Technological Innovation as a Factor of Demand for Energy Sources in Automotive Industry

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Abstract

The issue of forecasting demand for liquid fuels has become particularly significant in recent years with technological development and much tougher inter-fuel competition in the transport sector. In future, these developments could radically transform the oil, gas, and electricity markets. Therefore there is a greater need for improved forecasting methods that take into account the dynamics of market factors, primarily those related to the use of new technologies.

We analyse the difficulties of forecasting demand for liquid fuels in conditions of uncertainty related to future technological developments in car transport. We classify the technologies driving demand for motor fuels by the nature of their impact on the demand for petroleum products: technologies aimed at improving the energy efficiency of traditional cars, as well as drivers of inter-fuel competition, both in terms of direct and indirect substitutes for petroleum products. To resolve the problem of limited input information, the methodology incorporates clustering instruments, which enable us to group countries according to certain criteria. The use of economic and mathematical tools with optimizing units enables us to make integrated calculations that model the market for liquid fuels and assess its interactions with the markets of other energy resources.

Our proposed system for forecasting demand for liquid fuels, including petroleum products, can be used as an instrument to assess the future impact of technological innovation on the development of the oil industry when carrying out Foresight studies.

Keywords: oil products; alternative fuel; automotive transport; forecast of demand; technology; energy efficiency

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Liquid fuels, including oil and petroleum products, among of the most important components of the energy balance. According to data from the International Energy Agency (IEA) [IEA, 2014], oil alone accounts for roughly 31% of total global energy consumption and 93% of energy consumption in the transport sector.

In view of the acute significance of liquid fuels for the global energy sector and economy as a whole, the future development prospects of this market are the subject of detailed studies by both the expert community and representatives from business circles and government bodies. Development forecasts for the liquid fuel market (often called the oil market due to the dominance of oil as an energy resource) are compiled annually by the US Department of Energy [DOE, 2014a], IEA [IEA, 2014], the Organization of Petroleum Exporting Countries (OPEC) [OPEC, 2014] and the Energy Research Institute of the Russian Academy of Sciences [*Makarov et al.*, 2013]. One of the most important aspects of these studies is their evaluation of long-term trends for energy demand (in particular for oil-based fuel), and it is this demand that in many ways shapes the future configuration of the oil market, including prices. However, the prospect of a change in demand for liquid fuel is becoming increasingly uncertain, due to significant technological changes which are taking place in today's oil market, in particular in terms of technological developments in the transport sector, which now accounts for 64% of global oil consumption.

Active diversification of the fuel basket, expansion of inter-fuel competition between petroleum products and other energy sources and innovative developments in the technologies used in the consumption of the oil products themselves (especially in the transport sector) all require the modernization of existing and the development of new methods to forecast demand for liquid fuels while taking current and future technological changes into account.

In order to guarantee the quality required of the calculations using oil demand forecasting methods, we need a tool kit that can account for all three of the identified technology groups. However, existing approaches do not fully meet these requirements. Methods based on forecasting demand solely from macroparameters ('top-down') do not offer tools for explicitly taking the technologies into account, although they are noted for their simplicity and accessibility to a wide range of experts. The other category of methods ('bottom-up') involve a similar tool kit, but in practice require access to large data arrays, which is often not possible. Moreover, such methods are particularly sensitive to the accuracy of the initial data and scenario conditions.

The demand forecasting system proposed by the authors is an original approach combining the advantages of various existing methods, which will ultimately make it possible to form multi-factor scenarios and evaluate the impact of energy and industrial policy on the demand for motor fuel.

To account for the effects of technologies, the forecasting system provides for special 'technological' blocks and, in addition, evaluates demand from the perspective of inter-fuel competition between petroleum products and direct substitutes through data exchange with an optimized model of liquid fuel markets. The problem of the lack of information, which is characteristic of the 'bottom-up' model, has been eliminated by the use of clustering instruments, which make it possible to draw well-founded analogies between units and to establish values in correlation with countries (regions) exhibiting similar characteristics. As a whole, the entire system covers economic, demographic and technological factors.

Key technological changes in motor fuel consumption

We are seeing a relatively wide range of areas in which technology is developing, which is capable of having a significant impact on liquid fuel consumption in the transport sector. From the perspective of fuel expenditure, improvements to vehicle transport will have two opposing effects. On the one hand, the consumer properties of transport will improve, leading to an increase in fuel expenditure (increase in power, introduction of air conditioning systems, hydraulics, automated mechanisms, massage systems, additional media devices, etc.). On the other hand, technologies capable of increasing the energy efficiency of transport are being introduced. In sum, trends are geared towards reducing fuel expenditure. Looking at demand for petroleum products, it is also important to bear in mind the development of inter-fuel competition technologies, which allow for a reduction in petroleum product consumption in the transport sector by including other types of fuel in the energy basket.

Despite more than a hundred years of the automotive industry, modern vehicles still have significant energy-saving potential. According to estimates by the American Physical Society [APS, 2008], modern vehicles running on traditional fuel only effectively transfer 20% of the fuel's potential energy from the tank to the wheels, and this is bearing in mind that it was only from the early 1990s to 2010 that vehicle power globally increased on average by 42% and fuel expenditure fell by 37% [*Makarov et al.*, 2013]. This was achieved through the development and mass introduction of an entire range of technologies: turbochargers, direct fuel injection, cylinder deactivation and valve timing systems, improved gear boxes, reduced weight and increased vehicle aerodynamics, and hybrid vehicles.

