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Russia's Road Transport Sector: Prospects for Alternative Energy

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Diversification of energy sources in the road transport sector is becoming a global trend with the emergence of economically and technologically viable alternative fuels, such as electricity, biofuels, compressed natural gas, and others. With the transport sector generating over 50% of global oil demand, this trend obviously holds great significance. The Russian Federation, while being one of the world's major oil producers as well as energy consumers, is falling behind on this trend. However, the prospects for change are quite tangible. The article presents a long term outlook for changes in the Russian road transportation sector's fuel mix. The calculations demonstrate that switching to natural gas and electricity will reduce the share of petroleum products from 95% in 2015 to 74–86% by 2040. Nevertheless, the extent of support by the Russian Government for the infrastructural development will be the key factor to determine the end result. The incentives for natural gas and electric vehicles will also play a large role. The issue of fuel mix diversification will have to be resolved against the background of a 75% increase in the sector's energy consumption, expected in the next 20 yr. Petrol will remain a key fuel for transportation but its share will decrease from 59 to 40-47%, while the share of diesel will remain at 34-39%. Environ Prog, 37: 498–504, 2018

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INTRODUCTION

Diversification of the fuel mix in the road transportation sector is a relatively new global trend. According to the International Energy Agency (IEA), the share of petroleum products (which have historically dominated this sector's energy mix) decreased from 99% to 95% from 1990 to 2013 [1]. This change can be attributed to the emergence of electricity, natural gas, bio fuels and synthetic fuels produced from coal and natural gas as significant energy sources for transportation. The trend is inherent not only to major petroleum importers, for obvious reasons, but also to some leading crude oil producers, such as Iran and Brazil. As of 2013, alternative fuels in these two countries accounted for 14% and 19% of transportation energy demand respectively. Fuel mix diversification serves as a means to free up additional oil and petroleum products for exports, in addition to the global aim of reducing the transportation sector's environmental impact.

With the road transport sector accounting for around half of global crude oil demand, the impact of this trend on the world energy market is expected to be quite significant. The development of global inter-fuel competition is looked upon in more detail in the Global and Russian Energy Outlook 2016, that contains the research by the authors [2].

The Russian Federation is slow to respond to the trend of diversifying the energy mix in the transportation sector, as petroleum products are still used to meet 99% of the demand. Yet factors such as government support of alternative fuels, the environmental impact of the rapid automobilization of the last decades, which is especially severe in some major Russian cities, the rising domestic fuel prices and petroleum products supply shortages, coupled with shrinking export revenues, are acting as strong incentives for the emerging inter-fuel competition.

This study aims to identify key incentives for fuel mix diversification; assess the current state of inter-fuel competition in the road transportation sector; determine the potential of alternative fuels in Russian Federation and assess projected energy demand and supply balance in the transportation sector using the demand forecasting method developed by the authors.

LITERATURE REVIEW

The issue of forecasting energy demand in the road transportation sector is widely covered in literature. In practice, most models used to forecast energy demand are divided into "top-down" models, when demand is forecast based on stable statistical retrospective dependencies between the macro parameters (GDP and population size) and consumption of certain energy types and "bottom-up" models, which account for many factors, including fleet size, technical and economic parameters of vehicles operating on a specific type of fuel and consumer preferences. This classification of models was offered by the World Bank Development Research Group Environment and Energy Team in their study Energy Demand Models for Policy Formulation: A Comparative Study of Energy Demand Models [3].

The authors of this article made a comparative analysis of the existing methodologies in their previous articles [4,5], outlining the advantages and disadvantages of both approaches. As such, they named simplicity and a wide range of application as the advantages of the "top-down" approach. Its disadvantages included inflexibility of modeling calculations to changes in scenario conditions, primarily to such important parameters as changes in inter-fuel competition and technical and economic parameters of vehicles. The "bottom-up" approach had a single but extremely important disadvantage – the requirement to collect complicated statistical data, which is not available for a whole range of facilities.

As far as the practical implementation of the entire range of methods to forecast energy demand in the road transportation sector is concerned, even significant studies on global energy such as World Energy Outlook [1] , World Oil Outlook [6] do not analyze future demand development in Russia in detail. This is despite the fact that Russia is a key player in the world oil market. Even Russian studies, for instance, [7–9] contain only a fairly superficial analysis of key drivers able to influence petroleum product demand. Even the Energy Strategy of the Russian Federation to 2030 [10] does not estimate energy demand in the domestic road transportation sector, which is crucially important in producing an outlook of Russia's export potential. This makes forecasting energy demand in the road transportation sector extremely important and valuable in relation to the Russian market in particular.

