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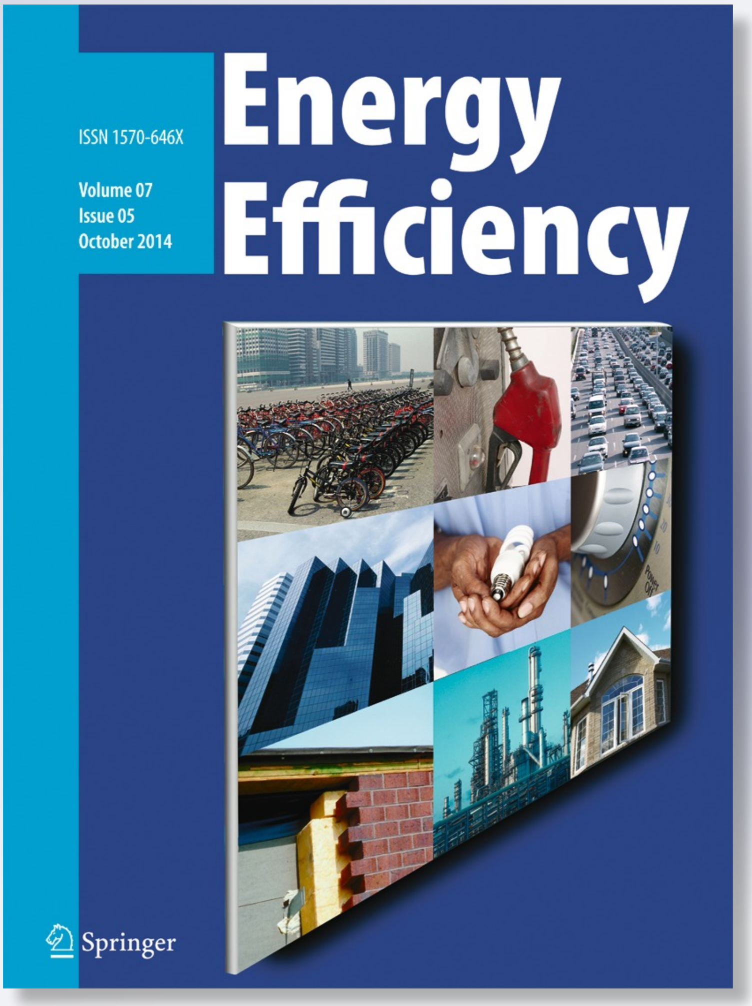

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ORIGINAL ARTICLE

# Russian energy efficiency accounting system

**Igor Bashmakov** · **Anna Myshak**

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**Abstract** This paper was developed to evaluate the effectiveness of energy efficiency policies recently launched in the Russian Federation. Pilot applications in 2011–2013 of the energy efficiency and energy savings accounting system in Russia and energy consumption growth decomposition analysis developed in this paper have shown that (1) its creation is possible even when using a noncomprehensive statistical database; (2) its application provides nontrivial results and shows that the impressive GDP energy intensity decline in the period 2000–2012 was mostly (to 64 %) driven by structural and other factors with limited contribution of technological ones failing to bridge the technological gap with advanced economies. Facing slowing economic growth in years to come, the federal policy to improve energy efficiency is to be focused on providing incentives for more dynamic penetration of energy-efficient technologies to improve the Russian economy, competitiveness, and energy security.

**Keywords** Energy efficiency accounting system · Energy efficiency indicators · Energy intensity · Energy productivity · Decomposition analysis

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## Introduction

The aim of this paper is to better understand the role that different factors play in driving the Russian GDP energy intensity since 2000 and so to evaluate effectiveness of energy efficiency policies recently launched in the Russian Federation. To address the objectives of the paper, a pilot effort to create energy efficiency and energy savings accounting system in Russia based on log-mean Divisia index methodology was tested. The "Introduction" deals with the methodology description. "Aggregated energy efficiency indices" presents results of decomposition analysis for the whole Russian economy, and "Results of the decomposition analysis" and "Industry" —for industrial and residential sectors correspondingly.

Recently (2009–2011), multiple new energy efficiency policies were launched, and some are presently in the process of implementation with diverse levels of success. An incomplete list[1] includes the following: federal support to the implementation of regional energy efficiency programs; mandatory energy efficiency programs for public utilities; investment tax credits and soft interest rates for eligible equipment, scaling up the level of energy and water metering especially in the housing and public sectors; enforcing building codes and standards; energy efficiency labeling; adoption of energy management standards; mandatory energy audits; procurement of energy-efficient equipment; promotion of energy performance contracting; mandatory 3 % annual reduction of specific energy consumption by the public sector; and information programs, training, and R&D on

[1] For a full discussion on policy list, see Bashmakov and Bashmakov (2012) and Bashmakov (2013).

energy efficiency. The proposed pilot system is already in use for 2 years to monitor first results of those new policies application.

## Aggregated energy efficiency indices

It is important to distinguish *energy efficiency*, *energy intensity*, and *energy conservation*, which are sometimes confused. Energy efficiency is the ratio of energy use services provided to energy resources consumed to provide these services (benefits), while energy conservation is reduction of energy use that originated either from implementation of organizational, regulatory, technical, technological, economic, and other measures to reduce energy resource consumption, or from scaling down provision of energy services. Declining energy use (energy conservation) may take place in case of reducing energy efficiency, if the benefits decline faster than energy use does. That was happening in Russia and also in German and Swedish industrial sectors in the recession year 2009. As the useful energy output of a system is not usually statistically reported, the energy intensity—the ratio of energy use to economic or physical output—is therefore often used to indicate energy efficiency.

The efficiency of energy use in the economy as a whole may be measured by a variety of indices:

| | |
|---|---|
| Energy productivity | GDP per unit of energy used |
| GDP energy intensity | Energy consumption per unit of GDP |
| Energy efficiency index | Specially calculated complex index that reflects energy intensity dynamics determined only by technology-based specific energy consumption or by efficiency improvement in different sectors while neutralizing the contribution of structural shifts and other factors). Sometimes, it is called real energy intensity index (Ang and Choi 2012). |

GDP energy intensity is most widely used, although energy productivity, similar to labor productivity, is more adequate. Energy efficiency improvement is accompanied by GDP energy intensity reduction and energy productivity growth. Energy intensity can be brought down by improved technology (commissioning of new equipment; upgrading existing or phasing out obsolete equipment); growing capacity load; structural shifts in the entire economy and/or in individual sectors (growing share of less energy-intense economic activities determined by their faster development). Structural shifts in the economy and capacity load dynamics can reflect either improvement of the economic structure (shifting to less energy-intensive activities) and manufacturing process management, or business cycle dynamics.

Various energy efficiency indices are used in many countries to identify the impacts of the technical and technology factors on the energy intensity evolution. Being relatively complicated to calculate and demanding much additional information, the energy efficiency index is used much more rarely than GDP energy intensity, but it reflects the contribution of the technology factor more accurately. Therefore, the energy efficiency accounting systems of many countries, or groups of countries (IEA, European Union, the USA, Canada, Australia, New Zealand, Singapore, etc.), measure energy efficiency progress using modifications of the energy efficiency index.

Different countries use various techniques of evaluating energy efficiency indices in their energy accounting systems. All of these methods are based on the index number theory that started developing back in the eighteenth century with price indices (Dutot and Carli) and now is developing for energy efficiency indices in the works of L. Schipper (Schipper et al. 2000), Ang and Choi (1997, 2010, 2012), F. Liu (Ang and Liu 2001), Boyd et al. (1987), and J.M. Roop (Boyd and Roop 2004), etc.

