale of existing reserves allow the gas industry (unlike the oil industry) to increase output much more significantly than in the proposed scenarios, which are calculated based on demand, rather than just production capabilities.

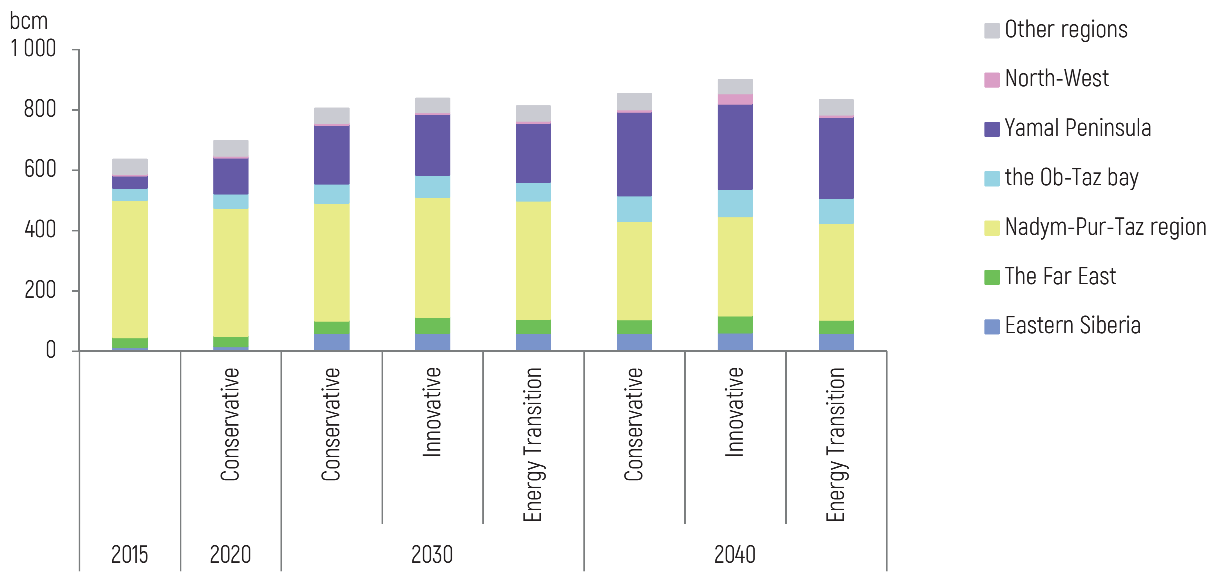
Given a decline in output in traditional gas producing regions (primarily in Nadym-Pur-Taz), most of the increase in production will come from the deposits of the Yamal Peninsula, the Ob-Taz Bay, as well as Eastern Siberia and the Far East (Fig. 3.21).

In the context of the transformation in global energy markets and given the large role of the gas industry for the Russian Federation, it is also necessary for to develop a strategy for this industry, to successfully adapt to new realities.

Inefficient use of gas is one of the key factors hindering the development of the economy. Large expenditure of gas forces a transition to more complex and expensive production projects, which leads to the need to increase sales prices in the domestic market and reduces competitive ability of Russian gas in foreign markets.

Ample opportunities for gas production given limited demand may become an incentive to substitute gas for petroleum products in the domestic market, as petroleum products can be sold for export with a higher margin. Along with power plants (fuel oil substitution), there is potential

**Figure 3.21 – Natural gas production by region, bcm**




Source: ERI RAS

An increase in competition in the gas market and inter-fuel competition, coupled with uncertain demand in individual markets, predetermines significant scenario discrepancies in terms of projected export potential.

for fuel substitution in the transportation sector. It is also possible to develop new integrated solutions in relation to energy supply that are of interest to consumers and are competitive in the inter-fuel market, such as autonomous energy supply using gas for the co-generation of heat and power. At the same time, hybrid energy systems with the connection of renewable energy sources are possible. These will enhance efficiency, reliability and environmental friendliness. Such technical solutions can be applied both domestically and in foreign markets.

An increase in competition in the gas market and inter-fuel competition, coupled with uncertain demand in individual markets, predetermines significant scenario discrepancies in terms of projected export opportunities. Under these conditions, an adaptation strategy is needed for the development of the gas industry. It should include phased introduction of new production, transportation and storage capacities, taking into account the signing of supply contracts, etc.

The strategy should provide for continuous monitoring of the situation and the possibility of flexible adjustment of work plans. At the same time, it is undoubtedly necessary to optimize costs in all directions in order to increase competitive capabilities, especially in the context of an inevitable transition to a more complex resource base.

# COAL INDUSTRY

## Domestic demand and export

Russia's coal industry, similarly to the gas industry, appears to be extremely dependent on the external environment. The main factor limiting further growth is precisely the capacity of the foreign market and price competitiveness, rather than restrictions on coal reserves or mining capacities. Domestic demand for solid fuels will decrease by 17% compared to 2018 in the Conservative and Innovative scenarios, in the context of slow economic growth and gas prices remaining low. The Energy Transition scenario specifies rising gas prices and intensification of energy conservation, therefore the reduction in domestic demand for coal will accelerate to 22%, mainly in power plants. Moreover, coal consumption in absolute terms will decrease radically only in households and utilities sector (by a factor of 4 compared to 2018), in all scenarios.

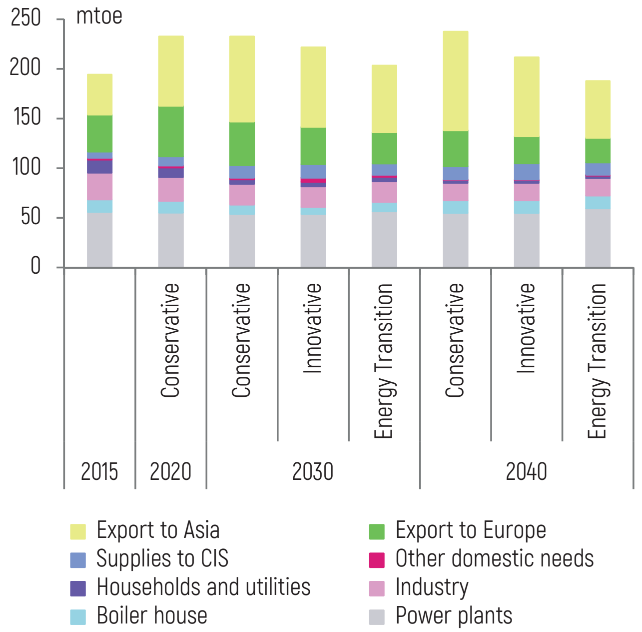
Combined with currency devaluation and a low Rouble exchange rate, this makes export the main driver of the development of the coal industry.

The processes taking place in the global coal market, in particular the climate policy of many countries (especially the EU and China), create high uncertainty for this industry in Russia. In the Conservative scenario, coal demand growth is expected to come from Asia-Pacific countries (primarily India and Southeast Asia, where demand for high-quality coal will increase), as well as countries in the Middle East and Africa. Demand is likely to stagnate in China and developed Asia (Japan, South Korea), and exports in the European direction will gradually decrease as a result of a contraction in both demand and need for imports. In the Innovative and especially the Energy Transition scenario a reduction in domestic demand will be coupled with lower coal exports not only in the European but also in the Asian direction (Fig. 3.22).

Important changes in the global market are also taking place on the supply side. The main leaders in global mining of tradable coal are the US, Indonesia, Australia, South Africa, Colombia and Russia. At the same time, several producers (primarily Indonesia) will continue to reduce their export volumes for various reasons, which will open up new opportunities for Russia for 5–7 years (Colombia will exhaust its main deposits by 2030, and Indonesia will be forced to redirect part of exported coal to meet domestic demand). Thus, real competition will unfold between Australia and Russia in key emerging markets: Southeast Asia, India, the Middle East and Africa.

The coal industry in Russia is extremely dependent on the external environment and the main factor limiting further growth is precisely the capacity of the foreign market and price competitiveness. In period to to 2040, both an increase in exports to the Asia-Pacific region, the Middle East and Africa, and a reduction in coal exports not only to Europe but also to Asia are possible, depending on global scenarios.

**Figure 3.22- Use of coal in the domestic and foreign markets, mtoe**




Source: ERI RAS

The key success factor here is for Russian coal to remain competitive. A reduction in exports by all suppliers is inevitable in the Energy Transition scenario.

Competitive ability of Russian coal is compromised by the fact that coal suppliers are located far from the seaports, and that distances of coal transportation by railway are great. In 2015–2018 Rouble devaluation abruptly increased the effectiveness and attractiveness of export deliveries; however, this effect will not be enough in the long term.

## Production

Coal production in Russia will be able to grow steadily (by 16% by 2040 in the Conservative scenario) as a result of transformations in the domestic and foreign markets. It is projected fall by 10% after 2020 in the Innovative scenario, and by 30% in the Energy Transition scenario. To a large extent, this reduction will be attributable to steam (thermal) coal production. In terms of geography, most of the reduction will be in the basins of Siberia and the Far East. Kuznetsk coal basin will remain the main coal mining area, with an increase in the mining of Kansk-Achinsk, Irkutsk and Far Eastern coals (Fig. 3.23).

Given the high risks of transformations in foreign markets, it is important for the Russian coal industry to pursue a very balanced investment policy in expanding production and transportation capacities. Long term contracts should be the basis for expanding capacities in the Asian direction, while it is advisable to attract investment in projects from consumer countries and create joint ventures at certain stages of the supply chain. This will enable to ensure their interest in the stability of production and deliveries and lower own risks. At the same time, it is essential to increase efficiency, in order to reduce costs in fairly tough (including pricewise) market conditions.

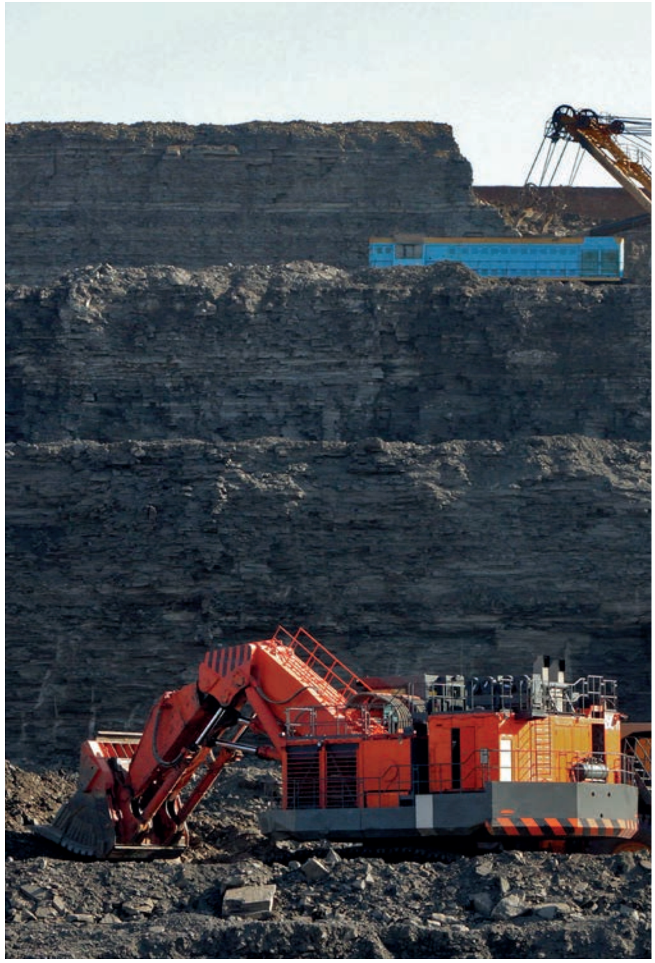
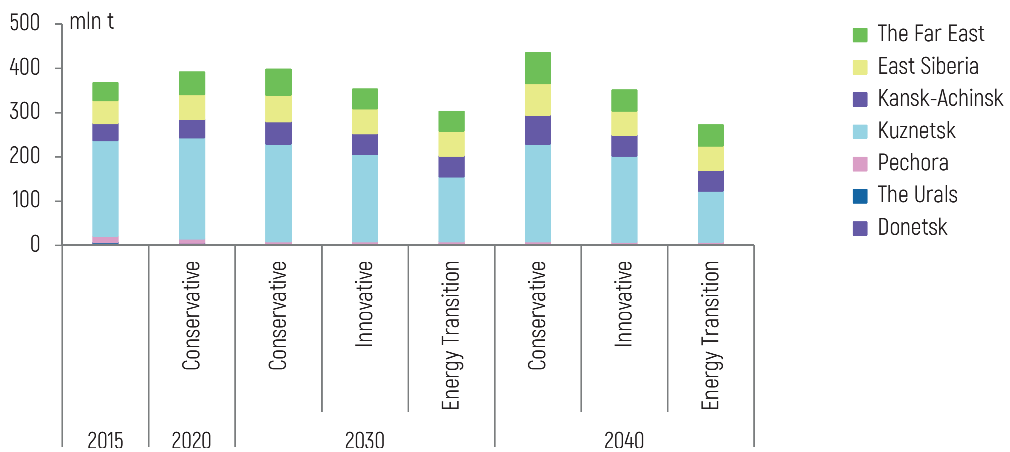


**Figure 3.23 - Scenario forecast of coal production by region and basin, mln t**



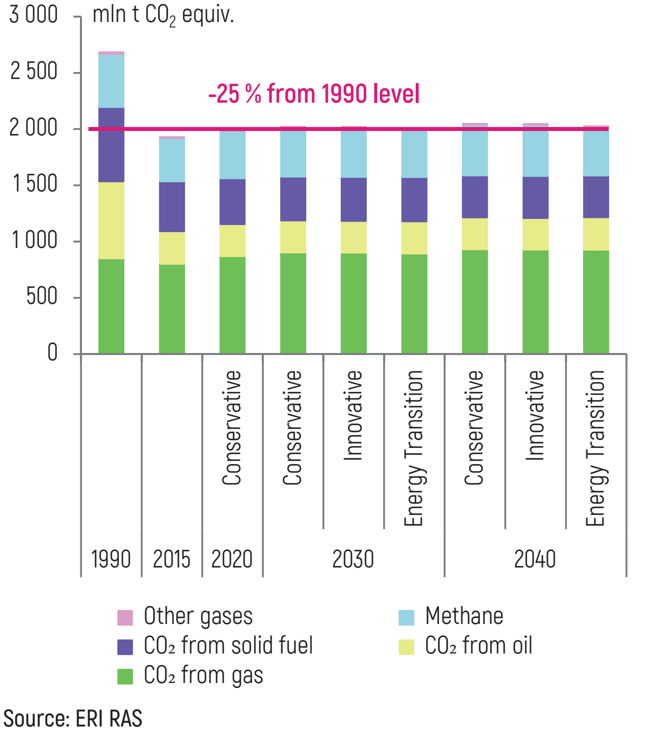

Source: ERI RAS

# $CO_2$ EMISSIONS

Russia's stance on the issue of climate change and related decarbonization policy is historically ambiguous. However, given relatively low economic growth, maintaining greenhouse gas emissions at 75% of 1990 levels does not require huge efforts (Fig. 3.24): a slow growth in emissions from fossil fuel combustion is expected in Russia in the period to the end of the 2030s, in any case. By 2040 the difference in emission volumes within different scenarios reaches 10%, and this is considering more intensive economic growth in the Energy Transition scenario.

In this scenario, increasing energy efficiency and an increase in the share of low carbon energy resources from 10% in 2015 to 19% in 2040 give Russia an opportunity to reach global average GDP growth (annual, %), while leaving $CO_2$ emissions at the level not above 75% of 1990 levels in the forecast period. However, high cost of capital, cheap domestic fuel resources and much lower population incomes (compared to the developed countries) still objectively impede the use of advanced (and more expensive) production technologies and the use of energy resources needed to further improve energy consumption structure in Russia.

**Figure 3.24 - Dynamics and structure of main greenhouse gas emissions for the three scenarios, mln t $CO_2$ equivalent**




Source: ERI RAS

# THE INFLUENCE OF THE ENERGY SECTOR ON THE NATIONAL ECONOMY

In recent years energy sector provided 20–23% of GDP, 25–26% of consolidated budget revenues and 55–60% of hard currency export revenues.

As we said in all the previous issues of "Outlook", the role of the fuel and energy complex in the Russian economy will continue to decline from the maximum of 2012–2013, affected by shifts in world energy markets. The transformation of world energy markets under the influence of technological progress in the energy sector can significantly enhance this trend. By 2040 value added by the fuel and energy sector will rise by 40% in the Conservative scenario and by 20% in the Energy Transition scenario (Fig. 3.25), and its share in Russia's GDP will decline to 17 and 14%. This signifies the end of the dominance of the fuel and energy complex in the national economy during the Energy Transition, due to an almost double acceleration of Russia's GDP growth. The Energy scenario also projects a reduction (faster than in other scenarios) in export revenues of the Russian fuel and energy complex while technological progress in the global energy sector intensifies.

The share of the oil industry in the GDP generated by the fuel and energy sector will decrease from 74% in 2015 to 61% by the end of the period in the Conservative scenario and to 47% in the Energy Transition scenario. This drop is offset by an increase in the share of the gas industry by a factor of 2 and 2.5, respectively, with an increase to 51% at the end of the period in the Energy Transition scenario.

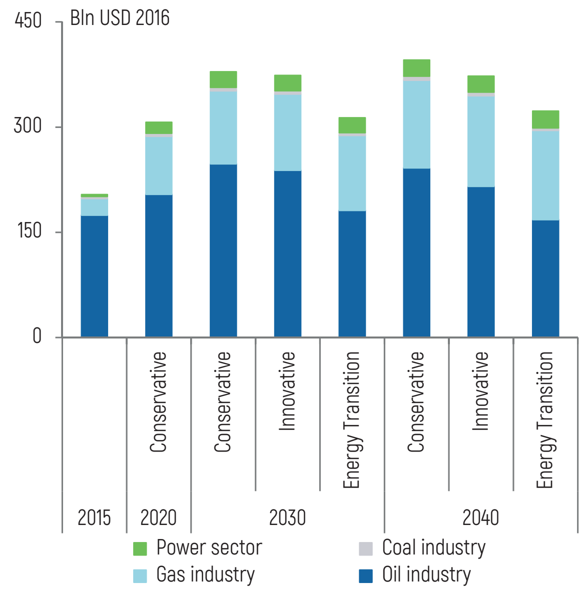
Alongside a direct contribution to the development of the Russian economy, the energy sector has a large indirect impact on it, mainly through the dynamics of fuel and energy prices for consumers (and this is all part of the national economy) and through the size of capital investments in the production and use of energy resources.

The role of the fuel and energy complex in Russia's economy will continue its decline from 20-23% to 14-17% under the influence of changing market conditions in world energy markets.

Scenario differences in the dynamics of external and domestic fuel prices are directly considered in the calculations of the contribution of the fuel and energy sector to Russia's GDP (Fig. 3.25). The influence of domestic and external fuel prices on the rest of the economy is determined by calculations on the cross-industry multi-agent model of Russian economic development[37].

