Energy Policy 117 (2018) 198–207

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Exploring the implications of Russian Energy Strategy project for oil refining sector

Nikita O. Kapustin*, Dmitry A. Grushevenko

The Department of Research of Energy Complex of Russia and the World, The Energy Research Institute of the Russian Academy of Sciences, Nagornaya st., 31, k.2, Moscow 117186, Russian Federation

ARTICLE INFO

Keywords:
Russia
Energy strategy of Russia up to 2035
Oil refining
Forecast
Modeling

ABSTRACT

Downstream is historically a problematic sector of Russian petroleum industry, suffering from many issues: low efficiency, import dependence and inferior products quality. In an effort to combat these problems, a large-scale modernization and renovation program has been initiated in 2011 resulting in over 35 billion US$ investments up to date, yet still many challenges remain. Russian government identifies development of hydrocarbon refining as one of the priorities of the country's strategic development, and as such has included several goals as a part of the Energy Strategy of Russia up to 2035 project to serve as guidelines for the industry.

In our research we have explored the implications and adequacy of these goals. Using the developed modeling tool, we composed a long term forecast of petroleum products output and investment up to 2035. The calculation show, that a full-scale renovation of the sector to meet the advanced global standards would require over 90 billion US$ of additional investment. The goals set by the Energy Strategy project were found to be lacking in several key areas. We propose adjusting the goals to include additional target indicators and put extra emphasis on the cooperation between government and companies, both domestic and international.

1. Introduction

For many years Russian Federation has been a major player in the global liquid fuels markets, as one of the world leaders in crude oil production and refining, as well as petroleum products exports. However, for a long period of time Russian petroleum industry had a pronounced leaning towards the upstream sector and crude exports; with the downstream receiving only a fraction of attention and investment. It was only in the early 2010's that the sector received proper attention. Yet, oil refining in Russia is still lagging behind in efficiency, which is reflected in several key qualitative parameters: Nelson Complexity Index[1] (Johnston, 1996); share of straight-run products in the refinery output[2]; production of high-quality motor fuels per ton of refined feedstock.[3] The further development of the downstream sector is one of the priorities of Russian energy policy, established by the Energy Strategy of Russia up to 2035 project[4] (Minenergo of Russia, 2017a).

This article aims to pinpoint the main challenges faced by the Russian downstream sector; conduct the analysis of goals set by the Energy Strategy Project to overcome these challenges and work out recommendations for improvement of Russian strategical approaches in the field of oil refining. For the sake of this research a long term forecast of major industrial and economic indicators of the downstream sector up to 2035 was composed with the use of the SCANER model complex developed by ERI RAS (Makarov, 2011). The modeling approach, presented in the study has shown its validity over the course of development of ERI RAS Global and Russian energy outlooks (Makarov et al., 2014, 2016) and may be adopted for analysis of other petroleum refining countries, first and foremost the Eurasian Economic Union, as the authors have already conducted an in-depth analysis of key technological and economic parameters of oil refining in the region (Kapustin and Grushevenko, 2017). The forecast will help evaluate the changes in the industry, the dynamics of domestic fuel balance and the industry's export potential.

* Corresponding author.
E-mail addresses: nikita.kapustin@mail.ru (N.O. Kapustin), grushevenkod@gmail.com (D.A. Grushevenko).

[1] The Nelson Index complexity index to quantify the relative cost of components that make up a refinery. It is a pure cost index that provides a relative measure of the construction costs of a particular refinery based on its crude and upgrading capacity and, by extension, the technological level of a given refinery.

[2] Straight-run distillation products (gasoline fraction, naphtha, light gasoil) and residues (vacuum gasoil, fuel oil).

[3] First and foremost, high-octane gasoline and low-sulfur diesel fuel of advanced environmental classes.

[4] Henceforth referred to as Energy Strategy Project.

https://doi.org/10.1016/j.enpol.2018.03.005
Received 7 November 2017; Received in revised form 2 March 2018; Accepted 3 March 2018
0301-4215/

Table 1
The plans for refineries modernization and their current status.
Source: Compiled by the authors based on: Qadripartite agreements; Oil companies' plans; Ministry of Energy reports; dataset by KORTES (2013).

Petroleum refining processes	Existing capacity in 2011, million tons/year	The sum of planned additional capacities by 2020, million tons/year	The degree of plans implementation in 2017
Upgrading processes	**56,35**	**51,9**	**44%**
Catalytic cracking	22,4	11,5	49%
Hydrocracking	8,3	40,4	23%
Visbreaking	18,13	Not included in the Agreements	
Coking	7,52	Not included in the Agreements	
Conversion processes	**94,75**	**70**	**26%**
Gasoil hydrotreating	55,0	44,8	26%
Catalytic reforming	30,85	7,2	24%
Isomerization	6,1	7,1	35%
Naphtha hydrotreating	1,3	8,5	17%
Alkylation	1,3	1,9	24%
Oxygenation	0,2	0,5	0,70%
Total	**151,1**	**121,9**	**34%**

2. Background

2.1. Analysis of the recent developments and current state of the Russian downstream sector

The annual cumulative crude processing capacity in Russia exceeds 300 million tones, made up by 32 major[5] as well as over 50 smaller refineries. Yet, despite the sheer volume of installed capacity, the downstream sector can hardly be characterized as advanced, as it is troubled by many persistent issues. In this chapter we will identify the most pressing strategic challenges for the sector as well as the recent developments.

Undoubtedly the most significant of hurdles for the downstream sector is the poor technological outfit of Russian refineries. This is illustrated by a relatively low average Nelson Complexity Index of 5.5. To put in perspective, according to data from the Oil & Gas Journal survey (OGJ, 2017) the global average is around 6, while the technically sophisticated USA downstream sector's average exceeds 11 (EIA, 2017). This causes many setbacks, with the most prominent being a disproportionally large share of fuel oil and straight-run products in the balance of Russian refineries and, consequently, a fairly tight supply-demand balance for high-octane gasoline.

Steady gasoline supply is one of the important factors for economic development and social stability and shortages of this important fuel were referred to as "nonsense for Russia" by then prime-minister Vladimir Putin in 2011 (BBC Russian, 2011). Thus, over the years, the Russian government has taken a number of fiscal and administrative measures, to ensure sector's development.

Since the mid 2000-s Russia has witnessed a considerable increase in the volumes of crude oil refining, from 207 million tons in 2005–290 million tons in 2014. Apart from the growing domestic market, this growth was largely supported by a system of tax incentives in the form of reduced customs duties for oil products in relation to crude oil (SKOLKOVO Energy Centre, 2013). The aim of these incentives was to secure investment into the downstream sector by providing increased refining margins and financial resources for the oil companies. Yet the ultimate effect of this policy was the rapid development of a very specific segment of oil refining: primitive splitting of oil into straight-run distillates with their subsequent export. Despite these half-products' low value, such activities were profitable due to the difference in export duties. This way, the growth of domestic oil refining had little to none effect on production of high-quality motor fuels and the sector's technological development, as up until 2014 Russia experienced gasoline crises (Kapustin and Grushevenko, 2016).