Energy consumption can be expressed as an aggregate of energy consumption in all sectors of the economy:

$$E = \sum_i E_i = \sum_i A_i \times I_i = A \times \sum_i S_i \times I_i \qquad (1)$$

where

| | |
|---|---|
| $E$ and $E_i$ | Total energy consumption and energy consumption in sector $i$ |
| $A$ and $A_i$ | Total economic activity level and economic activity indicator in sector $i$ |
| $S_i$ | Share of sector $i$ in total activity (if measured in the same units), or the relation of the activity index for sector $i$ to the activity index of the whole economy |
| $I_i = E_i / A_i$ | Energy intensity of sector $i$. |

There are two ways of forming Eq. (1). *Direct aggregating* is used when activity indicators of all sectors are of the same nature, measured in the same units, and sum up to total activity index (added value in sectors of economy, that sum up to GDP; cost of shipped goods that sum up to total cost of shipments in the industry sector or ton-kilometers for different kinds of freight transport). *The unit consumption approach* is used when activity of different sectors is measured mostly in physical units (square meters, tons, ton-kilometers, kilowatt hour, etc.) that cannot be aggregated.[2] The latter is used in this paper. In its multiplicative form, it is implemented through log-mean Divisia index (LMDI), that is getting more and more widespread because of its flexibility and adequacy to theory (Ang and Choi 1997). The basic way of calculating this index is developed in Divisia (1925), and log-mean weights were introduced to this index in the works of Vartia (1976). This index became a popular means of analysis at the end of the 1980's. It reflects the changing of the growth rate of the resulting variable through weighted growth rates of the factors affecting its dynamics.

Differentiation of Eq. (1) with respect to time gives:

$$\frac{\partial E}{\partial t}=\sum_i S_i I_i \frac{\partial A}{\partial t}+\sum_i A I_i \frac{\partial S_i}{\partial t}+\sum_i A S_{\mathrm{i}} \frac{\partial I_{\mathrm{i}}}{\partial t} \tag{2}$$

Dividing both sides of Eq. (2) by $E$ gives an expression for growth rates:

$$\frac{\partial E}{\partial t\times E}=\frac{\partial \ln E}{\partial t}=\frac{1}{E}\sum_i \mathrm{AS}_i I_i \frac{\partial \ln A}{\partial t}+\frac{1}{E}\sum_i \mathrm{AS}_i I_i \frac{\partial \ln S_i}{\partial t}+\frac{1}{E}\sum_i \mathrm{AS}_{\mathrm{i}} I \frac{\partial \ln I_{\mathrm{i}}}{\partial t} \tag{3}$$

If it is assumed that $w_i = \mathrm{AS}_i I_i$ is a share of sector $i$ in total energy consumption, Eq. (3) can be rewritten as a weighted average of rates of change of particular factors:

$$\frac{\partial \ln E}{\partial t}=\sum_i w_i^*\left[\frac{\partial \ln A}{\partial t}+\frac{\partial \ln S_i}{\partial t}+\frac{\partial \ln I_{\mathrm{i}}}{\partial t}\right] \tag{4}$$

Integrating Eq. (4) over the time interval [0,*t*] yields:

$$\ln\left(\frac{E}{E_0}\right)=\sum_i \int_0^t w_i^*\left[\frac{\partial \ln A}{\partial t}+\frac{\partial \ln S_i}{\partial t}+\frac{\partial \ln I_{\mathrm{i}}}{\partial t}\right] = \sum_i w_i^*\left(\ln\frac{A^t}{A^o}+\ln\frac{S_i^t}{S_i^o}+\ln\frac{I_i^t}{I_i^o}\right) \tag{5}$$

where $w_{\mathrm{i}}^*$ is the mean share of energy consumption in sector $i$ in total consumption over the time interval [0,*t*], or

$$\left(\frac{E}{E_0}\right)=\exp\left(\sum_i w_i^*\left(\ln\frac{A^t}{A^0}\right)\right)\times\exp\left(\sum_i w^*{}_i \ln\frac{S_i^t}{S_i^0}\right)\times\exp\left(\sum_i w_i^* \ln\frac{I_i^t}{I_i^0}\right) \tag{6}$$

The third component in Eq. (6) shows the contribution of changes of energy intensity to the overall change in energy consumption. This effect can also be reflected by the *energy efficiency index*. Peculiarities of calculating Eq. (6) depend on using a parametric method to approximate Eq. (5) or to determine $w_i^*$. The Arithmetic Mean Divisia Index (AMDI) expresses $w_i^*$ as an arithmetic mean of $w_i^0$ and $w_i^t$. This index usually leaves an unexplained residual. Ang and Choi (1997) developed the Log-Mean Divisia Index Method (LMDI-II). This method is based on an assumption that over the period [0,*t*] the share changes at a constant rate and the arithmetic weight function is expressed as a logarithmic mean:

$$w_i^*=L(w)=\frac{w_i^t-w_i^0}{\ln w_i^t-\ln w_i^0} \tag{7}$$

The LMDI-I modification of the LMDI method was introduced later by Ang and Liu (2001). It uses the simpler weighting function:

$$w_i^*=\frac{L\left(E_i^0,E_i^t\right)}{L\left(E^0,E^t\right)} \tag{8}$$

An overview of various methods of calculating energy efficiency indices is given in Ang and Choi (2010). As Ang and Liu (2001) have proven, LMDI-I is consistent in aggregation, does not depend on the succession of the evaluation of factors' contribution (factor reversal), treats base year and target year on an equal footing and gives stable results whatever base year is chosen

[2] Cahill and Ó Gallachóir (2011) demonstrated how physical and economic output data when fully available may be jointly used in decomposition analysis to reflect the interplay of both energy efficiency indicators based on physical units and those based on value added.

(time reversal), leaves no residual (perfect decomposition), and allows to easily aggregate results and to carry out chain analysis. This is a basic method for estimating energy efficiency indices in a number of countries. Its strong points also include the possibility of clear interpretation and of estimating contributions of individual factors using diverse statistical data for various energy consumption sectors, relative simplicity in usage, and possibility for international comparison of the results (Bataille and Nyboer 2005). Having considered these advantages, the authors chose LMDI-I for this study.

Canada's Office of Energy Efficiency (OEE) has been using LMDI-I to evaluate technologically driven energy savings since 2005. LMDI-I is also used in Australia. The International Energy Agency uses a relatively simple index based on Laspeyres method. The ODEX model, an approach recommended by the European Union (used by the ODYSSEE project), calculates the energy efficiency index differently[3] (ADEME 2009).

Ang et al. (2010) have presented a detailed overview of current methods of evaluating energy efficiency dynamics and estimating energy savings in different countries and compared the results. Their study showed that methods used in the USA, Canada, Australia, New Zealand, and Singapore give identical (or very close) estimates of energy savings. These estimates are higher than those obtained using the IEA approach, but considerably lower than those given by the European Union's ODEX method. As for the energy efficiency index, results produced by the US, Australia's, and Singapore's national accounting systems are the same. Frameworks used by Canada and the European Union show a faster decline of the energy efficiency index, while New Zealand's and IEA's accounting systems give a slower decline. Cahill et al. (2010) compared ODEX with LMDI and came to a conclusion that LMDI performs better than ODEX, but the results of using both methods depend to a large extent on data quality and dynamics. An ODEX modification, VALDEX, leaves a significant residual (Cahill and Ó Gallachóir 2010).

The result of factor analysis depends not only on the decomposition method used, but also on the level of disaggregation and on the interpretation of structural and technology factors. The more sectors used, the higher the contribution of the structure factor. While in New Zealand only 25 sectors of energy consumption are used, the ODEX model uses 28, and Canada's Office of Energy Efficiency divides economy into 100 sectors and subsectors.

Factor analysis can be used to evaluate contributions of not only the structure factor and the energy intensity factor, but also a larger number of factors. Having analyzed the results of 43 studies using structure decomposition methods, Su and Ang came to a conclusion that a large share of research projects use LMDI decomposition method, which makes it possible to analyze more factors—up to 8 and beyond (Ang and Su 2011).

Depending on the scope of analysis, evaluation of the energy intensity dynamics contribution to the evolution of the energy efficiency index is not necessarily the end of the story, because it does not adequately reflect the contribution of the energy efficiency improvements due to technological changes. When factors influencing energy intensity of Great Britain's road freight were studied, it turned out that organizational measures (empty truck mileage decrease) affect overall efficiency of road freight to a much greater extent than reduction of nameplate energy intensity of trucks (Champion et al. 2008).

