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Prospects for motorization and energy markets in the context of fully autonomous vehicles spread

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Abstract. The report is devoted to two interrelated issues: the impact of penetration of fully autonomous cars and car sharing on the car fleets, and in combination with an increase of the share of electric vehicles on the volume and structure of energy demand. For this, forecasting tools and motorization scenarios have been developed. Forecasts for car fleet and energy demand were obtained for Russia and the largest economies in the world (China, USA, EU, India, Japan).

1. Introduction
In the future, motorization and passenger cars energy demand will most probably be determined by three key factors.

1.1. The penetration of fully autonomous vehicles
Over the past decade, a significant breakthrough has been made in the development of automatic control systems: fully autonomous versions of cars have been developed, and their mass production and market entry are planned in the coming 3 - 5 years. Fully autonomous vehicles can become the basis for the "explosive" development of car sharing both in the commercial segment of passenger automobile transport (taxi, car sharing services) and in the household sector [1]. A more intensive operation will satisfy the need for transportation with a relatively smaller number of vehicles [2].

1.2. The increase in the share of electric vehicles in total sales
In many countries around the world populations who are concerned about the emissions produced by internal combustion engines express their intentions to ban the sale of cars with internal combustion engines and to pursue a policy in support of electric vehicles purchase. The penetration of electric vehicles in the future will be determined by their market price (first of all, the cost of batteries) and overcoming their limitations such as a limited range, long charge time, reduced battery capacity at low temperatures, etc.

1.3. Improving energy efficiency
The average fuel consumption rate of new cars decreased from 18 liters per 100 km in 1975 to 7.6 liters by 2015 due to improvements in the engine, reductions in the weight of cars, improvements in their aerodynamics, etc. According to EIA estimates, the average energy efficiency in the car fleet can significantly increase: from 10.5 liters per 100 km (2016) to 6.2 liters (2050). Fully autonomous shared cars can be even more efficient: by optimizing usage modes and routes, including them in

territorial traffic flow coordination systems, reducing the need in finding intermediate parking, which in cities accounts for a significant proportion (30% on average) of the time spent during a trip.

2. Description of forecasting tools

We developed forecasting and analytical tools to illustrate the importance of the penetration of fully autonomous shared cars to motorization.

The calculations are carried out in four stages. At the first stage, the potential demand for passenger car services is assessed, depending on the hypothesis of economic development and population growth with the assumption that the patterns of motorization prevailing in the past are preserved. To do so an aggregate time series model was applied [3]. We use a logistic curve to approximate car ownership (the number of cars per 1000 people):

$$O_1(t) = O_{max} \cdot \left(1 + \exp\left(a(b - W(t))\right)\right)^{-1}, \tag{1}$$

Where: $O_1(t)$ is car ownership at 1st stage of calculations, O_{max} is saturation level, $W(t)$ is an independent variable, a and b are estimated coefficients.

Following Tanner's work [4], as an independent variable we consider the sum of weighted current and past values of GDP per capita:

$$W(t) = c \cdot W(t-1) + GDP(t), \tag{2}$$

Where $GDP(t)$ is GDP per capita in constant prices; c are estimated coefficients, $0 \le c \le 1$.

Using a hypothesis on the prospects for population growth we calculate car fleet.

$$Fleet_1(t) = O_1(t) \cdot Pop(t) \cdot 10^{-3}, \tag{3}$$

Where $Fleet_1(t)$ is car fleet at 1st stage of calculations, $Pop(t)$ is population.

Using a hypothesis on car retirement rate we also calculate sales of cars at 1st stage of calculations:

$$Sales_1(t) = Fleet_1(t) - \left(1 - RtrRate(t)\right) \cdot Fleet_1(t-1), \tag{4}$$

Where $Sales_1(t)$ is car sales at 1st stage of calculations, $RtrRate(t)$ is car retirement rate.

At the second stage, we consider car fleet as a combination of two functionally different types: fully autonomous shared vehicles and traditional cars (cars used personally, partly autonomous cars are also included as they don't contribute in possibilities of sharing). The estimated car fleet at the first stage is adjusted taking into account the gradual penetration of fully autonomous vehicles (which, as part of the calculations, define speed of the penetration of car sharing and the substitution coefficient of traditional cars). The scenario parameters at the second stage of the calculation are: the share of fully autonomous vehicles in total passenger car sales at the starting point (2025); growth rate of fully autonomous vehicle sales; the number of traditional cars replaced by one fully autonomous shared car in sales (in other words, a substitution coefficient); retirement rate of traditional and fully autonomous shared cars. Car sales on the second stage can be calculated as follows.

$$Sales_2(t) = Sales_1(t) - \left(SubCoeff(t) - 1\right) \cdot SalesFAC(t), \tag{5}$$

Where $Sales_2(t)$ is car sales at 2nd stage of calculations, $SubCoeff(t)$ is substitution coefficient,

$SalesFAC(t)$ is sales of fully autonomous shared cars.

Then the car fleets for both types (traditional and fully autonomous) can be estimated.

At the third stage, the penetration of electric vehicles is modeled, depending on the hypotheses of their share in sales (provided by OPEC prospects). At the fourth stage, petroleum and electricity consumption by cars is calculated, depending on a hypothesis of average mileage and energy efficiency for each car type (depending on control system and energy used).

$$ConEnergy(t) = Fleet(t) \cdot Mil(t) \cdot RateCon(t), \tag{6}$$

Where $ConEnergy(t)$ is energy consumption (petroleum or electricity), $Mil(t)$ is average mileage of one car, $RateCon(t)$ is consumption rate.

For fully autonomous shared cars their additional efficiency is taken into account.