Macroeconomic consequences of the Energy Transition scenario (with adaptation) are of particular interest. Its

**Figure 3.25 - Dynamics of GDP produced by Russian energy sector, bln USD 2016**




Source: ERI RAS

[37] V.A. Malakhov , K.V. Nesytykh Possible macroeconomic consequences of the intensification of scientific and technological progress in the energy sector of the world and Russia // The role of scientific and technological progress in the development of the energy sector of Russia M. : ERI RAS, 2019. ISBN 978-5-91438-030-1.

Reducing energy intensity is a key factor in Russia's adaptation to the transformation of the world energy sector. By 2040 the implementation of economically justified energy saving measures in Russia will increase the country's GDP by 30%, taking into account the multiplier multiplicative effects.

implementation, along with the lower cost of capital, requires a 50–60% increase in domestic natural gas prices by 2030, after which they will follow moderate increases in the prices of foreign markets. The first consequences of this would be the energy consumers shifting part of the price increase (depending on the level of competition in relevant markets) to the prices of their products.

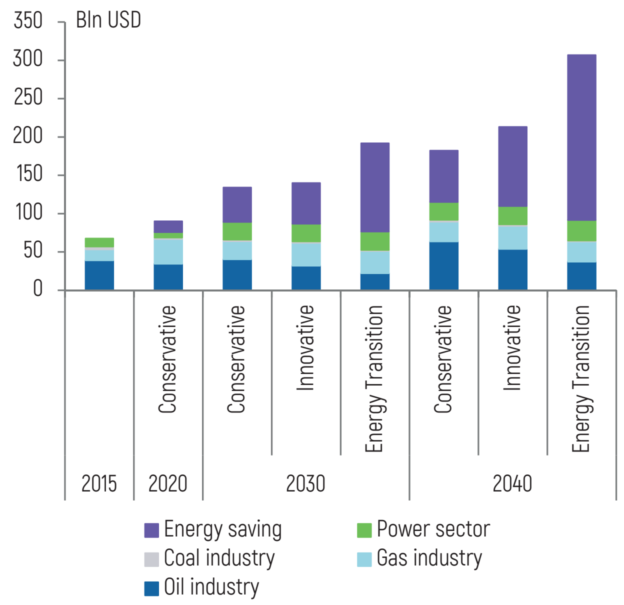
This will slow down the growth in GDP produced in other types of economic activity (by 24-25% in the forecast period, according to calculations). At the same time, rising gas prices stimulate energy saving in all sectors of the economy, which will require a 2.8-fold increase in investment in consumers' energy facilities under the Conservative scenario and up to 9 fold in the Energy Transition scenario (Fig. 3.26). The latter are 2.4 times larger than direct investments in the development of the fuel and energy complex. Most importantly, they will be market-efficient given increased gas prices and reduced interest rate on borrowed capital. The same calculations showed that orders on these investments, in turn, will increase the produced GDP 1.4 fold in all areas of activity which ensure the modernization of the energy facilities of consumers: machine and instrument manufacture, manufacturing of new construction and building materials, management and control systems, in agriculture and utility services, etc. Given a reduction in energy consumption in these industries, GDP growth in the Energy Transition scenario will be almost triple the amount of losses in the economy from rising fuel prices.

The scenarios also vary quite noticeably in relation to the size of capital investments in the development of the fuel and energy complex. A more sophisticated mining and geological and transportation environment for fuel production and the high capital intensity of growing low-carbon energy sources will increase the volume of capital investments in the fuel and energy complex by 70% in the Conservative scenario. A reduction in the amount of primary energy production after 2020 will require half the increase in investment in the development of the fuel and energy sector in the Energy Transition scenario (Fig. 3.26).

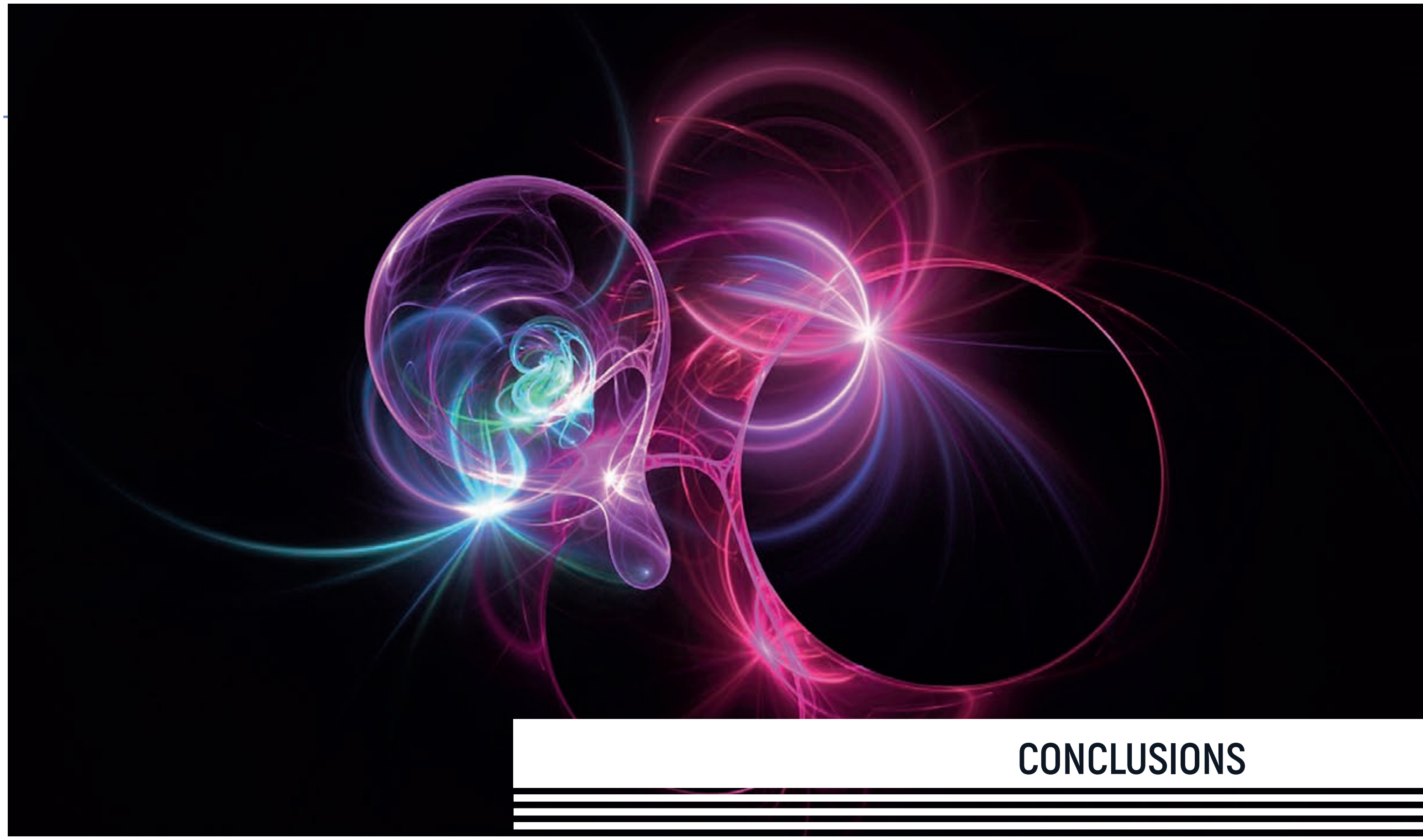
The Conservative scenario shows that the share of the oil industry in total investments in the fuel and energy sector will grow (51% in the first and 55% in the last five years), and the ratio between the gas industry will change (its share will decrease from 34 to 20%) and the electric power industry – its weighting in the investments in the fuel and energy complex will rise from 12 to 20%.

These processes will accelerate in the Energy Transition scenario: the share of capital investment in electricity and heat power will grow to 29%, investment in both gas (from 35 to 29%), and oil (from 50 to 41%) industries will decline. The reasons for this are both an accelerated increase in power generation capacity and a change in its structure - fossil fuel-based power plants are replaced by more capital-intensive low-carbon energy.

**Figure 3.26 - Dynamics of capital investment in the energy industries and growth in energy saving in Russia, bln. USD 2016**




Source: ERI RAS



# CONCLUSIONS

The technological transition of the world energy sector from the dominance of fossil fuels to low-carbon energy resources threatens Russia with a 16% reduction in fuel exports and an 8% reduction in primary energy production (relative to existing trends). In general, over the forecast period this can reduce value added in the fuel and energy complex itself by a quarter and value added in supporting enterprises by another 2–3%, due to a decrease in capital investments in the development of the sector. As a result, average GDP growth in the country will slow down in 2016–2040 from 1.7% to 0.6% per year (Conservative scenario).

The inadequacy of the institutional environment and the high cost of borrowed capital hinder investment in the economy and, together with the freezing of prices for natural gas (hence, thermal coal), actually block technological progress in the part of the Russian energy sector serving the domestic market. Scenario calculations show that at a cost of borrowed capital below 9% per year with domestic gas prices nearly doubling (Table 2.12), a 2.7 fold increase in technological[38] and product-related energy saving would be economically justified by 2040. And the reduction in intermediate consumption achieved in this way more than compensates for the negative consequences of rising domestic fuel and energy prices.

Moreover, capital investments in energy conservation will be five times higher than the reduction in investments in the fuel and energy complex under the Innovative scenario than in the Conservative one. The need for material content of these investments will accelerate the development of enterprises which modernize consumers' power facilities starting in the mid-2020s, and will increase their value added by 41% over the period (Table 3.2).

The combination of the considered factors will accelerate Russia's GDP growth to 2.5–2.8% in the 2020s and to 3% after 2030, while a slowdown in the growth rate of global GDP growth from 2.9% in the 2025-2030s to 2.3% in the 2035–2040s was adopted as a prerequisite for global scenarios. Nevertheless, the next quarter century will not be easy for the Russian economy and the energy sector. Serious shifts in the situation in foreign markets, combined with the accumulated problems of the Russian economy in

[38] We should not expect these would be the best global technologies.

### Table 3.2 – The role of the fuel and energy complex in Russia's macro-economic indicators, %

| | 2015 | 2020 | | | 2025 | | | 2030 | | | 2035 | | | 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Contribution to GDP produced, bln US Dollars | 295.5 | 306.8 | 292.1 | 292.1 | 406.6 | 375.4 | 375.4 | 417.8 | 366.7 | 366.7 | 445.1 | 371.6 | 371.6 | 412.9 | 349.3 | 349.3 |
| The same, % compared to 2015 | 100.0 | 103.8 | 98.8 | 98.8 | 137.6 | 127.0 | 127.0 | 141.4 | 124.1 | 124.1 | 150.6 | 125.7 | 125.7 | 139.7 | 118.2 | 118.2 |
| The share of the fuel and energy complex in GDP, % | 22.7 | 22.0 | 21.0 | 20.9 | 21.4 | 19.7 | 18.9 | 20.2 | 17.7 | 15.9 | 19.7 | 16.5 | 13.7 | 16.9 | 14.3 | 11.0 |
| The same, % compared to 2015 | 100.0 | 97.0 | 92.3 | 91.9 | 94.1 | 86.9 | 83.4 | 88.8 | 78.0 | 69.9 | 87.0 | 72.7 | 60.6 | 74.5 | 63.1 | 48.6 |
| Contribution to the consolidated budget, bln US Dollars | 152.2 | 48.6 | 45.4 | 45.4 | 51.1 | 43.4 | 43.4 | 52.2 | 44.8 | 44.8 | 55.6 | 45.4 | 45.4 | 51.9 | 41.7 | 41.7 |
| The same, % compared to 2015 | 100.0 | 31.9 | 29.8 | 29.8 | 33.6 | 28.6 | 28.6 | 34.3 | 29.5 | 29.5 | 36.5 | 29.8 | 29.8 | 34.1 | 27.4 | 27.4 |
| The share of the fuel and energy complex in the budget, % | 26.4 | 35.0 | 30.1 | 29.9 | 27.4 | 27.4 | 26.3 | 24.7 | 24.7 | 22.2 | 24.0 | 24.1 | 20.0 | 20.0 | 20.0 | 15.4 |
| The same, % compared to 2015 | 100.0 | 132.5 | 113.9 | 113.4 | 103.7 | 103.8 | 99.6 | 93.6 | 93.7 | 84.0 | 91.1 | 91.2 | 75.9 | 75.6 | 75.7 | 58.3 |
| **Multiplicative effects of scientific and technological progress in the energy sector** | | | | | | | | | | | | | | | | |
| | **2015** | **2020** | | | **2025** | | | **2030** | | | **2035** | | | **2040** | | |
| Investment in fixed capital in the fuel and energy complex, bln US Dollars | 67.5 | 68.4 | 69.4 | 69.4 | 67.1 | 66.7 | 66.7 | 89.0 | 76.7 | 76.7 | 109.7 | 84.8 | 84.8 | 115.2 | 91.8 | 91.8 |
| The same, % compared to 2015 | 100.0 | 101.2 | 102.7 | 102.7 | 99.4 | 98.7 | 98.7 | 131.8 | 113.5 | 113.5 | 162.4 | 125.6 | 125.6 | 170.6 | 135.9 | 135.9 |
| The share of the fuel and energy complex in national investments, % | 24.4 | 23.1 | 23.4 | 23.4 | 22.2 | 22.1 | 22.1 | 28.9 | 24.9 | 24.9 | 35.0 | 27.1 | 27.1 | 36.2 | 28.8 | 28.8 |
| The same, % compared to 2015 | 100.0 | 94.5 | 96.0 | 96.0 | 91.0 | 90.4 | 90.4 | 118.5 | 102.1 | 102.1 | 143.6 | 111.1 | 111.1 | 148.4 | 118.2 | 118.2 |
| Energy efficiency of the economy, thousand US Dollars/tonne of reference fuel. | 4.1 | 4.2 | 4.2 | 4.2 | 4.4 | 4.4 | 4.6 | 4.7 | 4.7 | 5.2 | 5.0 | 5.0 | 6.0 | 5.3 | 5.4 | 6.9 |
| The same, % compared to 2015 | 100.0 | 103.6 | 103.8 | 104.1 | 108.7 | 109.1 | 113.3 | 115.0 | 115.6 | 128.0 | 122.0 | 123.1 | 146.3 | 130.3 | 131.9 | 168.9 |
| Investment in energy saving, bln. US Dollars | 24.0 | 40.2 | 45.5 | 51.5 | 62.5 | 61.3 | 106.5 | 81.8 | 83.8 | 188.1 | 93.6 | 98.0 | 240.3 | 110.8 | 115.1 | 299.9 |
| The same, % compared to 2015 | 100.0 | 167.4 | 189.6 | 214.7 | 260.6 | 255.3 | 443.6 | 341.0 | 349.2 | 783.6 | 390.0 | 408.5 | 1001.4 | 461.5 | 479.5 | 1249.7 |

Source: ERI RAS

general and the fuel and energy sector in particular, place the Russian energy sector in rather severe conditions. It will be necessary to intensively solve the issues of increasing energy efficiency of the national economy, diversifying the structure and economic accessibility of energy supply to consumers, reducing the costs of fuel and energy industries and projects and ensuring rational use of natural resources and environmental protection.

# APPENDIX 1

## POPULATION AND GDP

Table A1.1 – Changes in world population and population structure by region in 2015–2040

| | Population, million people | | Average annual population growth, % | Urbanisation level, % | | Proportion of working age population, % | |
|---|---|---|---|---|---|---|---|
| | **2015** | **2040** | **2015–2040** | **2015** | **2040** | **2015** | **2040** |
| **North America** | 482 | 575 | 0,71 | 81 | 87 | 66 | 62 |
| US | 320 | 374 | 0,63 | 82 | 87 | 66 | 61 |
| **South and Central America** | 506 | 599 | 0,68 | 80 | 86 | 67 | 66 |
| Brazil | 206 | 232 | 0,47 | 86 | 91 | 70 | 66 |
| **Europe** | 618 | 636 | 0,12 | 74 | 81 | 66 | 59 |
| **EU-28** | 508 | 510 | 0,02 | 75 | 82 | 65 | 58 |
| **CIS** | 290 | 303 | 0,18 | 66 | 71 | 68 | 63 |
| Russia | 146 | 146 | 0,00 | 74 | 79 | 70 | 64 |
| **Developed Asia** | 207 | 204 | -0,06 | 88 | 90 | 65 | 56 |
| Japan | 128 | 115 | -0,42 | 91 | 94 | 61 | 54 |
| **Developing Asia** | 3846 | 4460 | 0,59 | 44 | 59 | 68 | 66 |
| China | 1405 | 1426 | 0,06 | 56 | 77 | 73 | 62 |
| India | 1309 | 1605 | 0,82 | 33 | 46 | 66 | 68 |
| **Middle East** | 242 | 342 | 1,41 | 71 | 79 | 66 | 68 |
| **Africa** | 1194 | 2100 | 2,28 | 41 | 54 | 55 | 61 |
| **Worldwide** | 7386 | 9221 | 0,89 | 54 | 64 | 66 | 64 |

Source: UN World Population Prospects, 2017 edition, World Urbanization Prospects: 2018 edition

### Table A1.1 – GDP dynamics by region and major country

| | GDP (PPP), trln US Dollars 2016 | | | | | | GDP growth rate, % | |
|---|---|---|---|---|---|---|---|---|
| | | All scenarios | | | | | All scenarios | |
| | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 1990–2015 | 2015–2040 |
| **North America** | 22,3 | 24,7 | 27,2 | 30,2 | 33,1 | 36,1 | 2,5 | 1,9 |
| US | 18,4 | 20,4 | 22,5 | 25,0 | 27,5 | 30,0 | 2,4 | 2 |
| **South and Central America** | 7,3 | 7,6 | 8,5 | 9,4 | 10,3 | 11,3 | 3,2 | 1,8 |
| Brazil | 3,3 | 3,3 | 3,6 | 3,8 | 4,1 | 4,3 | 2,7 | 1,1 |
| **Europe** | 22,7 | 24,7 | 26,6 | 28,6 | 30,4 | 32,1 | 2,0 | 1,4 |
| **EU-28** | 19,6 | 21,3 | 22,8 | 24,2 | 25,6 | 26,9 | 1,8 | 1,3 |
| **CIS** | 5,4 | 5,8 | 6,5 | 7,2 | 8,0 | 8,7 | - | 1,9 |
| Russia | 3,8 | 4,1 | 4,5 | 4,8 | 5,3 | 5,7 | 0,6 | 1,6 |
| **Developed Asia** | 8,4 | 9,0 | 9,6 | 10,2 | 10,7 | 11,2 | 1,9 | 1,2 |
| Japan | 5,2 | 5,4 | 5,5 | 5,6 | 5,7 | 5,8 | 1,0 | 0,5 |
| **Developing Asia** | 38,8 | 50,3 | 64,0 | 78,4 | 93,4 | 108,6 | 7,3 | 4,2 |
| China | 20,0 | 26,2 | 32,7 | 38,9 | 44,6 | 49,5 | 9,9 | 3,7 |
| India | 8,1 | 11,1 | 15,3 | 20,1 | 25,7 | 31,8 | 6,6 | 5,6 |
| **Middle East** | 5,7 | 6,5 | 7,3 | 8,3 | 9,4 | 10,5 | 4,2 | 2,4 |
| **Africa** | 5,9 | 6,8 | 8,0 | 9,5 | 11,3 | 13,4 | 3,8 | 3,3 |
| **Worldwide** | 116,4 | 135,4 | 157,8 | 181,8 | 206,7 | 231,7 | 3,8 | 2,8 |
| **OECD** | 53,1 | 58 | 63 | 68,4 | 73,8 | 79 | 2,2 | 1,6 |
| **Non-OECD** | 63,3 | 77,4 | 94,7 | 113,4 | 132,9 | 152,8 | 6,1 | 3,6 |