There is a possibility to separate out the impact of the technological factor from the impacts of other factors such as climate and amenities[4]. Variations of different building types structure, for example, growing share of the population living in low-rise buildings, can be interpreted in terms of the "structure" factor, or the "amenities" factor. Stable specific energy consumption by refrigerators per unit of living space or per household (intensity factor at higher aggregation analysis level) may camouflage doubled volume of the refrigerator (amenities factor) accompanied by doubled energy efficiency improvement per adjusted volume (technological factor). Therefore, evaluation of the technological factor largely depends on definitions, level of disaggregation, and availability of data required for disaggregation.

Different national energy efficiency accounting systems analyze contributions of various factors to the

[3] $$\mathrm{EPI} = \frac{\sum_{i=1}^{n} E_i^T}{\sum_{i=1}^{n} A_i^T \times I_i^0} = \frac{1}{\sum_{i=1}^{n} w^T \times \frac{I_i^T}{I_i^0}}$$

[4] Canada's Office of Energy Efficiency calls this factor "service level," but calling it "amenities," "equipment," "well-being," or "comfort" factor might be more accurate.

dynamics of energy efficiency indices. Economic activity growth, changes in the composition of economic activities, energy intensity reduction, and climate changes are considered in all national accounting systems. Some systems (Canada) also take into account the "service" level impact (improved amenities and growth of appliances saturation in the services and residential sectors) and the factor of energy carriers' consumption structure. New Zealand's national accounting system includes the "energy quality" factor (variations of the structure of energy carriers used).

Unfortunately, none of the systems described include the capacity load factor impact in the industrial sector. This factor is largely related to business cycles and has a considerable impact on energy intensity dynamics. Statistics in some countries provide data on capacity loads, which can be used as the basis for evaluating this factor's contribution using the same framework that Canada's Office of Energy Efficiency uses to evaluate the "service level" effect for the residential sector. For industrial output, Eq. (1) can be rewritten as follows:

$$E = \mathrm{PR}^t \times \sum_i \mathrm{Stec}_i^t \times \mathrm{In}_i^t \times \mathrm{CAP}_i^t / \mathrm{PR}_i^t, \qquad (9)$$

where

| | |
|---|---|
| $\mathrm{PR}^t$ | Industrial output in year $t$ |
| $\mathrm{Stec}_i^t$ | Share of product manufactured by technology $i$ in year $t$ |
| $\mathrm{In}_i^t$ | Specific energy consumption for product manufacture by technology $i$ in year $t$ with normal (design) equipment load |
| $\mathrm{CAP}_i^t$ and $\mathrm{PR}_i^t$ | Design equipment load and actual industrial output by technology $i$ in year $t$, respectively |

The above factor analysis framework has some restrictions. For example, it does not work with such an important factor as price. In an identity describing a combination of factors, a ratio of any physical parameter to price makes no physical sense. Nevertheless, price has an important impact on consumer behavior, making consumers change their equipment operation habits, adjusting equipment load and use modes. Part of these effects is reversible with the price decrease or with income growth and the ratio of energy costs to income reduction (rebound effect).

Unlike aggregated energy efficiency indices, mathematical models allow to evaluate integrated effects of a much larger number of factors. An energy demand function or a more complex model describing the dynamics of specific energy consumption for a certain economic activity may be used. For example, energy intensity dynamics of an industrial product of type $i$ may be shown as the following function:

$$I_i^t = \mathrm{In}_{it} \times \mathrm{CAP}_{it}^a \times (\mathrm{EP}_{it}/P_{it})^b \times \mathrm{HDD}_t^c. \qquad (10)$$

where

| | |
|---|---|
| $\mathrm{In}_{it}$ | Specific energy consumption (energy intensity) for product manufacture by technology $i$ in year $t$ with normal (design) technology load |
| $\mathrm{EP}_{it}$ | Average price of energy resources used to manufacture product $i$ in year $t$ |
| $P_{it}$ | Price of industrial product of type $i$ in year $t$ |
| $\mathrm{HHD}_t$ | Number of heating degree-days in year $t$ |

Then the energy intensity factor can be decomposed to the following components:

$$\frac{I_{it}}{I_{it-1}} - 1 = \mathrm{AI}_i + a \times \left(\frac{\mathrm{CAP}_{it}}{\mathrm{CAP}_{it-1}} - 1\right) + b \times \left[\left(\frac{\mathrm{EP}_{it}}{P_{it}}\right) \Big/ \left(\frac{\mathrm{EP}_{it-1}}{P_{it-1}}\right) - 1\right] + c \times \left(\frac{\mathrm{HDD}_t}{\mathrm{HDD}_{t-1}}^b - 1\right) + \varepsilon, \qquad (11)$$

where $\mathrm{AI}_i$ is an estimate of the average decline rate of specific energy consumption for the manufacture of a product using technology $i$ in year $t$ with normal (rated) equipment load.

In the literature, the $\mathrm{AI}_i$ parameter is called "autonomous technical progress" to highlight its independence from the price dynamics. Statistical estimation of the parameters of Eq. (11) for a given time sample leaves an unexplained residual, and the value of this residual depends on the quality of estimation. The sum of this residual and $\mathrm{AI}_i$ is considered as the contribution of the technological factor. The energy intensity factor is then expressed as a multiplicative function of autonomous technical progress adjusted by unexplained residual, capacity load, energy prices, and weather factor and is thus replaced in Eq. (1). Equation (1) is modified by introducing three additional multipliers from Eq. (11), each equal to the product of the corresponding elasticity coefficient by ratio of given year factor value to the average factor value for the whole time sample. This is one of the ways to reveal the factors' contributions to specific energy consumption dynamics and to separate the technology improvement factor. Unlike the above methods, this method allows to evaluate the impact of price change on the energy intensity dynamics.

**Results of the decomposition analysis**

In 1998–2008, after lagging behind for a long time, Russia was among the few countries with energy intensity annually going down by more than 5 % on average (Enerdata 2013)[5]. GDP energy intensity reduction neutralized energy consumption growth to a great extent and became the major energy resource for economic growth. If it had not been for energy intensity reduction, energy consumption in Russia in 2008 would have been 73 % above the real level, and net energy export would have dropped by 90 %.

The new deep economic crisis of 2009 changed this impressive dynamics: the energy intensity of Russia's GDP grew up by 2.1 % in 2009 and by an additional 1.7 % in 2010. Ironically, after Presidential Decree No. 889 dated June 4, 2008, "On some measures to improve energy and environmental efficiency of Russia's economy" and Federal Law No. 261-FZ dated November 23, 2009, "On energy saving and improving energy efficiency" were enforced, the energy intensity of Russia's GDP not only stopped declining, but showed growth in 2009–2010. Russia faced an energy efficiency policy paradox: GDP energy intensity had been going down at an impressive rate before federal energy efficiency policies were launched and stopped declining right afterwards. Only in 2011 did the GDP energy intensity go back to a declining trajectory, and it was down by 2 %. The decline equaled 2.5 % in 2012.

There is still no national energy efficiency accounting system in Russia, so until now, there have never been any attempts to evaluate savings at country-wide level, to decompose factors that determined GDP energy intensity dynamics, or to reveal the reasons behind this dynamics. Now, there is a possibility to do so and to discover the drivers behind unstable GDP energy intensity dynamics in 2000–2012.

Energy intensity can be driven down by improved technologies (commissioning of new equipment and decommissioning of the outdated stock); changes in capacity load; structural shifts in the economy (changing shares of economic activities with different energy intensity levels determined by different development rates); and changes in energy prices, climate, amenities, etc. Contributions of all these factors can be identified through a decomposition analysis. Such an analysis was conducted on two levels of aggregation: for 15 sectors of the economy and with inclusion of industrial products, modes of transport, space heating, and DHW in the residential sector for 44 sectors and subsectors (see the Appendix for the list as well as the activity indicators used). On the first stage of the analysis, only 15 sectors and 2 factors (structure and sectoral intensities) were included. Decomposition results from this analysis show that structural shifts were the major drivers for GDP energy intensity reduction in 2000–2012. They were responsible for 60 % of the energy savings achieved (Fig. 1).

Decomposition analysis for 44 economic sectors allows to identify the contribution of structural shifts in three sectors: industry, transport, and residential buildings. Disaggregation reduces the impact of the previously assessed energy intensity factor. In other words, the energy intensity decline in sectors was partly driven by changing combinations of economic activities within those sectors. The contribution of internal structural shifts was estimated as relatively small (Fig. 2).