FORECAST METHODOLOGY, DATA

To determine future energy demand and demand structure in the Russian transportation sector, the authors used the modeling tools, described in their previous articles [4,11] .

The basic steps in the calculations include:

Using scenario-based assumptions about demographics and GDP and capacity rates, obtained through a regression econometric analysis, a total number of vehicles is forecast. The vehicles are separated into broad categories: passenger vehicles, light commercial vehicles (LCV), trucks and buses.

Based on retrospective dynamics (according to Ref. 12), the number of cars to be retired from the fleet is calculated, per annum. New vehicles sales are estimated according to predicted fleet size and the number of retired cars. The number of new vehicles is divided by fuel type in accordance with predicted consumer attractiveness, according to formula 1:

$$NV_{i,t}= \frac{K_{\text{attractive}i,\ t}}{\left(\sum K_{\text{attractive}i,t}\right) \times \sum NV_t}, \tag{1}$$

t—year;

$NV_{i,t}$—the number of new car sales for cars operating on a particular type of fuel;

i—fuel type;

$K_{\text{attractive},t}$—attractiveness factor for cars operating on a particular type of fuel;

$\sum NV_t$—total new car sales

Attractiveness factor for cars operating on a particular type of fuel is generated by multiplying three factors. These factors represent the key parameters of the attractiveness of different fuel types.

1. Kopi—a coefficient showing the average annual cost of owning a car operating on a particular fuel type. It is determined by ranking ownership costs of a vehicle from the cheapest to the most expensive ranging from 0 to 1. The cost of car ownership itself includes the following:
   a. Average car price by fuel type, based on the analysis of prices of the most popular models at Russian car dealerships (according to the Ref. 13) and assumptions about price increases or reductions;
   b. Vehicle life (determined according to Ref. 12);
   c. Average specific fuel consumption based on current fuel consumption of the most popular cars in Russia (according to AEB) and assumptions about increases in their fuel efficiency (this study assumes a 25% increase in fuel efficiency by 2040);
   d. Price of the fuel used. For the purposes of this study, retail fuel prices in Russia were determined by applying the count-conversion factor to the wholesale prices in the baseline scenario of the Global and Russian Energy Outlook to 2040 [2]. The prices were adjusted at the start of the period.
2. Kinfi—reflects the development of infrastructure for a specific fuel type ranging from 0 to 1. To calculate this coefficient, parameters that could impact consumers' preferences for a specific fuel type are estimated. One example is the availability of refueling and service infrastructure. Infrastructure coefficients are critical for assessing the attractiveness of vehicles operating on natural gas, electricity or hydrogen. These factors can also shape different scenarios for the construction and development of infrastructure in various nodes while assessing the impact on demand. Infrastructure coefficient is set at 1 for fuel(s) with the best infrastructure; these are usually petroleum products. Coefficients for other fuels are defined as the ratio of the number of fueling stations selling a given fuel type to the number of fueling stations selling the most popular fuel type (according to the [14,15] . The coefficient may be altered empirically to include other factors, such as the lack of service centers for maintenance of certain equipment in a given country.
3. K_{popi}—coefficient of consumer preferences for certain fuels. It denotes the level of consumer convenience in using a specific vehicle type, ranging from 0 to 1.

The number of new car sales relating to a particular fuel type in any given year is calculated according to the following equation:

$$\text{DMF}_{i,j}=V_{i,j}\times M_{i,j}\times F_{i,j} \tag{2}$$

i – year;

j – motor fuel type;

DMF – motor fuel demand;

V – fleet size by motor fuel type;

M – vehicle mileage;

F –motor fuel consumption by type

Vehicle mileage and motor fuel consumption by type are determined according to average values for vehicle classes (passenger, light commercial, trucks and so forth) derived from the AUTOSTAT statistics [12].

INTER-FUEL COMPETITION IN THE RUSSIAN ROAD TRANSPORTATION SECTOR: CURRENT STATUS AND POSSIBLE DEVELOPMENTS

According to [12], in 2015 the Russian transportation sector consumed roughly 65 million tonnes of oil equivalent energy (mtoe), most of which was supplied by petroleum products (Figure 1). At the first glance, such a structure seems natural for a country ranking in the top three both in oil production and refining. However, there are several complications that provide the incentives to alter the situation.

