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Reduction of Energy Intensity of Gross Regional Product: Opportunities and Limitations

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Abstract: In the article, on the basis of model calculations, the possibilities and limitations of reducing the energy intensity of the Gross Regional Product (GRP) of the subject of the Russian Federation are investigated, provided that the region develops taking into account the requirements of the Energy Strategy of Russia for the period up to 2035. The calculations were carried out on interrelated models of the economy and energy of the Samara region, where scenarios for the region's energy-efficient development were worked out, taking into account the targets of state programs for energy saving and energy efficiency development, declared in the Energy Strategy. As a result of research, it has been established that economic growth is the most important condition for reducing the energy intensity of GRP, and, the higher economic growth, the greater its contribution to the decrease in the energy intensity of GRP. It is also shown that a 40% reduction in GRP within the period of 2018–2035 is feasible only with the average annual economic growth of at least 5%, even with the absolute implementation of all sectoral programs on energy saving and energy efficiency development. Similar conclusions are true for Russian economy as a whole. If Russian economy develops at an average annual rate of less than 5%, then the main target indicator of the Energy Strategy - a decrease in the energy intensity of GDP by more than forty percent by 2035 compared to 2007 will be fundamentally unattainable.

Keywords: Energy Intensity of GRP, Fuel and Energy Complex, Economic Growth, Modeling, Forecasting

1. Introduction

1.1. Establishing a Context

The main target of the energy policy of Russia, according to the Energy Strategy of the Russian Federation for the period until 2030 [1], is the energy efficiency development of production and consumption of energy resources and, as a result, reduction in the specific energy intensity of the economy. The main target indicator of the strategy at the federal level is the reduction in the energy intensity of GDP, and at the regional level, the reduction in the energy intensity of GRP. By the end of 2030, it is planned to reduce the energy intensity of GDP by more than forty percent compared to 2007. The updated Energy Strategy of Russia for the period up to 2035 plans to reduce the energy intensity of GDP by 34% over 20 years.

In the formation of regional energy-efficient development programs, the developers of regional strategies focus on the target indicators of the federal strategy, planning to reduce the energy intensity of GRP by 40% or more. The question arises: how these targets are justified, if it is possible to reduce the energy intensity of GRP by 40% within the period of 2018–2035, what limitations arise in reducing the energy intensity of GRP.

The energy intensity can be reduced due to improved technologies, new equipment and decommissioned old equipment, changes in production equipment loading parameters, and also structural shifts in the economy due to changes in the share of economic activities of different energy intensity levels taking into account the difference in their rates of development. The energy consumption in the industry of Russia accounts for more than 40% of the total energy consumption [2]. In some regions it is more than 60-70%. Such relatively high energy consumption is due to regional energy-intensive industries (metallurgy, oil refining, petrochemicals, etc.). Achieving energy policy targets in such regions, namely, reducing the energy intensity of GRP by more than forty percent is extremely difficult. This requires a complete re-equipment of production, the introduction of new energy-saving technologies, which requires huge investments and a long time period. The authors of studies conducted at the Center for Energy Efficiency [3], using the example of Moscow, conclude that 40% reduction in the energy intensity of GRP can be achieved in the near future, mainly by changing the production structure towards less energy-intensive types of products and sectors of the economy. But deliberate movement in this direction, without analyzing economic consequences, can damage the regional economy and its energy security, since developed production in the region, regardless of its energy intensity ensures stable development of the economy and the social sphere. Therefore, to assess the real prospects for reducing the energy intensity of GRP, it is necessary to link the goals of energy-efficient development of the region with the goals of the regional economy as a whole.

In the preparation of the State Program of the Russian Federation "Energy Saving and Energy Efficiency Development for the Period until 2020", the influence of various factors on the dynamics of the energy intensity of GDP was assessed [4]. Table 1 shows the results of this assessment for the innovative scenario of the Energy Strategy of the Russian Federation 2020 assuming that by 2020 the specific energy intensity of GDP will be reduced by 40% compared to 2017.

Table 1. *The contribution of factors to the decrease in the energy intensity of GDP for Energy Strategy 2020*.*

Indicators	Units of measure	Contribution of factors
Reduced energy intensity of GDP,%	%	40.0
including due to:		
structural changes%	%	17.7
product changes%	%	4.1
energy price increase%	%	4.2
autonomous technical progress%	%	6.2
implementation of the State Program "Energy Saving and Energy Efficiency Development of the Russian Federation for the Period until 2020"%	%	7.8

* Fragment of Table 4.1 from [4].

As follows from the table, the authors consider structural changes in the economy to be the most important factor in reducing the specific energy intensity of GDP. However, in our opinion, structural changes (as well as product changes) are not factors — they only reflect the action of real factors, such as, for example, economic growth and uneven rates of development. Therefore, when forecasting the dynamics of the specific energy intensity of GDP (GRP), it would be more correct to use these factors instead of structural shifts.

1.2. Brief Literature Review

In international practice, an approach based on the use of the results of factor analysis of changes in energy intensity (for example, within the framework of the ODYSSEE MURE project [5] is widely used to predict the energy intensity of GDP. Its general algorithm involves the following stages of forecasting:

a) Factor analysis of changes in the energy intensity of GDP in retrospect and the construction of a multi-factor model of energy intensity of GDP;

b) Forecast of the dynamics of influencing factors on the future;

c) Forecast of energy intensity of GDP using a factor model based on predicted factors.

A good overview of methods for factor analysis of the energy intensity is given in [4]. The most common method for factor analysis of the energy intensity is the LMDI index-linked analysis [6]. This method is used as a base when assessing the energy efficiency index in a number of countries, and is also widely used in the practice of the International Energy Agency. However, at the regional level, the described approach turns out to be unacceptable due to the lack of long series of comparable statistical data on changes in main energy intensity factors, which does not allow for providing statistically significant results of the analysis. It also seems questionable to apply the results of factor analysis in the long term (20 years), since such an approach cannot take into account the interrelated dynamics of influencing factors. Therefore, the only worthy method for forecasting the energy intensity of GRP is a controlled model experiment, when scenarios for energy-efficient development are worked out on interconnected models of the economy and energy.