While in 2000–2008 growing economic activities drove up energy consumption (with structural shifts and energy intensity reduction acting in the reverse direction), in 2009, the situation changed radically. GDP drop by 7.8 % pushed energy demand down, whereas structural shifts were hampering energy demand reduction. For the first time after 2001, the energy intensity factor also changed the direction of impact and started contributing to an energy demand growth. These last two factors halted the energy-saving process.

In 2010, despite partial economic recovery after the recession, structural shifts were still working against energy savings. Energy intensity was not improving. So, 2010 became the second year in a row characterized by energy overconsumption. Only in 2011 did both structural shifts and intensity factors start generating energy savings.

Obviously, recession-driven structural shifts in the economy were the main driver for GDP energy intensity increase in 2009 and had less impact in 2010. There was a much smaller decline in business activity in the electricity and heat production and distribution, oil refinery, gas and coal processing, agriculture and municipal utilities, and commercial, public, and housing sectors in 2009 than in GDP. In 2010, the positive impact of structural shifts on energy consumption growth was determined by the fact that electricity production, oil

[5] As GDP is expressed in constant prices, the GDP energy intensity evolution was hardly affected by oil and gas price growth in those years.

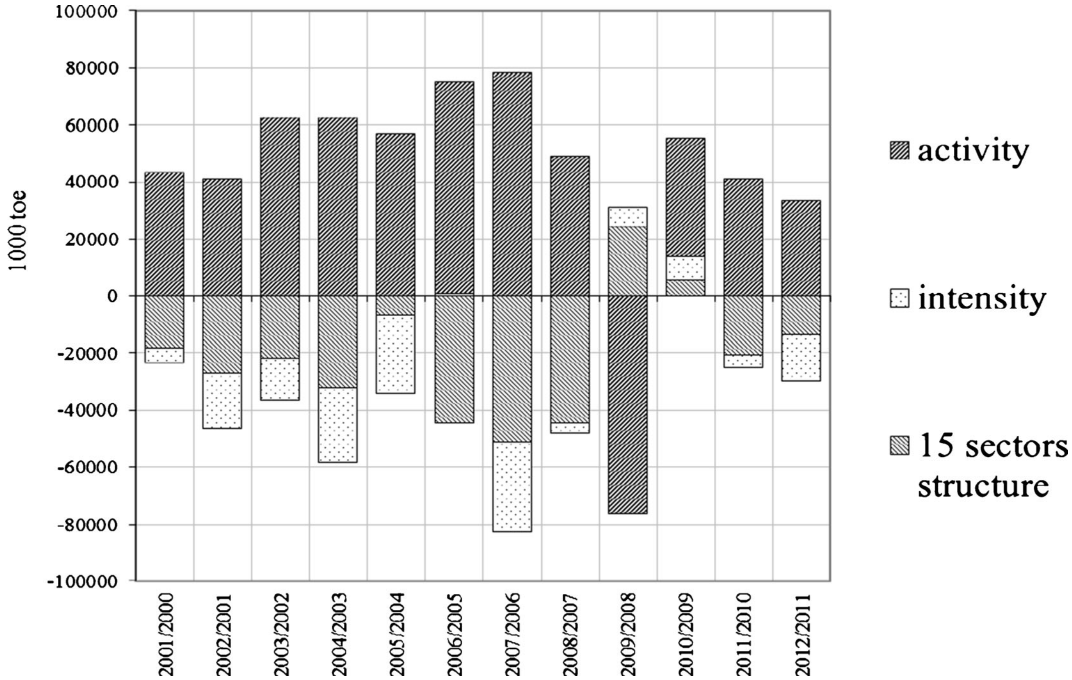


**Fig. 1** Contributions of individual factors to the evolution of primary energy consumption in 2000–2012 (analysis by 15 sectors). Source: developed by the authors on the basis of energy balances built by CENEF

refinery, industry, transport, and non-energy fuel use were growing at a higher rate than GDP was. The energy intensity factor in 2009–2010 contributed to energy consumption growth. In other words, isolation of

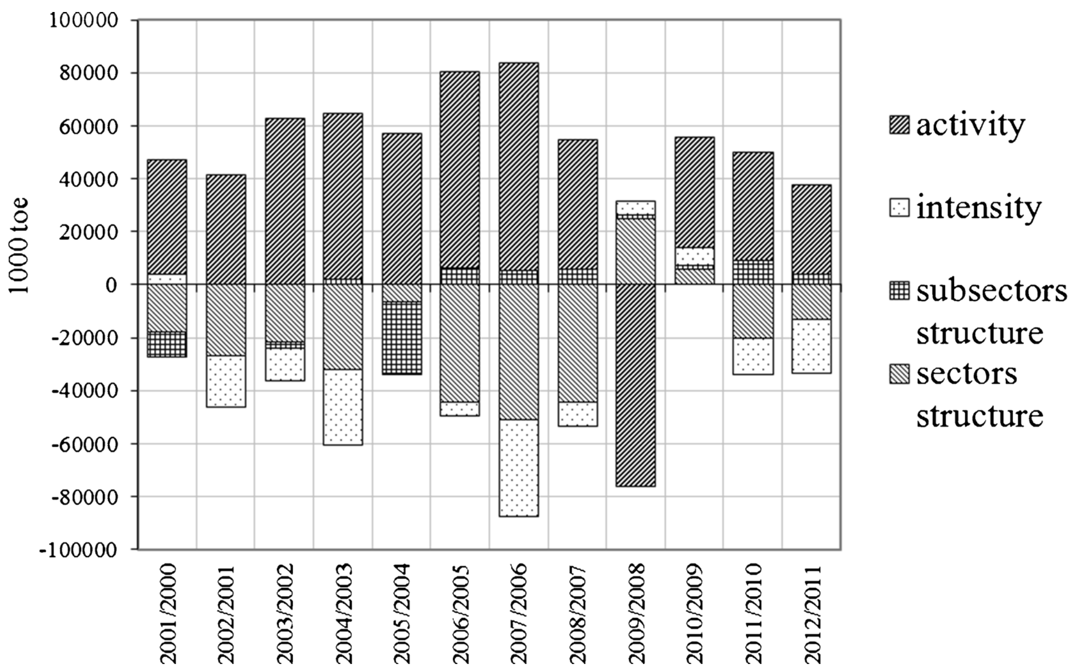


**Fig. 2** Contributions of individual factors to the evolution of primary energy consumption in 2000–2012 (analysis by 44 sectors and subsectors). Source: developed by the authors on the basis of energy balances built by CENEF

structural factors does not help clarify the Russian energy policy paradox, namely: energy intensity growth following energy efficiency activity boost.

There is a need for further decomposition of energy intensity dynamics drivers. Even if the structure of economy is shown in every detail, the energy intensity indicator still reflects the impacts provided by factors not related to the technology improvement. There are at least four of such factors:

- Capacity load. With capacity load increase, energy intensity decreases, because the ratio of fixed energy use (lighting, space heating, and ventilation of production premises, equipment idling, etc.) to the industrial output goes down. With decreasing capacity load, energy intensity, on the contrary, goes up.
- Changing ratio of energy price to output (or services/work) price in each sector, or to the consumer price index for the residential sector[6].
- Climate, expressed in heating degree-days[7]. When this indicator goes up, so does the space heating in residential and public buildings and production premises.
- Housing amenities and appliance saturation. The residential energy consumption divided by the living floor area or by the number of residents, if taken as a specific energy consumption indicator, distorts the estimate of the role played by the technical factor, because the share of heated floor area can grow and/or so can the share of residents with access to DHW supply and/or the number and capacity of appliances per unit of living area, per household, or per resident.

The results of the analysis with these additional factors considered are shown in Fig. 3. The contribution of the energy intensity factor to energy savings over 2000–2012 declined from 133 mtoe (analysis by 15 sectors) to 129 mtoe (analysis by 44 sectors and subsectors) and down to only 61 mtoe (analysis including capacity load, energy prices, climate, amenities, and saturation factors). Of all factors that contributed to energy savings in 2000–2012, structural shifts in the economy-wide sectoral structure were responsible for 62.9 % of energy saved, structural shifts in the subsectors for 1 %, capacity load for 16 %, energy prices for 4.6 %, and improved equipment or technology for 15 % of energy saved.