3. Scenarios of motorization

Four scenarios of motorization are considered, differing in penetration conditions and usage mode of fully autonomous shared vehicles (Table 1). A hypothesis regarding energy efficiency and the share of electric cars in total sales do not differ between scenarios.

Scenario 1 ("business-as-usual") is characterized by the inertial development of commercial sharing services, while fully autonomous vehicles do not have a significant impact on motorization. Scenario 2 ("autonomous cars in households") allows us to analyze the possibilities of reducing the personal fleet due to the more intensive use of fully autonomous vehicles compared to traditional ones within households. Fully autonomous vehicles in this scenario are mainly consumed by households. While the traditional car around 95% of time is parked, fully autonomous vehicle might serve different members of household. So it is used more intensively, as a result fully autonomous cars replace traditional cars in a 1: 2 ratio. In scenario 3 ("mobility as a service") the potential scale of "mobility as a service" systems development based on fully autonomous vehicles in large cities is considered. For many large cities it is a basic method of dealing with traffic problems and pollution. "Mobility as a service" means creating such a system that stimulates citizens to use public transport and sharing services and reduce personal cars usage. Fully autonomous shared cars are considered to be a key element of such a system. That means the penetration of fully autonomous shared vehicles in this scenario is significantly higher than in scenario 1. The substitution coefficient is higher than in Scenario 2, since autonomous cars serve not one, but several households. Scenario 4 ("distributed mobility") allows us to evaluate the effect of the distribution of traffic peaks (one in the morning and one in the evening) during the day, which increases the intensity of fully autonomous shared vehicles usage.

Table 1. The main hypotheses in different scenarios (in the case of Russia).

	2017 year	2045 year			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Fuel consumption rate, litres per 100 km	10,3	6,2			
Electricity consumption rate, kWh per 100 km	20-	17			
The share of electric vehicles in sales,%	~0%	15%			
Sales of fully autonomous shared cars, thousand units	~0	250	1300	1300	1000
Share of fully autonomous shared cars in total sales, %	-	8%	50%	50%	50%
Substitution coefficient	-	4	2	4	8

4. Results and Discussion

The main calculation results are shown in table 2. They are given for Russia, China and for five largest economies (China, India, US, EU, Japan) aggregated.

Table 2. Calculations results for the car fleet and its energy consumption in Russia, China and five largest economies by 2045.

	2017 year	2045 year			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Russia					
Passenger car fleet, mln. units.	44	56	45	40	33
Share of fully autonomous shared cars in the fleet,%	-	2%	10%	12%	16%
Share of electric vehicles in the fleet,%	0%	7%	7%	7%	8%
Share of electric vehicles in VMT,%	0%	7%	8%	9%	11%
Consumption of petroleum products, million tons.	54	40	39	38	36
Electricity consumption, billion kWh	0	13	14	15	16
China					
Passenger car fleet, mln. units.	185	470	390	347	238
Share of fully autonomous shared cars in the fleet,%	-	2%	21%	15%	16%
Share of electric vehicles in the fleet,%	1%	26%	26%	25%	32%
Share of electric vehicles in VMT,%	1%	26%	27%	29%	34%
Consumption of petroleum products, million tons.	178	283	269	264	221
Electricity consumption, billion kWh	4	405	417	430	477
Five countries (China, US, EU, India, Japan)					
Passenger car fleet, mln. units.	784	1 273	1 028	927	684
Share of fully autonomous shared cars in the fleet,%	-	2%	22%	16%	17%
Share of electric vehicles in the fleet,%	~0%	25%	24%	23%	27%
Share of electric vehicles in VMT,%	~0%	27%	29%	30%	36%
Consumption of petroleum products, million tons.	758	771	738	726	618
Electricity consumption, billion kWh	10	1 106	1 602	1 100	1 214

Calculation results for different scenarios give us information on how different conditions of motorization influence the car fleet and energy demand. Scenarios 3 – 4, in which fully autonomous cars are more widespread than in scenario 2, the car fleet is estimated to be significantly lower. Scenarios 2 and 3 differ primarily in usage mode (within household or within "mobility as a service" system). The more intensive usage in scenario 3 leads to lower values of car fleet (by 10-12% comparing to scenario 2) and petroleum demand from cars (by 2% comparing to scenario 2). Distribution of traffic peaks during the day in scenario 4 leads to a decrease in our estimations by an

additional 30% (compared to scenario 3) for car fleet and 15 – 17% for petroleum demand. Scenario 4 is significantly different from scenario 1: the car fleet is expected to be 50% lower than in scenario 1 and petroleum demand to be 20% lower. The difference in energy demand between the scenarios is much lower than the difference in car fleet values. This is connected with the fact that despite car fleet decreases usage intensity will grow. The decrease in energy demand is a consequence of two factors: the higher electrification rate of shared cars and the relative efficiency of fully autonomous cars. Intensive usage means higher retirement rate and accelerated renewal. As a result the same hypothesis on electric cars share in total sales gives a different electric cars share in total fleet (Table 1 and 2). The higher share of electric cars in the shared car fleet combined with more intensive usage gives higher electric cars share in total VMT (Vehicle Miles Travelled) and as a result lower petroleum consumption by passenger cars. Electricity consumption grows in all the scenarios due to electric car fleet increase but we consider such a growth by 3 – 4% of total electricity consumption of considered countries in 2045.

5. Conclusion
The penetration of fully autonomous cars has a significant impact on the car fleet and its petroleum demand. In scenario 4 (in which the transport systems of cities are based on "mobility as a service" and traffic peaks are distributed during the day) the total car fleet is estimated to be 50% lower than in the "business as usual" scenario, petroleum demand will be 20% lower and electricity demand 10% higher. For energy suppliers that might mean structural changes in demand for their products: lower demand for oil and higher demand for gas or renewables.

6. References
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