Existing approaches to modeling the economy and energy are characterized by a large variety of models, reviews, discussions and comparison [7, 8]. The article [9] considers a review of more than two hundred models widely used in different countries to analyze and forecast the development of the energy sector, and to study problems related to energy modeling. The article [10] illustrates decision support models for studying the interaction between the energy system and the economy at the national level. A special place in the modeling literature is given to computable general equilibrium (CGE) models [11]. Due to their ability to simulate the response of the system to external influences, these models are widely used to analyze the consequences of managerial decisions [12]. In particular, in the field of energy, the CGE-models are used as useful tools to assess the extent of economic consequences in implementing energy and environmental policies [13].

Of greatest interest to us were Russian studies in the field of energy modeling and forecasting as part of the economy, since they more closely take into account the specifics of national management institutions and the statistical description of modeling objects. At present, the technology of modeling and forecasting the economy and energy, developed at the Institute for Energy Research of the Russian Academy of Sciences [14], deserves the most attention. This technology is successfully used to forecast both the Russian and global energy [15]. The main feature of this technology is the development of a consistent and mutually agreed system of forecasts of the country's economic development, consumption and production of basic fuels and energy, as well as financing of individual sectors of the fuel and energy complex (FEC). The iterative coordination in the forecast system is carried out through energy balances, which are formed for the country as a whole and for individual regions, production characteristics and financial balances of FEC, locked onto inter-industry balances of the national economy.

At the regional level, it is necessary to note the forecast-analytical complex "Economy & Energy", developed at Samara State University of Economics [16]. It has to support management decisions of regional authorities in the tasks of improving energy efficiency and energy security of the regional economy. The "Economy & Energy" complex implements a technology for forecasting the balanced development of the economy and FEC, within which information is compiled and iteratively coordinated between forecasts of the energy consumption and energy production based on the regional fuel and energy balance [17].

1.3. Purposes and Objectives of the Study

The main purpose of this study was to assess the possible reduction in the energy intensity of GRP of the subject of the Russian Federation using the example of the Samara region within the period of 2018-2035 within the framework of the Energy Strategy of Russia until 2035 [18]. When conducting research, the following tasks were set and solved:

- Collect reporting information on the FEC development of the Samara region and the regional economy as a whole in the required volume;
- Develop scenarios for the Samara region within the framework of the Energy Strategy of Russia until 2035, including the prospects for domestic demand for fuel and energy;
- Conduct scenario forecasts for the forecast-analytical complex "Economy & Energy";
- Assess the prospects and conditions for reducing the energy intensity of GRP for the region-subject of the Russian Federation based on the results of predictive experiments.

2. Methods

2.1. Formal Statement of the Problem

The energy intensity of GRP is calculated by the following formula:

$$EI_{GRP}(t) = \frac{TFC(t)}{GRP(t)}, \quad (1)$$

where $EI_{GRP}(t)$ - energy intensity of GRP in the *t-th* year, tons of fuel equivalent for 1 ruble of value added;

$TFC(t)$ - final consumption of fuel and energy in the *t-th* year, tons of fuel equivalent;

$GRP(t)$ - gross regional product in the *t-th* year, rub.

When calculating the final consumption of fuel and energy, we take into account fuel and energy resources spent on the final consumption in all sectors of the regional economy, including households. To eliminate double counting, fuel and energy resources, converted into thermal and electrical energy, and fuel and energy resources, processed into non-energy raw materials for chemical enterprises, are excluded.

The structure of the final consumption of fuel and energy resources in the Samara region for the reporting period is shown in Table 2.

Table 2. *Structure of the final consumption of fuel and energy resources (Samara region)*.*

Economic sectors	Units of measure	2010	2011	2012	2013	2014	2015	2016	2017
Fuel and energy resources	%	29.2	29.3	29.1	28.8	28.2	28.4	29.3	29.6
Production of goods (except for fuel and energy resources)	%	28.9	27.4	28.5	28.5	27.4	26.6	25.1	24.9
Production of services	%	15.4	16.2	16.4	17.2	16.3	16.3	16.5	16.4
Households	%	26.5	27.1	26.0	25.5	28.1	28.6	29.2	29.0
The Economy – total	%	100	100	100	100	100	100	100	100

* Rosstat data for the Samara region

Of particular interest is the specific energy intensity of GRP, which is calculated relative to the base year in comparable prices:

$$EI_{GRP}(t \mid 0) = \frac{EI_{GRP}(t)}{EI_{GRP}(0)} I_{GRB}^{def}(t \mid 0). \quad (2)$$

where: $EI_{GRP}(0)$ - energy intensity of GRP for the base year; $I_{GRB}^{def}(t \mid 0)$ - GRP deflator index calculated for the t -*th* year relative to the base year.

Whereas

$$GRP(t) = GRP(0) I_{GRP}^{gr}(t \mid 0) I_{GRP}^{def}(t \mid 0),$$

where $I_{GRP}^{gr}(t \mid 0)$ - growth index of the physical volume of GRP, then the specific energy intensity of GRP can be represented in a more convenient form:

$$EI_{GRP}(t \mid 0) = \frac{TFC(t)}{TFC(0) I_{GRB}^{gr}(t \mid 0)} = \frac{TFC(t)}{TFC^{(0)}(t)}, \quad (3)$$

where the indicator

$$TFC^{(0)}(0) = TFC(0)I^{gr}_{GRB}(t \mid 0) \quad (4)$$

makes sense to the final consumption of fuel and energy resources in the t-*th* year, provided that the energy intensity of GRP is maintained at the level of the base year.

To assess the dynamics of the indicator (3), forecast calculations were carried out for various scenarios of energy saving and economic growth.

2.2. Tools and Solutions

Forecast experiments were conducted on the forecast-analytical complex "Economy & Energy", developed at Samara State University of Economics [16]. The core of the "Economy & Energy" complex is a dynamic multi-industry model of the fuel and energy complex as part of a general model of the region's socio-economic activity, which forms interrelated processes for production, processing, transportation and use of all types of fuel and energy resources in the region. The model developed by the authors in the class of CGE-models for regional forecasting is used as a model of the subject of the Russian Federation [19]. In this model, the regional economy is represented as a set of economic agents by sections of OKVED [20] with the addition of agents: "households", "state authorities", "external environment", and also the agent "invisible hand of the market" responsible for balance supply and demand in markets of products. Economic agents produce one or more products from the basic set that are sold within the region or exported. For the activity agents buy necessary intermediate products (including necessary TER) and factors of production from the same basic set in the markets. The regional model uses the following basic set of conditional products: 1 - intermediate goods and services (including fuel and energy resources); 2 - investment goods and services; 3 - consumer goods and services (including types of fuel and energy resources for the population); 4 - government services; 5 - infrastructure services; 6 - labor services.