The conclusion that energy efficiency of equipment was declining in 2009, drawn from the analysis including only energy intensity and structural factors (Figs. 1 and 2), is not correct. On the contrary, it was growing (Fig. 3). Importantly, the contribution made by improved technologies to energy savings was the largest ever since 2000. Partially, this can be explained by phasing out the most outdated technologies in 2009. Reduced capacity load and colder weather were camouflaging this fact and distorting the impact of the technology factor. In 2010, the number of degree-days of the heating period was even larger than in 2009. This contributed to energy consumption growth. Economic recovery in 2010 was basically following the increased capacity load path, which, contrary to that of 2009, hampered energy demand growth. The role of the technology factor in 2010 was negative. Like in 2009, growing relative energy prices hampered energy consumption increase. Improved amenities and appliance saturation caused energy consumption increase during the entire period under review.

Therefore,

- The major factors that determined energy intensity growth in 2009 included recession-related structural shifts in the economy and reduced capacity load and winter colder than in 2008, combined with accelerated reduction of technology energy intensity.
- The major factors that determined GDP energy intensity increase in 2010 included structural shifts in the economy, partly compensated by capacity load growth. As old technologies came back to production, the technology energy intensity grew up. All those factors were accompanied by a winter colder than in 2009.
- In 2011, GDP energy intensity decline was mostly driven by further capacity load growth and structural shifts with moderate impact from the technology factor.
- In 2012, GDP energy intensity decline for the first time since 2000 was mostly driven by the technology factor moving structural shifts to the second plan followed there by capacity load growth.

In 2000–2012, GDP energy intensity dropped by 34.3 % or was annually going down by 3.4 % on average (Fig. 4). However, as shown above, a large part

[6] It is not really energy price dynamics that matters to consumers, but the share of energy costs in the overall income as shown in Bashmakov (2004b, 2007).

[7] Specific energy consumption for space heating is usually defined as the ratio of energy consumption per 1 $m^2$ per degree-day of the heating season. Degree-days for the whole of the Russian Federation were assessed as the average for 20 Russian regions.

of this effect was driven by structural shifts in the economy, which were working to reduce energy intensity in 2000–2008 and in 2011 as well as in the reverse direction in 2009–2010. Decomposition of the role of structural factors allows to estimate the energy efficiency index (EEI) dynamics (see Eq. 6). This estimation depends on the extent to which the structure of energy consumption sectors is detailed. It turns out that reduction of energy intensities brought EEI-15 (index evaluated based on 15 sectors energy intensities) down by 13.4 % over 2000–2012 (1.2 % annual reduction) and EEI-44 (index evaluated based on 44 sectors and subsectors energy intensities) by 12.9 % (1 % annual reduction). This means that structural shifts in the economy were the major driver of GDP energy intensity reduction in 2000–2012.[8] Isolating the role of the technology factor in the course of decomposition analysis allows to estimate the dynamics of the energy efficiency index driven by only improved technology (EEI-44T). This index declined by only 5.6 % in 2000–2012 (i.e., was decreasing annually by 0.6 % on average).

Therefore,

- The EEI-44T energy efficiency index went down by only 5.6 % in 2000–2012.
- Average annual contribution of the technology factor to GDP energy intensity reduction was below 1 %.
- It is about the same rate as in the advanced economies.
- The technology gap in energy efficiency between Russia and advanced economies did not narrow in 2000–2012.
- Federal energy efficiency policies should target a more vigorous reduction of the energy efficiency index and the narrowing of the technology gap between Russia and advanced economies.

The technology factor produced the most visible impact on energy intensity dynamics (due to the commissioning of new capacities and upgrades of the existing capacities) in such activities as electricity transmission and distribution; coal production and processing; production of pellets, synthetic rubber, and ammonia; in pulp and paper, food, and other industries; construction; agriculture; and rail transport.

## Industry

Russian statistics on industrial energy consumption provides data on the evolution of energy consumption for a large variety of industrial products. The list of these products has been expanding in the recent years. However, sustained data series for a decomposition analysis are unavailable for some products that have been statistically monitored for only a short period. Data are available only for energy consumption by large- and medium-size enterprises.

Selection of industrial products for the decomposition analysis was determined by the following considerations: significant amount of energy used and minimum distorting role of small-size enterprises in the industrial output. In the end, 23 industrial products were identified plus "other industry" as an additional product. Russian statistics does not provide details on energy consumption in machinery, so "other industry" is hard to divide further. It is important to mention that industry does not include energy transformation (electricity and heat production by public utilities or by autoproducers' plants and boilers) or oil, gas, and coal processing, refinery, and enrichment. They are reflected in the energy sector. However, production of oil, gas, and coal is part of industry. All industrial activities are presented in the physical volumes of production; thus, any effects of accounting in given year prices (especially important for oil and gas sectors) have no influence on the analysis results.

[8] Voigt et al. (2014) conducted a decomposition analysis for Russia (among 40 countries) over the 1995–2007 time horizon. Total energy use was split to 34 economic activity sectors. Impacts of only two factors—structural changes and technological improvements (using as proxy energy intensity per unit of value added)—were assessed. The study concluded that Russia's energy intensity decline over 1995–2007 was mostly driven by structural shifts, which is very much in line with this paper conclusion. The approach used accounts shifts towards lower energy-intensive products within every value added sectors as energy efficiency improvement, while the approach applied in this paper accounts them as structural shifts. Voigt et al. estimates of the technological factor contribution are higher comparing with our findings due to the following: (a) smaller number of sectors used in decomposition; (b) less factors considered, and (c) different approach to energy use split and energy efficiency indicators evaluation. Comparison of results illustrates that using product, works, and services energy use split along with more factors in the decomposition analysis allows for better reflection of technological progress impact on GDP energy intensity evolution.

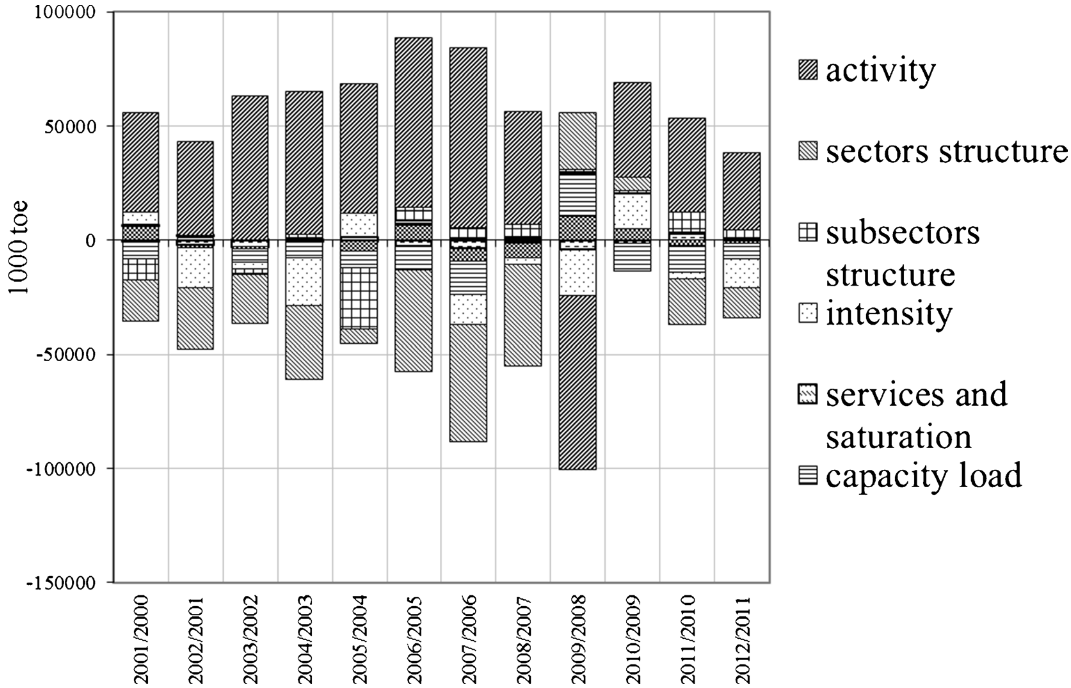


**Fig. 3** Decomposition of factors that determined the evolution of primary energy consumption in 2000–2012 by 44 sectors and subsectors and by eight factors. Source: developed by the authors on the basis of energy balances built by CENEF