In 2014 a major reform of the hydrocarbon taxing system has been initiated, known as "tax maneuver". A part of this reform was the elimination of incentives to export fuel oil and straight-run oil products. The duty on fuel oil ("mazut" in Russian classification) was equated with duty on crude; the duties on naphtha and high-sulfur diesel were also raised substantially (Gazprom Neft, 2017). The downstream sector reacted with a steady decline in refining volumes in 2015 and 2016, and several of refining companies have reported a major drop in profitability (Ivashenko and Zorina, 2017; Podobedova, 2015). Yet still, the new system maintains incentives for complex refineries as the duties on motor gasoline and diesel were even reduced.

To compensate for tax incentive policy, which has shown dubious effectiveness, the Russian government has demonstrated a more direct approach to ensuring the refining sector development. It came in the form of Quadripartite Agreements between oil companies, FAS (Federal Antimonopoly Service), Rosstandart (Federal Agency on Technical Regulating and Metrology) and Rostechnadzor (Federal Environmental, Industrial and Nuclear Supervision Service). Signed in 2011, these agreements, that included most of the major oil companies, contained detailed plans for massive refineries modernization up to the year 2020, which were developed as a joint effort of the government and the companies. Moreover, the oil companies were legally bound to carry out their refinery modernization plans while public authorities were tasked with monitoring the execution and punishing non-compliance (Kapustin and Osipova, 2015).

The plans were extremely ambitious, amounting to almost doubling the total secondary processes capacity of Russian refineries. As of 2017, the Quadripartite Agreements enjoyed relative success, as more than 32 billion $ have been invested in refineries modernization and over 60 refining units have been built and reconstructed (Novak, 2016). Yet these capacities make up only a third of the initial projects (Table 1). The underfulfillment of plans can be attributed to the following factors:

- The plans, compiled during the hydrocarbon price boom were inherently overreaching;
- Excessive focus on production of diesel fuel on the background of struggling domestic demand and shrinking export niches in Europe;
- Unfavorable prices for oil and petroleum products in 2014–2016, and the economic crisis in Russia.

As things stand, it is almost certain that the modernization plans will not be carried out in their entirety by 2020.

The other major challenge for Russian refineries is a high level of import dependence. The most prominent is the dependence on external supply of catalysts for petroleum refining. Minenergo (2015) evaluated the extent of this dependence for the key catalytic refining processes (Table 2).

We estimate current overall annual consumption of catalysts in

[5] With annual crude refining capacity in excess of 2 million tons.

Table 2
Share of foreign companies in Russian catalysts for oil refining market.

Unit designation	Imports share
Isomerization	50%
Catalytic reforming	60%
Catalytic cracking	65%
Hydrotreating	97%
Hydrocracking	100%

Russia at 24 thousand tons. Considering the ongoing large scale modernization of the sector, the demand is expected to grow in the forecast period (more information in the Section 5).

A similar situation exists in the field of refining technologies. Only a handful of Russian companies possess capability of producing competitive technologies, with some imports having no domestic alternative in short and medium term as noted by Khadzhiev et al. (2014) (Table 3).

The quality of petroleum products manufactured by Russian refineries has also been an issue. Leaded petrol was completely phased out only by the mid-2000 and fuel quality has many times been cited as a source of concern by experts and business (Streltsov, 2010; Alexandrov, 2017). Not only did this negatively affected the car owners and undermined the competitiveness of Russian oil products in the international markets but also hindered Russia's integration into the global auto-market, as modern engines are highly sensitive to the fuel characteristics. One of the most important achievements of the modernization program of the quadripartite agreements was a large-scale switching of all major Russian refineries to production of Class 5 quality (equivalent of EURO 5) fuels in 2016, ahead of schedule laid out by the government (Krasilnikov, 2016). The leap in quality was a crucial factor for the development of Russian automotive industry, as some of the major auto manufacturers, like Ford, Nissan and BMW have established production plants within the country (RBC Autonews, 2017). Despite this, maintaining a set bar for the high quality of the produced fuels against the growing demand is one of the crucial tasks for the industry.

The brief analysis of the downstream sector shows, that after the prolonged period of stagnation in the 90's and 00's the industry is now on the way to solving the accumulated problems. It is up to the national strategic documents to lay the directions for further development. Having identified the most important challenges for the sector, we will conduct an overview of the goals and objectives, set by the Energy Strategy Project.

2.2. Overview of the goals set by the Energy Strategy Project for oil refining sector

The Energy Strategy Project is an extensive multi-sector document aimed at providing guidelines and milestones for the whole energy industry and some adjacent sectors, such as petrochemistry. The sections dedicated to oil refining set the following goals and indicators for the sector:

- Modernization and development of the sector based on the advanced mostly domestic technologies;
- Increase in average refining depth[6] from 74.1 to 90–91 per cent with the production of motor fuels of highest environmental classes by the year 2035;
- Increase in average light oil products[7] yield from 58.6 to 70–79 per cent by 2035;
- Completion of the modernization and further optimization of the oil refineries capacities;
- Stimulating the improvement of the motor fuels qualitative (including environmental) characteristics;
- Stimulation of measures, aimed at increasing the number of deep conversion units at Russian refineries;
- Continuation of the Quadripartite Agreements modernization program will be the key process for the sector;
- The key indicator for import substitution will be the increase of the share of Russian producers in the energy companies' procurements to 85–90% in 2035.

Besides the aforementioned goals, the Energy Strategy Project outlines the target volumes of crude oil refining along two scenarios of the energy sector's development:

- In the Optimistic scenario annual refining volumes gradually reduce from 285 million tons in 2015–250 million tons in 2030 and 2035;
- The Conservative scenario assumes a sharper decline in crude refining to only 225 million tons in 2035.

At a glance, the strategic targets, set by the Energy Strategy Project correspond well with the challenges, faced by the downstream sector, that have been identified in the previous section. A more in-depth analysis of the goals and the outlook of oil refining in Russia will require implementation of the forecasting tools, described in the following section.

3. Forecast methodology

Generally, we have identified two main approaches to oil refining modeling: top-down and bottom-up. First, demonstrated by large-scale analytical models, such as World Energy Model (IEA, 2016) and Petroleum Market Model of the National Energy Modeling System (EIA, 2012) treat downstream sector strictly as means of satisfying demand. Oil refining is usually represented as aggregate capacities of countries' regions or whole countries without distinguishing individual refineries. This approach is perfect for country-wide and global energy systems balances and long-term forecasting, but is strictly implicit for the downstream sector and thus cannot take into account economics and possible technological constraints of oil refineries.