Models of economic agents are implemented as control systems operating on deviations [21]. The basis of the behavior of each economic agent is the target installations (trajectories), which orient the agent's actions in the direction ensuring the achievement of the set goals. The agent on the observed parameters of the situation (market conditions and the state of resources), current values of indicators and taking into account their target values, as well as external (scenario) management forms control actions on the agent's bidirectional production function. This function, on the one hand, forms the agent's offer on relevant markets, and on the other, it generates effective demand for intermediate products and production factors in accordance with the j-*th* agent's technological matrix A_j. In response to the movement of products, cash flows from the sale of manufactured products and the purchase of necessary products for the production process. Equilibrium in markets of conditional products describes the product-sector balance, built in the framework of SNA 2008 [22, p. 317-346]. Balance relations are formed in discrete time $t = 0, t_1, t_2, ..., t_T$ with one year in natural and cost form for all conditional products used in the model.

Economic agents associated with production, transformation and processing of fuel and energy resources are combined into the FEC model, which is represented by activities listed in Table 3.

Table 3. *Sectors and types of activities of the FEC model*.*

Sector of FEC	Type of activity by OKVED
Sector of fuel mining and production	05. Coal mining 06. Extraction of crude oil and natural gas 09. Provision of services in the field of mining 19. Production of coke, petroleum products 35.2. Production and distribution of gaseous fuels
Electricity and heat production sector	35.1. Production, transmission and distribution of electricity 35.3. Production, transmission and distribution of steam and hot water
Pipeline transport	49.50.1. Transportation of oil and petroleum products through pipelines 49.50.2. Transportation of gas and processed products through pipelines

* compiled from [20]

The generalized production function (GPF) of the economic agent owned by the FEC forms the following resource and cash flows:

1 - Flows of produced fuel and energy resources and purchased factors of production;

2 - Cash flows received from the sale of fuel and energy resources and paid for the supply of production factors.

The potential release of the j-*th* agent is calculated by the formula:

$$X^{pot}_J(t) = B_j\sqrt{k_j(t)l_j(t)g_j(t)}, \quad (5)$$

where B_j - technological vector connecting the production volume of fuel and energy resources with the values of production factors; $k_j(t)$ - total cost of fixed assets of the *j-th* agent; $l_j(t)$ - number of employees; $g_j(t)$ - growth rate of total labor productivity and capital.

In the FEC model, balance relations are formed for all types of fuel and energy resources used in the model (coal, oil, gas, oil products by type, electricity, heat energy). The fuel and energy balances formed in the framework of the FEC model are part of the overall product-sector balance, which plays the role of a "balance sheet of balance sheets", which allows interconnecting relations to simulate the interaction between FEC and the rest of the economy.

The developed model was calibrated on the statistical material of the Samara region provided by Samarastat. Calibration involves assigning numerical values to exogenous parameters of the model, which best correspond to real values of similar parameters. In particular, during the calibration, the parameters of technological matrices - A_j and economic agents - B_j, the elasticity ratio of fuel and energy resources for production, tariffs and climatic conditions were estimated. Debugging of the FEC model was carried out on consolidated fuel and energy balance (FEB) of the Samara region, built for 2011–2017. Consolidated FEBs were formed on the basis of single-product balances of certain types of fuel and energy resources according to the methodology of Rosstat [23] and the Ministry of Energy of the Russian Federation [24].

When conducting forecast calculations on the basis of the "Economy & Energy" complex, two scenarios are formed: the regional economic development scenario $U_{econ}(t)$ and energy scenario $U_{ener}(t)$. The regional economic development scenario $U_{econ}(t)$ contains empirical assumptions about the behavior of economic agents (except for FEC) within the forecast period. These are: expected production indices and price and tariff deflator indices; parameters of tax, investment and budget policy; demographic scenario. Based on the scenario $U_{econ}(t)$, the gross output and value added in regional economic sectors are projected on the regional economic model and the primary forecast of energy consumption in these sectors is calculated. According to the results of these calculations, the demand for components of fuel and energy resources in kind is formed. These requirements for fuel and energy resources are detailed as requirements for production of fuel and energy resources and the production base development of relevant sectors of FEC. The energy development scenario $U_{ener}(t)$ contains the following expert assumptions within the forecast period: price deflator indices for main types of fuel and energy resources, loss reduction factors for production and distribution of energy resources, reduction factors for the specific energy consumption of products of economic sectors; obligations for the export of fuel and energy resources, including abroad.

Then, on the models of economy and energy, balancing and iterative coordination of forecasts of necessary energy consumption and possible production of energy resources for the main types of fuel and energy resources is provided. The integrating function in the coordination process is performed by the fuel and energy balance, which provides for consistent and mutually agreed forecasts for the regional economic development, consumption and production of main types of fuel and energy, as well as the production potential of the fuel and energy complex. In the process of coordination, growth rates are calculated for production of fuel and energy resources within the boundaries of potential opportunities and necessary investments in fixed capital by the fuel and energy sectors taking into account scenario conditions for the export and import of fuel and energy resources.

3. Results

The main purpose of scenario calculations was to assess the degree of influence of economic growth rates on reducing the specific energy intensity of GRP. The forecasts for the economic and energy development of the Samara region within the period of 2018-2035 for 6 scenarios including the regional economic development scenario $U_{econ}(t)$, energy saving and energy efficiency development scenarios $U_{ener}(t)$ were compared.

The regional economic development scenarios $U_{econ}(t)$ differed in average annual growth rates of value added in the sector of production of goods and services within the forecast period (Table 4).

Table 4. *Options for the studied scenarios.*

№	Name of the scenario	Economic development scenario $U_{econ}(t)$		Energy development scenario $U_{ener}(t)$
		Average annual growth rate of the gross value added in the sector of goods and services (except for FEC)	Deflator indices of prices and tariffs; parameters of tax, budget and demographic policy	
1	"Zero growth"	0%	taken from the forecast of the socio-economic development of the Russian Federation	indicators of energy saving and energy efficiency development (Table 5)
2	"Growth 1%"	1%	- "-	- "-
3	"Growth 2%"	2%	- "-	- "-
4	"Growth 3%"	3%	- "-	- "-
5	"Growth 4%"	4%	- "-	- "-
6	"Growth 5%"	5%	- "-	- "-

The baseline scenario was a zero growth scenario. The deflator indices of prices and tariffs, as well as parameters of tax, budget and demographic policy were adopted the same in all scenarios $U_{econ}(t)$ and were taken from the forecast of the socio-economic development of the Russian Federation [25].