In 2000–2010, Russia managed to decouple industrial output growth and energy consumption. In 2002–2006, industrial energy consumption was growing, then started to decline, and in 2011 was still 7 mtoe below the 2006 level. "Other industry" showed the most prominent decline (3.4 mtoe), followed by pig iron, open-

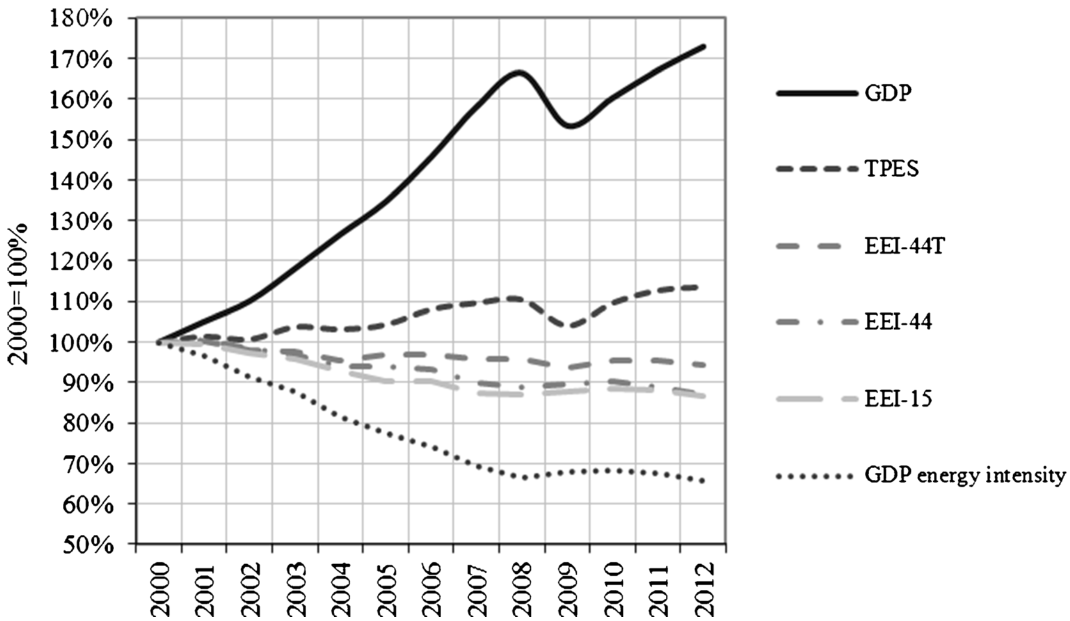


**Fig. 4** Evolution of GDP energy intensity and energy efficiency index (EEI) in 2000–2012. *EEI-15* energy efficiency index with 15 economic sectors; *EEI-14* energy efficiency index with 44 economic sectors and subsectors; *EEI-44T* energy efficiency index with 44 economic sectors and subsectors, with the impact of the technology factor isolated. Source: developed by the authors on the basis of energy balances built by CENEF

hearth steel and rolled steel, pellets, and synthetic rubber production. On the contrary, energy consumption showed significant growth in cement, aluminum, EAF steel, and oil and gas production over 2000–2012.

Uneven dynamics of industrial energy use is determined both by uneven output evolution and uneven decline of specific energy consumption. The first aspect is reflected by structural shifts in the industry. Apart from these, the decomposition analysis includes the following factors: evolution of technology energy intensity, capacity load, energy prices (related to product prices), and climate (Fig. 5). Nearly for all time spans, except 2006 and 2010–2012, structural shifts in the industry have been driving industrial energy consumption down. In the recession year 2009, they determined substantial energy use decline. Output growth in energy-intense industries promoted energy consumption increase in 2010–2012.

Energy intensity was another factor that made a visible contribution to the slowing of industrial energy use growth. However, this contribution was not as significant as that of the capacity load factor. In 2005, 2008, and 2010 (3 years of the decade), technologies did not reduce industrial energy demand. In 2005, however, industrial energy demand increased due to energy intensity growth in "other industries." It is important to highlight that estimates of energy use in "other industries" are not very reliable after 2007, when changes introduced to the statistical system made estimating more difficult. All these affected the assessment of the role played by this factor in 2007/2008. Besides, in 2007, statistics on energy consumption for synthetic ammonia, cement, and clinker production were revised.

In the recession year 2009, the impact of the technology factor was the most prominent. Plants were no longer willing to use the most outdated technologies and closed down or dismantled corresponding capacities. In 2010–2011, the technology factor did not hamper energy consumption growth, which was primarily driven by increasing energy intensity in "other industries." However, this indicator is not disaggregated, so it is impossible to statistically reveal the reasons for such increase. In 2009, industrial output dropped by 9.3 % and in the manufacturing industry by 15.2 %, so that year reduced industrial output determined a drop in industrial energy demand by almost 16 mtoe. On the contrary, in 2010–2012, industrial recovery promoted an energy demand increase nearly as significant as in 2003 and 2004.

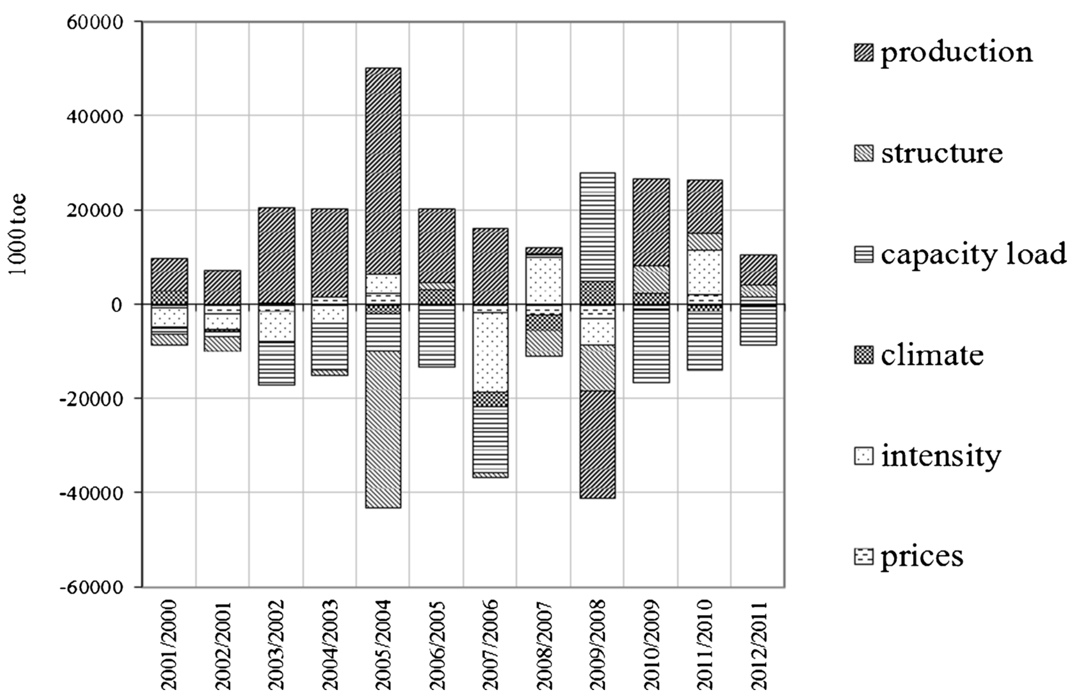


**Fig. 5** Decomposition of factors that determined evolution of industrial energy consumption. Source: developed by the authors on the basis of energy balances built by CENEF

The climate factor is not normally associated with industry. However, the floor area of industrial buildings accounts for 30–40 % of the entire heated floor area. Therefore, in the manufacturing industry, the share of heat used for space heating and ventilation of industrial buildings is significant and climate dependent, although this fact is not well recognized. Soft winters in 2007, 2008, 2011, and 2012 contributed to lower energy consumption growth, while cold winters in 2009 and 2010, on the contrary, promoted energy demand increase.