On the other hand, there are sophisticated refinery models, which accurately simulate every aspect of a plant's operation. These models are used by both corporate (Honeywell, 2018) and academic (Ghaithan et al., 2017; Zhao et al., 2017) researchers and can provide a wealth of information on a single refinery or a complex of several refineries, including in-depth production and economic indicators. Yet, being very complex, narrow-focused and dependent on a large number of variables and data this approach is not fit for long-term industry-scale outlooks.

As obvious, neither of these approaches is fit for the task at hand. Thus for the sake of this research we have used the combined approach. Russian petroleum refining industry Model is based on a fairly simple but robust bottom-up algorithm, modeling individual refining units in the form of generalized annual material balances, while the connection to the extensive ERI RAS modeling complex (Makarov, 2011) provides data for top-down model calibration. The combination of explicit and implicit approaches provides opportunities for unique research.

Russian petroleum refining industry model is intended for forecasting and analysis of operation and development of the downstream sector of the Russian Federation. The output of the Model consists of data for petroleum products manufacture, investment, processing costs and key industrial indicators organized in different forms and levels of scale.

The basis of the forecasting method are the aggregate material balances of the major oil and condensate refineries of the Russian Federation, grouped on the geographical basis, making up material

[6] Production of petroleum products per ton of refined crude sans the output of mazut (fuel oil).
[7] LPG, Naphtha, gasoline, diesel etc.

Table 3
Major oil refining technologies licensors in the world and Russia.

Technology designation	Technology subtype (feedstock)	Licensor	
		World	Russian
Catalytic cracking	Vacuum gas oil	Axens, CBI Lummus, KBR, Exxon Mobil, Shell, Stone & Webster, UOP, Haldor Topsoe	TIPS RAS, VNII NP, OAO «VNIPIneft»
	Residue	Shevron Lummus, IFP, KBR, UOP	Developed by TIPS RAS and VNIPIneft
Hydrocracking	Vacuum gas oil	Shevron Lummus, Axens, UOP	None
	Residue	UOP, Axens, KBR, Shevron Lummus	TIPS RAS
Coking	Delayed	CBI Lummus, Foster Wheeler, Conoco Philips	Bashkir Scientific Research Institute of Petroleum Refining
	Fluid	Exxon Mobil	None
High-quality motor oil production		Shevron Lummus, Exxon Mobil	None

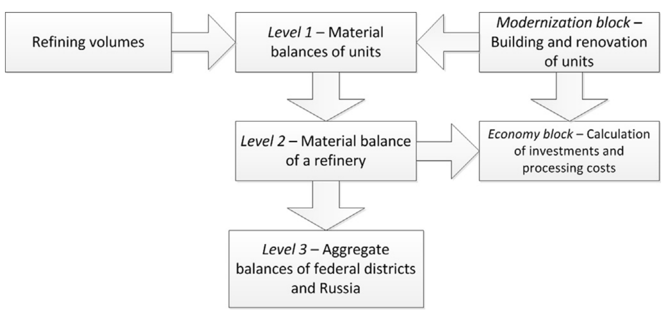

Fig. 1. Flowchart of the model.

balances of the federal districts and the country as a whole. In turn, material balance of each refinery is a sum of material balances of all hydrocarbon refining units, operational in the given period.

The theoretical basis of the Model is the estimated and the empirical material balances of the refining units derived from a variety of sources: scientific literature, periodicals, operation manuals and R&D reports.

In general, Russian petroleum refining industry model consists of three hierarchically related levels of scale, representing the production section of the model and two auxiliary blocks (Fig. 1).

The production section's primary function is calculation of petroleum products output capacity and it operates according to the following algorithm:

Level 1 conducts calculations of material balances for all the refining units based on the designated crude refining volumes and technological schemes of the refinery in the given year. The data on petroleum products output is carried over to *Level 2*.

Level 2 forms the material balance of the whole refinery, based on the production data from Level 1. The main indicators, such as refining depth, light oil products yield and Nelson Complexity Index are calculated at this level.

At *Level 3* annual balances and indicators of the refineries are consolidated into analytical tables, the Federal Districts' and Country balances are calculated.

The auxiliary blocks are necessary to ensure accuracy of the production section's calculations and also provide additional data on the downstream sector. The auxiliary blocks of the Model include:

The *Modernization block* contains data on the planned constructions, renovations and retirement of the refining units for each refinery and each year over the forecast period.

The *Economy block* evaluates capital expenditures and cost of processing in the refining industry.

The Model requires the following initial data for calculations:

1. Database on the current active units in the Russian refineries;
2. Methodological and empirical data for the formulation of material balances of the most prominent oil refining units;
3. Annual crude processing volumes in Russia;
4. Companies' and the Government's plans for construction, renovation and retirement of the hydrocarbon refining units.

3.1. The specification of computational algorithms

3.1.1. Level 1 – units' material balances

The basic functional unit of the Model is a material balance of a hydrocarbon refining process. The calculation of a material balance follows the algorithm below:

1. The data on the nomenclature and capacity of operational refining units is double-checked in accordance with the *Modernization block*'s data.
2. The template for the material balance of the unit is formed (Table 4), with the key parameter being the composition of the finished products mix, expressed in mass fractions (X'_i in the example below), determined based on theoretical and empirical data.
3. The exact volume and composition of the feedstock is determined according to the volume and properties of the crude for the distillation unit or based on the data from the calculations for other units.
4. The following system of Eq. (1) is composed:

$$X'_n * Y = Y'_n \tag{1}$$

The validity of the calculations is double-checked with the following Eq. (2):

Table 4
General form of a unit's material balance.

Feedstock		%mass	Tons per annum
	Feedstock 1	X_1	Y_1
	Feedstock 2	X_2	Y_2
	…	…	…
	Feedstock n	X_n	Y_n
	Sum	100%	Y
Products			
	Product 1	X'_1	Y'_1
	Product 2	X'_2	Y'_2
	…	…	…
	Product n	X'_n	Y'_n
	Sum	100%	Y

$$\sum_{i=1}^{n} Y_i = Y \quad (2)$$

If the equation is correct, we add the resulting data into the template.

The distribution of hydrocarbon half-products within the refinery is optimized to ensure the maximum yield of the most valuable product, mainly motor fuels and lubricants.

The input data for *Level 1* consists of the volume and composition of the refined crude and the list and capacities of operational refining units for a given plant.

3.1.2. Level 2 – material balance of the refinery

At *Level 2* the data from material balances of refining units is aggregated into a material balance of the whole plant. The half-products of the units are combined into larger product groups. For example, a product group "Motor gasoline" is made up of some or all of the following half-products:

- "Straight-run gasoline fraction" from a Distillation unit;
- "Reformate" from a Catalytic Reformer unit;
- "Izomerizate" from an Isomerization unit;
- "Alkylate" from an Alkylation unit;
- "MTBE" from an Etherification unit;
- "Cracked Gasoline" from an FCC unit;
- "Hydrotreated petroleum fraction" from a Hydrotreater unit;
- "Coking gasoline" from a Delayed Coking unit;
- etc.