This development and diffusion of energy-efficient technologies was helped in no small part by government measures to increase the efficiency of road transport. In the US, for example, reinforced Corporate Average Fuel Economy (CAFÉ) standards have been in effect since 1975, which oblige vehicle manufacturers to ensure that their products meet fuel economy standards, expressed as the minimum number of miles that a vehicle can travel on one gallon of fuel. In 1995, the European Union adopted standards (which are regularly reviewed) to limit carbon emissions from cars. Similar, but far stricter standards were adopted in 1999 for vehicle manufacturers in Japan, and in 2004 in China. All of these standards are continually adapted and tightened as vehicle manufacturers develop new fuel-efficient technologies. Furthermore, it is this expectation that standards will inevitably become more exacting that encourages producers to improve their technologies. According to data from the US Environmental Protection Agency, long-term CAFÉ target figures assume a reduction in average fuel expenditure for light vehicles by 60% and for heavy goods vehicles by 30% over the period 2014–2025.[1] Such targets are not only set for road transport, but the aviation industry as well: the International Air Transport Association (IATA) has adopted a target of increasing civil aviation fuel-efficiency by 25% by 2020 compared with 2005.[2]

An analysis of technology development areas shows that further increases in vehicle fuel-efficiency will mainly come about as a result of the improved and higher energy conversion efficiency of all components (including the engine), developments in hybrid vehicles, active use of intelligent control systems and use of composite materials in the cabin and bodywork for weight reduction.

Inter-fuel competition technology will also have a significant impact on petroleum product consumption. Alternative energy sources are gradually starting to occupy a niche in the transport sector and can be classified into:

- direct petroleum product substitutes — types of fuel not requiring serious changes in the construction of engines and consumer infrastructure (these might include biofuels and liquid petroleum products produced from gas and coal using *coal-to-liquids* (CTL) and *gas-to-liquids* (GTL) technologies);
- fuels which are indirect substitutes, and their use in transport directly involves a need to modify vehicles and set up the corresponding consumer infrastructure. Indirect substitutes include: natural gas-based motor fuel, electricity and fuel cells.

It is worth noting that direct substitutes have a far greater diffusion than indirect, which is linked to their availability for consumers. However, their share in the transport sector as of 2015 is extremely small (roughly 2% of total transport energy consumption), which can in part be explained by the relatively high pro-

[1] Available at: www.epa.gov, accessed 16.09.2015.
[2] Available at: https://www.iata.org/whatwedo/ops-infra/Pages/fuel-efficiency.aspx, accessed 16.09.2015.

duction costs. According to IEA calculations, biofuels (with current production technologies) become efficient when oil prices range from 70 to 150 US dollars per barrel (depending on the location and method of production), synthetic coal-based fuels from 45 to 105 US dollars per barrel, and gas from 60 to 105 US dollars per barrel. The direct unit costs of extracting all accessible and technically possible conventional oil supplies globally (excluding deposits in the Arctic circle and deep-sea oil) vary between 15 and 70 US dollars per barrel (including the cost of processing into petroleum products) [IEA, 2013].

It is important to stress that all of these figures are highly conditional and in reality could sit within a far wider range depending on the cost of gas and coal, the tax burden and other factors. However, even such 'conditional' assessments point to the fact that direct substitutes are in fact competing with petroleum products produced from oil obtained from marginal deposits (deep-sea deposits lying in complex reservoir conditions) and from unconventional sources: oil sands, shale deposits and kerogen (for more cf. [*Makarov et al.*, 2013]) which, according to IEA data, could be involved in the economy with oil prices between 50 and 100 US dollars per barrel. Nonetheless, this competition is being won by unconventional oil sources, which can be explained, among other things, by the trend in recent years for significant reductions in production costs. For example, the development of shale oil extraction technologies has made it possible to reduce total extraction unit costs in the US by more than 40% over the period 2006 to 2010 [*Grushevenko, Grushevenko*, 2012), while the unit costs of setting up businesses to produce synthetic fuel derived from coal and gas have, on the contrary, risen.

Aside from the relatively high production costs, the emergence of new oil substitutes on the market is being held back by a number of other restrictions. For biofuels it is being shaped by production capabilities, which (with existing technologies) are limited by the amount and condition of fertile soil and arable fields, as well as the needs of the global food industry. This restriction can in theory be removed through the commercial development of second-generation biofuel production technologies[3], which, according to IEA experts, are capable of supplying 700 million tonnes of oil equivalent of this energy resource [OECD, IEA, 2010] or roughly 17% of global oil demand in 2014.

Other direct petroleum product substitutes, or rather the raw materials to produce them — gas and coal — also have their own restrictions: the resource base of each of these materials is not unlimited and demand is steadily growing. There then is the question of how to make efficient use of these resources.