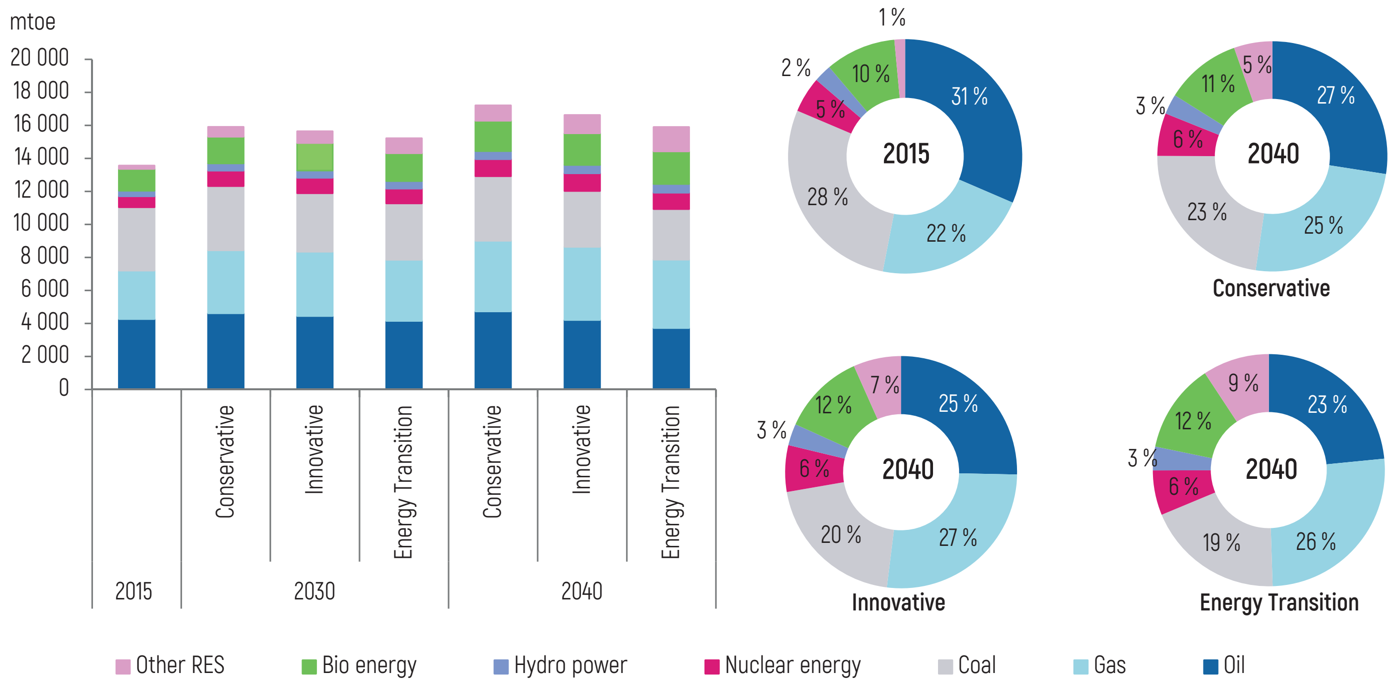
Source: UN World Population Prospects, 2017 edition, World Urbanization Prospects: 2018 edition

# APPENDIX 2

## ENERGY BALANCES

# World

Figure A2.1 – Global primary energy consumption by fuel and its structure, by scenario




Source: ERI RAS

Table A2.1 - Global indicators of development

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,12 | 0,09 | 0,09 | 0,08 | 0,07 | 0,07 | 0,07 | -1.8% | -1.9% | -2.1% |
| Per capita energy consumption, toe/capita | 1,84 | 1,86 | 1,83 | 1,78 | 1,87 | 1,80 | 1,72 | 0.1% | -0.1% | -0.3% |
| $CO_2$ emissions, mln. tonnes | 31892 | 34199 | 32682 | 31056 | 35263 | 32361 | 29372 | 0.4% | 0.1% | -0.3% |

**Table A2.2 - Global consumption of primary energy resources, mtoe**

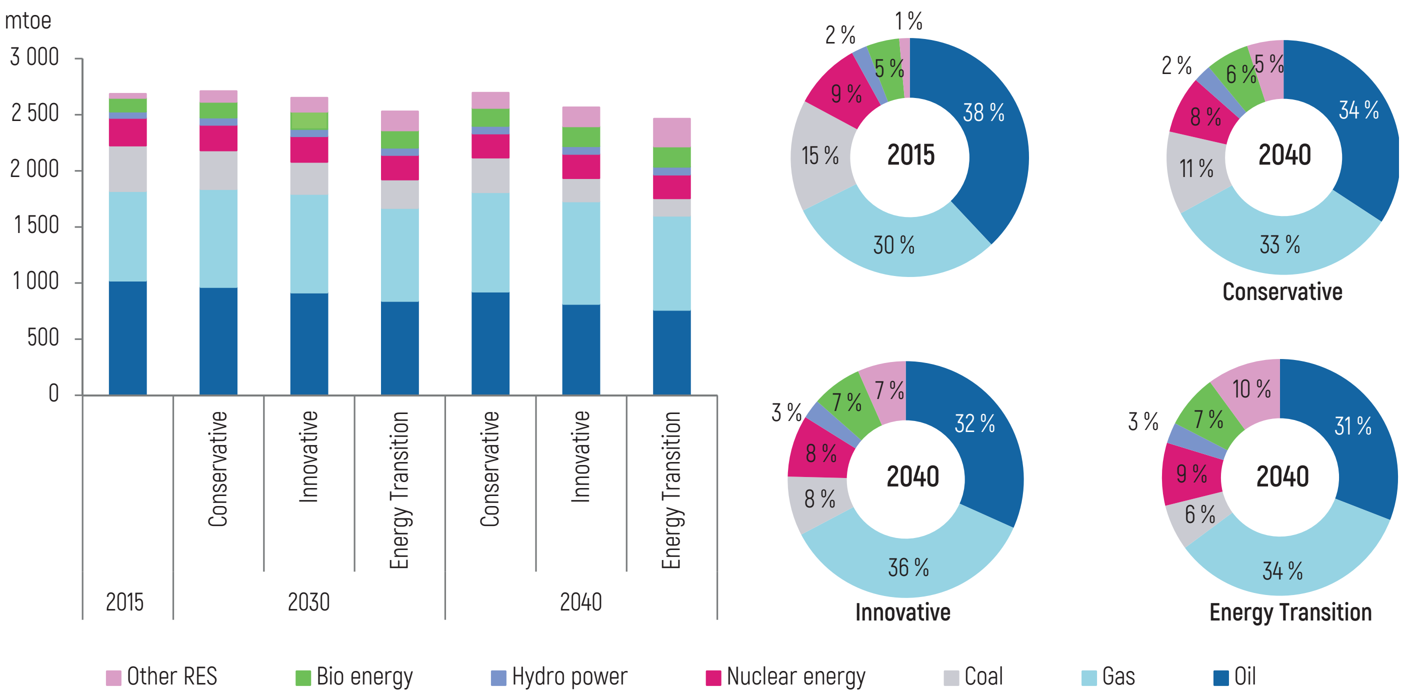
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 13566 | 15913 | 15647 | 15225 | 17214 | 16634 | 15904 | 1.0% | 0.8% | 0.6% |
| Oil | 4267 | 4618 | 4452 | 4151 | 4729 | 4212 | 3725 | 0.4% | -0.1% | -0.5% |
| Gas | 2932 | 3814 | 3891 | 3709 | 4277 | 4432 | 4144 | 1.5% | 1.7% | 1.4% |
| Coal | 3839 | 3892 | 3546 | 3417 | 3916 | 3378 | 3062 | 0.1% | -0.5% | -0.9% |
| Nuclear energy | 671 | 935 | 938 | 895 | 1033 | 1079 | 991 | 1.7% | 1.9% | 1.6% |
| Hydro power | 334 | 435 | 440 | 452 | 487 | 501 | 527 | 1.5% | 1.6% | 1.8% |
| Bio energy | 1322 | 1623 | 1664 | 1691 | 1841 | 1924 | 1979 | 1.3% | 1.5% | 1.6% |
| Other RES | 201 | 596 | 716 | 910 | 930 | 1109 | 1477 | 6.3% | 7.1% | 8.3% |

**Table A2.3 - Global electric power generation, TWh**

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 24251 | 32736 | 33197 | 34428 | 39045 | 39842 | 42117 | 1.9% | 2.0% | 2.2% |
| Oil | 990 | 655 | 584 | 526 | 566 | 386 | 233 | -2.2% | -3.7% | -5.6% |
| Gas | 5523 | 7764 | 8227 | 7849 | 9551 | 10291 | 9597 | 2.2% | 2.5% | 2.2% |
| Coal | 9553 | 10275 | 8852 | 8363 | 11242 | 8951 | 7994 | 0.7% | -0.3% | -0.7% |
| Nuclear energy | 2571 | 3583 | 3591 | 3428 | 3958 | 4130 | 3795 | 1.7% | 1.9% | 1.6% |
| Hydro power | 3890 | 5022 | 5114 | 5254 | 5640 | 5815 | 6128 | 1.5% | 1.6% | 1.8% |
| Bio energy | 528 | 938 | 1100 | 1172 | 1232 | 1507 | 1663 | 3.4% | 4.3% | 4.7% |
| Other RES | 1195 | 4501 | 5728 | 7836 | 6856 | 8762 | 12708 | 7.2% | 8.3% | 9.9% |

# North America

## Figure A2.2 - Primary energy consumption by fuel and its structure, by scenario, North America




Source: ERI RAS

## Table A2.4 - Main indicators of development, North America

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,12 | 0,09 | 0,09 | 0,08 | 0,07 | 0,07 | 0,07 | -1.9% | -2.1% | -2.2% |
| Per capita energy consumption, toe/capita | 7,69 | 7,38 | 4,88 | 4,66 | 7,00 | 4,46 | 4,29 | -0.4% | -2.2% | -2.3% |
| $CO_2$ emissions, mln. tonnes | 5900 | 5587 | 5263 | 4846 | 5351 | 4772 | 4286 | -0.4% | -0.8% | -1.3% |

### Table A2.5 - Consumption of primary energy resources, North America, mtoe

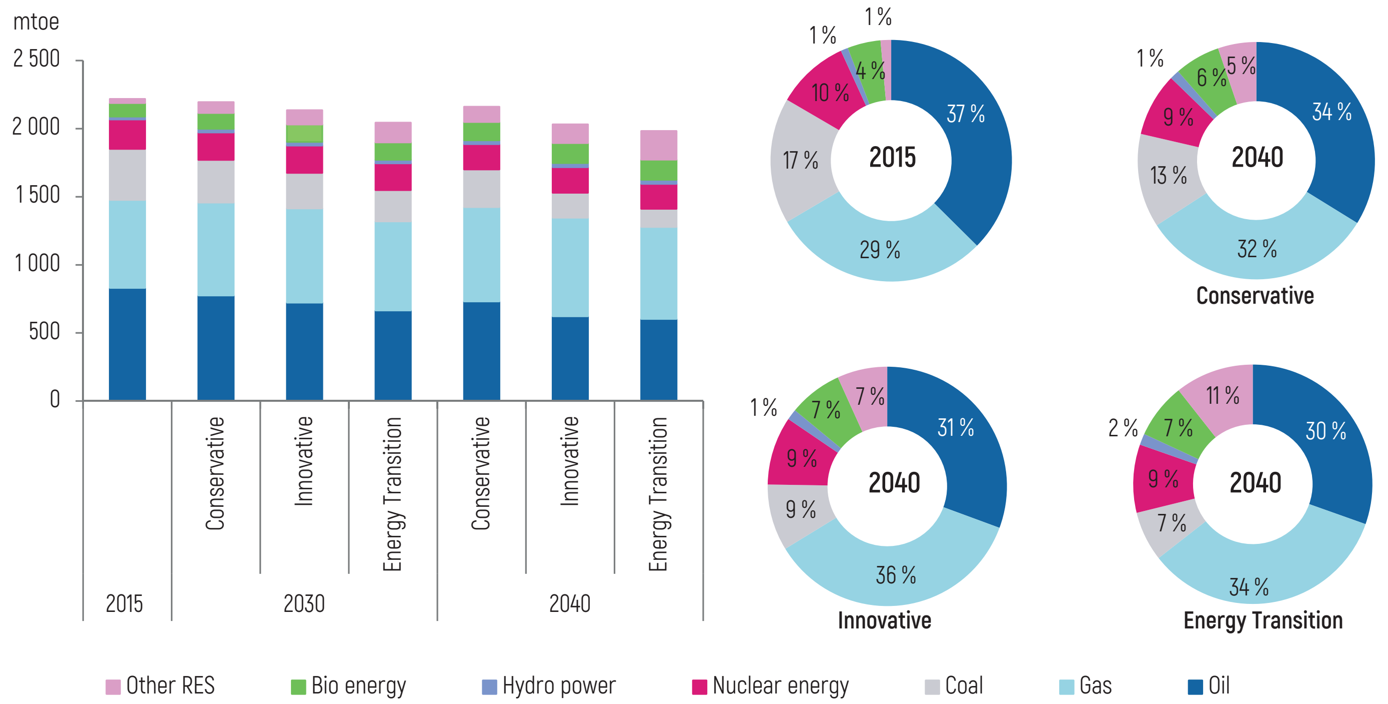
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 2687 | 2711 | 2652 | 2530 | 2697 | 2566 | 2466 | 0.0% | -0.2% | -0.3% |
| Oil | 1021 | 964 | 915 | 840 | 923 | 813 | 761 | -0.4% | -0.9% | -1.2% |
| Gas | 798 | 873 | 878 | 828 | 887 | 914 | 839 | 0.4% | 0.5% | 0.2% |
| Coal | 406 | 344 | 287 | 254 | 308 | 208 | 155 | -1.1% | -2.6% | -3.8% |
| Nuclear energy | 246 | 228 | 229 | 219 | 214 | 216 | 211 | -0.5% | -0.5% | -0.6% |
| Hydro power | 57 | 65 | 65 | 65 | 67 | 68 | 70 | 0.7% | 0.7% | 0.8% |
| Bio energy | 121 | 141 | 154 | 154 | 161 | 177 | 181 | 1.1% | 1.5% | 1.6% |
| Other RES | 38 | 96 | 125 | 170 | 136 | 169 | 249 | 5.2% | 6.1% | 7.8% |

### Table A2.6 - Electric power generation, North America, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 5279 | 5930 | 6105 | 6249 | 6308 | 6326 | 6715 | 0.7% | 0.7% | 1.0% |
| Oil | 79 | 25 | 26 | 30 | 12 | 7 | 4 | -7.3% | -9.1% | -11.3% |
| Gas | 1626 | 1934 | 2044 | 1867 | 2042 | 2141 | 1885 | 0.9% | 1.1% | 0.6% |
| Coal | 1571 | 1341 | 1089 | 939 | 1236 | 784 | 554 | -1.0% | -2.7% | -4.1% |
| Nuclear energy | 943 | 874 | 875 | 837 | 821 | 828 | 809 | -0.6% | -0.5% | -0.6% |
| Hydro power | 662 | 754 | 751 | 759 | 780 | 795 | 811 | 0.7% | 0.7% | 0.8% |
| Bio energy | 95 | 149 | 196 | 197 | 191 | 251 | 261 | 2.8% | 4.0% | 4.1% |
| Other RES | 303 | 853 | 1124 | 1619 | 1227 | 1520 | 2391 | 5.8% | 6.7% | 8.6% |

# USA

## Figure A2.3 - Primary energy consumption by fuel and its structure, by scenario, USA




Source: ERI RAS

## Table A2.7 - Main indicators of development, USA

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,12 | 0,09 | 0,09 | 0,08 | 0,07 | 0,07 | 0,07 | -2.0% | -2.3% | -2.4% |
| Per capita energy consumption, toe/capita | 6,94 | 6,19 | 6,02 | 5,76 | 5,78 | 5,43 | 5,30 | -0.7% | -1.0% | -1.1% |
| $CO_2$ emissions, mln. tonnes | 4959 | 4583 | 4278 | 3939 | 4333 | 3791 | 3459 | -0.5% | -1.1% | -1.4% |

### Table A2.8 - Consumption of primary energy resources, USA, mtoe

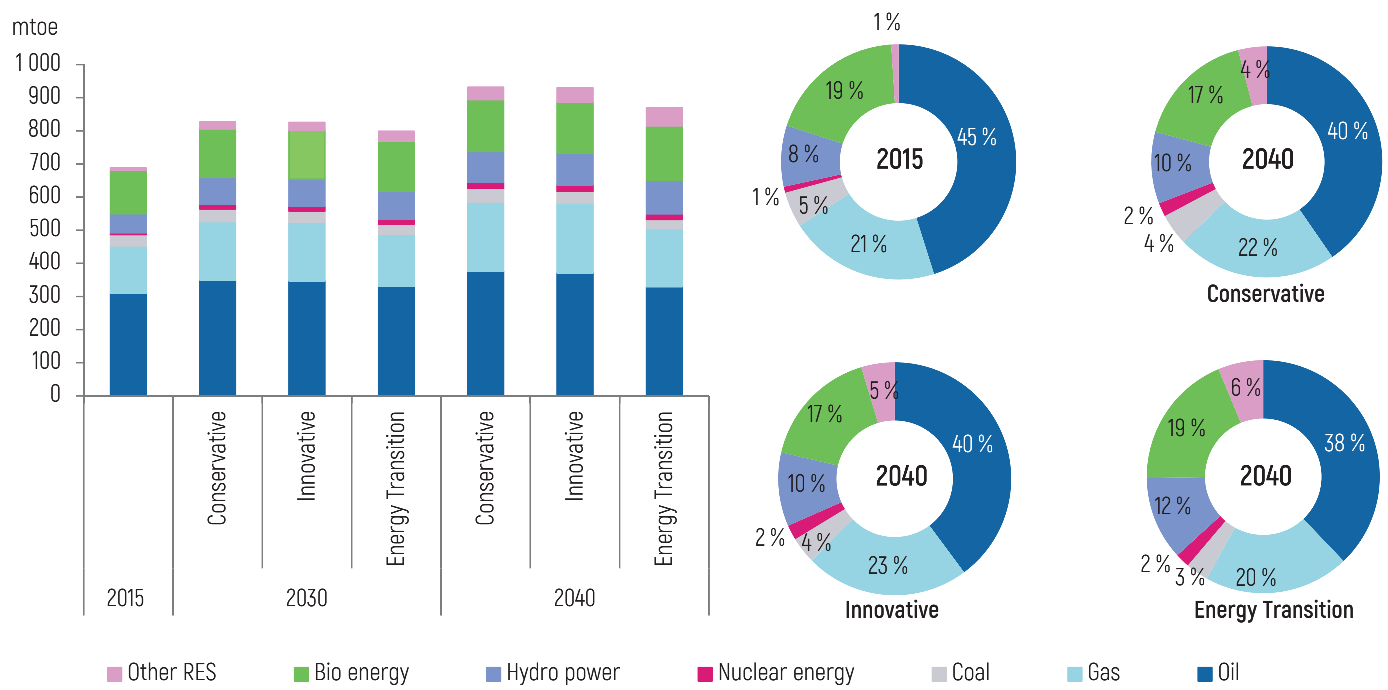
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 2219 | 2196 | 2137 | 2045 | 2162 | 2032 | 1984 | -0.1% | -0.4% | -0.4% |
| Oil | 830 | 775 | 722 | 665 | 731 | 622 | 603 | -0.5% | -1.1% | -1.3% |
| Gas | 646 | 682 | 692 | 653 | 693 | 724 | 675 | 0.3% | 0.5% | 0.2% |
| Coal | 374 | 314 | 261 | 230 | 276 | 183 | 134 | -1.2% | -2.8% | -4.0% |
| Nuclear energy | 216 | 201 | 201 | 196 | 186 | 188 | 183 | -0.6% | -0.6% | -0.7% |
| Hydro power | 22 | 27 | 27 | 27 | 28 | 29 | 30 | 1.1% | 1.2% | 1.3% |
| Bio energy | 99 | 116 | 128 | 127 | 135 | 147 | 148 | 1.2% | 1.6% | 1.6% |
| Other RES | 31 | 81 | 106 | 146 | 113 | 138 | 211 | 5.3% | 6.1% | 7.9% |