In the energy development scenario $U_{ener}(t)$, it was assumed that within the forecast period, price growth indices for main types of fuel and energy resources coincide with the GRP deflator index. The output of FEC corresponds to the needs of the economy and is calculated endogenously (per model). It was also assumed that within the period of 2018-2035, all economic sectors of the Samara region, including households, will be engaged in energy saving and energy efficiency development, while achieving targets for government programs declared in energy strategies [1, 18]. The average annual coefficients of energy saving and energy efficiency by type of activity (Table 5) were calculated on the basis of these strategies.

Table 5. *Coefficients of energy saving and energy efficiency development*.*

1. Energy saving and energy efficiency in the fuel and energy complex	
Average annual change in specific losses in the distribution of electricity	98.6%
Average annual change in specific losses in the distribution of thermal energy	97.9%
Average annual change in specific technological losses of oil	94.7%
Average annual change in specific technological losses for other fuel and energy resources	99.0%
Average annual change in specific fuel consumption for electricity generation by thermal power plants (kg of fuel equivalent / thous. kW • h)	99.4%
Average annual change in specific fuel consumption for heat generation (kg of fuel equivalent / Gcal)	99.7%
Average annual change in specific energy consumption for oil refining per unit of primary processing	99.0%
Average annual change in the specific electrical intensity of the products of energy companies	98.6%
Average annual change in the specific heat of the products of energy companies	97.8%
Average annual change in the gas intensity of the products of energy companies	98.9%
Average annual change in the unit cost of oil products of energy companies	99.1%
2. Energy saving and energy efficiency improvement in the goods sector	
Average annual change of specific electrical intensity of goods production	98.9%
Average annual change of specific heat intensity of goods production	97.7%
Average annual change of specific gas intensity of goods production	99.0%
Average annual change in unit costs of petroleum products in the production of goods	99.2%
3. Energy saving and energy efficiency improvement in the service sector	
Average annual change of specific electrical intensity in the service sector	98.7%
Average annual change of specific heat intensity in the service sector	97.4%
Average annual change of specific gas intensity in the service sector	99.2%
Average annual change of specific costs of oil products in the production in the service sector	99.4%
4. Energy saving and energy efficiency in the household sector	
Average annual change of specific electrical intensity of households	98.5%
Average annual change of specific heat intensity of households	97.6%
Average annual change of specific gas intensity of households	99.1%

* compiled from [1, 18]

There are the results of model calculations for the stated development scenarios. Table 6 shows the dynamics of main indices calculated for 2035 with respect to 2017 for all scenarios.

Table 6. *Forecast dynamics of main indices*.*

Economic sectors	**Scenario**					
	Zero growth	**Growth 1%**	**Growth 2%**	**Growth 3%**	**Growth 4%**	**Growth 5%**
The growth index of physical volume of the value added in the sector of goods and services production in 2035, in% by 2017	100.0	119.6	142.8	170.2	202.6	240.7
The growth index of the physical volume of GRP in 2035, in% of 2017	98.5	115.6	135.6	159.1	186.7	219.1
The growth index of the physical volume of FEC in 2035, in% of 2017	91.1	99.3	108.0	117.6	128.2	140.0
The growth index of the physical volume of the added value of FEC in 2035, in% of 2017	95.1	102.3	109.8	117.9	126.6	135.9
The growth index of real disposable incomes of the population in 2035, in% of 2017	98.5	116.2	137.2	162.1	191.5	226.1
The growth index of the area of residential premises in 2035, in% of 2017	109.4	119.5	130.5	142.3	155.1	168.9
The population growth index in 2035, in% of 2017	93.2	93.2	93.2	93.2	93.2	93.2

*Compiled by the authors

Table 7 shows the dynamic structure of the final consumption of fuel and energy resources in the region for two extreme economic development scenarios. In the case of simple reproduction (zero growth), the structure of the final consumption of fuel and energy resources does not significantly change as a result of measures taken to save energy and improve the energy efficiency of the economy. These actions lead to a decrease in the energy consumption in the economy and, as a result, to a decrease in growth rates and energy consumption of FEC. The consumption of fuel and energy resources by the population, on the contrary, is growing, because even with zero economic growth, the property of the population (real estate, cars, household appliances) that consume fuel and energy resources is growing. The area of housing stock can grow even with a decrease in GRP.

Table 7. *Forecast structure of the final consumption of fuel and energy resources (Samara region) for two extreme scenarios*.*

Economic sectors	Units of measure	2017	2020	2025	2030	2035
Scenario “Zero growth”						
FEC	%	29.1	28.6	27.7	27.0	26.4
Production of goods (except for fuel and energy resources)	%	25.1	25.0	24.8	24.5	24.3
Production of services	%	16.5	16.7	16.8	16.9	17.0
Households	%	29.2	29.8	30.7	31.5	32.4
Scenario “Growth 5%”						
FEC	%	29.1	28.0	26.1	24.4	22.6
Production of goods (except for fuel and energy resources)	%	25.1	25.9	27.5	29.0	30.7
Production of services	%	16.5	17.2	18.3	19.4	20.6
Households	%	29.2	28.9	28.1	27.2	26.1

* Compiled by the authors

With the economic development according to “Growth 5%” scenario, the effects of actions to save energy and improve the energy efficiency of the economy are imposed by the effects of economic growth, which redistribute the final consumption of fuel and energy resources in favor of goods and services production.