Large-scale use of synthetic coal-based fuels is limited by the energy-efficiency of the processes used to produce such fuels. Often, the normalized EROI (Energy Return on Investment) is used to evaluate the energy efficiency of energy resource production, defined as the amount of energy derived from the raw energy material relative to the amount of energy used to produce it. For petroleum products — petrol and diesel — this figure is 25 on average [*Cleveland, O'Connor*, 2010], but for fuels produced using CTL technologies, the figure varies between 0.6 and 6 [*Kong et al.*, 2015]. For comparison, burning coal at power stations gives an EROI of 40–80 [*Raugei et al.*, 2011], which is clearly more efficient than converting it to liquid fuels.

Synthetic gas-based fuels (under current technological conditions) are more efficient from the perspective of energy-conversion efficiency than coal-based fuels. However, we have not seen widespread distribution of industrial GTL facilities, which can be explained not only by the relatively costly production compared with oil-based fuels, but also the fact that the natural gas itself coming into such projects is an extremely efficient indirect substitute for petroleum products without the need for additional costly processing.

In spite of the existing price and volume restrictions, further reductions in the cost of technologies to produce full petroleum product substitutes or the formation of a favorable market climate for them (high oil prices) are both capable of having an impact on demand for motor fuel, which means that it is essential

[3] For more on the different generations of biofuel cf. [*Makarov et al.*, 2013].

that the factor of inter-fuel competition with these types of energy resources be taken into account when forecasting demand for petroleum products.

At the current stage, indirect petroleum product substitutes are losing the competition with petroleum products not only due to the price and costliness of production (often a directly alternative resource, for example, natural gas, is cheaper for consumers than petroleum products), but also due to the less appealing consumer qualities of the transport and the lack of infrastructure. For some forms of transport, in particular electric cars, their higher sale cost is also significant. And in the case of refitting, for example, a petrol car with gas-cylinder equipment, the corresponding costs fall to the consumer. In addition, in most countries there is no developed infrastructure to service and refuel vehicles running on alternative fuels, which makes running such vehicles inconvenient and reduces their consumer appeal. The infrastructure itself is not appealing to business as an investment, as demand for the corresponding services is limited to a small number of consumers. Weak demand holds back even the strongest automotive concerns from mass production of these types of vehicles [*Mitrova, Galkina*, 2013].

The use of electricity in vehicles is restricted by the size of the service infrastructure and certain technological improvements in modern electric cars, primarily the low energy capacity per charge, short journey length and cost of the electrical equipment, which all have an impact on the cost of the vehicle and therefore the appeal of such transport for consumers.

Nonetheless, innovations in indirect petroleum product substitute technologies and associated marketing and PR programs are making them more and more competitive on the market. The Tesla electric car produced in the US, for instance, is even becoming more attractive than traditional cars for some of its consumer characteristics — acceleration, noise, not having to regularly replace the engine and transmission oil, etc. It is getting ever closer to its competitors in this class, not only in terms of price, but journey length without recharging too. One of its main advantages is the lack of exhaust gases, ignoring of course the emissions from the power station producing the electricity. This market cue suggests that potential technological innovations could, in the not too distant future, have a significant impact on demand for oil and petroleum products by displacing them from the transport sector in favour of indirect substitutes.

These changes in vehicle manufacturing innovation and improvements to energy consumption technologies in the transport sector in turn require flexible mechanisms to take all of these technological factors into account in modern petroleum product demand forecasting systems.

Review of petroleum product demand forecasting methods

Far from all existing forecasting methods are capable of taking into account technological development factors. Often these factors are not examined at all or are evaluated in a generalized, implicit form through changes in energy and oil capacity.

As shown in a study by the World Bank [*Bhattacharyya, Timilsina*, 2009], two approaches tend to be used to forecast demand for petroleum products:

- ‘top-down’, when the forecast is based on macro-parameters;
- ‘bottom-up’, when the situation with specific types of fuels is analyzed, which can include technological parameters.

Forecasting methods adopting the ‘top-down’ principle have seen the most widespread use. These methods are based on the fundamental dependence between demand for petroleum products and economic and demographic indicators (GDP and population figures)[4]. The correlation between macro-economic variables and energy resource consumption is usually attained using regression models [*Makarov et al.*, 2013], but heuristic search algorithms [*Behrang et al.*, 2011], genetic programming [*Forouzanfar et al.*, 2012] and other methods can also be used. Often these models analyze the oil capacity (petroleum product capacity) of GDP (the ratio of GDP to demand for petroleum products).

[4] The nature of these correlations is described in more detail in [*Grigoryev, Kurdin,* 2013].

The technological factor of increasing energy-efficiency is generally taken into account in models using a 'top-down' method by shifting the forecast oil capacity (petroleum product capacity) dynamics more rapidly downwards (if the scenario assumes substantial technological developments) or slowing the downturn (if, on the contrary, technological developments come about at a more moderate pace). To evaluate technological improvements from the perspective of inter-fuel competition, the model includes the elasticity of demand for petroleum products by price [*Nakanishi*, 2006; *Bobylyov et al*, 2006].

From the perspective of technological forecasting, key shortcomings in the 'top-down' approach are the difficulty in taking into account the impact of specific innovations on future demand, the lack of flexibility in specific scenarios and the lack of transparency in the actual procedure used to evaluate technological factors. Moreover, [*Cleveland et al.*, 2000] casts doubt on the relevance of tying demand for petroleum products in with GDP dynamics. The authors of this work point to the recent loss of close correlation between GDP dynamics and energy resource consumption, which makes it all the more important that we search for alternative approaches to forecasting demand for petroleum products.