### Table A2.9 - Electric power generation, USA, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 4297 | 4783 | 4923 | 5074 | 5063 | 4965 | 5376 | 0.7% | 0.6% | 0.9% |
| Oil | 39 | 12 | 10 | 15 | 5 | 4 | 2 | -7.7% | -9.0% | -11.6% |
| Gas | 1373 | 1570 | 1679 | 1549 | 1663 | 1720 | 1573 | 0.8% | 0.9% | 0.5% |
| Coal | 1471 | 1264 | 1030 | 886 | 1163 | 739 | 520 | -0.9% | -2.7% | -4.1% |
| Nuclear energy | 830 | 769 | 771 | 751 | 714 | 721 | 700 | -0.6% | -0.6% | -0.7% |
| Hydro power | 251 | 314 | 311 | 314 | 326 | 341 | 348 | 1.1% | 1.2% | 1.3% |
| Bio energy | 80 | 126 | 171 | 163 | 161 | 214 | 211 | 2.8% | 4.0% | 3.9% |
| Other RES | 253 | 728 | 951 | 1394 | 1030 | 1227 | 2023 | 5.8% | 6.5% | 8.7% |

# South and Central America

**Figure A2.4 - Primary energy consumption by fuel and its structure, by scenario, South and Central America**




Source: ERI RAS

**Table A2.10 - Main indicators of development, South and Central America**

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,09 | 0,09 | 0,09 | 0,09 | 0,08 | 0,08 | 0,08 | -0.5% | -0.5% | -0.8% |
| Per capita energy consumption, toe/capita | 1,36 | 1,45 | 1,45 | 1,40 | 1,55 | 1,55 | 1,45 | 0.5% | 0.5% | 0.3% |
| $CO_2$ emissions, mln. tonnes | 1235 | 1400 | 1378 | 1283 | 1543 | 1510 | 1304 | 0.9% | 0.8% | 0.2% |

### Table A2.11 - Consumption of primary energy resources, South and Central America, mtoe

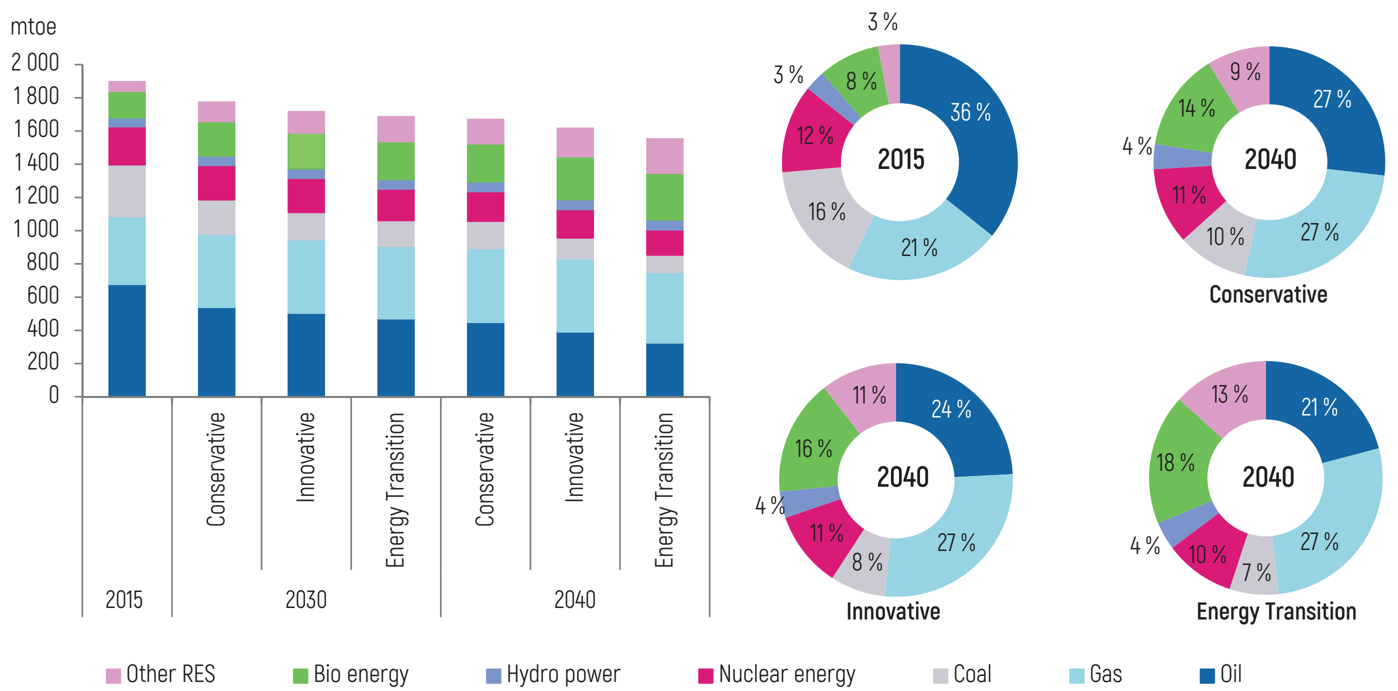
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 688 | 826 | 825 | 799 | 931 | 930 | 870 | 1.2% | 1.2% | 0.9% |
| Oil | 310 | 350 | 346 | 331 | 376 | 370 | 329 | 0.8% | 0.7% | 0.2% |
| Gas | 143 | 176 | 177 | 158 | 209 | 212 | 175 | 1.5% | 1.6% | 0.8% |
| Coal | 34 | 38 | 34 | 30 | 41 | 34 | 27 | 0.8% | 0.0% | -0.8% |
| Nuclear energy | 6 | 14 | 14 | 14 | 18 | 19 | 17 | 4.7% | 5.0% | 4.5% |
| Hydro power | 58 | 81 | 82 | 85 | 93 | 95 | 101 | 2.0% | 2.0% | 2.3% |
| Bio energy | 131 | 146 | 147 | 150 | 157 | 156 | 164 | 0.7% | 0.7% | 0.9% |
| Other RES | 7 | 20 | 25 | 30 | 37 | 43 | 55 | 7.0% | 7.6% | 8.6% |

### Table A2.12 - Electric power generation, South and Central America, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 1287 | 1725 | 1773 | 1787 | 2056 | 2135 | 2168 | 1.9% | 2.0% | 2.1% |
| Oil | 167 | 116 | 107 | 86 | 91 | 79 | 34 | -2.4% | -2.9% | -6.2% |
| Gas | 250 | 311 | 320 | 283 | 400 | 413 | 339 | 1.9% | 2.0% | 1.2% |
| Coal | 73 | 57 | 43 | 37 | 47 | 25 | 19 | -1.7% | -4.2% | -5.2% |
| Nuclear energy | 22 | 55 | 56 | 55 | 68 | 74 | 66 | 4.7% | 5.0% | 4.5% |
| Hydro power | 671 | 942 | 954 | 989 | 1087 | 1107 | 1177 | 2.0% | 2.0% | 2.3% |
| Bio energy | 67 | 99 | 107 | 103 | 119 | 131 | 130 | 2.3% | 2.7% | 2.7% |
| Other RES | 38 | 144 | 188 | 234 | 243 | 306 | 403 | 7.7% | 8.7% | 9.9% |

# Europe

## Figure A2.5 - Primary energy consumption by fuel and its structure, by scenario, Europe




Source: ERI RAS

## Table A2.13 - Main indicators of development, Europe

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,08 | 0,06 | 0,06 | 0,06 | 0,05 | 0,05 | 0,05 | -1.9% | -2.0% | -2.2% |
| Per capita energy consumption, toe/capita | 3,07 | 2,79 | 2,70 | 2,66 | 2,62 | 2,54 | 2,44 | -0.6% | -0.8% | -0.9% |
| $CO_2$ emissions, mln. tonnes | 3809 | 3073 | 2831 | 2700 | 2684 | 2387 | 2115 | -1.4% | -1.9% | -2.3% |

### Table A2.14 - Consumption of primary energy resources, Europe, mtoe

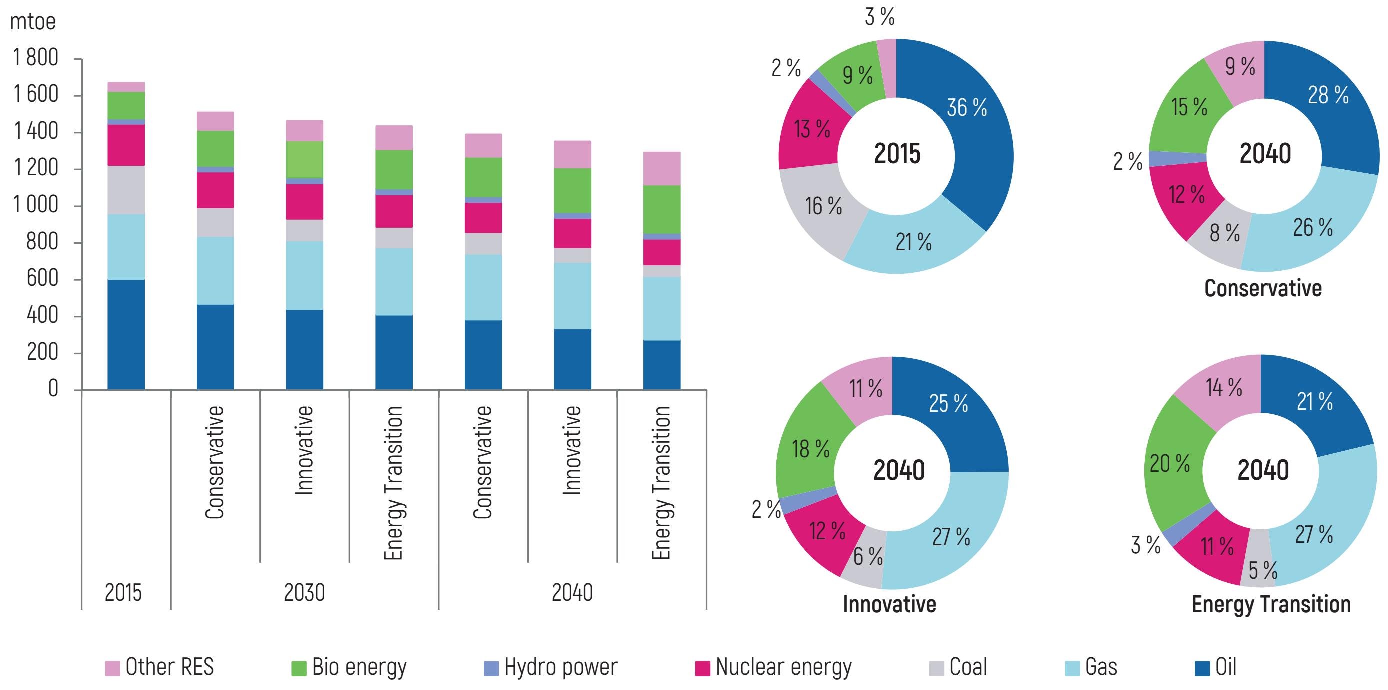
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 1897 | 1773 | 1716 | 1686 | 1670 | 1616 | 1552 | -0.5% | -0.6% | -0.8% |
| Oil | 678 | 539 | 504 | 470 | 448 | 391 | 325 | -1.6% | -2.2% | -2.9% |
| Gas | 407 | 440 | 443 | 437 | 444 | 441 | 424 | 0.4% | 0.3% | 0.2% |
| Coal | 312 | 208 | 164 | 154 | 165 | 124 | 105 | -2.5% | -3.6% | -4.3% |
| Nuclear energy | 230 | 207 | 205 | 189 | 178 | 171 | 151 | -1.0% | -1.2% | -1.6% |
| Hydro power | 54 | 57 | 57 | 58 | 59 | 59 | 60 | 0.4% | 0.4% | 0.5% |
| Bio energy | 160 | 208 | 215 | 228 | 229 | 259 | 280 | 1.4% | 1.9% | 2.3% |
| Other RES | 57 | 115 | 127 | 149 | 147 | 170 | 206 | 3.9% | 4.5% | 5.3% |

### Table A2.15 - Electric power generation, Europe, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 3763 | 4194 | 4227 | 4450 | 4418 | 4632 | 4940 | -2.0% | -5.6% | -5.9% |
| Oil | 64 | 22 | 24 | 28 | 12 | 4 | 4 | -6.6% | -10.3% | -10.6% |
| Gas | 600 | 857 | 854 | 890 | 1026 | 1053 | 1052 | 2.2% | 2.3% | 2.3% |
| Coal | 944 | 569 | 441 | 404 | 414 | 283 | 211 | -3.2% | -4.7% | -5.8% |
| Nuclear energy | 880 | 792 | 787 | 724 | 683 | 655 | 580 | -1.0% | -1.2% | -1.7% |
| Hydro power | 623 | 662 | 666 | 674 | 681 | 688 | 702 | 0.4% | 0.4% | 0.5% |
| Bio energy | 206 | 293 | 325 | 361 | 336 | 412 | 469 | 2.0% | 2.8% | 3.4% |
| Other RES | 446 | 1000 | 1130 | 1369 | 1265 | 1537 | 1922 | 4.3% | 5.1% | 6.0% |

# EU-28

## Figure A2.6 - Primary energy consumption by fuel and its structure, by scenario, EU-28




Source: ERI RAS

## Table A2.16 - Main indicators of development, EU-28

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,09 | 0,06 | 0,06 | 0,06 | 0,05 | 0,05 | 0,05 | -2.0% | -2.1% | -2.3% |
| Per capita energy consumption, toe/capita | 3,29 | 2,94 | 2,85 | 2,80 | 2,72 | 2,65 | 2,53 | -0.8% | -0.9% | -1.0% |
| $CO_2$ emissions, mln. tonnes | 3324 | 2555 | 2352 | 2237 | 2162 | 1914 | 1668 | -1.7% | -2.2% | -2.7% |

**Table A2.17 - Consumption of primary energy resources, EU-28, mtoe**

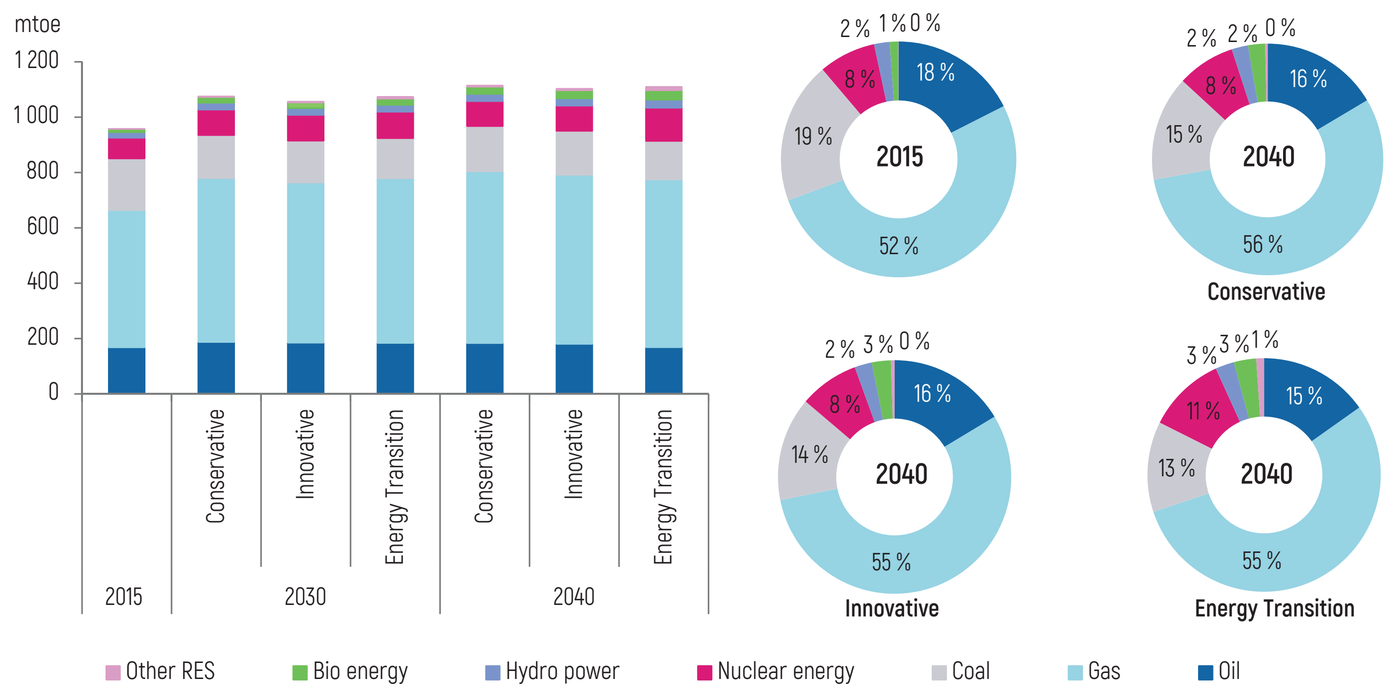
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 1672 | 1510 | 1463 | 1435 | 1390 | 1352 | 1292 | -0.7% | -0.8% | -1.0% |
| Oil | 604 | 469 | 440 | 411 | 384 | 336 | 274 | -1.8% | -2.3% | -3.1% |
| Gas | 358 | 368 | 373 | 366 | 358 | 361 | 345 | 0.0% | 0.0% | -0.1% |
| Coal | 263 | 157 | 118 | 112 | 117 | 80 | 64 | -3.2% | -4.6% | -5.5% |
| Nuclear energy | 223 | 194 | 193 | 176 | 164 | 159 | 139 | -1.2% | -1.4% | -1.9% |
| Hydro power | 29 | 31 | 31 | 32 | 31 | 32 | 32 | 0.2% | 0.3% | 0.4% |
| Bio energy | 149 | 195 | 202 | 214 | 215 | 243 | 263 | 1.5% | 2.0% | 2.3% |
| Other RES | 46 | 96 | 105 | 126 | 122 | 142 | 175 | 4.0% | 4.7% | 5.5% |