First, in its current state, the Russian refining sector sometimes finds itself incapable of providing a stable supply of petrol to the domestic market even at the current consumption level [16] . Petrol shortages and imports have become commonplace. Thus, diversification can be utilized to offset petrol demand growth and reduce the pressure on the refineries.

Second, many of the major Russian cities are faced with serious environmental issues, to a substantial degree brought about by rapid automobilization. It is common knowledge that petroleum products are a relatively "dirty" energy source. In comparison, natural gas vehicles (NGVs) on average emit 20 to 25% less carbon dioxide (CO_2) and 90% less toxic nitrogen oxide (NO, NO_2 etc.) than conventional petrol and diesel cars [17] , while electric vehicles (EVs) are considered emission-free, as long as electricity production is not taken into account.

And last, but not least, we consider the factor of Russia's economy and budget. The Russian Federation generated over 45% of its foreign trade income from oil and petroleum products, even during the period of falling oil prices in 2015 [18]. A promising way to increase this income is to tap deeper into the vast natural gas resources, either to produce more electricity, or to use gas directly as a motor fuel. The effect can be twofold, as increased domestic demand for natural gas can provide a much-needed stimulus for gas field and infrastructure development, as outlined by Ref. 19 .

That said these incentives may be the basis for governmental support of alternative fuels. However, the final decision will be made by consumers based on the attractiveness of a specific fuel type. Therefore, a long-term evaluation of the fuel mix requires an analysis of inter-fuel competition, as well as consumer preferences and state regulation.

Inter-fuel competition is present between conventional petroleum fuels (petrol, diesel fuel and, to a lesser extent, liquefied petroleum gases (LPG)) and alternative fuels that have been classified by the authors in other studies [4] . This process is under way both globally and in the Russian Federation. Alternative fuels include:

1. Direct substitutes that do not require any substantial changes in vehicle construction and infrastructure, such as:
   a. biofuels manufactured mostly from plant material: bioethanol and biodiesel [20];
   b. synthetic fuels from coal-to-liquids [21] and gas-to-liquids [22] processes.
2. Indirect substitutes that require major changes in both vehicle construction and consumer infrastructure, including:
   a. Electricity used in electric vehicles, or hybrid cars;
   b. Fuels cells used to convert chemical energy of hydrogen oxidation to electricity [23].
   c. Gas fuel, produced from natural gas or biomethane.

It is clear, however, that not all alternative fuels have equal potential. Table 1 gives a brief comparison of the most important characteristics affecting the fuel's competitiveness. Some of the alternatives, such as synthetic fuels and fuel cells, are not represented in the table because of their extremely high prices and the lack of real basis s for comparison.

Electric vehicles tend to be the most expensive and the least practical, due to weak infrastructure and cold climate limitations. The government is taking some measures to remedy the situation, such as removing import duties for EVs and providing support for the charging infrastructure, but they will hardly be sufficient. Biofuels are undermined by the Russian taxation system, which classifies them as alcoholic beverages rather than fuels. As such, biofuels prices are 2–3 times higher than conventional fuel prices.

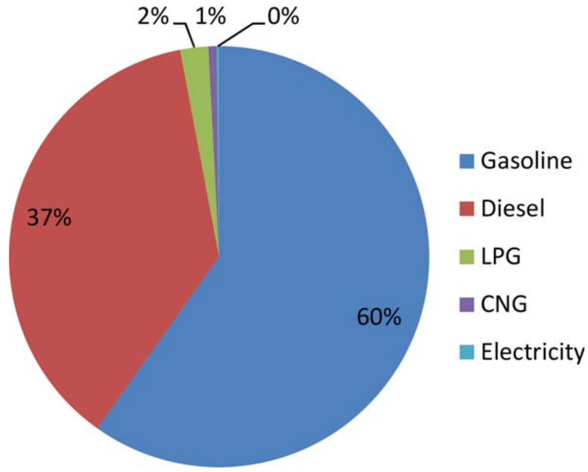

Figure 1. Energy mix of the Russian transportation sector [12]. [Color figure can be viewed at **wileyonlinelibrary.com**]

All things considered, compressed natural gas (CNG) seems to hold the most promise as an alternative fuel for most vehicle classes. On the plus side, natural gas is approximately half the price of petrol and is readily available throughout most of the country, as Russia benefits from considerable gas reserves and a well-developed gas transit system. It is also considered good for the internal combustion engine, lengthening service periods and is much safer compared to other fuels [24]. Moreover, switching to CNG does not entail abandoning conventional fuels completely, as most natural gas vehicles (NGVs) are flex-fuel and can easily operate on both fuel types. Despite all of these factors, CNG takes up only 0.5% of Russian motor fuels market with 0.4 mtoe consumed in 2015 [25], as there are also some major barriers to using this fuel type.