Models based on the 'bottom-up' principle are often used to evaluate demand for energy resources in the transport sector. They involve developing a forecast for demand for motor fuels by including various data in the calculation — data on the size of the fleet, its structure, rate of renewal and retirement and technical and economic figures. These approaches are used in the models adopted by the IEA [IEA, 2011], US Department of Energy [DOE, 2014b], World Energy Council [World Energy Council, 2011] and other researchers [*Wang et al.*, 2006; *Bouachera, Mazraati*, 2007; *Braginsky*, 2012]. They also allow for flexible scenarios and evaluation of the effects of developing new technologies on demand. Demand calculations based on the scale, make-up and characteristics of a fleet allow both improvements to traditional technologies and new technologies (including those based on alternative forms of energy) to be taken into account.

The main problems in the 'bottom-up' approach are the need for high detail in the input data and difficulties in coordinating demand calculations in the transport sector with evaluations in other sectors. The difficulties in forecasting demand with insufficient data are explored in the work [*Bhattacharyya, Timilsina*, 2009]. In order to overcome these problems, some researchers have tried to group countries according to certain characteristics [*Button et al.*, 1993].

There are however some shortcomings characteristic of the existing methods:

- 'Top-down':
  - taking account of a limited number of factors, which is insufficient for variable-based calculations and scenarios allowing an impact assessment of S&T progress, energy policy, etc.
- 'Bottom-up':
  - the need for a large set of initial figures and high level of detail in the figures;
  - the lack of transparency in calculations where there is a shortage of initial data;
  - inadequate consideration of marketing factors affecting demand (consumer preferences, fashion, accessibility of infrastructure and services);
  - lack of a direct mechanism to indicate errors when using incorrect initial data or premises.

The method that we have proposed looks to solve these very problems.

System of forecasting demand for liquid fuels

The method developed by the authors of this study to forecast demand for petroleum products and other liquid fuels (biofuel, synthetic fuels made from gas and coal) combines various forecasting approaches and involves elements to eliminate the shortcomings of existing approaches and to make effective use of their strengths (Table 1).

As noted above, we can identify the following advantages of the method developed by us, compared with previously adopted methods:

Table 1. **Comparative analysis of methods to forecast demand for liquid fuels**

Problem	'Top-down' method	'Bottom-up' method	Proposed method
The dependence of the forecast on a limited number of macro-economic indicators, the inability to take technological development factors into account	Characteristic of such methods	Solved by including multiple indicators in the calculation	Covers multiple indicators
Shortage of statistical data	By taking a small number of required input parameters into account, this problem is generally not characteristic of such methods	A key problem of applying such methods	Application of multi-criteria clustering of countries to search for common characteristic patterns, allowing the problem of insufficient information to be partly eliminated
Taking demand by sector into account	Does not make it possible to identify individual sectors or base calculations exclusively on the economic indicators of an economic sector (gross value added of a sector)	As a general rule, used to forecast demand only in a particular sector (transport); needs 'links' with other consumer sectors to define aggregate demand in other models	Combination of the 'top-down' approach when assessing aggregate demand for petroleum products and the 'bottom-up' approach when assessing demand for motor fuels, followed by interlinking the assessments
Taking marketing factors into account	Not taken into account	Taken into account partially, depending on the parameters set by the authors	Taken into account
Lack of transparency in mechanisms to take account of inter-fuel competition	As a general rule, this is done as a formality, by assessing 'price elasticity'; requires additional 'extras' to take account of inter-fuel competition	Can involve technical and economic indicators which are used to take account of inter-fuel competition; as a general rule, requires the use of additional calculation systems	Proposes the use of a method closely linked to the 'resource block' imitating the functioning of the market, including aspects of inter-fuel competition

Source: compiled by the authors.

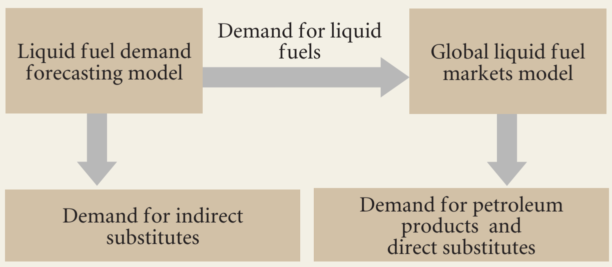
- the application of multi-criteria clustering to eliminate the problem of insufficient data for certain countries;
- the combination of 'bottom-up' and 'top-down' approaches to solve the problem of linking forecasts of demand for petroleum products in the transport and other sectors, and to indicate calculation errors resulting from the use of incorrect initial data and assumptions;
- a detailed analysis of marketing factors affecting demand. These include consumer preferences and fashions (when buyers are prepared to buy vehicles with worse economic indicators thanks to other attractive characteristics or due to the influence of advertisements and the accessibility of infrastructure and services);
- the drafting of forecasts as part of a comprehensive system of forecasting for the global energy industry, which make it possible to take account of the impact on demand for petroleum products of various factors in neighbouring industries, as well as any adverse effects.