**Table A2.18 - Electric power generation, EU-28, TWh**

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 3204 | 3454 | 3495 | 3687 | 3578 | 3805 | 4071 | 0.4% | 0.7% | 1.0% |
| Oil | 61 | 21 | 24 | 27 | 11 | 4 | 4 | -6.5% | -10.2% | -10.5% |
| Gas | 497 | 680 | 697 | 726 | 799 | 870 | 867 | 1.9% | 2.3% | 2.3% |
| Coal | 826 | 452 | 346 | 312 | 318 | 203 | 137 | -3.7% | -5.5% | -6.9% |
| Nuclear energy | 857 | 743 | 738 | 675 | 627 | 608 | 533 | -1.2% | -1.4% | -1.9% |
| Hydro power | 341 | 360 | 365 | 369 | 362 | 369 | 376 | 0.2% | 0.3% | 0.4% |
| Bio energy | 201 | 284 | 313 | 347 | 324 | 393 | 446 | 1.9% | 2.7% | 3.2% |
| Other RES | 421 | 913 | 1013 | 1231 | 1137 | 1358 | 1709 | 4.1% | 4.8% | 5.8% |

# CIS

## Figure A2.7 - Primary energy consumption by fuel and its structure, by scenario, CIS




Source: ERI RAS

## Table A2.19 - Main indicators of development, CIS

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,18 | 0,15 | 0,14 | 0,14 | 0,13 | 0,13 | 0,11 | -1.4% | -1.4% | -2.1% |
| Per capita energy consumption, toe/capita | 3,35 | 3,57 | 3,50 | 3,55 | 3,69 | 6,99 | 3,66 | 0.4% | 3.0% | 0.4% |
| $CO_2$ emissions, mln. tonnes | 2222 | 2337 | 2286 | 2297 | 2401 | 2356 | 2244 | 0.3% | 0.2% | 0.0% |

### Table A2.20 - Consumption of primary energy resources, CIS, mtoe

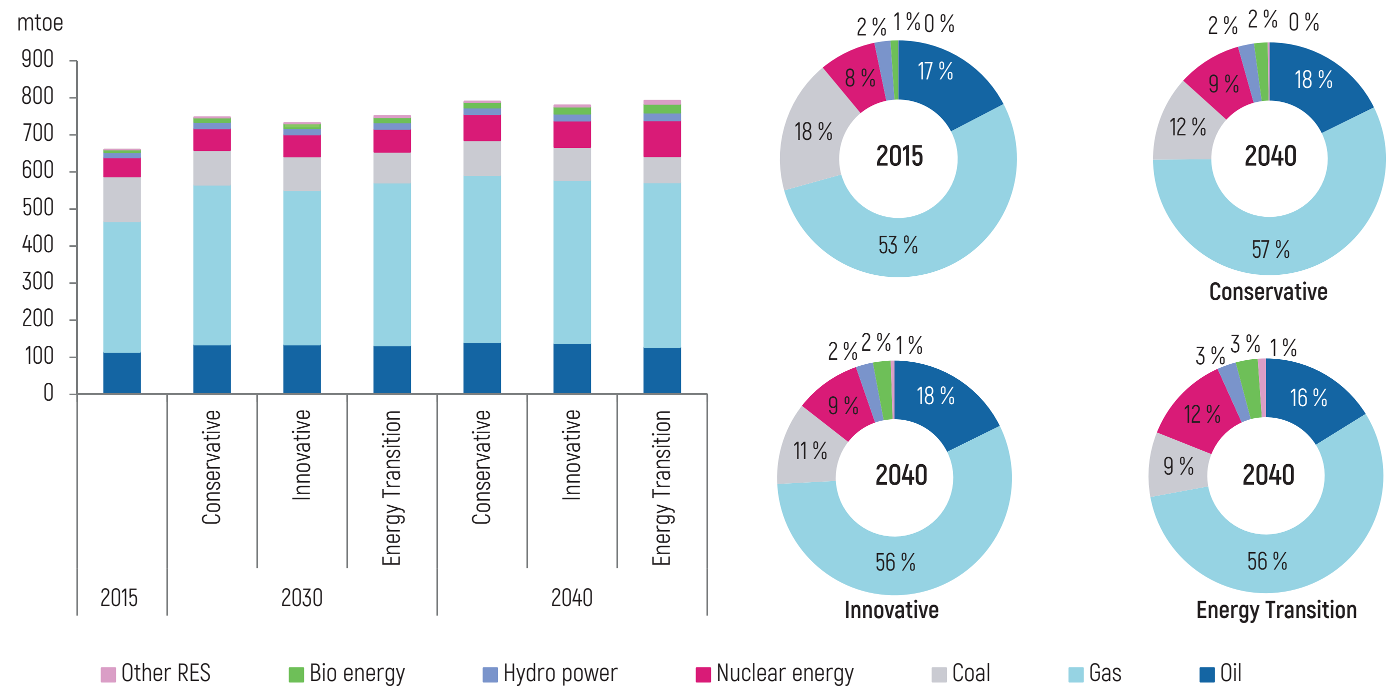
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 958 | 1075 | 1056 | 1073 | 1114 | 1103 | 1109 | 0.6% | 0.6% | 0.6% |
| Oil | 168 | 187 | 185 | 184 | 184 | 181 | 169 | 0.4% | 0.3% | 0.0% |
| Gas | 496 | 592 | 579 | 595 | 621 | 612 | 607 | 0.9% | 0.8% | 0.8% |
| Coal | 186 | 155 | 151 | 145 | 164 | 159 | 139 | -0.5% | -0.6% | -1.2% |
| Nuclear energy | 75 | 93 | 93 | 95 | 90 | 91 | 120 | 0.8% | 0.8% | 1.9% |
| Hydro power | 20 | 25 | 25 | 25 | 26 | 27 | 29 | 0.9% | 1.1% | 1.4% |
| Bio energy | 12 | 21 | 21 | 23 | 27 | 29 | 34 | 3.4% | 3.8% | 4.5% |
| Other RES | 0 | 2 | 3 | 6 | 4 | 5 | 12 | 10.1% | 11.9% | 15.4% |

### Table A2.21 - Electric power generation, CIS, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 1530 | 1799 | 1802 | 1879 | 1953 | 1937 | 2188 | 1.0% | 0.9% | 1.4% |
| Oil | 14 | 4 | 6 | 6 | 2 | 1 | 1 | -7.6% | -11.5% | -11.5% |
| Gas | 670 | 807 | 818 | 869 | 901 | 898 | 959 | 1.2% | 1.2% | 1.4% |
| Coal | 316 | 319 | 306 | 293 | 346 | 333 | 305 | 0.4% | 0.2% | -0.1% |
| Nuclear energy | 286 | 355 | 355 | 365 | 346 | 346 | 460 | 0.8% | 0.8% | 1.9% |
| Hydro power | 237 | 287 | 287 | 292 | 303 | 304 | 336 | 1.0% | 1.0% | 1.4% |
| Bio energy | 3 | 7 | 7 | 11 | 9 | 10 | 28 | 4.4% | 4.7% | 9.4% |
| Other RES | 3 | 21 | 23 | 43 | 46 | 46 | 100 | 11.4% | 11.5% | 15.0% |

# Russia

## Figure A2.8 - Primary energy consumption by fuel and its structure, by scenario, Russia




Source: ERI RAS

## Table A2.22 - Main indicators of development, Russia

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,18 | 0,15 | 0,15 | 0,14 | 0,14 | 0,13 | 0,11 | -1.0% | -1.1% | -2.0% |
| Per capita energy consumption, toe/capita | 4,59 | 5,05 | 4,94 | 5,08 | 5,38 | 5,28 | 5,44 | 0.6% | 0.6% | 0.7% |
| $CO_2$ emissions, mln. tonnes | 1521 | 1623 | 1581 | 1603 | 1651 | 1609 | 1546 | 0.3% | 0.2% | 0.1% |

## Table A2.23 - Consumption of primary energy resources, Russia, mtoe

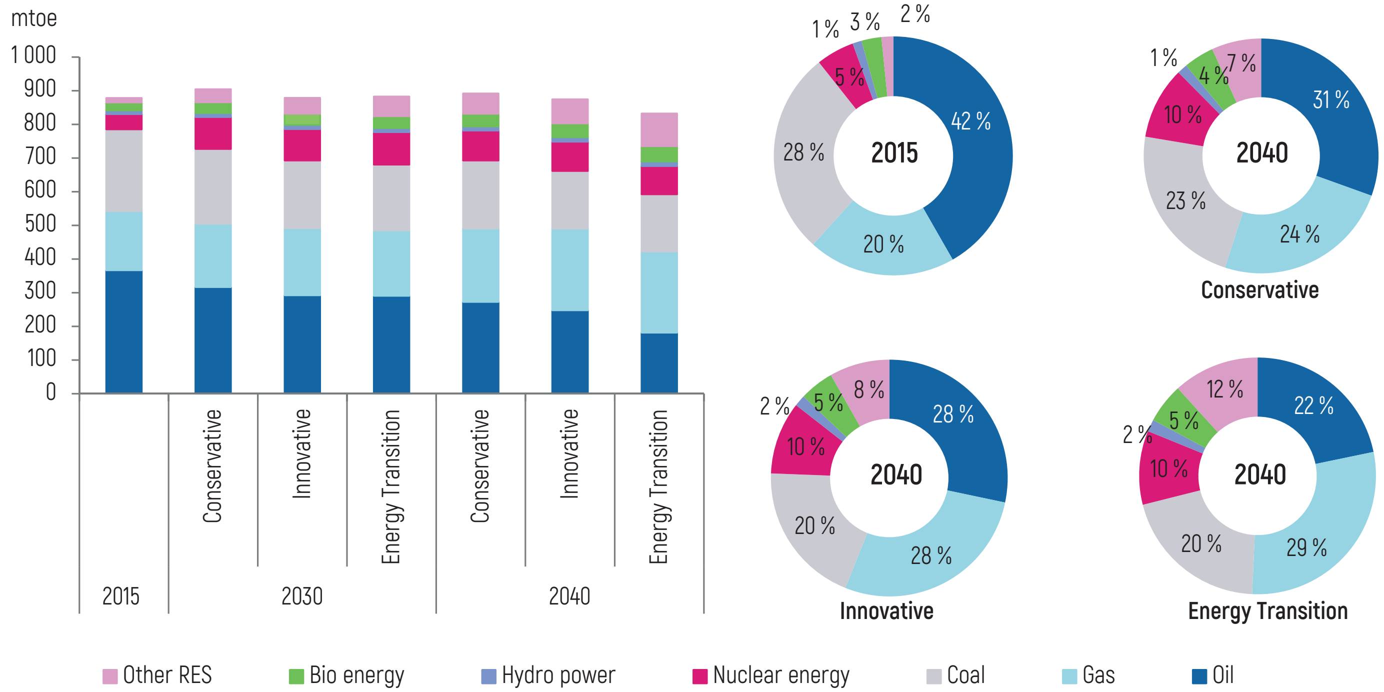
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 660 | 748 | 733 | 751 | 790 | 780 | 792 | 0.7% | 0.7% | 0.7% |
| Oil | 115 | 134 | 134 | 132 | 140 | 138 | 128 | 0.8% | 0.7% | 0.4% |
| Gas | 352 | 431 | 417 | 439 | 452 | 440 | 443 | 1.0% | 0.9% | 0.9% |
| Coal | 121 | 93 | 91 | 83 | 93 | 89 | 71 | -1.0% | -1.2% | -2.1% |
| Nuclear energy | 51 | 59 | 59 | 62 | 71 | 71 | 97 | 1.3% | 1.3% | 2.6% |
| Hydro power | 14 | 17 | 17 | 18 | 18 | 19 | 21 | 0.8% | 1.0% | 1.4% |
| Bio energy | 7 | 12 | 13 | 14 | 15 | 19 | 24 | 3.2% | 4.1% | 5.1% |
| Other RES | 0 | 1 | 2 | 4 | 2 | 4 | 9 | 10.5% | 13.8% | 17.5% |

## Table A2.24 - Electric power generation, Russia, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 1068 | 1241 | 1241 | 1307 | 1354 | 1333 | 1556 | 1.0% | 0.9% | 1.5% |
| Oil | 10 | 3 | 4 | 4 | 1 | 0 | 0 | -7.7% | -11.6% | -11.6% |
| Gas | 509 | 615 | 619 | 679 | 652 | 642 | 711 | 1.0% | 0.9% | 1.3% |
| Coal | 180 | 182 | 174 | 153 | 188 | 173 | 143 | 0.2% | -0.1% | -0.9% |
| Nuclear energy | 195 | 224 | 224 | 237 | 270 | 270 | 371 | 1.3% | 1.3% | 2.6% |
| Hydro power | 170 | 200 | 200 | 204 | 210 | 210 | 240 | 0.9% | 0.9% | 1.4% |
| Bio energy | 2 | 5 | 6 | 10 | 6 | 8 | 26 | 3.8% | 4.6% | 9.9% |
| Other RES | 1 | 11 | 13 | 21 | 25 | 30 | 64 | 14.8% | 15.6% | 19.2% |

# Developed countries of Asia

### Figure A2.9 - Primary energy consumption by fuel and its structure, by scenario, Developed countries of Asia




Source: ERI RAS

### Table A2.25 - Main indicators of development, Developed countries of Asia

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,10 | 0,09 | 0,15 | 0,09 | 0,08 | 0,13 | 0,07 | -1.1% | 1.0% | -1.4% |
| Per capita energy consumption, toe/capita | 4,25 | 4,35 | 4,23 | 4,25 | 4,38 | 4,29 | 4,08 | 0.1% | 0.0% | -0.2% |
| $CO_2$ emissions, mln. tonnes | 2243 | 2019 | 1905 | 1870 | 1886 | 1766 | 1590 | -0.7% | -1.0% | -1.4% |

### Table A2.26 - Consumption of primary energy resources, Developed countries of Asia, mtoe

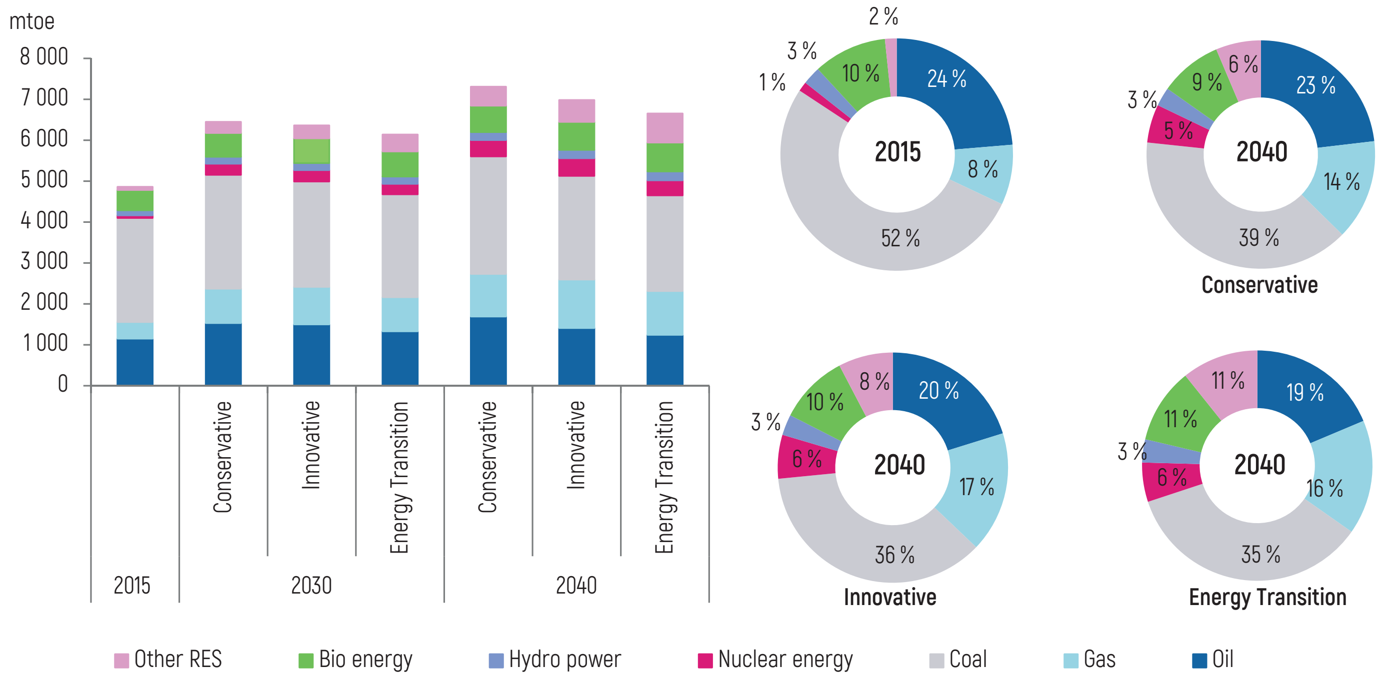
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 879 | 905 | 879 | 883 | 892 | 874 | 833 | 0.1% | 0.0% | -0.2% |
| Oil | 367 | 317 | 292 | 290 | 272 | 248 | 181 | -1.2% | -1.6% | -2.8% |
| Gas | 176 | 188 | 200 | 194 | 218 | 242 | 241 | 0.9% | 1.3% | 1.3% |
| Coal | 243 | 222 | 201 | 196 | 202 | 171 | 169 | -0.7% | -1.4% | -1.4% |
| Nuclear energy | 45 | 95 | 93 | 96 | 89 | 87 | 84 | 2.7% | 2.6% | 2.5% |
| Hydro power | 11 | 12 | 12 | 12 | 12 | 13 | 14 | 0.6% | 0.9% | 0.9% |
| Bio energy | 24 | 32 | 33 | 35 | 37 | 41 | 45 | 1.8% | 2.2% | 2.6% |
| Other RES | 14 | 39 | 48 | 59 | 61 | 72 | 98 | 6.1% | 6.8% | 8.1% |

### Table A2.27 - Electric power generation, Developed countries of Asia, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 1881 | 2204 | 2236 | 2353 | 2619 | 2663 | 2951 | 1.3% | 1.4% | 1.8% |
| Oil | 122 | 40 | 44 | 44 | 20 | 7 | 6 | -7.0% | -11.0% | -11.1% |
| Gas | 592 | 674 | 719 | 721 | 935 | 1001 | 1045 | 1.8% | 2.1% | 2.3% |
| Coal | 740 | 660 | 570 | 557 | 693 | 559 | 568 | -0.3% | -1.1% | -1.1% |
| Nuclear energy | 174 | 363 | 357 | 369 | 340 | 333 | 322 | 2.7% | 2.6% | 2.5% |
| Hydro power | 125 | 139 | 143 | 144 | 145 | 155 | 159 | 0.6% | 0.9% | 0.9% |
| Bio energy | 49 | 55 | 62 | 69 | 65 | 80 | 98 | 1.2% | 2.0% | 2.8% |
| Other RES | 79 | 272 | 340 | 449 | 421 | 529 | 753 | 6.9% | 7.9% | 9.5% |