Insufficient infrastructure is the key factor, as with most other alternative fuels. Only around 260 CNG stations operate in the Russian Federation [26], most of which were built in the 80-s and 90-s and need to be fully renovated. In comparison, there are over 25 thousand conventional filling stations [15]. And even the present CNG stations operate at only 20% of the 2 billion m^3 capacity, due to a small number of NGVs, estimated at 110,000 [27], or 2% of the whole fleet. It is safe to say that this is a prime example of the infrastructural paradox: consumers do not buy NGVs because of insufficient infrastructure, whereas business does not develop the infrastructure due to a lack in demand [28] .

The second barrier to using CNG is the issue of NGVs' availability. Currently, there are no factory-made NGVs in the passenger auto and LCV markets. To switch to CNG, a consumer is forced to undertake an uncertified and costly retrofitting procedure, which, in most cases, means waiving the warranty.

The third barrier is future CNG price uncertainty. Resolution of the Government of the Russian Federation N 338 of April 2015 "On annulment of the resolution of the Government of the Russian Federation of January 15, 1993 N 31 "abolished the link of CNG prices to the long-obsolete A-76 petroleum. However, the new pricing mechanism is yet to be introduced. This situation puts both consumers and suppliers at risk of an unfavorable development, should the prices turn out too high or low and undermines the economic attractiveness of CNG.

Table 1. Key consumer characteristics for different fuel type vehicles, 2015.

Fuel type	Fuel costs, $/100 km milage	Vehicle cost in relation to the cheapest in class	Infrastructure condition	CO2 emissions, g/km
Petroleum products	4.7–6.2	100%	24,000 Fueling stations	290–320
CNG	2–2.5	120%	250 CNG stations	200–250
Electricity	0.8–2.3	150–350%	40 charging stations*	0†
Biofuels	12.4–15.6	100%	24,000 Fueling stations**	95–114

*This figure includes only "fast chargers", without accounting for ability to charge cars through socket in private estates or at the public parking lots.
**Assuming a separate tank for biofuels available at each fueling station or blending with conventional fuels.
†CO_2 emissions from electric vehicles do not take into account emissions in electricity generation.