In order to assess the impact of economic growth on the energy intensity, let us compare energy intensity forecasts of economic sectors for two extreme scenarios (Table 8). The calculation of the specific energy intensity of economic sectors (except for households) was carried out according to the formula:

$$EI_i(t \mid 0) = \frac{TFC_i(t)}{Y_i(t)} / \frac{TFC_i(0)}{Y_i(0)} I_i^{def}(t \mid 0). \quad (6)$$

where: $TFC_i(0)$, $TFC_i(t)$ - final consumption of fuel and energy resources in the *i-th* economic sector in the base year and in the t *-th* year, respectively; $Y_i(0)$, $Y_i(t)$ - gross value added produced in the *i-h* economic sector in the base year and in the t *-th* year, respectively; I_i^{def} - index deflator of the sector calculated for the l *-th* year relative to the base year. Whereas

$$Y_i(t) = Y_0(0) I_i^{gr}(t \mid 0) I_i^{def}(t \mid 0),$$

where $I_i^{gr}(t \mid 0)$ - growth index of the physical volume of the value added calculated for the t *-th* year relative to the base year, then formula (6) can be represented in a more convenient form:

$$EI_i(t \mid 0) = \frac{TFC_i(t)}{TFC_i(0) I_i^{gr}(t \mid 0)}. \quad (7)$$

where: $I_i^{gr}(t \mid 0)$ - growth index of the physical volume of the gross value added of the *i-th* sector, calculated for the t *-th* year relative to the base year.

The energy intensity of households is calculated according to a similar formula:

$$EI_H(t \mid 0) = \frac{TFC_H(t)}{M_H(t)} / \frac{TFC_H(0)}{M_H(0)} I_H^{def}(t \mid 0) = \frac{TFC_H(t)}{TFC_{iH}(0) I_H^{gr}(t \mid 0)} \quad (8)$$

here: $TFC_H(0)$, $TFC_H(t)$ - final consumption by the population in the base year and in the t *-th* year, respectively; $M_H(0)$, $M_H(t)$ - monetary incomes of the population in the base year and in the t *-th* year, respectively; I_H^{def} - consumer price index calculated for the t *-th* year relative to the base year; $I_H^{gr}(t \mid 0)$ - growth index of real incomes of the population, calculated for the t *-th* year relative to the base year.

Table 8. *Forecast dynamics of the specific energy intensity of economic sectors (Samara region) for extreme scenarios*.*

Economic sectors	Units of measure	2017	2020	2025	2030	2035
Scenario “Zero growth”						
FEC	%	100.0	94.8	87.0	80.2	74.2
Production of goods (except for fuel and energy resources)	%	100.0	95.8	89.3	83.3	77.8
Production of services	%	100.0	96.2	89.9	84.2	78.9
Households	%	100.0	97.8	94.2	90.7	87.4
Scenario “Growth 5%”						
FEC	%	100.0	95.2	87.9	81.6	76.0
Production of goods (except for fuel and energy resources)	%	100.0	94.2	85.8	78.5	72.2
Production of services	%	100.0	92.6	81.8	72.8	65.3
Households	%	100.0	90.2	75.7	63.2	52.6

* Compiled by the authors

With zero economic growth, the decrease in the specific energy intensity of economic sectors occurs only through energy saving and energy efficiency development actions in sectors. In households, the reduction in the specific energy consumption is partially offset by an increase in energy-using property.

With the economic development according to "Growth 5%" scenario, in addition to energy saving actions, the following factors, due to economic growth, affect the reduction in the energy intensity of economic sectors:

- Economies of scale in the production of goods and services, allowing enterprises to reduce the specific cost of energy by increasing production volumes;
- Lagging in growth rates of FEC behind economic growth rates in the economy as a whole due to the high capital intensity;
- Lagging in growth rates of the property of the population consuming fuel and energy resources behind economic growth rates of the economy as a whole.

Table 9 and Figure 1 show forecast values of the specific energy intensity of economic sectors calculated for the end of the forecast period (2035) for all six scenarios.

Table 9. *Energy intensity of economic sectors, 2035 to the base year,% (forecast for 6 scenarios)*.*

Economic sectors	Scenario					
	Zero growth	**Growth 1%**	**Growth 2%**	**Growth 3%**	**Growth 4%**	**Growth 5%**
FEC	74.2	74.2	74.4	74.8	75.4	76.0
Production of goods (except for fuel and energy resources)	77.8	76.2	74.8	73.8	72.9	72.2
Production of services	78.9	75.1	72.0	69.4	67.2	65.3
Households	87.4	79.0	71.3	64.4	58.2	52.6
Regional economy	79.0	74.5	70.4	66.8	63.6	60.8

* Compiled by the authors

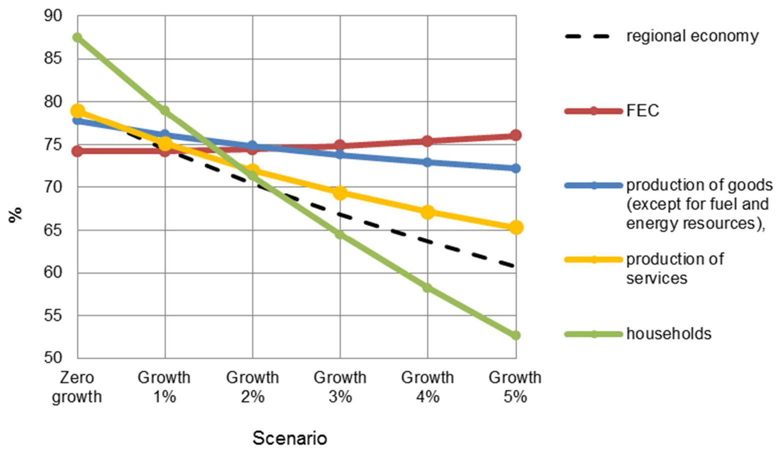

Figure 1. *Specific energy intensity of economic sectors (2035 to 2017).*

Some increase in the energy intensity of FEC for scenarios with higher growth is explained by the change in the FEC structure in favor of oil production and refining due to a decrease in the demand for electricity and thermal energy.