# The developing countries of Asia

## Figure A2.10 - Primary energy consumption by fuel and its structure, by scenario, the developing countries of Asia




Source: ERI RAS

## Table A2.28 - Main indicators of development, the developing countries of Asia

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,13 | 0,08 | 0,08 | 0,08 | 0,07 | 0,06 | 0,06 | -2.5% | -2.6% | -2.8% |
| Per capita energy consumption, toe/capita | 1,26 | 1,50 | 1,48 | 1,43 | 1,64 | 1,57 | 1,49 | 1.0% | 0.9% | 0.7% |
| $CO_2$ emissions, mln. tonnes | 13464 | 15886 | 15211 | 14388 | 16880 | 15267 | 13894 | 0.9% | 0.5% | 0.1% |

### Table A2.29 - Consumption of primary energy resources, the developing countries of Asia, mtoe

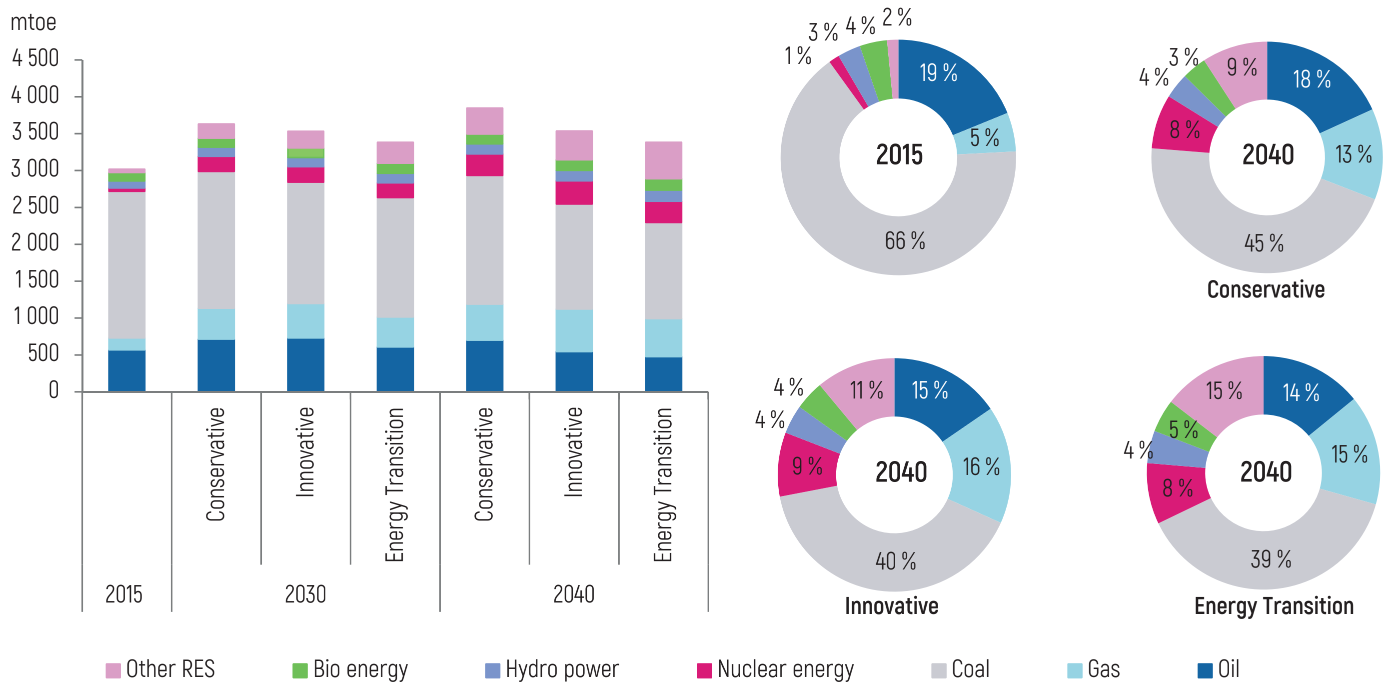
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 4862 | 6448 | 6364 | 6139 | 7309 | 6982 | 6656 | 1.6% | 1.5% | 1.3% |
| Oil | 1149 | 1530 | 1499 | 1330 | 1691 | 1409 | 1242 | 1.6% | 0.8% | 0.3% |
| Gas | 407 | 840 | 917 | 834 | 1041 | 1184 | 1071 | 3.8% | 4.4% | 3.9% |
| Coal | 2541 | 2782 | 2574 | 2514 | 2873 | 2535 | 2339 | 0.5% | 0.0% | -0.3% |
| Nuclear energy | 65 | 271 | 278 | 255 | 397 | 431 | 368 | 7.5% | 7.8% | 7.2% |
| Hydro power | 123 | 170 | 173 | 180 | 195 | 202 | 217 | 1.9% | 2.0% | 2.3% |
| Bio energy | 497 | 582 | 603 | 613 | 647 | 686 | 705 | 1.1% | 1.3% | 1.4% |
| Other RES | 79 | 273 | 320 | 413 | 466 | 535 | 714 | 7.4% | 8.0% | 9.2% |

### Table A2.30 - Electric power generation, the developing countries of Asia, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 8620 | 13858 | 13975 | 14631 | 17768 | 18148 | 19138 | 2.9% | 3.0% | 3.2% |
| Oil | 135 | 89 | 70 | 69 | 71 | 24 | 23 | -2.5% | -6.7% | -6.8% |
| Gas | 763 | 1446 | 1816 | 1681 | 1987 | 2767 | 2419 | 3.9% | 5.3% | 4.7% |
| Coal | 5623 | 7028 | 6128 | 5885 | 8194 | 6713 | 6114 | 1.5% | 0.7% | 0.3% |
| Nuclear energy | 251 | 1039 | 1066 | 977 | 1521 | 1650 | 1409 | 7.5% | 7.8% | 7.1% |
| Hydro power | 1434 | 1942 | 2010 | 2090 | 2245 | 2354 | 2524 | 1.8% | 2.0% | 2.3% |
| Bio energy | 106 | 313 | 374 | 401 | 458 | 567 | 616 | 6.0% | 6.9% | 7.3% |
| Other RES | 309 | 2001 | 2511 | 3529 | 3293 | 4075 | 6033 | 9.9% | 10.9% | 12.6% |

# China

## Figure A2.11 - Primary energy consumption by fuel and its structure, by scenario, China




Source: ERI RAS

## Table A2.31 - Main indicators of development, China

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,15 | 0,09 | 0,09 | 0,09 | 0,08 | 0,07 | 0,07 | -2.6% | -2.9% | -3.1% |
| Per capita energy consumption, toe/capita | 2,15 | 2,50 | 2,44 | 2,33 | 2,70 | 2,48 | 2,37 | 0.9% | 0.6% | 0.4% |
| $CO_2$ emissions, mln. tonnes | 9348 | 9514 | 8892 | 8362 | 9125 | 7771 | 7031 | -0.1% | -0.7% | -1.1% |

### Table A2.32 - Consumption of primary energy resources, China, mtoe

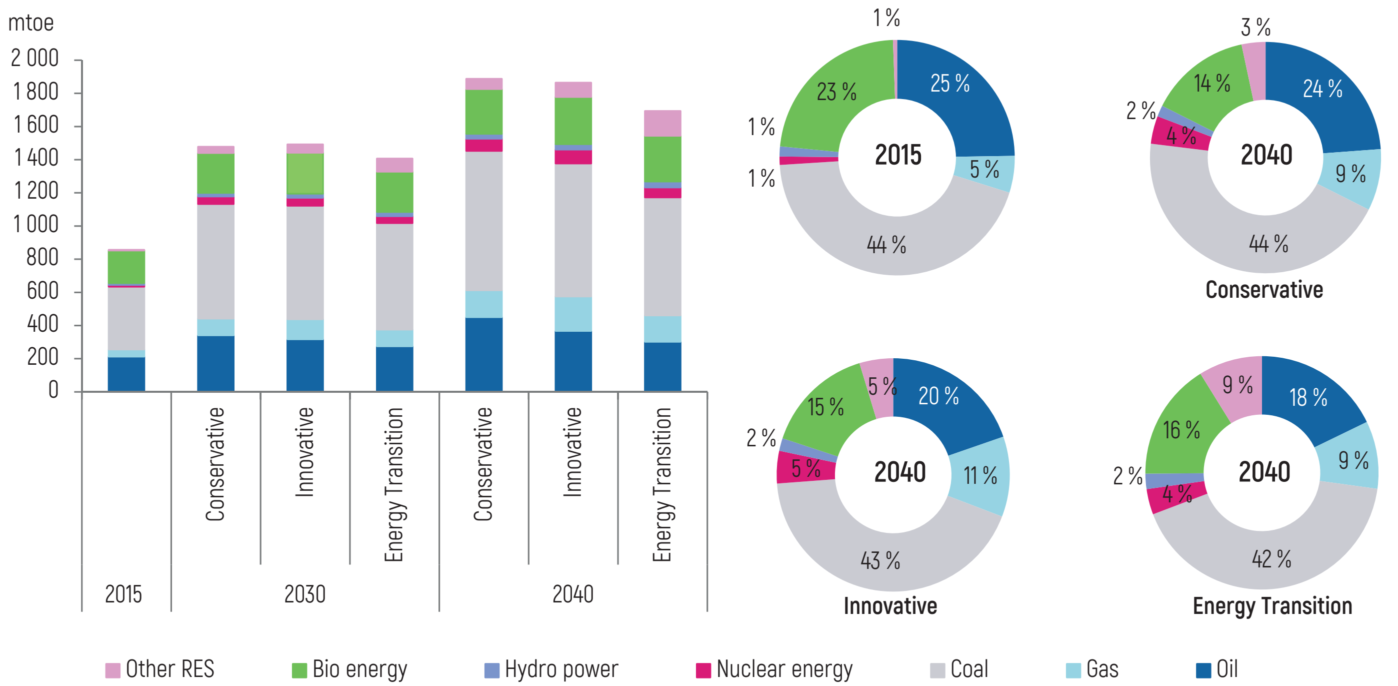
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 3019 | 3632 | 3532 | 3383 | 3847 | 3537 | 3384 | 1.0% | 0.6% | 0.5% |
| Oil | 569 | 714 | 730 | 609 | 700 | 545 | 477 | 0.8% | -0.2% | -0.7% |
| Gas | 161 | 420 | 468 | 406 | 489 | 577 | 516 | 4.5% | 5.2% | 4.8% |
| Coal | 1989 | 1853 | 1644 | 1619 | 1745 | 1424 | 1304 | -0.5% | -1.3% | -1.7% |
| Nuclear energy | 45 | 206 | 210 | 199 | 291 | 314 | 286 | 7.8% | 8.1% | 7.7% |
| Hydro power | 96 | 124 | 124 | 130 | 137 | 141 | 152 | 1.4% | 1.6% | 1.9% |
| Bio energy | 114 | 121 | 130 | 137 | 132 | 144 | 155 | 0.6% | 1.0% | 1.2% |
| Other RES | 46 | 193 | 225 | 284 | 353 | 390 | 494 | 8.5% | 8.9% | 9.9% |

### Table A2.33 - Electric power generation, China, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 5882 | 8861 | 8618 | 8986 | 11009 | 10709 | 11175 | 2.5% | 2.4% | 2.6% |
| Oil | 10 | 1 | 5 | 4 | 0 | 0 | 0 | -16.5% | -17.5% | -20.1% |
| Gas | 158 | 403 | 662 | 527 | 571 | 1088 | 790 | 5.3% | 8.0% | 6.6% |
| Coal | 4134 | 4547 | 3633 | 3444 | 4947 | 3507 | 3062 | 0.7% | -0.7% | -1.2% |
| Nuclear energy | 171 | 789 | 803 | 762 | 1116 | 1201 | 1096 | 7.8% | 8.1% | 7.7% |
| Hydro power | 1114 | 1408 | 1446 | 1506 | 1569 | 1644 | 1769 | 1.4% | 1.6% | 1.9% |
| Bio energy | 64 | 209 | 238 | 255 | 311 | 350 | 378 | 6.5% | 7.0% | 7.4% |
| Other RES | 231 | 1505 | 1832 | 2487 | 2495 | 2919 | 4079 | 10.0% | 10.7% | 12.2% |

# India

## Figure A2.12 - Primary energy consumption by fuel and its structure, by scenario, India




Source: ERI RAS

## Table A2.34 - Main indicators of development, India

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,11 | 0,07 | 0,07 | 0,07 | 0,06 | 0,06 | 0,05 | -2.3% | -2.3% | -2.7% |
| Per capita energy consumption, toe/capita | 0,65 | 0,98 | 0,99 | 0,93 | 1,18 | 1,16 | 1,06 | 2.4% | 2.3% | 1.9% |
| $CO_2$ emissions, mln. tonnes | 2074 | 3612 | 3571 | 3267 | 4516 | 4269 | 3673 | 3.2% | 2.9% | 2.3% |

### Table A2.35 - Consumption of primary energy resources, India, mtoe

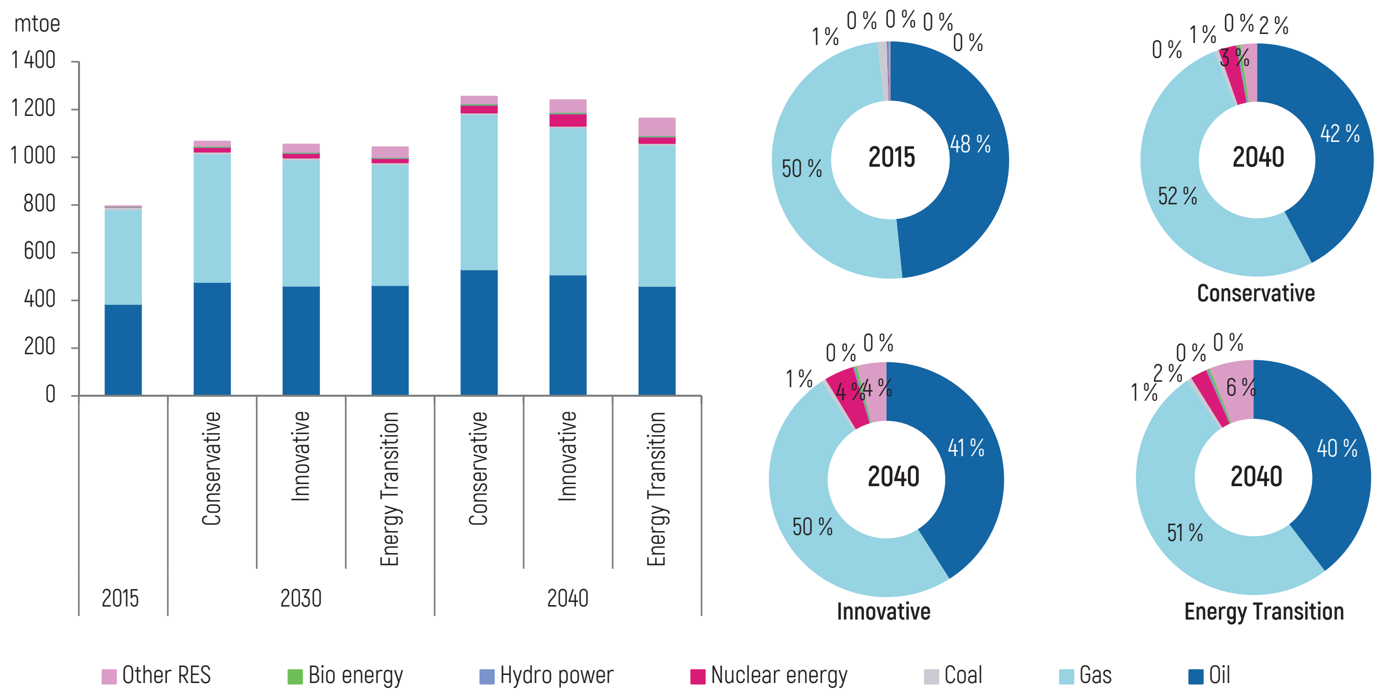
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 857 | 1479 | 1493 | 1407 | 1888 | 1865 | 1694 | 3.2% | 3.2% | 2.8% |
| Oil | 212 | 341 | 317 | 275 | 450 | 367 | 302 | 3.1% | 2.2% | 1.4% |
| Gas | 43 | 101 | 121 | 101 | 162 | 207 | 159 | 5.4% | 6.5% | 5.4% |
| Coal | 379 | 691 | 684 | 642 | 840 | 802 | 711 | 3.2% | 3.0% | 2.6% |
| Nuclear energy | 10 | 45 | 48 | 41 | 73 | 84 | 60 | 8.4% | 9.0% | 7.5% |
| Hydro power | 12 | 22 | 24 | 26 | 30 | 33 | 36 | 3.8% | 4.1% | 4.5% |
| Bio energy | 196 | 240 | 247 | 243 | 270 | 284 | 276 | 1.3% | 1.5% | 1.4% |
| Other RES | 5 | 39 | 51 | 80 | 63 | 87 | 150 | 10.8% | 12.3% | 14.7% |

### Table A2.36 - Electric power generation, India, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 1383 | 2856 | 3165 | 3286 | 4008 | 4543 | 4744 | 4.3% | 4.9% | 5.1% |
| Oil | 23 | 15 | 11 | 11 | 10 | 3 | 3 | -3.2% | -7.4% | -7.7% |
| Gas | 68 | 136 | 262 | 186 | 202 | 493 | 309 | 4.5% | 8.2% | 6.2% |
| Coal | 1042 | 1777 | 1761 | 1642 | 2370 | 2229 | 1949 | 3.3% | 3.1% | 2.5% |
| Nuclear energy | 37 | 172 | 183 | 157 | 281 | 323 | 230 | 8.4% | 9.0% | 7.5% |
| Hydro power | 138 | 255 | 285 | 301 | 347 | 381 | 419 | 3.8% | 4.1% | 4.5% |
| Bio energy | 27 | 68 | 85 | 81 | 97 | 131 | 123 | 5.3% | 6.6% | 6.3% |
| Other RES | 48 | 432 | 579 | 908 | 701 | 983 | 1711 | 11.3% | 12.8% | 15.3% |

# The Middle East

## Figure A2.13 - Primary energy consumption by fuel and its structure, by scenario, the Middle East




Source: ERI RAS

## Table A2.37 - Main indicators of development, the Middle East

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,14 | 0,13 | 0,13 | 0,12 | 0,12 | 0,12 | 0,11 | -0.6% | -0.6% | -0.9% |
| Per capita energy consumption, toe/capita | 3,29 | 3,49 | 3,45 | 3,41 | 3,66 | 3,62 | 3,40 | 0.4% | 0.4% | 0.1% |
| $CO_2$ emissions, mln. tonnes | 1891 | 2403 | 2343 | 2300 | 2738 | 2612 | 2437 | 1.5% | 1.3% | 1.0% |