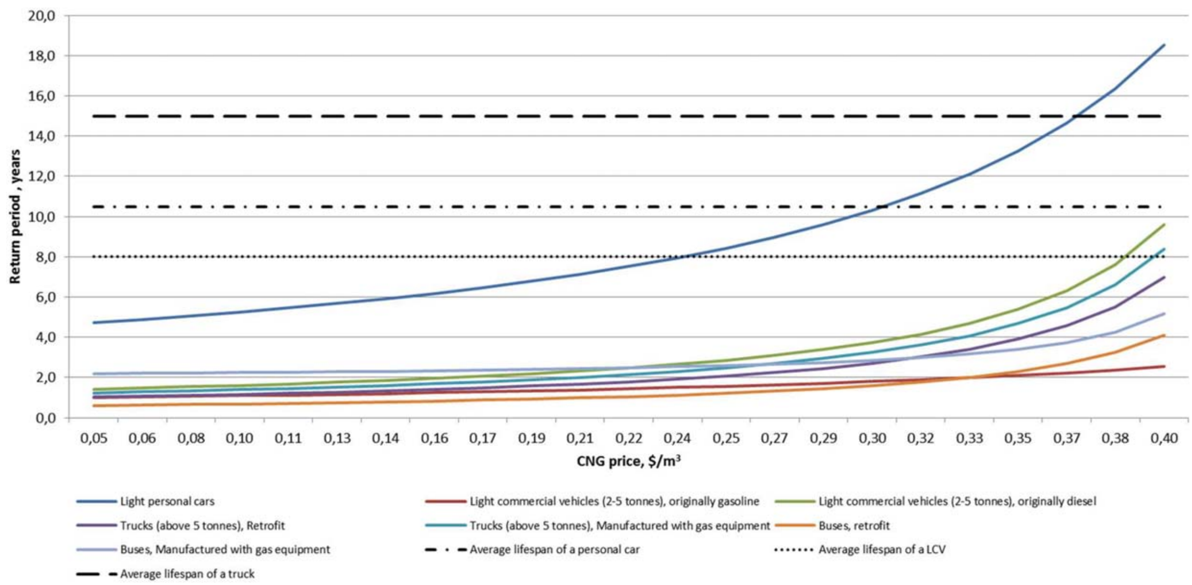

Figure 2. Payback period for conversion to NGV depending on the average CNG price, with petroleum products prices set at 0.65$/liter. [Color figure can be viewed at **wileyonlinelibrary.com**]

The issue of increasing the share of CNG in the energy mix and overcoming the barriers to its use has been named as a strategic priority by the Russian Government in the Energy Strategy 2030 [10]. Some important steps have already been made. In May 2013, the Government issued Resolution № 767, which set a mandatory minimum percentage of NGVs among the public transportation vehicles, depending on city size. A specialized company "Gazprom gas fuel" was also set up, its main goals being to develop the CNG infrastructure and promote NGVs [24]. However, these efforts have not been sufficient to tip the scales in favor of NGVs in the most important passenger car market, where the price of switching and ownership costs remain the key factors.

An economic analysis of the NGVs shows that lightweight personal transport is the most susceptible to CNG price changes (Figure 2). At the price level over 0.3 $/m^3, the payback period for refitting a car exceeds its average lifespan, and makes switching to CNG economically unviable. At the same time, our calculations show that 0.25–0.3 $/m^3 price range ensures bottomline profitability for the supplier. As such, an equilibrium price of 0.28 $/m^3 will be adopted for further calculations. Curiously enough this price is roughly equivalent to one half of petroleum price that has been in place for decades.

SCENARIO ASSUMPTIONS

The energy demand forecast was conducted along two scenarios:

- Baseline—a "business-as-usual" scenario that presumes all of the current governmental decrees will be implemented. Production of heavy-duty NGVs will be set up. Yet no further incentives for passenger and light-duty NGVs will be established. The share of electric vehicles share will slowly grow, however no fast-charging infrastructure will be developed.
  - Diversification—a more optimistic scenario. By 2030 the barrier of insufficient CNG infrastructure setback will be fully eliminated by setting up mandatory natural gas filling stations at conventional fuel stations. NGV incentives will be expanded, and purchase price difference between NGVs and conventional vehicles negated (either through direct financing, or large-scale domestic production of gas equipment). Between 2025 and 2040 fast-charging infrastructure will be established and EV prices will become more competitive due to more beneficial taxation. Alternative vehicles will receive additional support for promotion and marketing.

Both scenarios share the same macro parameters and some common beneficial factors:

Table 2. Attractiveness factors ratios for different vehicle and fuel types in different scenarios.

Vehicle class	Fuel type	Base (2014)	Baseline scenario, 2040	Diversification scenario, 2040
Two and three wheeled transport	LPG	0	0	0
	Gasoline	1	1	1
	Diesel	0	0	0
	CNG	0	0	0
	Electricity	0	0.2	0.44
Light weight road transport	LPG	0.01	0.02	0.02
	Gasoline	1.00	1.00	0.93
	Diesel	0.66	0.55	0.51
	CNG	0.0025	0.55	1.00
	Electricity	0.00	0.13	0.60
Meduim weight road transport	LPG	0.01	0.01	0.01
	Gasoline	0.40	0.35	0.35
	Diesel	0.71	0.82	0.82
	CNG	0.35	0.47	0.68
	Electricity	0.003	0.05	0.11
Heavy weight road transport	LPG	0.01	0.004	0.005
	Gasoline	0.39	0.18	0.23
	Diesel	0.66	0.75	0.96
	CNG	0.003	0.66	0.68
	Electricity	0.00	0.11	0.31

- Average annual GDP growth of 2% between 2014 and 2040;
- Population decreases by 0.5% annually between 2014 and 2040;
- Domestic petroleum product prices increase from 0.28–0.57 $/l in 2014 to 0.42–1.01 $/l in 2040;
- Natural gas prices grow from 0.25 $/m^3 in 2014 to 0.40 $/m^3 in 2040;
- Electricity prices increase from 0.14 $/kWt*h in 2014 to 0.24 $/kWt*h in 2040;
- Fuel efficiency of new liquid and gas fueled vehicles will increase by 20–25% in 25 yr, while new EVs will become 5% more efficient;
- CTL and fuel cells technologies will not make major advances.