Thus the output of the model consists of the following product groups:

- Motor gasoline;
- Jet fuel;
- Diesel fuel;
- Fuel oil (mazut);
- Dry gas;
- LPG;
- Naphtha;
- Aromatics;
- Light gas oil;
- Vacuum gas oil;
- Petroleum coke;
- Lubricants;
- Asphalt;
- Sulfur and sulfuric acid;
- Other.

In addition, *Level 2* contains calculations for the key industrial indicators (Refining Depth and Light Petroleum Products Yield) and refinery's complexity:

To calculate the **Refining Depth** a following formula is used (3):

$$D = \frac{P_{OP} - P_{FO}}{R}, \%_{mass} \quad (3)$$

P_{OP} – all petroleum products production volumes;
P_{FO} – fuel oil (or mazut) and vacuum gas oil production volumes;
R – crude refining volumes.

Light oil products yield is determined according to the formula (4):

$$L = \frac{P_{Gas} + P_{JF} + P_{DF} + P_{LPG} + P_{N} + P_{LGO}}{R}, \%_{mass} \quad (4)$$

P_{Gas} – high-octane gasoline production volumes;
P_{JF} – jet fuel production volumes;
P_{DF} – diesel fuel production volumes;
P_{LPG} – liquefied petroleum gasses production volumes;
P_{N} – naphtha and other light fractions production volumes;
P_{LGO} – light gas oil production volumes;
R – crude refining volumes.

Nelson Complexity Index – reflects equipment of a plant with secondary processing units and is an indicator of refinery's technological level. The calculation of the Nelson Index for a refinery is carried out according to the formula (5):

$$N = \sum \frac{C_x * I_x}{C_{DC}} \quad (5)$$

C_x – hydrocarbon refining process unit capacity (including both primary and secondary processes);
I_x – Unit's complexity index;
C_{DC} – refinery's atmospheric distillation capacity.

3.1.3. Level 3 – consolidation of calculation results

The scaling of calculations from *Level 1* and *Level 2* is conducted in three steps:

1. Association of a single refinery's material balances for different years into one table;
2. Establishment of the Federal District balances by adding up the data from the balances of the local refineries;
3. Combining the Federal District balances to produce a final oil refining balance of the Russian Federation.

3.1.4. Modernization block – refining units' construction and renovation

Probably, the most important step of the forecasting is taking into account the changes in the fleet of the refining units. The *Modernization block* contains information on all plans for construction, renovation and retirement of refining units for every major plant on a year-by-year basis, derived from the companies' and government's official plans and strategies, including the building, renovation and processing costs indexes.

3.1.5. Economy block – calculation of investment and processing costs

Based on the production section of the Model, some key economic indicators of a refinery are calculated:

- Processing costs;
- Capital investment.

Processing cost is calculated along the following formula (6):

$$E_i^{op} = U_i^{op} * N_i * R_i \quad (6)$$

E_i^{op} – total processing cost of the refinery in the i-th year, million rubles (us$mil.);
U_i^{op} – processing cost index in the i-th year, RUB (us$)/ton;
N_i – complexity index of the refinery in the i-th year;
R_i – crude refining volumes in the i-th year, tons.

The key parameter – processing costs index is determined for each refinery individually based on the financial data provided by the companies and, given the lack of such data, regional average. The forecast is calculated on the basis of cost escalation and the inherent direct relation between processing cost and refinery complexity.

The Capital Investments are a sum of two components: investment in constructing new units and investment in renovations, reflected in the formula (7).

$$E_i^{cap} = B_i + R_i \quad (7)$$

E_i^{cap} – total capital investment into refinery in the i-th year, million rubles (us$mil.);
B_i – capital investment into constructing new units in the i-th year, million rubles (us$mil.);
R_i – capital investment in renovation of existing units in the i-th year, million rubles (us$mil.).

In turn, these investments are determined according to formulas (8) and (9).

$$B_i = \sum U_x^B * C_x \quad (8)$$

$$R_i = \sum U_x^R * C_x \quad (9)$$

U_x^B – building cost index for the x-th unit, RUB (us$)/ton of annual capacity;
U_x^R – renovation cost index for the x-th unit, RUB (us$)/ton of annual capacity;
C_x – hydrocarbon refining process unit capacity (including both primary and secondary processes).

The key parameters – building and renovating costs indexes are determined for each refinery individually based on the financial data provided by the companies and, given the lack of such data, regional average.

4. Scenario assumptions

The forecast was calculated along two scenarios, in accordance with the scenarios laid down in the Energy Strategy Project: Conservative and Optimistic. The main variables between scenarios are crude refining volumes and domestic demand for petroleum products.

Crude refining volumes are assumed to be equal to the difference between the volumes of produced and exported oil in the corresponding Energy Strategy Project scenario, in other words, it is assumed that all annually produced but not exported oil, is processed within the country.

The figures of the projected demand for petroleum fuels in Russia are derived from the extensive Global and Russian energy outlook 2016 (Makarov et al., 2016), co-written by the authors of the current study. Optimistic scenario sees a small but steady increase in domestic demand over the forecast period from 138 Mtoe in 2015–142Mtoe in 2035. Crude refining volumes decline from 285 million tons in 2015–250million tons in 2035 (Fig. 2).

On the other hand, Conservative scenario predicts a more unstable demand, with initial decrease to 128 Mtoe in 2025 and subsequent partial recovery to 131 Mtoe. The structure of demand also shifts, with the increase in diesel demand and rapid phasing out of fuel oil consumption in both scenarios. Crude refining volumes see a more rapid decline from 285 million tons in 2015 to just 225 million tons in 2035 (Fig. 3).

The expected changes in technological configuration of Russian refineries were determined in accordance with the official plans of the companies. This data is common for both scenarios, as most plans are short and medium-term and will most probably not be altered substantially.

All oil companies are assumed to have sufficient funding and access

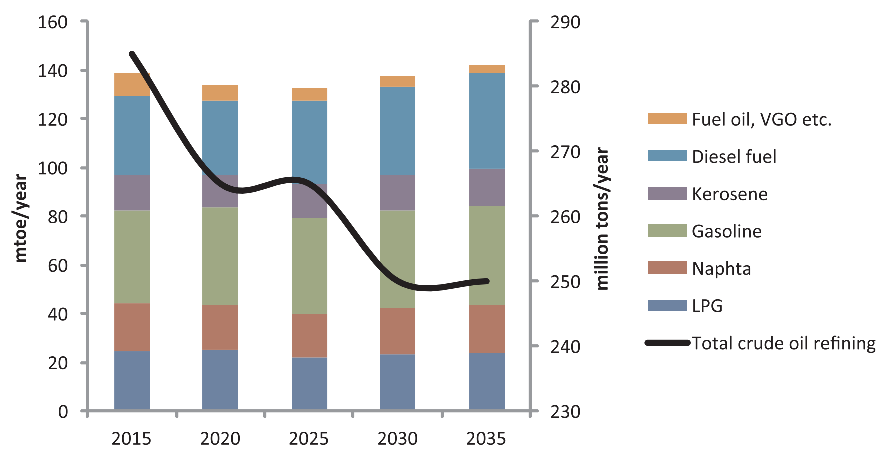

Fig. 2. Crude oil refining (right axis) and petroleum products demand (left axis) in the Optimistic scenario.