### Table A2.38 - Consumption of primary energy resources, the Middle East, mtoe

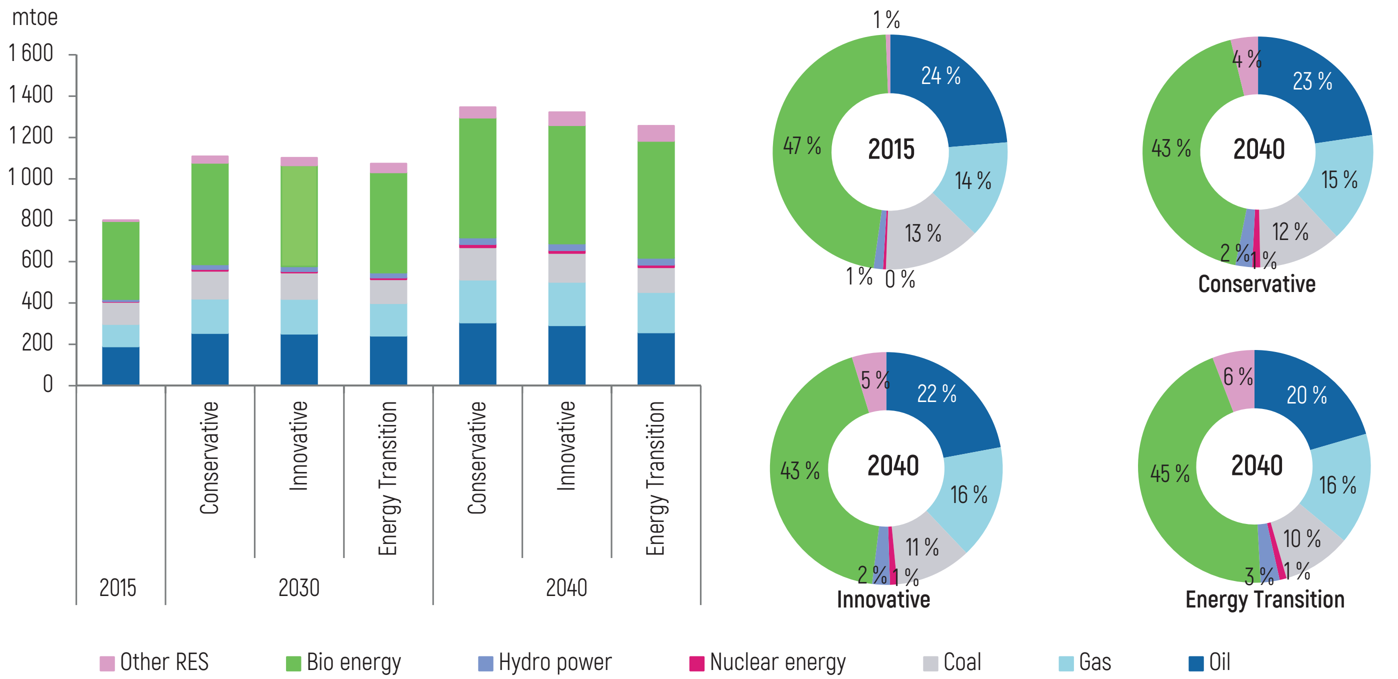
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 795 | 1066 | 1053 | 1042 | 1254 | 1239 | 1163 | 1.8% | 1.8% | 1.5% |
| Oil | 385 | 477 | 461 | 464 | 530 | 508 | 461 | 1.3% | 1.1% | 0.7% |
| Gas | 397 | 537 | 528 | 506 | 650 | 616 | 591 | 2.0% | 1.8% | 1.6% |
| Coal | 10 | 9 | 8 | 8 | 7 | 7 | 7 | -1.1% | -1.3% | -1.3% |
| Nuclear energy | 1 | 19 | 19 | 18 | 31 | 51 | 27 | 16.1% | 18.3% | 15.3% |
| Hydro power | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 2.4% | 2.4% | 2.5% |
| Bio energy | 1 | 3 | 3 | 3 | 5 | 4 | 3 | 7.1% | 6.1% | 5.5% |
| Other RES | 1 | 18 | 31 | 41 | 28 | 50 | 71 | 15.7% | 18.4% | 20.0% |

### Table A2.39 - Electric power generation, the Middle East, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 1111 | 1666 | 1675 | 1671 | 2075 | 2092 | 2084 | 2.5% | 2.6% | 2.5% |
| Oil | 322 | 267 | 226 | 183 | 265 | 188 | 88 | -0.8% | -2.1% | -5.0% |
| Gas | 737 | 1185 | 1100 | 1029 | 1480 | 1246 | 1187 | 2.8% | 2.1% | 1.9% |
| Coal | 30 | 9 | 6 | 5 | 1 | 1 | 0 | -12.4% | -14.7% | -15.6% |
| Nuclear energy | 3 | 72 | 72 | 67 | 120 | 194 | 102 | 16.0% | 18.3% | 15.3% |
| Hydro power | 18 | 28 | 28 | 28 | 32 | 32 | 32 | 2.4% | 2.4% | 2.5% |
| Bio energy | 0 | 8 | 8 | 6 | 13 | 10 | 9 | 22.3% | 21.0% | 20.3% |
| Other RES | 2 | 96 | 233 | 352 | 163 | 421 | 665 | 19.8% | 24.5% | 26.8% |

# Africa

## Figure A2.14 - Primary energy consumption by fuel and its structure, by scenario, Africa




Source: ERI RAS

## Table A2.40 - Main indicators of development, Africa

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,14 | 0,12 | 0,12 | 0,11 | 0,10 | 0,10 | 0,09 | -1.2% | -1.3% | -1.5% |
| Per capita energy consumption, toe/capita | 0,67 | 0,65 | 0,65 | 0,63 | 0,64 | 0,63 | 0,60 | -0.2% | -0.2% | -0.5% |
| $CO_2$ emissions, mln. tonnes | 1128 | 1494 | 1466 | 1373 | 1780 | 1692 | 1501 | 1.8% | 1.6% | 1.1% |

### Table A2.41 - Consumption of primary energy resources, Africa, mtoe

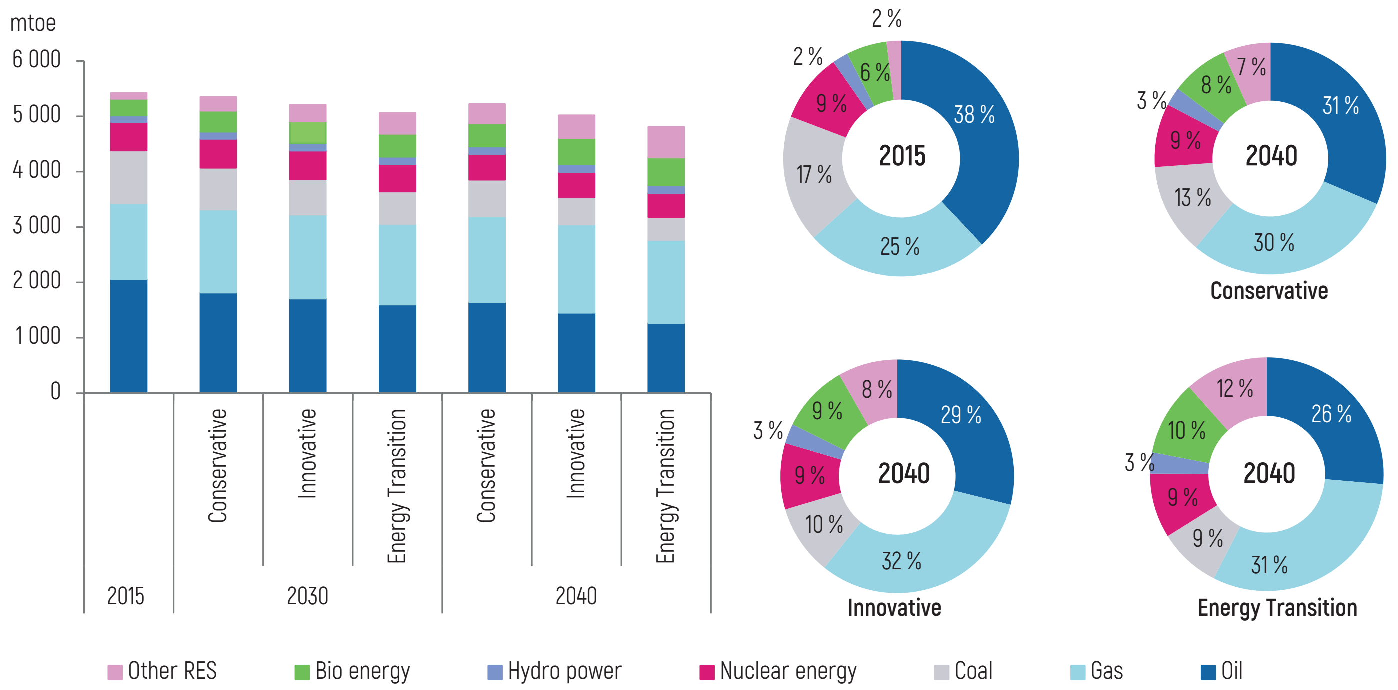
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 800 | 1109 | 1102 | 1074 | 1347 | 1323 | 1257 | 2.1% | 2.0% | 1.8% |
| Oil | 189 | 254 | 251 | 241 | 305 | 292 | 257 | 1.9% | 1.7% | 1.2% |
| Gas | 108 | 166 | 168 | 157 | 207 | 210 | 195 | 2.6% | 2.7% | 2.4% |
| Coal | 107 | 134 | 128 | 116 | 157 | 140 | 120 | 1.5% | 1.1% | 0.5% |
| Nuclear energy | 3 | 8 | 6 | 8 | 15 | 13 | 12 | 6.5% | 5.8% | 5.5% |
| Hydro power | 10 | 23 | 24 | 24 | 32 | 33 | 33 | 4.6% | 4.7% | 4.8% |
| Bio energy | 377 | 491 | 488 | 485 | 580 | 572 | 565 | 1.7% | 1.7% | 1.6% |
| Other RES | 5 | 31 | 37 | 43 | 51 | 63 | 73 | 9.9% | 10.8% | 11.5% |

### Table A2.42 - Electric power generation, Africa, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 781 | 1360 | 1405 | 1407 | 1847 | 1907 | 1933 | 3.5% | 3.6% | 3.7% |
| Oil | 88 | 91 | 82 | 80 | 94 | 77 | 73 | 0.3% | -0.6% | -0.8% |
| Gas | 285 | 549 | 555 | 510 | 780 | 772 | 711 | 4.1% | 4.1% | 3.7% |
| Coal | 257 | 291 | 270 | 243 | 311 | 255 | 222 | 0.8% | 0.0% | -0.6% |
| Nuclear energy | 12 | 32 | 23 | 32 | 59 | 50 | 47 | 6.5% | 5.8% | 5.5% |
| Hydro power | 121 | 267 | 275 | 278 | 367 | 380 | 388 | 4.6% | 4.7% | 4.8% |
| Bio energy | 2 | 15 | 21 | 23 | 40 | 46 | 50 | 12.9% | 13.6% | 14.0% |
| Other RES | 16 | 113 | 178 | 241 | 197 | 328 | 442 | 10.5% | 12.8% | 14.1% |

# OECD countries

## Figure A2.15 - Primary energy consumption by fuel and its structure, by scenario, OECD countries




Source: ERI RAS

## Table A2.43 - Main indicators of development, OECD countries

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,10 | 0,08 | 0,08 | 0,07 | 0,07 | 0,06 | 0,06 | -1.7% | -1.9% | -2.0% |
| Per capita energy consumption, toe/capita | 4,23 | 3,90 | 3,80 | 3,69 | 3,71 | 3,57 | 3,42 | -0.5% | -0.7% | -0.8% |
| $CO_2$ emissions, mln. tonnes | 11874 | 10598 | 9923 | 9341 | 9872 | 8861 | 7926 | -0.7% | -1.2% | -1.6% |

### Table A2.44 - Consumption of primary energy resources, OECD countries, mtoe

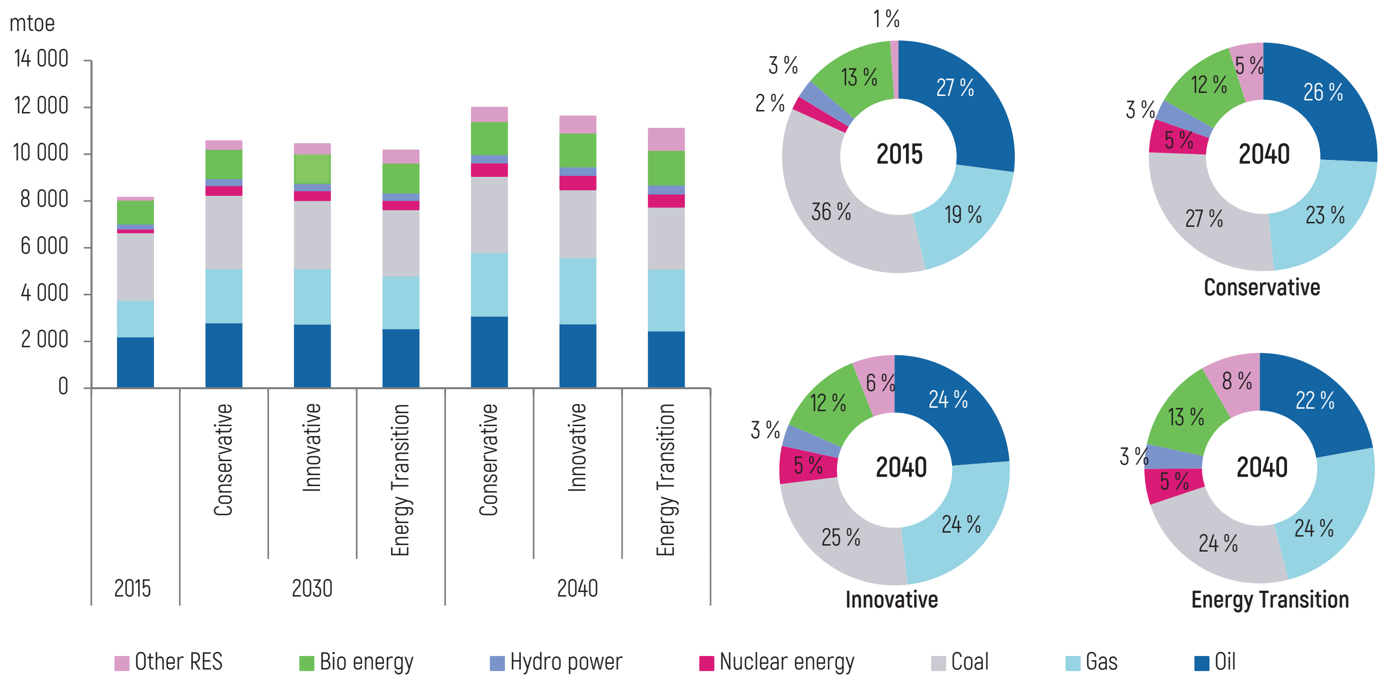
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 5424 | 5352 | 5211 | 5063 | 5222 | 5019 | 4811 | -0.2% | -0.3% | -0.5% |
| Oil | 2060 | 1815 | 1708 | 1600 | 1641 | 1452 | 1268 | -0.9% | -1.4% | -1.9% |
| Gas | 1374 | 1500 | 1518 | 1453 | 1551 | 1595 | 1498 | 0.5% | 0.6% | 0.3% |
| Coal | 948 | 755 | 634 | 587 | 663 | 487 | 414 | -1.4% | -2.6% | -3.3% |
| Nuclear energy | 514 | 522 | 519 | 496 | 464 | 460 | 432 | -0.4% | -0.4% | -0.7% |
| Hydro power | 119 | 131 | 132 | 133 | 135 | 138 | 141 | 0.5% | 0.6% | 0.7% |
| Bio energy | 301 | 377 | 399 | 414 | 422 | 473 | 501 | 1.4% | 1.8% | 2.1% |
| Other RES | 108 | 251 | 301 | 380 | 345 | 414 | 557 | 4.7% | 5.5% | 6.8% |

### Table A2.45 - Electric power generation, OECD countries, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 10858 | 12286 | 12515 | 12990 | 13322 | 13571 | 14547 | 0.8% | 0.9% | 1.2% |
| Oil | 261 | 87 | 93 | 100 | 44 | 18 | 14 | -6.9% | -10.1% | -11.0% |
| Gas | 2847 | 3539 | 3678 | 3524 | 4101 | 4264 | 4027 | 1.5% | 1.6% | 1.4% |
| Coal | 3228 | 2517 | 2046 | 1846 | 2306 | 1573 | 1280 | -1.3% | -2.8% | -3.6% |
| Nuclear energy | 1971 | 1997 | 1988 | 1899 | 1779 | 1761 | 1657 | -0.4% | -0.4% | -0.7% |
| Hydro power | 1381 | 1524 | 1529 | 1547 | 1575 | 1607 | 1639 | 0.5% | 0.6% | 0.7% |
| Bio energy | 354 | 499 | 582 | 625 | 595 | 743 | 826 | 2.1% | 3.0% | 3.5% |
| Other RES | 818 | 2122 | 2598 | 3449 | 2922 | 3605 | 5104 | 5.2% | 6.1% | 7.6% |

# Non-OECD countries

**Figure A2.16 - Primary energy consumption by fuel and its structure, by scenario, non-OECD countries**




Source: ERI RAS

**Table A2.46 - Main indicators of development, non-OECD countries**

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,13 | 0,09 | 0,09 | 0,09 | 0,08 | 0,08 | 0,07 | -2.0% | -2.1% | -2.3% |
| Per capita energy consumption, toe/capita | 1,34 | 1,47 | 1,45 | 1,41 | 1,54 | 1,49 | 1,42 | 0.6% | 0.4% | 0.2% |
| $CO_2$ emissions, mln. tonnes | 20018 | 23601 | 22759 | 21716 | 25391 | 23501 | 21446 | 1.0% | 0.6% | 0.3% |