The beneficial factors listed above were formalized and used to calculate the attractiveness factor of new vehicles that depends on fuel costs, infrastructure development and consumer preferences (more on the methodology in the previous papers by the authors [4,11] . The resulting values are shown in Table 2.

RESULTS AND DISCUSSION

In both scenarios, total fleet size in Russia increases by over 200% to 97 million vehicles. This, in turn, leads to energy demand growth up to 109 mtoe, despite growing energy efficiency (Figure 3).

The calculation results shown in Figure 4 and Table 3 indicate that diversification will happen to some extent within the Baseline scenario. CNG will grow to provide 10% of the energy demand. However, 35% of the CNG demand is attributed to the public transport NGVs, supported by the state. Electricity demand will also rise to 1.6 mtoe by 2040. The reduction in the number of the public EVs will be offset by personal electric cars. Petroleum products, however, will continue to dominate the energy mix, with demand growing to 95.8 mtoe.

Additional incentives for the alternative fuels in the Diversification scenario lead to more significant changes in the energy mix. Namely, CNG share expands to 21% or 23 mtoe, squeezing out petroleum products, mainly expensive petrol. EV fleet grows steadily to produce 3% of energy demand, as opposed to 1% in the baseline scenario, most of the growth coming from passenger EVs.

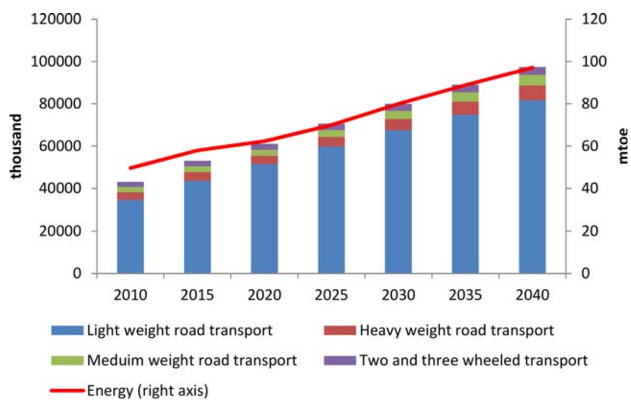

Figure 3. Fleet size per class vs. total energy demand. [Color figure can be viewed at **wileyonlinelibrary.com**]

CONCLUSIONS

The research shows that the Russian Federation has a number of strong incentives for the diversification of the transportation sector's fuel mix:

1. Structural incentive. As of 2015 petrol, the dominant fuel, has been imported in small volumes; however, petrol production capacities at the Russian refineries are already at the limit. Should the demand continue to increase as rapidly, Russia may face a partial fuel import dependency;
2. Environmental incentive. Petroleum products are the least "clean" fuels. CNG use can reduce toxic emissions by 25% to 90%, while EVs are emission-free;
3. Export incentive. Domestic demand reduction can free up additional oil and petroleum products for exports, boosting foreign trade income;
4. Gas incentive. Domestic market development may provide a support and development stimulus for Russian gas companies, especially given the contracting traditional European export market [29].