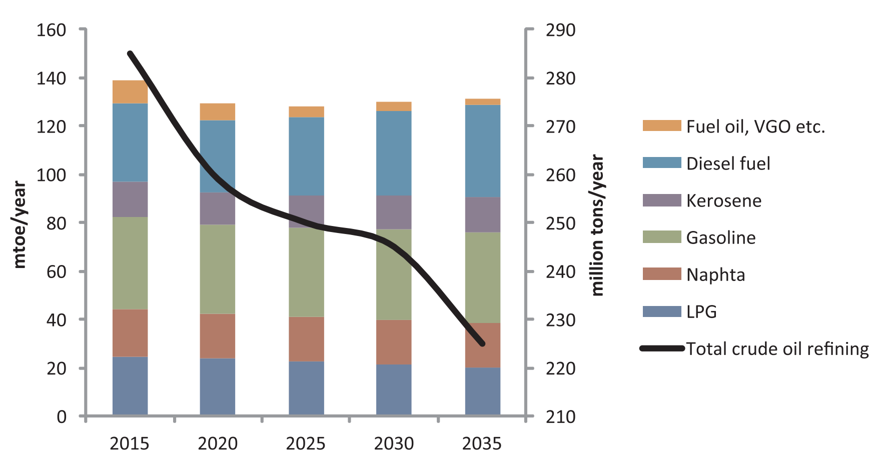

Fig. 3. Crude oil refining (right axis) and petroleum products demand (left axis) in the Conservative scenario.

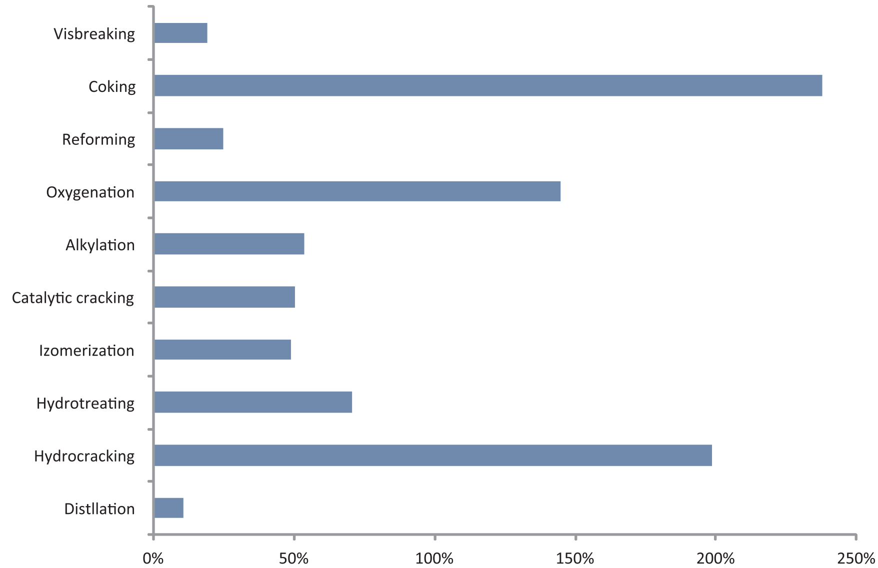

Fig. 4. Increase in capacity of key oil refining processes in 2035, compared to 2015.

to technologies throughout the forecasting period to carry out their current plans for modernization.

No new breakthrough technologies are expected to emerge; average refining unit efficiency will remain at contemporary levels.

Imported and domestic technologies and catalysts are considered equal. The quality and composition of the crude are considered constant in the forecast period.

5. Results and discussion

For the sake of this research, we analyzed the current official plans of the oil companies for the downstream modernization. The cumulative planned new capacities exceed 100 million tons per annum. The focus is on the coking and hydrocracking – the key bottom-of-the-barrel refining technologies, which will show the greatest increment in capacity. Substantial additional capacities of etherification and hydrofining are also scheduled, with the aim of further improving the quality of motor fuel pool (Fig. 4).

As the result, the average value of Nelson Complexity index for Russian refineries will increase from the contemporary 5.5–7.47, attaining European levels.

The accumulated investment in the 2010–2035 will amount to over 120 billion US$. It is worth noting, however, that the field of investment will shift in the forecast period. Most of the new construction plans will be completed by the year 2025, and since then the main objective for the sector will be maintaining the achieved high technological level resulting in the predominance of investments into reconstruction and renovation of already existing units (Fig. 5).

Due to the introduction of new secondary facilities, the aggregate demand for catalysts for oil refining will increase by 30% to more than 31 thousand tons per year. The highest growth in demand is expected for hydrotreating and hydrocracking catalysts; as their combined share will reach 40% of total consumption (Fig. 6).

Based on the plans for the sector's development the Russian petroleum refining industry model has been adjusted and a production capacity forecast has been carried out along two scenarios of the Energy Strategy Project: Optimistic and Conservative. Export potential has also been determined in accordance with the demand data, derived from the Forecast 2016 (Makarov et al., 2016). The calculation results are presented in the graphs below for the Optimistic (Fig. 7) and the Conservative scenarios (Fig. 8). Comparison of calculations results for the scenarios are presented in table (Table 5).

In both scenarios the industry achieves the target indicators set by the Energy Strategy Project by 2035: Refining Depth reaches 90.5% in Optimistic scenario and 91.2% in the Conservative; the Light Oil Products Output amounts 75% in both scenarios.

The production of motor fuels grows in both physical volumes[8] as well as relative indicators,[9] despite significant cuts in crude refining. The production of gasoline and diesel fuel per ton of refined crude exceeds 55% and reaches advanced world standards.

Oil product exports are expected to decrease in the forecast period in both scenarios. This is mostly due to two major factors: declining refining volumes; as well as growing domestic demand. The export basket, however, will undergo considerable changes. Heavy oil products (first and foremost, fuel oil) will yield their dominant role to diesel fuel, although will still retain a share of over 22%. The export potential for high-octane gasoline will see substantial growth.

Scenario comparison shows, that the industry possesses significant resilience and adaptability. Despite almost twofold difference between the reductions in crude refining volumes in the scenarios, the performance indicators do not demonstrate a corresponding gap. Redistribution of the crude to the most complex and effective refineries allows the industry to reach even higher indicator levels in the Critical scenario, all the while higher refining volumes of the Optimistic scenario allow to maintain superior export potential, shifting to high-value products exporting.