In general terms, forecasting using this method involves carrying out calculations in two inter-related model blocks: in the demand forecasting model for liquid fuels, where demand for liquid fuels is calculated taking into account technical and economic factors and inter-fuel competition with indirect petroleum product substitutes, and in the global model of liquid fuel markets, where demand for petroleum products is calculated by taking into account inter-fuel competition between petroleum products and direct substitutes (fig. 1).

In order to calculate demand for liquid fuels in line with the standard fractional composition of oil and the consumer characteristics of the individual distillates and their direct substitutes, the following petroleum product groups have been identified for use in the model:

1. Liquefied oil gases including ethane and propane-butane fraction. From the perspective of the market, this group combines all gaseous petroleum products used in the transport sector as motor fuels, in the household and commercial sectors as fuel for small-scale heating and electricity generation, and in petrochemicals as a raw material.

Fig. 1. **Structure of the demand forecasting system for liquid fuels**



Source: compiled by the authors.

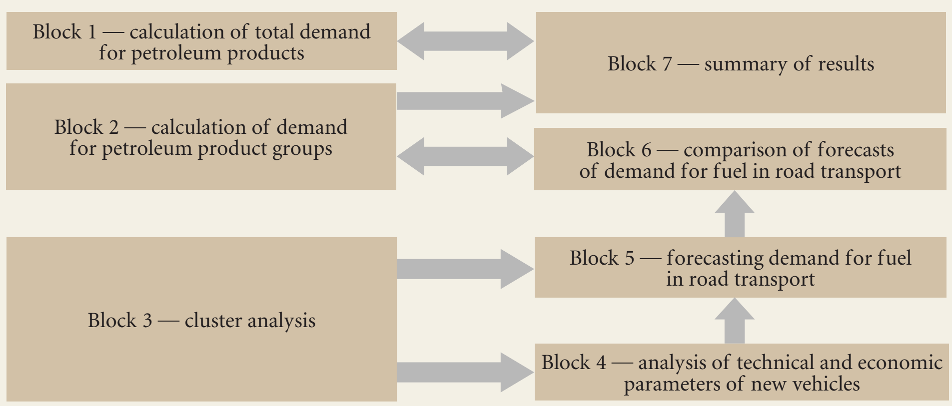
2. Straight-run petroleum (naphtha), which are light petroleum distillates not suitable for use as fuel and often used as a solvent or raw material in the petrochemical industry.
3. Vehicle petrol — a multi-component mix of straight-run naphtha, secondary and enhanced petrol and chemical additives suitable for use in petrol-fuelled vehicle engines. Substitutes include petrol produced from coal, gas and biomass.
4. Aviation kerosene — fuel for jet engines.
5. Diesel fuel — diesel distillates having gone through hydro-treatment and other petroleum product refinement processes, used in road and rail transport, as ship fuel, in diesel generators, etc. Substitutes include biofuel and fuels produced from coal and gas.
6. Fuel oil and other heavy petroleum products — a broad group of dark, high-density petroleum products, including naval and furnace fuel oil, tar, bitumen, vacuum gasoil and other heavy petroleum processing residues. The products in this group are used in various sectors: in water-based transport, in heating and electricity production, and construction.

The demand forecasting model for petroleum products has seven interdependent blocks (fig. 2): three blocks for forecasting demand for petroleum products, differing in their methodological approaches (blocks 1, 2 and 5), two preparatory research blocks (blocks 3 and 4), and two aggregating blocks (blocks 6 and 7).

Each block of the model is dedicated to specific tasks.

Block 1 involves calculations of total demand for petroleum products based on correlation dependencies between demand and fundamental macro-economic indicators: GDP and population figures. Based on retrospective dynamics of petroleum product consumption figures relative to GDP (oil capacity) and popu-

Fig. 2. **Integrated forecasting model**



Source: compiled by the authors.

lation (per capita consumption), future values are forecast by constructing various types of trends, after which the total demand for petroleum products in the future period is determined.

Block 2 is dedicated to forecasting total petroleum product consumption by aggregating forecasts of demand for individual petroleum product groups. Assessments are based on GDP forecasts and population figures by building trends from retrospective GDP capacity figures and per capita consumption for each petroleum product group. Another methodological feature of block 2 was dictated by the specific way in which initial data is presented by consumption of individual petroleum products, which are as a general rule recorded statistically in metric tonnes, rather than in their energy equivalent. This means that conversion ratios need to be applied, calculated using the calorific value of the fuel, to compare the results of the forecasts in blocks 1 and 2.

Block 3 makes preparations for the calculations in blocks 4 and 5. This block aggregates the units into clusters using the *k-means* method. A more detailed mathematical description of the algorithm and the way in which it is used are presented in [*Hartigan, Wong*, 1979; *Telgarsky, Vattani*, 2010]. Indicators describing a unit from economic and energy perspectives are used as criteria in the calculation: GDP, net oil and petroleum product exports, composition of the fuel basket in the transport sector, etc. The results of the analysis are then used to cluster the units under study (amalgamating them into groups). The results of this aggregation of units into groups are used when determining the individual members of the cluster-specific, average-cluster indicators, information on which may be difficult to access for certain units. These indicators could include, for example, average annual mileage of vehicles or their service length. It should be noted that the number of clusters, make-up of units and set of characteristics used to create the clusters can be changed depending on the preferences of the researchers or research objectives. A special case of clustering countries based on three characteristics — GDP per capita, net oil exports and the ratio of petrol to diesel consumption — carried out to test the described demand forecasting system is examined in the article [*Grushevenko, Grushevenko*, 2015].