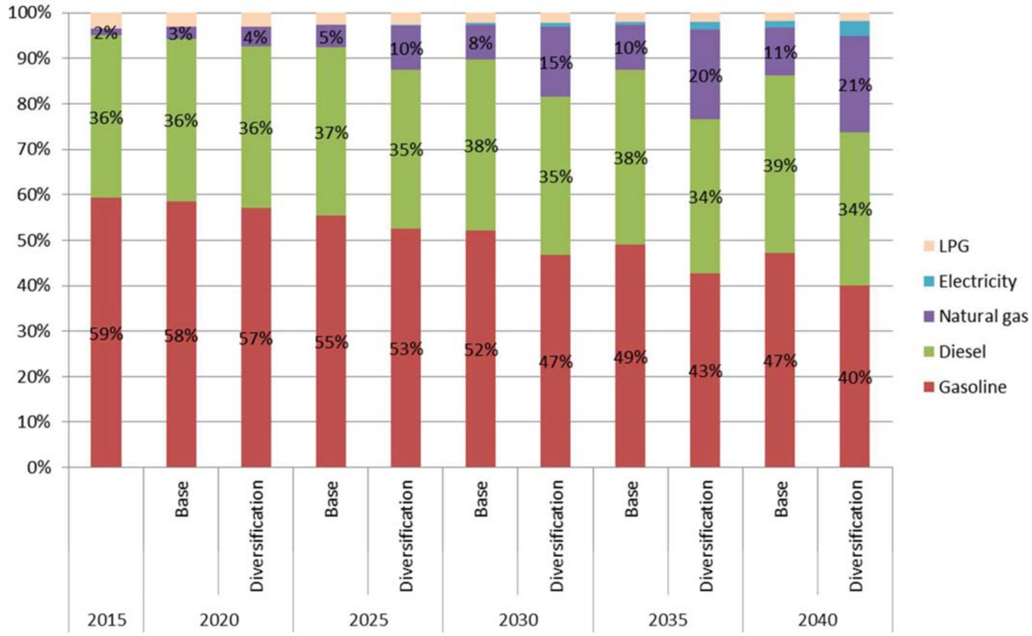

Figure 4. Russian transportation sector demand structure in the Baseline and «Diversification» scenarios. [Color figure can be viewed at **wileyonlinelibrary.com**]

Table 3. Road transportation energy demand in the baseline scenario, mtoe.

Vehicle class	Fuel type	Base (2015)	2020	2025	2030	2035	2040
Two and three wheeled transport	LPG	0	0	0	0	0	0
	Gasoline	0.17	0.18	0.19	0.21	0.22	0.24
	Diesel	0	0	0	0	0	0
	CNG	0	0	0	0	0	0
	Electricity	0	0	0.001	0.002	0.004	0.005
Light weight road transport	LPG	0.5	0.5	0.5	0.5	0.5	0.5
	Gasoline	34.4	36.7	39	40.7	41.7	41.8
	Diesel	4.7	7.4	9.9	11.7	13.1	14
	CNG	0.1	0.6	1.6	2.9	4.2	4.8
	Electricity	0.0002	0.014	0.097	0.3	0.7	1.5
Meduim weight road transport	LPG	0.4	0.4	0.3	0.3	0.2	0.2
	Gasoline	1.8	2	2.3	2.8	2.9	3.3
	Diesel	6.5	5.8	5.9	6.3	6.8	7.3
	CNG	0.1	0.6	1.4	2.1	2.5	2.6
	Electricity	0	0	0	0	0	0
Heavy weight road transport	LPG	1.3	1.3	1.3	1.3	1.3	1.3
	Gasoline	3.8	3.8	4.3	5	5.6	6
	Diesel	13	12.8	14.8	17.2	19.5	21.2
	CNG	0.8	0.7	1.1	2.1	3.4	4
	Electricity	0.00001	0.0001	0.0001	0.0001	0.0001	0.0001
Summ	LPG	2.3	2.2	2.1	2.1	2	2
	Gasoline	39.2	42.8	45.9	48.9	50.6	51.6
	Diesel	24.2	26.1	30.5	35.3	39.4	42.4
	CNG	1.1	1.9	4.1	7.1	10.0	11.5
	Electricity	0.0001	0.02	0.1	0.31	0.7	1.6

Nevertheless, all of these incentives are just the grounds for Government's work to support the diversification, as the end results relies heavily on the attractiveness of the alternative fuels for the end-user.

The analysis show that even now CNG can compete with the conventional fuels based on price and technological advantages. Among other alternatives, electricity has a competitive potential, albeit considerably smaller. But to fully realize the potential of alternative fuels, the existing measures are insufficient.

In addition to the already considerable support for CNG, we recommend the development and implementation of additional incentives for vehicles on other alternative fuels, such as EVs. The examples of such measures include: subsidies and tax deductions for companies building charging stations; preservation of reduced import duties on electric vehicles. Moreover, some nonmonetary incentives can be introduced for cars onalternative fuels, such as the right to travel on a dedicated lane in large metropolitan areas, free parking in the city center and others.

The simulation process shows that large-scale infrastructure development coupled with financial and other incentives could free up to 13 mtoe of petroleum fuels to be potentially exported.

These changes will certainly demand considerable investment. However, as diversification process progresses, the burden can be shared between the Government, oil, gas and energy companies, consumers and auto manufacturers, as the end result is mutually beneficial for all parties.

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