To assess the contribution of economic sectors in reducing the specific energy intensity of GRP, we will present the final consumption of fuel and energy resources in the region in the following form:

$$TFC(t) = TFC_{FEC}(t) + TFC_{G}(t) + TFC_{S}(t) + TFC_{H}(t). \quad (9)$$

where: $TFC_{FEC}(t), TFC_{G}(t), TFC_{S}(t), TFC_{H}(t)$ - final consumption of fuel and energy resources by FEC, the sector for the production of goods (except for fuel and energy resources), the sectors for the production of services and households, respectively. Then the specific energy intensity of GRP (3) can be decomposed into the following items:

$$EI_{GRP}(t \mid 0) = \frac{TFC_{FEC}(t)}{TFC^{(0)}(t)} + \frac{TFC_{G}(t)}{TFC^{(0)}(t)} + \frac{TFC_{S}(t)}{TFC^{(0)}(t)} + \frac{TFC_{H}(t)}{TFC^{(0)}(t)} \quad (10)$$

For FEC and sectors for the production of goods and services, the final consumption of fuel and energy resources is calculated as follows:

$$TFC_{i}(t) = \sum_{j \in J_i} \sum_{n \in N_n} TFC_{i,j,n}(0)\,(a_{i,j,n} + (1 - a_{i,j,n})I_{i,j}(t \mid 0))k_{i,j,n}(t \mid 0) \quad (11)$$

where: $TFC_{i,j,n}(0)$ - final consumption of the *n-th* type of fuel and energy resources by the industry belonging to the *i-th* sector ($j \in J_i$) in the base year; $I_{i,j}(t \mid 0)$ - growth index of the physical volume of output of the *j-th* industry per t *-th* year relative to the base year; $a_{i,j,n}$ - ratios of fixed costs of the *n-th* type of fuel and energy resources in the *j-th* industry; $k_{i,j,n}(t \mid 0)$ - ratio of reduction in the energy intensity of the *j-th* industry by the *n-th* type of fuel and energy resources in the t *-th* year relative to the base year.

Energy intensity reduction ratios $k_{i,j,n}(t \mid 0)$ are calculated according to the energy scenario (see Table 5) using the chain method. The growth indices of the physical volume of output $I_{i,j}(t \mid 0)$ for sectors producing goods and services are calculated according to the economic development scenario $U_{econ}(t)$. For TEC industries, growth indices of the physical volume of output $I_{FEC,j}(t \mid 0)$ are calculated in the FEC model depending on the needs of the economy for fuel and energy resources.

For the household sector, the final consumption of fuel and energy resources is calculated as follows:

$$TFC_H(t) = \sum_{n \in N_n} TFC_{H,n}(0) I_{H1}^{b_{1,n}}(t \mid 0) I_{H2}^{b_{2,n}}(t \mid 0) I_{H3}^{b_{3,n}}(t \mid 0))k_{H,n}(t \mid 0) \quad (12)$$

where: $TFC_{H,n}(0)$ - final consumption of the *n-th* type of fuel and energy resources by households in the base year; $I_{H1}^{b_{1,n}}(t \mid 0)$ - growth index of the total area of residential premises per t *-th* year relative to the base year; $I_{H2}^{b_{2,n}}(t \mid 0)$ - growth rate of real incomes of the population in the t *-th* year relative to the base year; $I_{H3}^{b_{3,n}}(t \mid 0)$ - population growth index per t *-th* year relative to the base year; $k_{H,n}(t \mid 0)$ - energy saving ratio of the *n-th* type of fuel and energy resources in the t *-th* year relative to the base year.

Table 10 and Figure 2 show the components of the specific energy intensity of GRP (10) calculated for the end of the forecast period (t = 18) for all 6 scenarios of economic growth (see Table 4).

Table 10. *Components of the energy intensity of GDP (forecast)*.*

Indicator	Scenario					
	Zero growth	Growth 1%	Growth 2%	Growth 3%	Growth 4%	Growth 5%
Energy intensity of GRP in 2035, in% to the base year	78.9	74.5	70.4	66.8	63.6	60.8
including the components of the formula (10):						
FEC, percentage point (p. p.)	20.8	19.1	17.6	16.2	14.9	13.7
production of goods (except for fuel and energy resources), p. p.	19.1	19.0	18.8	18.7	18.7	18.6
production of services, p. p.	13.4	13.1	12.9	12.7	12.6	12.5
households, p. p.	25.6	23.2	21.1	19.2	17.5	15.9

* Compiled by the authors

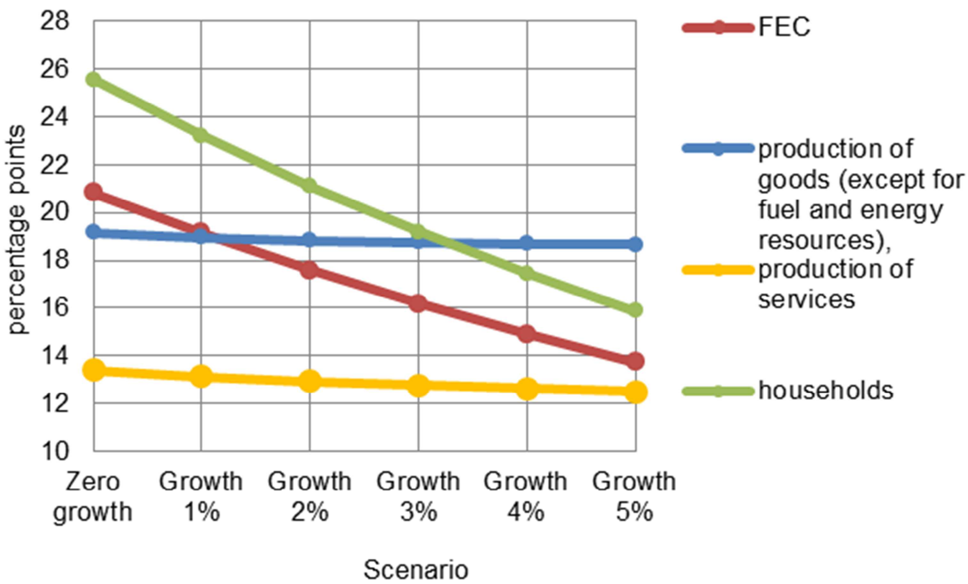

Figure 2. *Dynamics of components of the energy intensity of GDP (2035 to 2017).*

As can be seen in the figure, with economic growth, the largest decrease in the energy intensity of GRP (10) occurs according to the components: “Fuel and Energy Complex” and “Households”. As for households, it is explained by the fact that rates of the final consumption of fuel and energy resources by the population are lagging behind the growth rates of GRP more, if the rate of economic growth is higher. In fact, the population spends its income growing at the rate of GRP growth on final consumption and it spends only a certain part on the purchase of additional real estate, vehicles and household appliances, the total growth of which provides an increase in the consumption of fuel and energy resources. The decrease in the energy intensity of GRP in FEC during economic growth (see Table 10, the FEC line, p. p.) occurs for the following reasons:

- The additional decrease in demand for fuel and energy resources in the economy as a result of savings on the production volume;
- Lagging in growth rates of FEC behind growth rates of the regional economy as whole due to the high capital intensity of FEC. There is a hard link between the economic growth of the industry and its capital intensity. To measure the capital intensity of the industry in the English-language literature is used the intensity of capital consumption (ICC), which is part of the value added that needs to be invested in fixed capital to offset its retirement in order to ensure simple reproduction [26]. The higher ICC, the more investment is required for 1% of economic growth. Table 11 shows ICC for industries of the US economy, which with some correction can be applied to the regional economy.