The results of the distribution of geographical units by cluster are used in blocks 4 and 5. If the researchers have problems in accessing any information required on a particular unit for the forecast, the values characteristic of the cluster to which the unit belongs are to be used.

Block 4 involves preparatory calculations to forecast demand for fuel in the automotive transport sector. In particular, it takes into account the technical and economic indicators of vehicles using various types of fuels, makes scenario assumptions regarding the technological development of automotive transport, and evaluates consumer preferences when acquiring particular vehicles. All of these parameters are defined by calculating vehicle appeal coefficients for each type of fuel (taking into account the potential for technology to be modernized) based on the cost of ownership and factors describing clearly economic, but not formalized consumer preferences (access to infrastructure, 'fashion' for a specific type of transport) which have no clear economic characterization.

The most important task in block 4, and later in block 5, is taking account of inter-fuel competition. The model calculations allow competition with indirect petroleum product substitutes to be taken into account, including with fuel types used on transport and requiring significant changes to the consumer infrastructure. These include electricity and compressed natural gas, the use of which is considered to involve significant modifications to the vehicle's construction and the construction of refuelling and service infrastructure to guarantee their appeal to a wider consumer base. By analyzing the technical and economic indicators and prospective development trends of technologies using these fuels, block 4 makes scenario assumptions which are then formalized in corresponding coefficients for subsequent calculations.

It should be noted that inter-fuel competition between petroleum products and direct substitutes (i.e. types of fuel which can be used in existing vehicles with existing infrastructure) — bioethanol and biodiesel, as well as diesel and petrol produced using GTL and CTL technologies — are taken into account after the transfer of results from the liquid fuel demand forecasting model into the global liquid fuel markets model.

The output parameters from the calculations in block 5 are:

- demand for petroleum products and their direct substitutes by type — petrol (bioethanol, GTL and CTL petrol), diesel (biodiesel, GTL and CTL diesel), liquefied hydrocarbon gases;
- demand for indirect petroleum product substitutes by type — compressed natural gas, fuel cells, electricity used in the transport sector.

Block 5 covers calculations of forecast demand values for fuel for automotive transport based on the size and structure of the vehicle fleet of each unit, consumer preferences and technological development trends in the sector, as examined in block 4. Block 5 establishes a forecast of the demand for automotive petrol and diesel (including fuel produced from coal, gas and biomass), liquefied hydrocarbon gases and indirect oil-based fuel substitutes equivalent in their make-up to those taken into account when forming the appeal coefficients in block 4 (electricity, compressed gas, hydrogen).

The forecast demand values obtained in block 5 for petroleum products are then transferred to block 6 for comparison with the forecast demand from block 2. The GDP capacity and per capita consumption trends for automotive petrol, diesel and liquefied hydrocarbon gases from block 2 are then adjusted on this basis.

Block 7 summarizes the results obtained in block 2 (taking into account the adjustment in blocks 5 and 6) and the results of block 1 following adjustment after switching over to the alternative indirect petroleum product substitutes in blocks 4 and 5.

The results from block 1 are adjusted by reducing the obtained total demand for petroleum products by the amount of demand for indirect motor fuel substitutes (electricity, fuel cells, compressed gas) expressed in their energy equivalent (from block 5).

The demand from block 1, adjusted by the amount of demand for indirect petroleum product substitutes, is compared with the results of the calculations in block 2. These results are entered into block 7 in the form of summary demand for all petroleum products, expressed in their energy equivalent (to allow for comparison between results). In this case, the comparison serves as an indicator of serious errors which may have emerged in the calculations.

Where necessary, if there are serious discrepancies between the results, following expert analysis of the causes, calculations can be reverted to blocks 3–6 for secondary analysis of the set parameters or to the algorithm in block 1, where the adjustment of GDP oil capacity or per capita petroleum product consumption trends is carried out. Based on the expert assessment of the quality of the calculations, the results of the comparison in block 7 can call for an adjustment in the calculations of per capita consumption or GDP capacity trends for specific product groups (block 2).

The final results of the model are estimates of the demand for liquid fuels. The output parameters are broken down in the same detail by geographical characteristic and are intended to solve a wide range of analytical problems. The model therefore allows a definition of:

- Total demand for liquid fuels (including petrol and diesel produced from gas, coal and biomass) taking into account technological factors and adjusted for inter-fuel competition with energy resources which are indirect competitors with petroleum products in the transport sector. This figure can be applied in systematic studies of the future legitimacy of energy developments, the formation and adjustment of forecast energy balances and to determine the role of oil-based fuels in these balances.
- Demand for specific petroleum product groups: automotive petrol and diesel (including fuels produced from gas, coal and biomass), liquefied hydrocarbon gases, aviation kerosene, straight-run petroleum (naphtha) and others. The forecast demand for petroleum product groups is expressed in energy and metric units and serves as a basis to analyze the corresponding markets, solve modelling problems and for forecasting in oil refinement sectors.