In both scenarios, the decline in primary processing in the country forces the shutdown of the most minor refineries and several least sophisticated major ones. The effect is particularly acute in the Conservative scenario, with a score of refineries in the Volga region forced to operate at a critically low level of utilization.

6. Conclusions and policy implications

Russian petroleum refining industry Model can be categorized as deterministic discrete static linear model. Each refinery is calibrated to produce maximum of light oil products and motor fuels over the forecast period. However, the Model is not optimized based on demand, supply or economic parameters. Instead it is geared towards evaluating the production potential, main industry indicators and capital and operational expenditures of the downstream sector based on the given scenario assumptions: crude oil refining volumes and capacities

[8] Expressed in physical units.

[9] The production of motor fuels per ton of crude.

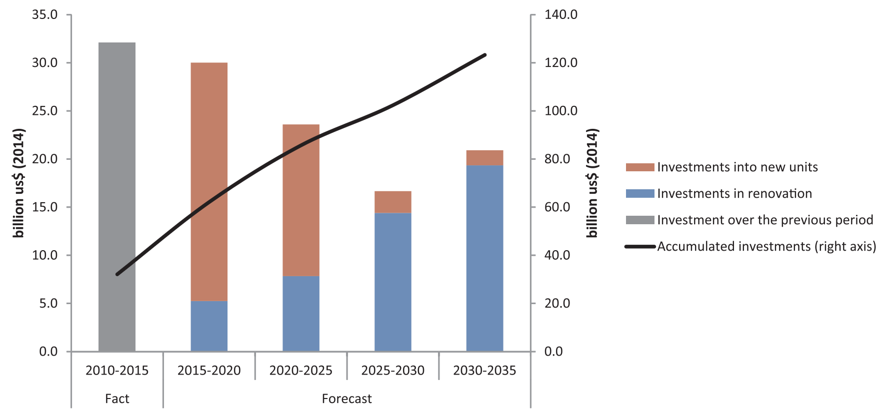

Fig. 5. Investments and accumulated investment in oil refining in Russia.

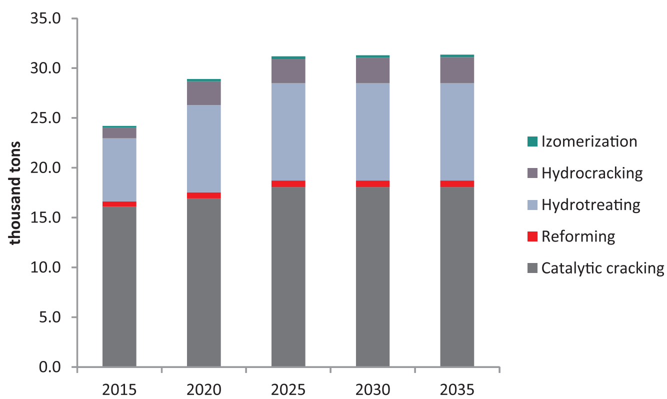

Fig. 6. Projected demand for catalysts in Russian Federation.

building, modernization and retirements. Thus the model is directly sensitive to any changes in this input data. Limitations on capital investments and refining technologies availability may also be considered sensitive indicators, yet not used in this research.

The main uncertainty of the calculations is the cost dynamics of refining units' construction over the forecast period. This is alleviated through stable currency assumption, with investments calculated in 2016 US$. The other uncertainty is the possible change in production characteristics of new and renovated oil refining units covered by the Model or introduction of entirely novel oil refining technologies in the forecast period. This uncertainty is resolved through the assumption of immutability of these characteristics on the 2017 levels and the absence of technological breakthroughs in oil refining.

The overview of goals set by the Energy Strategy Project has shown their general adequacy to the challenges, faced by the downstream sector. Yet our research has allowed us to articulate a number of comments and suggestions that will, in our opinion, be advantageous for improving the quality of strategic policymaking for the oil refining industry.

The Energy Strategy Project establishes refining depth and light oil products yield as the key (and only) indicators of the downstream sector's technological development. Yet, practice shows, that the dynamics of these indicators do not necessarily relate to the real progress in the sector and neither do they reflect the actual product output of the refineries. According to the report of the Ministry of Energy of the Russian Federation, in 2016 over 280 million tons of crude oil and condensate have been refined in Russia. Refining depth amounted to 79.2%, having increased by impressive 5% points compared to 2015 (Minenergo of Russia, 2017b). However the cumulative yield of gasoline and diesel fuel constituted only 41%, virtually unchanged compared to the previous year (Minenergo of Russia, 2017c). In contrast, contemporary USA refineries are capable of producing almost 50% of just gasoline per ton of refined crude (EIA, 2017).

In this research we have used the following indicators in addition to those, utilized by the Energy Strategy Project, to ensure better assessment the development of the sector:

- Average Nelson Complexity Index – estimates the average technological complexity of oil refineries in Russia and secondary units capacities;
- The yield of high-quality motor fuels per ton of refined crude – reflects the efficiency of oil refining and the industry's capacity to supply the domestic market.

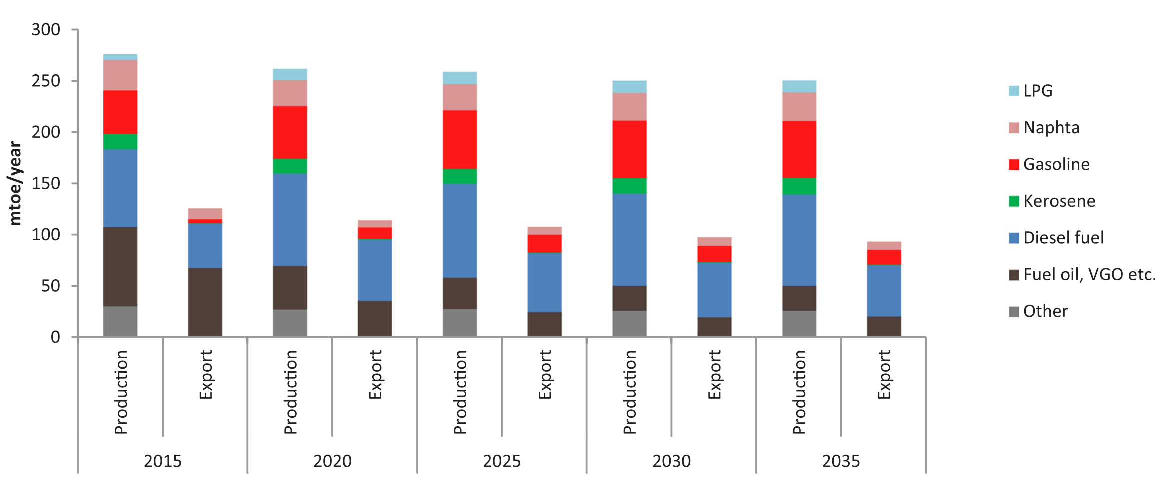

Fig. 7. Petroleum products output and export potential in the Optimistic scenario.