Table 11. *Intensity of capital consumption of industries (USA)*.*

Economic sector	ICC
Mining (all resources)	45.7%
Crude oil and natural gas production	55.0%
Power industry	26.0%
Metallurgy	8.8%
Chemistry and petrochemistry	12.2%
Mechanical engineering and metalworking	13.0%
Light industry	5.7%
Food industry	13.3%
Agriculture	16.9%
-Construction	6.9%
Transport and communications	19.4%
Wholesale retail	7.6%
Economy average	12.8%

* Compiled by J. Ross [26]

According to the table, in order to ensure simple reproduction in extractive industries of FEC, investments in fixed capital are needed at the level of 50% of the value added in these industries (of course, this indicator is highly dependent on world oil prices and may be significantly lower, but the trends of recent years do not inspire optimism about this). The authors in [27] showed that in order for the industry to move to economic growth with the q *-th* pace, the rate of capital accumulation is necessary (the share of the value added sent to investments)

$$S^{(q)} = (1 + qT_0)S^{(0)}, \qquad (13)$$

where T_0 - standard service life of fixed capital; $S^{(0)}$ - rate of accumulation in simple reproduction.

At T_0 = 15 years, which is quite realistic for extractive industries of FEC, the industrial growth at a rate of 1% will require an investment of 65% of the value added, and a growth of 2% - 80%. In the power industry, the requirements for investments necessary for economic growth will be lower than in oil and gas production, but they will be rather high.

Thus, the high intensity of the capital consumption in fuel and energy sectors does not allow them to grow at rates higher than 2-2.5% per year [26], and high rates of economic growth lead to a sharp decrease in the ratio $TFC_{FEC}(t) / TFC^{(0)}(t)$.

The overall contribution of economic growth to the reduction in the energy intensity of GRP can be estimated from Table 10 using the following formula:

$$\Delta EI_{GRP}^{(n\%)}(t \mid 0) = EI_{GRP}^{(0\%)}(t \mid 0) - EI_{GRP}^{(n\%)}(t \mid 0). \qquad (14)$$

where $EI_{GRP}^{(0\%)}(t \mid 0)$ - specific energy intensity of GRP for “Zero growth” scenario; $EI_{GRP}^{(n\%)}(t \mid 0)$ - specific energy intensity of GRP for “Growth *n*%” scenario; t = 18 years - forecast period.

By analogy, the contribution of economic growth to the decrease in the energy intensity of GRP by economic sectors is estimated by the formula:

$$\Delta EI_{GRP,i}^{(n\%)}(t \mid 0) = EI_{GRP,i}^{(0\%)}(t \mid 0) - EI_{GRP,i}^{(n\%)}(t \mid 0),$$

where $EI_{GRP,i}^{(0\%)}(t \mid 0)$ - specific energy intensity of GRP by the *i-th* sector for “Zero growth” scenario; $EI_{GRP,i}^{(n\%)}(t \mid 0)$ - specific energy consumption of GRP by the *i-th* sector for “Growth *n%*” scenario; t = 18 years - forecast period.

Table 12 shows the overall reduction in the energy intensity of GRP due to economic growth and the contribution of economic sectors to this decline.

Table 12. *Contribution of economic growth to the decrease in the energy intensity of GRP by economic sectors.*

Indicator	Scenario					
	Zero growth	Growth 1%	Growth 2%	Growth 3%	Growth 4%	Growth 5%
Energy intensity of GRP, in% to the base year	78.9	74.5	70.4	66.8	63.6	60.8
Reduction in the specific energy intensity of GRP compared to zero growth, p. p.	0.0	4.47	8.50	12.10	15.31	18.18
Contribution of economic growth by economic sectors:						

Indicator	Scenario					
	Zero growth	Growth 1%	Growth 2%	Growth 3%	Growth 4%	Growth 5%
FEC, p. p.	0.0	1.69	3.26	4.68	5.95	7.09
including due to:						
decrease in demand for fuel and energy resources in the economy as a result of savings on the increase in production volumes	0.0	0.63	1.09	1.41	1.63	1.78
lagging in growth rates of FEC behind growth rates of the regional economy due to the high capital intensity	0.0	1.06	2.18	3.27	4.31	5.31
production of goods (except for fuel and energy resources), p. p.	0.0	0.18	0.31	0.40	0.47	0.50
production of services, p. p.	0.0	0.27	0.48	0.66	0.80	0.91
households, p. p.	0.0	2.33	4.44	6.36	8.10	9.67

*Compiled by the authors

Summing up, it is possible to classify the factors that reduce the energy intensity of GRP as follows:

1 – Energy saving and energy efficiency development of production and consumption of fuel and energy resources;

2 - Economies of scale for the production of goods and services;

3 - Lagging in growth rates of FEC behind growth rates of the regional economy due to the high capital intensity of mining and production of fuel and energy resources;

4 - Lagging in growth rates of energy-using property of the population (real estate, vehicles, household appliances) behind growth rates of GRP.

The contribution of these factors to the overall reduction in the energy intensity of GRP is shown in Table 13. The net contribution of the first factor was calculated according to "Zero growth" scenario and it is 21.1 percentage points. The contribution of economic growth to the overall reduction in the specific energy intensity of GRP improves depending on the average annual growth rate of the economy and for "Growth 5%" scenario it is 18.2 percentage points - this is 46.3% of the total decrease in the specific energy intensity of GRP for this scenario.