Industrial recovery of 2000–2008 was driven not so much by investment in new technologies as by increased load of earlier built capacities. This facilitated industrial output increase without significant energy consumption growth and helped decouple industrial production index and the industrial energy demand. In some years, the relative energy price factor was hindering energy demand growth, while in other periods, it was not. The industrial boom of 2004–2007 has led to an escalation of industrial products' prices, which left energy prices behind. A natural consequence was relatively cheaper energy and lower energy cost savings projects on the strategic plans agenda. In the recession years 2008 and 2009, prices of industrial products dropped, while domestic energy prices kept growing. This situation was reversed in 2010–2012.

Energy intensity evolution of different industrial products looks very much like a ball of multicolor yarn. To reveal the order camouflaged by this Brownian motion, integral indicators of energy efficiency progress are needed. Energy efficiency index for industry (EEI-industry) is evaluated to isolate the contribution of improved technology to energy intensity evolution. While industrial energy intensity dropped by 30 % over 2000–2011, i.e., was annually declining by 4.5 % on average, industrial energy efficiency index dropped by only 4 %, i.e., was annually declining by 0.3 % on average (Fig. 6). In 2000–2009, it was nearly equal to the decline shown by the USA in 1985–2004 or EU in 2000–2009.

In 2000–2009, the technology improvement factor was responsible for only 30 % of the industrial energy intensity decline. In the USA, on the contrary, this factor was responsible for 65 % of the industrial energy intensity decline. The other 70 % were determined by structural shifts, capacity load, energy prices, and climate. In the recession year of 2009, reduced capacity load hampered industrial energy consumption decline and was an important driver for industrial energy intensity growth. In 2010–2012, on the contrary, it is capacity load that basically determined energy intensity reduction.

## Residential sector

Russian statistics does not provide ready-to-use data on overall energy consumption in the residential sector. These data need to be assessed by examining various statistical forms, many of which provide controversial information[9]. A significant share of energy is used for space heating. This part of energy consumption is determined by the floor area, thermal performance of buildings, climate, and energy price dynamics. Energy consumption for hot water supply is determined by population, technology efficiency of water heaters, and prices. Finally, energy consumption by appliances depends on the purpose of usage and in some cases on population, floor area, appliance saturation, capacity, time of usage, etc. Many national energy efficiency accounting systems allow a quite detailed analysis of residential energy consumption. In Russia, statistics does not provide enough data for an analysis in comparable detail, so such an analysis is possible for just three directions of energy use in the residential sector, namely: space heating, DHW, and appliances.

The entire consumption of coal and other solid fuel is attributed to space heating. Besides, CENEf used a special model to assess natural gas consumption for this purpose, as well as the consumption of liquefied and network natural gas for hot water supply. Information on the district heat consumption for both heating and hot water is available from the Russian statistics. All other energy uses in the residential sector are attributed to "other needs," which basically include energy consumption by gas and electric appliances. They also include some electricity use for water and space heating. However, they are accounted for as a part of "other needs" to minimize the usage of expert assessments for calculations.

Energy consumption in this sector grew up in 2000–2012 by 12.2 mtoe, including 7.1 million toe for space heating and 10.8 mtoe for "other needs." Energy consumption for hot water supply declined by 5.7 mtoe, partly due to population reduction. Heat dominates in

[9] Those statistical forms are developed by Rosstat (http://www.gks.ru), but very limited amount of information from those forms is published.

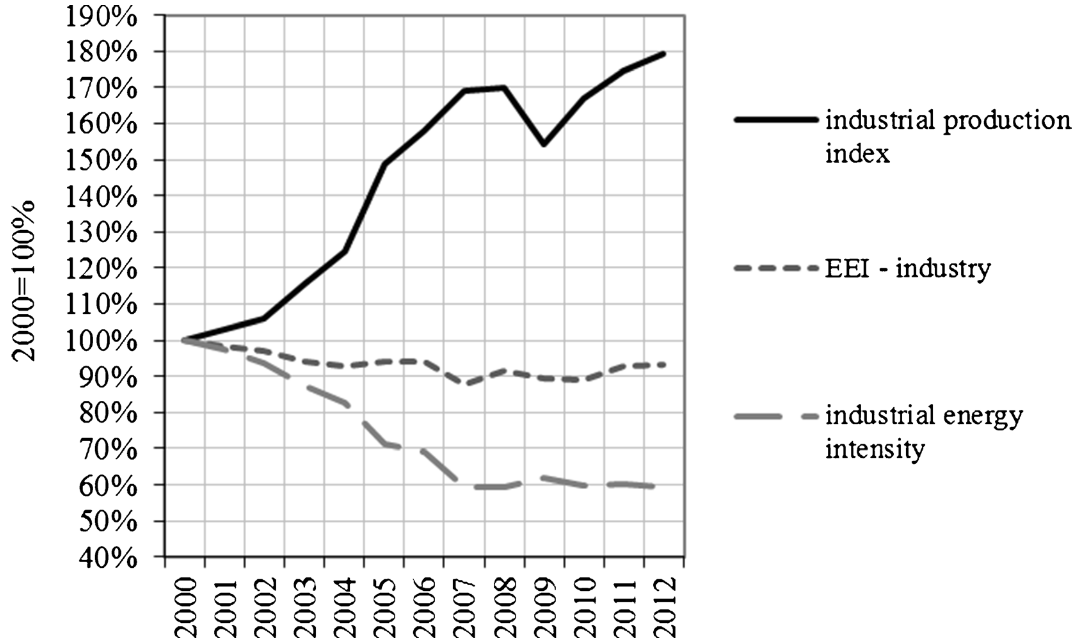


**Fig. 6** Evolution of GDP energy intensity and energy efficiency index (EEI) in industry in 2000–2012. *EEI-industry* energy efficiency index in the industrial sector estimated for six factors decomposition: activity, structure (24 types of industrial products), technical intensity, capacity load, energy prices, and climate). Source: developed by the authors on the basis of balances built by CENEF

the structure of final energy use in the residential sector. However, its share declined from 51.3 % in 2000 to 46.2 % in 2012, primarily due to dynamically growing energy consumption for "other needs," where electricity and natural gas take the lead. In space heating and in hot water supply, the share of district heat slightly declined. The share of natural gas in the structure of final energy consumption in the housing sector increased from 34.3 to 40.3 % and the share of electricity from 9.6 to 10.6 %. The share of coal dropped from 2.6 to 2.0 %, of liquid fuel from 1.2 to 0.6 %, and of other solid fuels (primarily wood) from 1 to 0.4 %.

Six factors were identified as determining energy consumption dynamics in residential buildings in 2000–2012: activity growth (residential floor area is used as an activity indicator for space heating and "other uses," while population is used as an activity indicator for hot water); structural factor (the difference between total residential floor area and population dynamics); energy intensity of buildings (per square meter), hot water systems (per capita), and appliances (firstly per capita and then per appliance); climate (degree-days of the heating period during the year); amenities (share of residential floor area with district heating, share of population with access to district hot water systems) and appliance saturation; and average energy prices for households compared with consumer price index.

Nearly a 22 % increase in living floor area over 2000–2012 overlapped the impact of population reduction, so the activity index was continuously working to increase residential energy use since 2009 and so was the amenities and saturation factor in 2000–2012 (Fig. 7). This impact of the latter factor was comparable with that of the activity factor. In the recession years, abrupt slowdown in personal income growth hampered the appliance saturation increase, and so its impact declined. Two cold years, 2009 and 2010, contributed 6.5 mtoe and 3.1 mtoe, respectively, to the housing sector energy demand increase. The structural factor promoted energy consumption growth (growing housing stock). The large impact of the price factor is the result of higher than in other sectors price elasticities as well as escalation of household energy expenditures by 11 times in 2000–2011 (comparing with 3.3 times growth of consumer price index) only partly compensated by growing incomes.