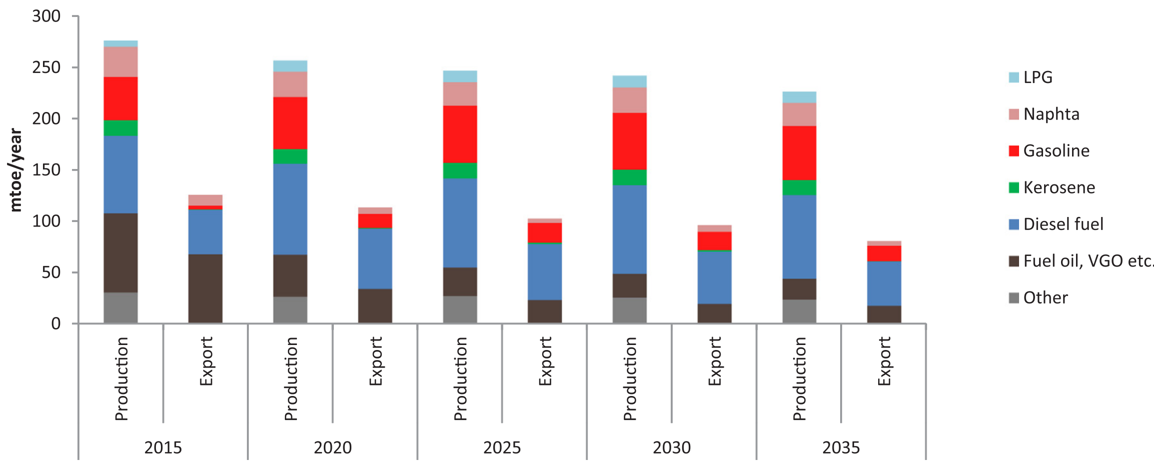

Fig. 8. Petroleum products output and export potential in the Conservative scenario.

Table 5
Calculation results comparison.

	2015	2035	
		Optimistic scenario	Conservative scenario
Refining volumes	285	250	225
Increment to 2015		*− 12%*	*− 21%*
Refining depth	73%	90,5%	91,2%
Light oil products yield	59%	75,2%	75,3%
Average Complexity Index	5,66	7,47	
Motor fuels output	130	156	145
Increment to 2015		*20%*	*12%*
Gasoline yield	14%	21%	22%
Diesel fuel yield	26%	35%	36%
Motor fuels consumption, Mtoe	85	95	90
Increment to 2015		*12%*	*6%*
Petroleum products export, Mtoe	126	94	81
Increment to 2015		*− 26%*	*− 36%*
Export basket structure			
Gasoline	3%	16%	19%
Diesel fuel	34%	53%	54%
Heavy petroleum products	54%	23%	22%
Other	8%	8%	5%

It is worth noting, however, that none of the aforementioned indicators can be regarded as exhaustive for strategic planning and it is important to maintain a multifaceted approach to goal-setting in the industry.

The ambitious goals achievement will be based on the implementation of the companies' relevant plans of for the continuation of refinery modernization. The most important task of the governmental policies is to create a favorable environment for this. The current draft of the Energy Strategy Project does not contain any transparent mention of a long term state actions to achieve the objectives of the Project for the downstream sector.

We deem the tax regime adjustment to incentivize the high-quality products output and the continuation of the policy of cooperation between the state and oil companies in the development of modernization plans, established by the Quadripartite Agreements should be among the priorities of Russian government, and, as such, ought to be reflected in the strategic documents.

That said entitling the implementation of the Quadripartite Agreements as "the primary process for the sector" as it currently is in the Energy Strategy project can by no means be considered accurate. The plans for the Agreements have been in development in the late 2000s – early 2010s and by now are somewhat outdated and have

Table 6
The revisions of the Quadripartite Agreements plans.
Sources: compiled by the author based on: Quadripartite agreements and plans of the major oil refining companies.

	Quadripartite agreements	Companies' current plans	
		Up to 2020	Up to 2035
Catalytic hydrocracking	40,4	31,4	35,2
Hydrofining	44,8	34,2	42,9
Isomerization	7,1	3,5	4,2
Catalytic cracking	11,5	8,3	14,3
Alkylation	1,9	0,9	0,9
Oxygenation	0,5	0,4	0,8
Reforming	7,2	6,1	8,1
Coking	n/a	13,6	31,2
Visbreaking	n/a	6,8	9,5

undergone major revisions by the oil companies (Table 6). Moreover, these plans have been imperfect to begin with, for example, bearing no mention of one of the most important bottom-of-the-barrel refining processes - coking.

The concept of domestic technology based modernization, implied in the Energy Strategy Project appears not only extremely hard to achieve, but might even turn out detrimental for the industry. As it has already been noted, according to the relevant plans, much of the modernization should be complete by 2025. Given the current Russian technological level; the domestic producers can readily cover only a fraction of the modernization needs and the development of adequate import substitutes can take up decades of expensive R&D, setting back the sectors development even further. And even in this case, the future of these technologies is vague at best, as the domestic demand is inherently limited and competition in the international technological market is highly intense.

We consider that as a strategic priority for the state it would be better to support the adoption of the existing domestic technologies and breakthrough research, at the same time providing the most favorable conditions for cooperation and the exchange of expertise between Russian and foreign technological companies. The significant investments in reconstruction of production facilities due after 2025 provide opportunities for domestic manufacturers and service companies. The same is true for the market of catalysts for oil refining. The government strategies should identify these opportunities and guide the efforts of domestic companies.

Our research shows that Russia is very serious about maintaining its status as an important player in global liquid fuels market all the while shifting from exporting cheapest oil products to high-margin fuels, evidenced by the planned investments far exceeding both immediate and long-term needs of domestic consumers. This strategic course is supported by both the government and national oil companies. The projected capacity additions clearly indicate focus on ultra-low sulfur middle distillates that, by many projections (Makarov et al., 2016; OPEC, 2017; IEA, 2017), will become increasingly sought after on fuel markets all over the world. Given, that Russia provides short of half of Europe's oil products imports, while maintaining shares in most regional markets (British Petroleum Company, 2017); all parties involved in oil products production and trade should pay close attention to the developments in the country.

Overall, Russian oil refining sector is still in the midst of resolving its many chronic issues with a lot to be done. Yet, should the vector and pace of progress demonstrated in 2010–2015 be preserved and given the sound government policy in key areas, by 2035 the industry has very good prospects of achieving a highly advanced stage of development.

Acknowledgements

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Alexandrov D., 2017. Volkswagen пожаловался на низкое качество бензина в России [Volkswagen complained about the low quality of gasoline in Russia]. RBC Autonews. 15 September. Available at: ⟨https://www.autonews.ru/news/59bbb2a09a79470ad70d056d⟩ (Accessed 24 October 2017).