Table 13. *Contribution of main factors to the overall reduction of the specific energy consumption of GRP.*

Indicator	Scenario					
	Zero growth	Growth 1%	Growth 2%	Growth 3%	Growth 4%	Growth 5%
Contribution of the factor to the overall reduction in the energy intensity of GRP, in percentage points						
Overall reduction in the energy intensity of GRP, p. p.	21.1	25.5	29.6	33.2	36.4	39.2
Contribution of factors, p. p.:						
1 - energy saving and energy efficiency development of production and consumption of fuel and energy resources	21.1	21.1	21.1	21.1	21.1	21.1
2 – economic growth	0.0	4.5	8.5	12.1	15.3	18.2
including by factors:						
economies of scale for the production of goods and services	0.0	1.1	1.9	2.5	2.9	3.2
lagging in growth rates of FEC behind growth rates of the regional economy due to the high capital intensity	0.0	1.1	2.2	3.3	4.3	5.3
lagging in growth rates of energy-using property of the population behind growth rates of GRP	0.0	2.3	4.4	6.4	8.1	9.7
Share of the factor in the total decrease in the energy intensity of GRP, in%						
Overall reduction in the energy intensity of the GRP,%	100.0	100.0	100.0	100.0	100.0	100.0
Contribution of factors to the decrease in the energy intensity of GRP, p. p.:						
1 – energy saving and energy efficiency development of production and consumption of fuel and energy resources	100.0	82.5	71.2	63.5	57.9	53.7
2 – economic growth	0.0	17.5	28.8	36.5	42.1	46.3
including by factors:						
economies of scale in the production of goods and services	0.0	4.2	6.4	7.5	8.0	8.1
lagging in growth rates of FEC behind growth rates of the regional economy due to the high capital intensity	0.0	4.2	7.4	9.9	11.9	13.5
lagging in growth rates of energy-using property of the population behind growth rates of GRP	0.0	9.1	15.0	19.2	22.3	24.7

*Compiled by the authors

4. Discussions

The results of the research show that economic growth is the most important condition for reducing the energy intensity of GRP, and the higher the economic growth, the greater its contribution to the reduction in the energy intensity of GRP. Economic growth reduces the energy intensity of GRP through the following factors:

1 - Economies of scale in the production of goods and services;

2 -Lagging in growth rates of FEC from growth rates of the regional economy due to the high capital intensity of mining, production and processing of fuel and energy resources;

3 - Lagging in growth rates of energy-using property of the population from growth rates of GRP.

The first factor has a double effect on reducing the specific energy consumption of GRP, which is taken into account in formula (10). First, savings on production volumes reduce the demand for fuel and energy resources and, accordingly, the final consumption of fuel and energy $TFC_G(t)$, $TFC_S(t)$ in sectors for the production of goods and services (second and third items), and secondly, a decrease in demand for fuel and energy resources reduces the production of fuel and energy, respectively, the value of the final consumption of fuel and energy in the FEC $TFC_{FEC}(t)$ (the first item). The second factor is associated with the fact that the rapid growth of non-energy sectors is changing the structure of the regional economy in favor of these less energy-intensive industries. The third factor is caused by lagging in growth rates of household energy consumption property behind growth rates of real per capita income.

The results obtained are testimony in the near Russian history. For example, in 1999–2008, when the Russian economy grew at an average rate of 7% per year, after a long lag, Russia emerged as the world leader in terms of reducing the energy intensity of GDP: this figure fell by 42% and decreased on average by more than 5% in year, which is significantly faster than in many countries of the world. Reducing the energy intensity of GDP to a large extent neutralized the growth of the energy consumption and became the main energy resource for economic growth [3]. Regional studies also confirm that the dynamics of the regional economy is an important factor in reducing the energy intensity of GRP. In regions where GRP grew dynamically, the energy intensity of GRP declined faster and vice versa [2]. The rapidly developing countries also show a tendency towards a steady decline in the energy intensity of GDP. For example, China, which has shown high rates of economic growth since the 1990s, has rapidly reduced the energy intensity of GDP during this period. In the 2000s, these processes in China slowed down a little because of the growth in average per capita energy consumption, which is typical of countries overcoming the threshold level of well-being until they reach the level of “energy saturation” [28].

The conducted research on the material of the Samara region, which is in many ways the average statistical subject of the Russian Federation, allows us to reasonably answer the question whether the reduction of GRP by 40% within the period of 2018-2035 is feasible. The results show that achieving this goal is possible only with the average annual economic growth of at least 5%, even with the absolute implementation of all sectoral energy saving and energy efficiency programs declared in energy strategies 2030 and 2035 [1, 18]. Energy saving and energy efficiency development actions without economic growth will reduce the energy intensity of GRP in 2035 to the level of 2017 by only half of the stated goal (see Table 13). Since capital-intensive regions (Lipetsk region, Khanty-Mansiysk autonomous region, Yamalo-Nenets autonomous region, Krasnoyarsk region and others) cannot develop at rates higher than 2-2.5% due to the high intensity of the capital consumption (see Table 11), For these regions, target indicators for reducing the energy intensity of GRP set in federal strategies are fundamentally unachievable. Therefore, when developing attainable targets for energy-efficient development strategies for these regions, we need calculations that take into account the real capital intensity of the regional economy.

Similar conclusions are true for the Russian economy as a whole. If the Russian economy develops at an average annual rate of less than 5%, then the main target indicator of the Energy Strategy - a decrease in the energy intensity of GDP by more than forty percent by 2035 compared to 2007 will be fundamentally unattainable.

It should be noted that factors such as prices for fuel and energy resources and the technological process remained outside the scope of the research. Their contribution to forecast dynamics of the specific energy intensity of GRP will be assessed at the next stage of this study.

5. Conclusion

On bases of model calculations, the article considers the possibilities and limitations of reducing the energy intensity of GRP of the subject of the Russian Federation within the period of 2018–2035 with the regional development taking into account the requirements of the Energy Strategy of Russia for the period up to 2035. The calculations were carried out on interrelated models of the economy and energy of the Samara region, where the scenarios for the regional energy-efficient development were worked out, taking into account the targets of state programs for energy saving and energy efficiency development declared in the Energy Strategy. As a result of research, it has been established that economic growth is the most important condition for reducing the energy intensity of GRP, and, the higher economic growth, the greater its contribution to the decrease in the energy intensity of GRP. It is also shown that a 40% reduction in GRP within the period of 2018–2035 is feasible only with the average annual economic growth of at least 5%, even with the absolute implementation of all sectoral programs on energy saving and energy efficiency development. The conclusions made are also true for the Russian economy as a whole. If the Russian economy will grow at an annual average of less than 5% within the period of 2018-2035, then the main target indicator of the Energy Strategy - a decrease in the energy intensity of GDP by more than forty percent by 2035 compared to 2007 will be unattainable.

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the Subject of the Russian Federation”.

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