- The breakdown of demand for liquid fuels: liquefied hydrocarbon gases, automotive petrol and diesel (including fuels produced from gas, coal and biomass) used as motor fuels (in the automotive transport sector). These are expressed in metric tonnes or in energy equivalent and can be used when analyzing transport sector development trends and forecasting specific petroleum product markets.
- Demand for non-oil-based fuels which are indirect competitors for petroleum products in the transport sector and require fundamental changes to the structure of the vehicle fleet and servicing infrastructure (electricity, fuel cells, compressed natural gas). Demand for such fuels is expressed in their energy equivalent. These data are needed to analyze innovative paths to develop the energy industry, inter-fuel competition, forecast the markets of these fuels and petroleum products, and form and adjust energy balances.

The assessments of total demand for liquid fuels (including petrol and diesel produced from gas, coal and biomass) adjusted for inter-fuel competition with energy resources which are indirect competitors with petroleum products in the transport sector are used in the global liquid fuel markets model, where it is adjusted and stripped from demand for direct petroleum product substitutes. This is a statistically optimized model of complete equilibrium with the target function to satisfy demand in six petroleum product groups taking into account minimum total expenditure across the entire oil and petroleum product supply chain, from deposit to consumer.

The production chain presented in the model covers:

- The extraction block, which selects the deposits to be commissioned, taking into account the cost of extraction and potential future volumes. These are forecast for the largest deposits and oil and gas regions, based on data on supplies, depletion dynamics and extraction profiles. For existing or confirmed extraction projects the extraction profile for the forecast period is determined on the basis of data from the operator companies, and for the remainder by building a forecast extraction profile using Hubbert's linearization method [*Hubbert*, 1962] and more modern modifications [*Hook*, 2009; *Michel*, 2010].
- The transport block, which links the production and consumption of oil and petroleum products, simulating the transportation of energy resources by pipeline, rail and water transport.
- The oil refining block, which contains information on 872 oil refineries in different countries and regions around the world. This imitates petroleum product production operations with minimal restrictions and expenditure on processing. The minimal restrictions on petroleum product output are set on the basis of the potential selection of oil distillates, taking into account their chemical make-up and current processing possibilities.
- The inter-fuel competition block takes account of competition between petroleum products and biofuels and synthetic fuels produced from coal and gas. It is in this block that the liquid fuel demand indicators entered into the model are disaggregated into demand for oil-based fuels and their full substitutes.

To calculate the different scenarios and carry out a quantitative assessment of the expected changes in the fuel market climate, the liquid fuel market model allows the amount and structure of potential oil extraction and processed oil to be varied, transport capacity and supplies to be adjusted, and scenario conditions under which petroleum products are replaced with direct substitutes to be changed.

In terms of taking inter-fuel competition between petroleum products and direct substitutes into account, the model looks at the possibility of displacing a portion of petroleum products. This is based on information regarding the price of switching over and potential maximum production volumes for alternative fuel types. When assessing the scale of the displacement, the potential volume and full estimated cost of supplying petroleum products to the consumer market (including the cost of the oil extraction, transportation and processing) are taken into account, together with the potential volume and full estimated cost of supplying a competing energy resource to the same market (biofuel, fuel produced using GTL and CTL technology). At first, the market is supplied with the cheapest competing energy resources, and later, if volumes are insufficient to cover demand, energy resources with higher supply costs.

Analysis of the scenario-specific changes regarding the volumes and prices of a potential switch to alternative energy resources allows different development scenarios to be formulated for bio- and synthetic fuel production.

Combining the liquid fuel demand forecasting model with the global liquid fuel market model serves as a basis for forecasts of oil and petroleum product demand taking into account scenario-specific assumptions regarding future technological changes related to increases in the energy-efficiency of transport and changes to technologies used to produce and consume energy resources competing with petroleum products, both existing and future.

Opportunities for practical application of the developed method

In practice, the method has been tested in the context of liquid fuel demand forecasting system which is part of the global SCANER modelling and information complex (fig. 3) [*Makarov et al.*, 2011]. It was included in the 'Population — GDP — Energy consumption — Electricity consumption — Liquid fuels consumption' module and is closely linked in with balance and resource oil modules [*Makarov et al.*, 2013]. The resource module is a model of the liquid fuel markets, described in [*Goryacheva et al.*, 2013].

The co-dependency between the liquid fuel markets model and the liquid fuel demand forecasting model is achieved as follows: the calculations of demand for liquid fuels obtained using the forecasting method described above serve as input data for the former model. Aside from the calculations of production indicators, it allows for the assessments of liquid fuel demand to be adjusted to take into account inter-fuel competition (the model can contain information on additional volumes of alternative fuels) and to break it down into petroleum products and direct substitutes.