### Table A2.47 - Consumption of primary energy resources, non-OECD countries, mtoe

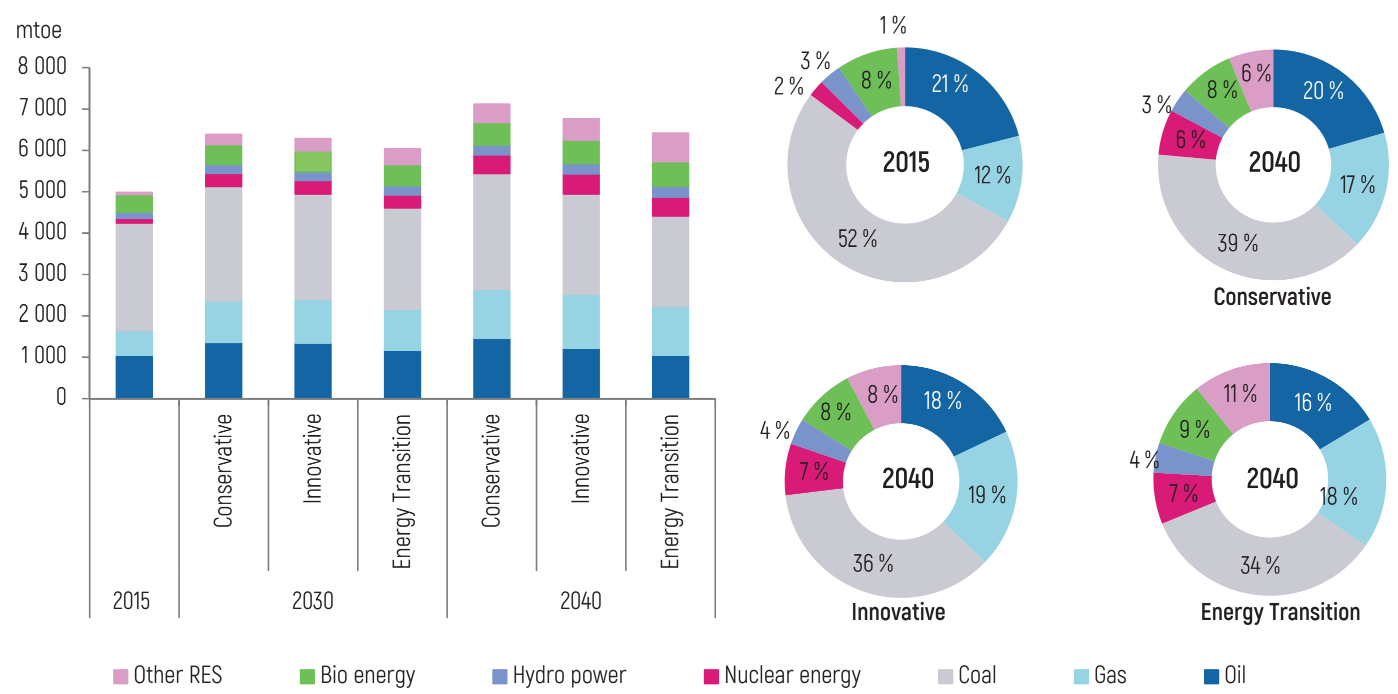
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 8142 | 10562 | 10436 | 10162 | 11992 | 11615 | 11093 | 1.6% | 1.4% | 1.2% |
| Oil | 2207 | 2803 | 2745 | 2551 | 3088 | 2760 | 2456 | 1.4% | 0.9% | 0.4% |
| Gas | 1558 | 2314 | 2373 | 2256 | 2726 | 2836 | 2645 | 2.3% | 2.4% | 2.1% |
| Coal | 2891 | 3137 | 2912 | 2830 | 3254 | 2891 | 2648 | 0.5% | 0.0% | -0.4% |
| Nuclear energy | 157 | 414 | 419 | 399 | 569 | 619 | 559 | 5.3% | 5.6% | 5.2% |
| Hydro power | 216 | 304 | 308 | 319 | 351 | 362 | 386 | 2.0% | 2.1% | 2.4% |
| Bio energy | 1021 | 1245 | 1264 | 1277 | 1419 | 1451 | 1478 | 1.3% | 1.4% | 1.5% |
| Other RES | 92 | 345 | 415 | 530 | 585 | 695 | 921 | 7.7% | 8.4% | 9.6% |

### Table A2.48 - Electric power generation, non-OECD countries, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 13392 | 20449 | 20683 | 21438 | 25723 | 26271 | 27571 | 2.6% | 2.7% | 2.9% |
| Oil | 729 | 568 | 492 | 426 | 522 | 368 | 219 | -1.3% | -2.7% | -4.7% |
| Gas | 2676 | 4224 | 4549 | 4325 | 5450 | 6028 | 5571 | 2.9% | 3.3% | 3.0% |
| Coal | 6326 | 7757 | 6806 | 6517 | 8937 | 7377 | 6714 | 1.4% | 0.6% | 0.2% |
| Nuclear energy | 601 | 1585 | 1604 | 1529 | 2179 | 2369 | 2138 | 5.3% | 5.6% | 5.2% |
| Hydro power | 2509 | 3497 | 3584 | 3708 | 4065 | 4208 | 4489 | 1.9% | 2.1% | 2.4% |
| Bio energy | 174 | 439 | 517 | 546 | 637 | 764 | 837 | 5.3% | 6.1% | 6.5% |
| Other RES | 378 | 2379 | 3131 | 4387 | 3934 | 5157 | 7604 | 9.8% | 11.0% | 12.8% |

# The BRICS countries

## Figure A2.17 - Primary energy consumption by fuel and its structure, by scenario, the BRICS countries




Source: ERI RAS

## Table A2.49 - Main indicators of development, the BRICS countries

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,14 | 0,09 | 0,09 | 0,09 | 0,08 | 0,07 | 0,07 | -2.3% | -2.5% | -2.8% |
| Per capita energy consumption, toe/capita | 1,60 | 1,88 | 1,85 | 1,78 | 2,05 | 1,94 | 1,84 | 1.0% | 0.8% | 0.6% |
| $CO_2$ emissions, mln. tonnes | 13850 | 15743 | 15015 | 14106 | 16346 | 14661 | 13107 | 0.7% | 0.2% | -0.2% |

### Table A2.50 - Consumption of primary energy resources, the BRICS countries, mtoe

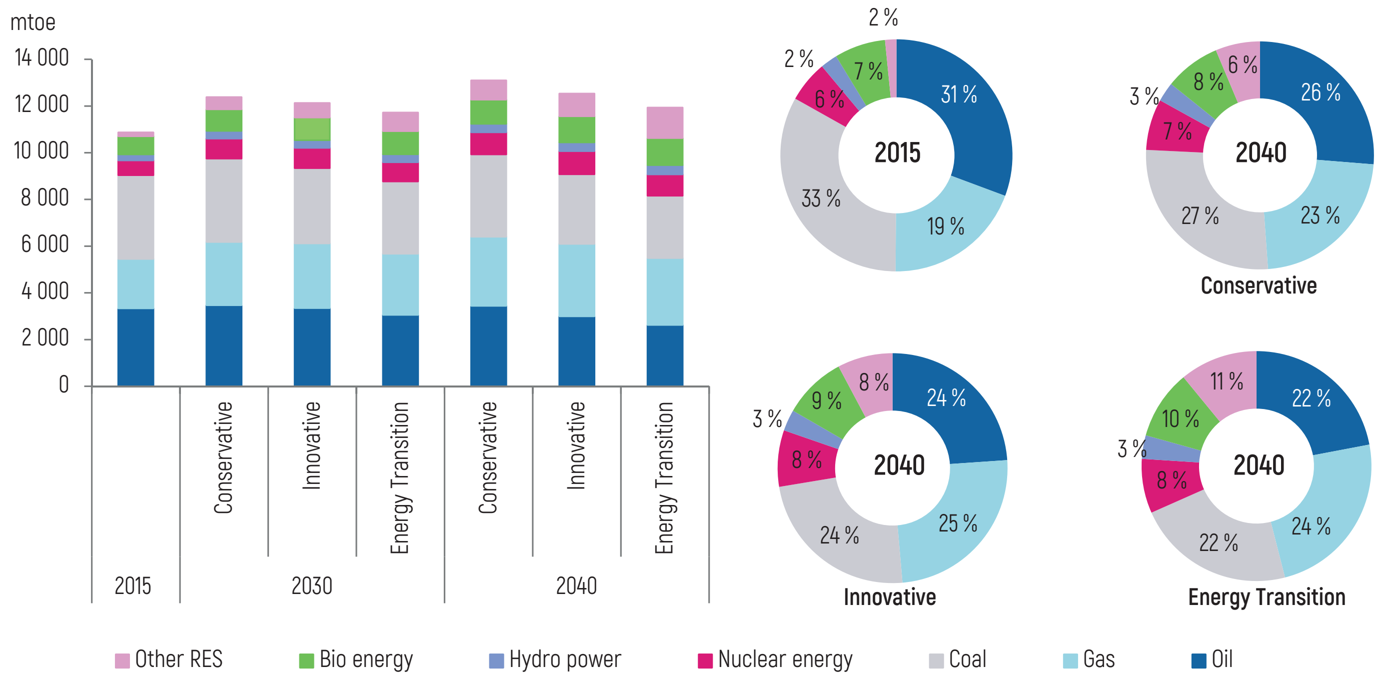
| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 4985 | 6387 | 6286 | 6045 | 7118 | 6768 | 6419 | 1.4% | 1.2% | 1.0% |
| Oil | 1047 | 1356 | 1346 | 1167 | 1459 | 1217 | 1053 | 1.3% | 0.6% | 0.0% |
| Gas | 596 | 1009 | 1063 | 991 | 1180 | 1301 | 1173 | 2.8% | 3.2% | 2.7% |
| Coal | 2603 | 2760 | 2537 | 2454 | 2801 | 2430 | 2191 | 0.3% | -0.3% | -0.7% |
| Nuclear energy | 113 | 320 | 327 | 312 | 452 | 484 | 457 | 5.7% | 6.0% | 5.8% |
| Hydro power | 153 | 210 | 212 | 221 | 238 | 246 | 266 | 1.8% | 1.9% | 2.2% |
| Bio energy | 419 | 486 | 504 | 511 | 543 | 575 | 587 | 1.0% | 1.3% | 1.4% |
| Other RES | 54 | 246 | 296 | 388 | 445 | 515 | 692 | 8.8% | 9.4% | 10.7% |

### Table A2.51 - Electric power generation, the BRICS countries, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 9161 | 14054 | 14182 | 14748 | 17665 | 18097 | 19159 | 2.7% | 2.8% | 3.0% |
| Oil | 72 | 33 | 35 | 33 | 19 | 12 | 6 | -5.1% | -7.1% | -9.4% |
| Gas | 815 | 1220 | 1618 | 1441 | 1502 | 2311 | 1849 | 2.5% | 4.3% | 3.3% |
| Coal | 5611 | 6764 | 5813 | 5462 | 7733 | 6116 | 5343 | 1.3% | 0.3% | -0.2% |
| Nuclear energy | 431 | 1225 | 1250 | 1195 | 1731 | 1851 | 1750 | 5.7% | 6.0% | 5.8% |
| Hydro power | 1783 | 2401 | 2468 | 2571 | 2748 | 2857 | 3095 | 1.7% | 1.9% | 2.2% |
| Bio energy | 142 | 348 | 406 | 420 | 500 | 589 | 624 | 5.2% | 5.9% | 6.1% |
| Other RES | 307 | 2063 | 2592 | 3627 | 3432 | 4361 | 6492 | 10.1% | 11.2% | 13.0% |

# The G-20 countries

## Figure A2.18 - Primary energy consumption by fuel and its structure, by scenario, the G-20 countries




Source: ERI RAS

## Table A2.52 - Main indicators of development, the G-20 countries

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,12 | 0,09 | 0,08 | 0,08 | 0,07 | 0,07 | 0,07 | -1.9% | -2.1% | -2.3% |
| Per capita energy consumption, toe/capita | 2,30 | 2,41 | 2,36 | 2,28 | 2,49 | 2,38 | 2,27 | 0.3% | 0.1% | -0.1% |
| $CO_2$ emissions, mln. tonnes | 26776 | 27722 | 26282 | 24746 | 27787 | 25005 | 22441 | 0.1% | -0.3% | -0.7% |

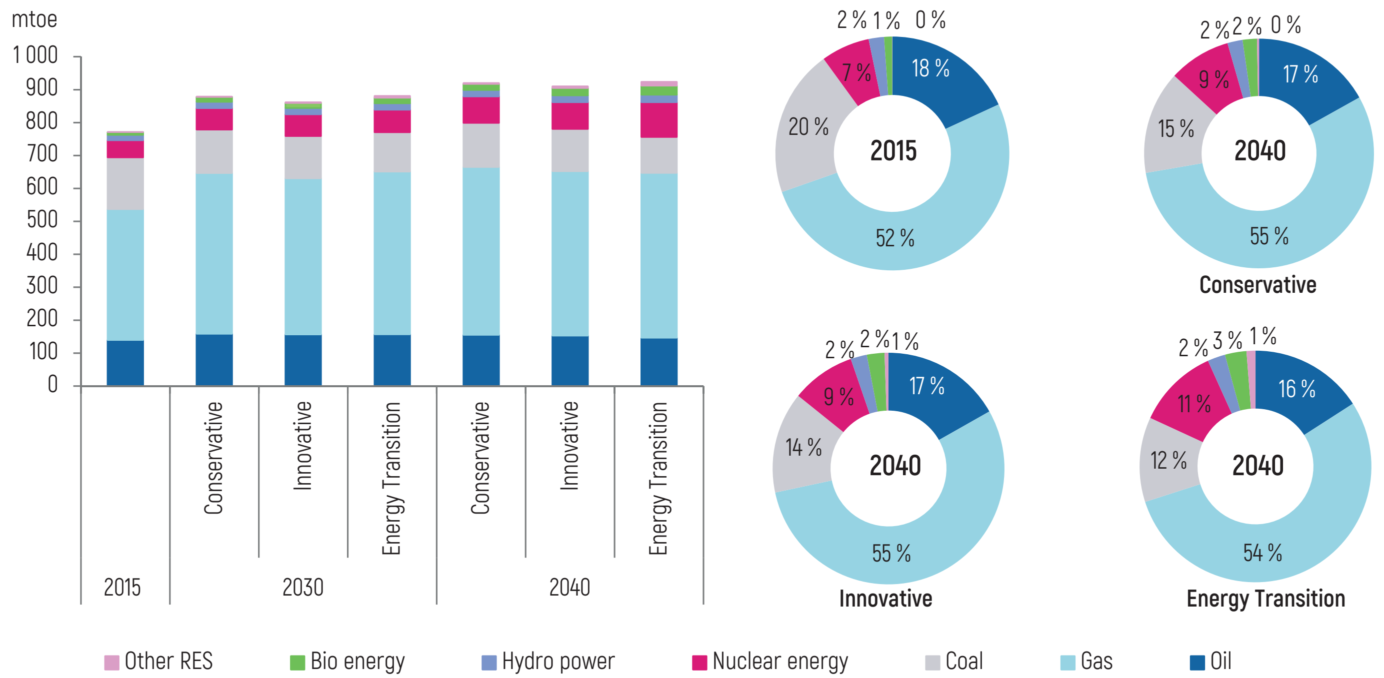
### Table A2.53 - Consumption of primary energy resources, the G-20 countries, mtoe

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 10875 | 12384 | 12132 | 11725 | 13101 | 12535 | 11935 | 0.7% | 0.6% | 0.4% |
| Oil | 3336 | 3467 | 3343 | 3054 | 3439 | 2994 | 2626 | 0.1% | -0.4% | -1.0% |
| Gas | 2115 | 2711 | 2775 | 2622 | 2964 | 3102 | 2865 | 1.4% | 1.5% | 1.2% |
| Coal | 3590 | 3571 | 3224 | 3094 | 3524 | 2978 | 2666 | -0.1% | -0.7% | -1.2% |
| Nuclear energy | 629 | 858 | 863 | 821 | 949 | 995 | 913 | 1.7% | 1.9% | 1.5% |
| Hydro power | 258 | 328 | 331 | 342 | 361 | 373 | 396 | 1.3% | 1.5% | 1.7% |
| Bio energy | 776 | 926 | 966 | 988 | 1036 | 1117 | 1160 | 1.2% | 1.5% | 1.6% |
| Other RES | 171 | 524 | 628 | 804 | 829 | 975 | 1308 | 6.5% | 7.2% | 8.5% |

### Table A2.54 - Electric power generation, the G-20 countries, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 20460 | 27089 | 27465 | 28505 | 31991 | 32716 | 34769 | 1.8% | 1.9% | 2.1% |
| Oil | 528 | 247 | 233 | 229 | 157 | 97 | 52 | -4.7% | -6.6% | -8.9% |
| Gas | 3942 | 5240 | 5748 | 5385 | 6238 | 7080 | 6402 | 1.9% | 2.4% | 2.0% |
| Coal | 8956 | 9454 | 8030 | 7488 | 10237 | 7901 | 6856 | 0.5% | -0.5% | -1.1% |
| Nuclear energy | 2412 | 3288 | 3303 | 3143 | 3633 | 3810 | 3497 | 1.7% | 1.8% | 1.5% |
| Hydro power | 3006 | 3773 | 3854 | 3974 | 4176 | 4332 | 4605 | 1.3% | 1.5% | 1.7% |
| Bio energy | 491 | 852 | 997 | 1054 | 1104 | 1344 | 1465 | 3.3% | 4.1% | 4.5% |
| Other RES | 1126 | 4237 | 5300 | 7231 | 6447 | 8153 | 11892 | 7.2% | 8.2% | 9.9% |

## Figure A2.19 - Primary energy consumption by fuel and its structure, by scenario in




Source: ERI RAS

## Table A2.55 - Main indicators of development, The Eurasian Economic Union countries

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| GDP energy intensity, toe/thousand US Dollars | 0,17 | 0,15 | 0,15 | 0,14 | 0,13 | 0,13 | 0,11 | -1.1% | -1.2% | -1.9% |
| Per capita energy consumption, toe/capita | 4,29 | 4,68 | 4,59 | 4,68 | 4,92 | 4,83 | 4,92 | 0.5% | 0.5% | 0.5% |
| $CO_2$ emissions, mln. tonnes | 1822 | 1950 | 1902 | 1914 | 1981 | 1934 | 1851 | 0.3% | 0.2% | 0.1% |

### Table A2.56 - Consumption of primary energy resources, the Eurasian Economic Union countries, mtoe

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 771 | 879 | 862 | 881 | 920 | 910 | 924 | 0.7% | 0.7% | 0.7% |
| Oil | 140 | 159 | 156 | 157 | 156 | 153 | 147 | 0.4% | 0.4% | 0.2% |
| Gas | 398 | 488 | 474 | 494 | 510 | 499 | 500 | 1.0% | 0.9% | 0.9% |
| Coal | 157 | 132 | 128 | 120 | 134 | 129 | 109 | -0.6% | -0.8% | -1.4% |
| Nuclear energy | 52 | 65 | 66 | 68 | 81 | 81 | 105 | 1.8% | 1.8% | 2.9% |
| Hydro power | 16 | 19 | 19 | 20 | 20 | 21 | 23 | 0.7% | 0.9% | 1.3% |
| Bio energy | 9 | 15 | 15 | 17 | 18 | 22 | 28 | 3.1% | 3.9% | 4.8% |
| Other RES | 0 | 1 | 2 | 5 | 3 | 5 | 11 | 11.5% | 14.2% | 18.2% |

### Table A2.57 - Electric power generation, the Eurasian Economic Union countries, TWh

| | 2015 | 2030 | | | 2040 | | | Growth rates 2015 - 2040 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition | Conservative | Innovative | Energy Transition |
| Total | 1229 | 1456 | 1460 | 1534 | 1606 | 1590 | 1833 | 1.1% | 1.0% | 1.6% |
| Oil | 12 | 4 | 5 | 5 | 2 | 1 | 1 | -7.7% | -11.7% | -11.7% |
| Gas | 565 | 674 | 681 | 741 | 724 | 716 | 791 | 1.0% | 1.0% | 1.4% |
| Coal | 258 | 286 | 275 | 251 | 296 | 280 | 250 | 0.6% | 0.3% | -0.1% |
| Nuclear energy | 198 | 250 | 250 | 262 | 309 | 309 | 403 | 1.8% | 1.8% | 2.9% |
| Hydro power | 192 | 224 | 225 | 229 | 234 | 235 | 266 | 0.8% | 0.8% | 1.3% |
| Bio energy | 3 | 5 | 7 | 11 | 7 | 9 | 27 | 4.2% | 4.9% | 9.8% |
| Other RES | 1 | 13 | 18 | 36 | 34 | 40 | 95 | 15.1% | 15.9% | 19.9% |