BBC Russian, 2011. Путин обязал нефтяников производить больше бензина [Putin ordered the oil companies to produce more gasoline], BBC Russian official website. 8 July. Available at: http://www.bbc.com/russian/russia/2011/07/110708_putin_oil_kirishi.shtml (accessed 24 October 2017).

British Petroleum Company, 2017. BP Statistical Review of World Energy 2017. British Petroleum Co, London.

Changes to Taxation for the Russian Oil and Gas Sector, 2017. Gazprom Neft web-site. Available at: ⟨http://ar2014.gazprom-neft.com/strategic-report/market-review/russian-market/taxation⟩ (Accessed 24 October 2017).

EIA 2017. US Refinery Yield. Available at: ⟨https://www.eia.gov/dnav/pet/pet_pnp_pct_dc_nus_pct_m.htm⟩ (Accessed 24 October 2017).

EIA, 2012. Petroleum Market Model of the National Energy Modeling System: Model Documentation 2012, Part 1 - Report and Appendix A. U.S. Energy Information Administration, Washington.

Ghaithan, Ahmed M., Attia, Ahmed, Duffuaa, Salih O., 2017. Multi-objective optimization model for a downstream oil and gas supply chain. Appl. Math. Model. 52, 689–708.

Honeywell, 2018. Symphonite Refining and Petrochemical Modeling System (RPMS). Honeywell international Inc., Available at: ⟨https://www.honeywellprocess.com/en-US/explore/products/advanced-applications/software-production-management/Pages/rpms.aspx⟩ (Accessed 1 March 2018).

International Energy Agency, 2016. World Energy Model Documentation. OECD/IEA, Paris.

International Energy Agency, 2017. World Energy Outlook 2017. OECD/IEA, Paris.

Ivashenko M., Zorina S., 2017. Индекс успеха [Index of success]. Siberian Oil Online Magazine. No. 140, April. Available at: ⟨http://www.gazprom-neft.ru/press-center/sibneft-online/archive/2017-april/1119179⟩ (Accessed 24 October 2017).

Johnston D., 1996. Refining Report Complexity index indicates refinery capability, value. Oil and Gas Journal. Available at: ⟨http://www.ogj.com/articles/print/volume-94/issue-12/in-this-issue/general-interest/refining-report-complexity-index-indicates-refinery-capability-value.html⟩ (Accessed 24 October 2017).

Kapustin N., Osipova E., 2015. Системный анализ мероприятий четырёхстороннего соглашения [A systematic analysis of the activities of the quadripartite agreement]. Oil, Gas an Business. No. 6. pp. 13–18.

Kapustin N., Grushevenko D., 2016. Russia refines on. Energy Focus. No. 26. pp 89–94.

Kapustin N., Grushevenko D., 2017. Состав технологических установок и материальные балансы нефтеперерабатывающих заводов стран-членов ЕАЭС [Composition of units and material balances of oil refineries of the EAEU member States]. Rospatent No. 2017361350. 22 November.

Khadzhiev S., Kapustin V., Maximov A., Chernysheva E., Kadiev K.h, Gerzeliev I., Kolesnichenko N., 2014. Promising technologies for petroleum refining and petrochemistry. Oil refining and petrochemistry. No. 9.

KORTES, 2013. Состав основных технологических установок и перспективы модернизации НПЗ Российской Федерации [The composition of the main technological units and prospects of modernization of the refineries of the Russian Federation]. KORTES Centre.

Krasilnikov S., 2016. Россия полностью переходит на топливо стандарта не ниже Евро-5 [Russia fully transferred to the fuel standard Euro-5]. TASS Russian news agency. Available at: ⟨http://tass.ru/ekonomika/3417906⟩ (Accessed 24 October 2017).

Makarov, A. (Ed.), 2011. SCANER: Super Complex for Active Navigation in Energy Research. ERI RAS, Moscow.

Makarov, A., Grigoriev, L., Mitrova, T. (Eds.), 2014. Global and Russian Energy Outlook to 2040. ERI RAS – ACFR, Moscow.

Makarov, A., Grigoriev, L., Mitrova, T. (Eds.), 2016. Global and Russian Energy Outlook. ERI RAS – ACFR, Moscow, pp. 2016.

Minenergo of Russia, 2015. Decree No. 210. 31 March.

Minenergo of Russia, 2017a. Energy Strategy of Russia up to 2035 project. Available at: ⟨https://minenergo.gov.ru/node/1920⟩ (Accessed 24 October 2017).

Minenergo of Russia, 2017b. Переработка нефти и газового конденсата [Processing of oil and gas condensate]. Available at: ⟨https://minenergo.gov.ru/node/1212⟩ (Accessed 24 October 2017).

Minenergo of Russia, 2017c. Производство нефтепродуктов [Petroleum products output]. Available at: ⟨https://minenergo.gov.ru/node/1213⟩ (Accessed 24 October 2017).

Novak A., 2016. Итоги работы топливно-энергетического комплекса Российской Федерации в первом полугодии 2016 года [The performance of the fuel and energy complex of the Russian Federation in the first half of 2016]. Minenergo of Russia official web site. Available at: ⟨https://minenergo.gov.ru/node/5660⟩ (Accessed 24 October 2017).

Oil and Gas journal, 2017. Worldwide Refinery Survey with Complexity Analysis. January 2017.

Organization of the Petroleum Exporting Countries, 2017. 2017 OPEC World Oil Outlook. October. Available at: ⟨http://www.opec.org⟩ (Accessed 1 March 2018).

Podobedova L., 2015. Нефтяники попросили Путина скорректировать налоговый маневр [Oil companies asked Putin to adjust the tax maneuver]. RBC. 21 January 2015. Available at: ⟨http://www.rbc.ru/business/21/01/2015/54bfb5009a7947654f870e74⟩ (Accessed 24 October).

RBC Autonews, 2017. Карта заводов: где и какие автомобили собирают в России [Plants map: where and what cars are assembled in Russia], RBC Autonews official website. 22 February 2017. Available at: https://www.autonews.ru/news/58adca6a9a79479c3a3967a8 (accessed 24 October 2017).

SKOLKOVO Energy Centre, 2013. Система «60-66-90-100» и сценарии развития нефтепереработки в России [System "60-66-90-100" and scenarios of development of oil refining in Russia]. February. Available at: ⟨http://www.skolkovo.ru/public/en/research/news-research/96/3257-2013-02-08-15⟩ (Accessed 24 October 2017).

Streltsov F., 2010. Будет ли в России качественный бензин? [Will there be high-quality gasoline in Russia?]. Auto72.ru. 28 May. Available at: ⟨http://auto.72.ru/text/auto/290240.html⟩ (Accessed 24 October 2017).

Zhao, Hao, Ierapetritou, Marianthi G., Shah, Nikisha K., Rong, Gang, 2017. Integrated model of refining and petrochemical plant for enterprise-wide optimization. Comput. Chem. Eng. 97, 194–207.