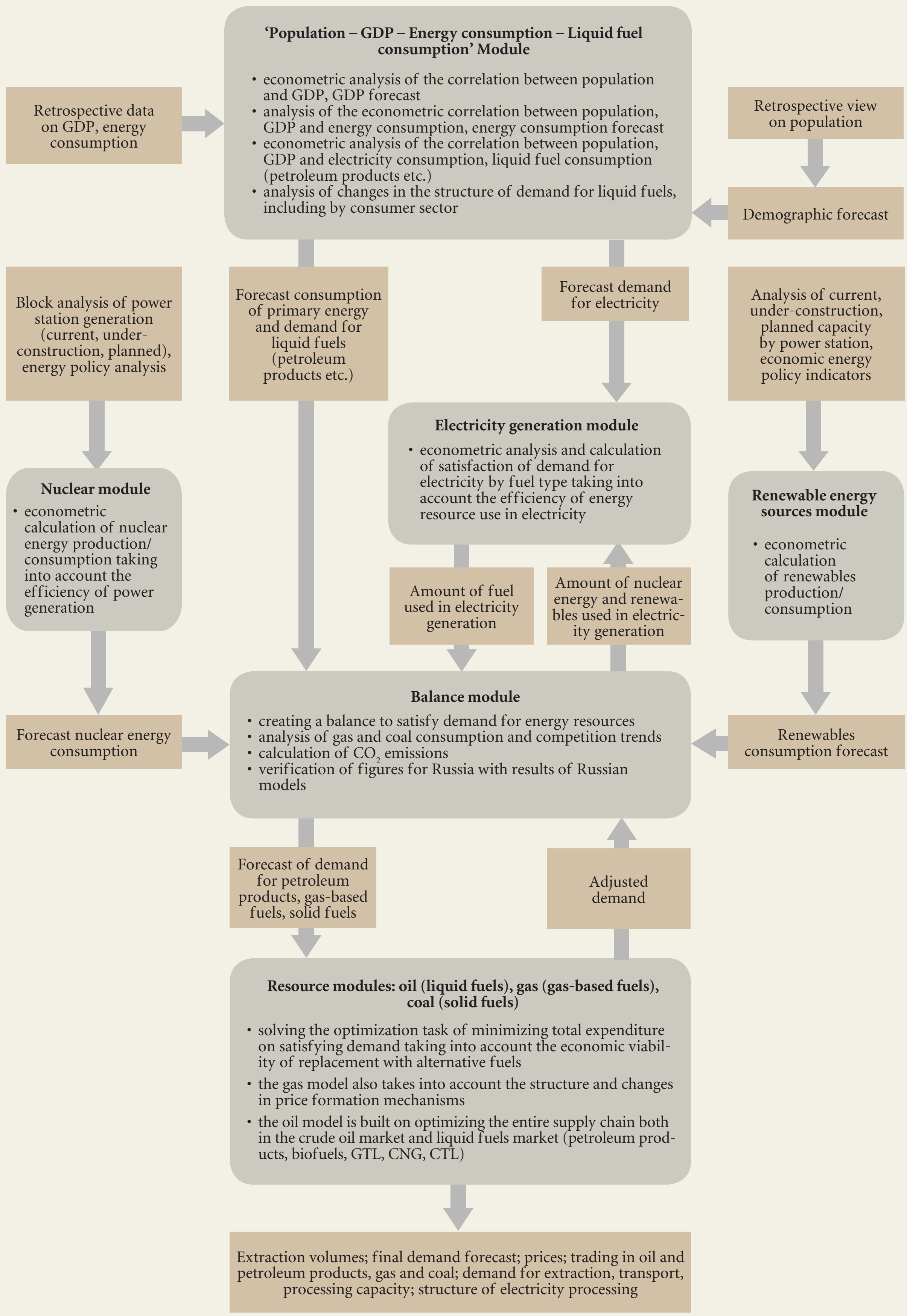
Breaking down demand into petroleum product groups makes it possible to use this system to solve a wide range of scientific and practical purposes: from forecasting the market of a specific petroleum product in a particular country or region to systematically studying the development prospects of the global oil market or the role of oil in the global energy balance. The existence of such a tool kit allows foresight studies to be carried out on the development of the oil complex taking into account prospective technological changes, and to evaluate the effect of developing already developed technologies on future demand for oil and petroleum products and identifying the most promising technologies that are capable of having the greatest impact on reducing demand. Analyzing how effective the impact of different variants of energy and technology policy on market development is also growing in importance.

Conclusion

Innovative technologies in the automotive transport industry are capable of having and are already having a significant impact on the petroleum product market. From the perspective of impact on demand, these technologies could be classified as energy-saving or energy-efficiency technologies bringing about a reduction in the growing demand for oil by improving conventional vehicles and inter-fuel competition technologies allowing petroleum products to be replaced with alternative fuels.

The signs — which are already becoming clear — of a slowdown in demand for petroleum products under the influence of innovation require in-depth study, including through economic and mathematical modelling. Analyses of future demand for petroleum products taking into account technological developments require modernization of the existing evaluation methods.

Fig. 3. **Block diagram of the calculations in the SCANER modelling and information complex**



Note. The calculations in each block are by country (unit). The resource modules contain a more in-depth breakdown.

Source: [*Makarov et al.*, 2013].

The systematic tool kit proposed by the authors of this study makes it possible to combine the advantages and eliminate the disadvantages of different petroleum product demand forecasting methods by combining the advantages of the corresponding approaches into a single algorithm. This ultimately helps to markedly increase the quality of energy development forecasting to take account of the impact of technological progress.

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