Nearly throughout the whole analysis horizon, declining energy intensity of equipment and buildings

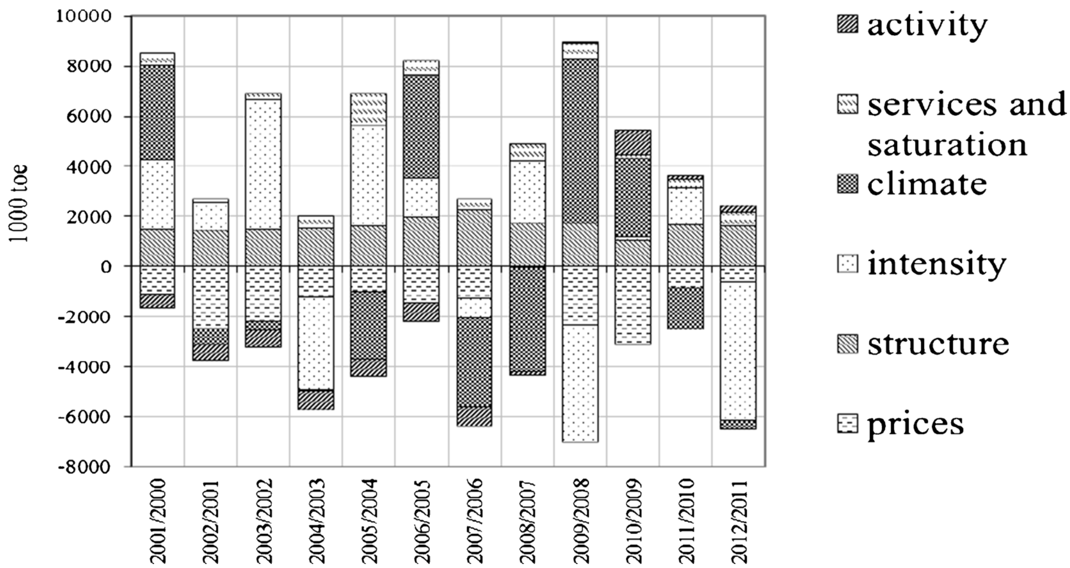


**Fig. 7** Decomposition of factors that determined energy consumption by residential buildings. Source: Developed by the authors on the basis of energy balances built by CENEF

hampered energy consumption growth in the residential sector. Contribution of the price factor was also sustainable: in 2000–2012, energy prices were growing faster than consumer price index. The share of energy and municipal utilities bills in overall residential costs went beyond the thresholds. These thresholds are universal for various countries and are in the first case around 3–4 % (for medium-income households) and 7–8 % (for low-income households). When these thresholds are approached or stepped over, price demand elasticity considerably increases, and residents change their behavior to reduce energy consumption (Bashmakov 2004a, b, 2007).

Growth of specific energy consumption for "other needs" by about 74 % reflects improving amenities and appliance saturation to a great extent (Fig. 8). An attempt to identify the contribution of the technology factor produced a significantly smaller estimate of energy intensity in this sector in 2000–2012 (by 18 %). However, a more detailed analysis is needed to assess the role of the technology factor for "other needs" adequately. So, a special model was used to evaluate the dynamics of average weighted specific energy consumption by the appliances fleet. Average specific energy consumption by different appliances in 2000 was used as a weight. It turned out that technical efficiency of electric appliances improved by 14 %[10], and that of gas appliances by 5 %, which brings 10 % overall average appliance efficiency improvement. Therefore, the impact of the technology factor in the improvement of "other needs" energy efficiency in 2000–2012 can be assessed at around 10 %.

In hot water supply, replacement of sanitary equipment with new, efficient models and installation of water meters led to technology-induced energy efficiency improvement by 16.2 % in 2000–2012 or by 1.1 % per annum on average. The European Union did not demonstrate any energy efficiency progress in this area in 1997–2007 (ADEME 2009). Since in 2011 over 20 % of housing stock were buildings erected after 2000, mostly in compliance with the new building codes with more stringent energy efficiency requirements, technology-induced energy efficiency of residential space heating improved by 10 % in 2000–2012 due to new thermal performance technologies. In the European Union, the relevant indicator was down by 12 % in 1997–2007.

The resulting energy efficiency index in the housing sector declined by 11.8 % in 2000–2012, i.e., was annually declining by 0.9 %. In the European Union, average annual reduction over 1997–2007 was 0.8 % as shown in ADEME (2009). If an indicator assessed on the base of average weighted specific energy consumption by the appliance fleet was used for "other needs," the energy efficiency index would have declined by 11 %.

[10] Very much like in the European Union

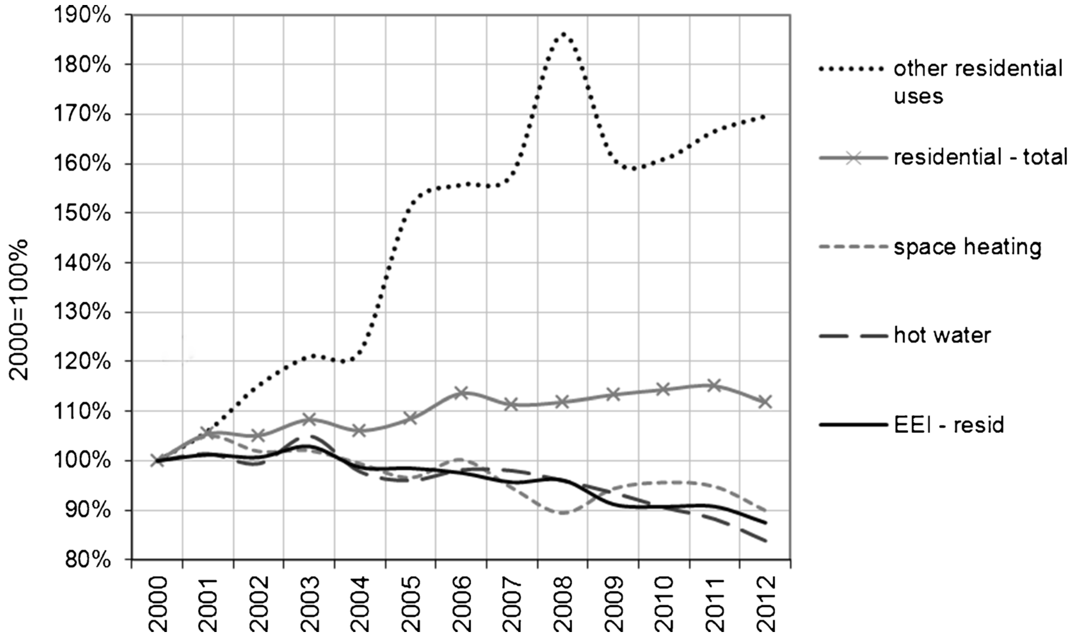


**Fig. 8** Evolution of energy efficiency of residential energy uses and of the energy efficiency index. *EEI-resid* energy efficiency index of residential buildings. Source: developed by the authors on the basis of energy balances built by CENEF

Summing up, it is important to mention that the housing stock comes third after transport and electricity sector in energy consumption increase over 2000–2012. Energy price increase was the major deterrent for energy consumption growth in the housing sector—real energy prices (corrected for consumer price index) tripled in 2000–2012. While in 2000 Russians spent 114 billion roubles to pay their housing energy bills, in 2010, they paid 11 times that amount (1,240 billion roubles). Population decrease and related hot water demand reduction also hindered energy consumption growth. Growing living space, improved housing amenities, and appliance saturation were the major factors that determined energy demand increase. The cold years 2009 and 2010 contributed to the housing sector energy demand increase.

## Conclusions

This paper was developed to evaluate effectiveness of energy efficiency policies recently launched in the Russian Federation. Using energy intensity of GDP as a metric to demonstrate effectiveness of policy packages may be very misleading as it is shown in this paper for two recession years (2009 and 2010). Up to date, the impressive success in declining Russian GDP energy intensity was the result of policies to restructure the Russian economy, rather than of the policies to promote intensive penetration of new energy-efficient technologies. For the economy as a whole and for the considered energy use sectors, the rate of technologically driven energy efficiency improvements reflected by energy efficiency indexes was roughly comparable with the advanced economies, which means that the technology gap in energy efficiency between Russia and those countries did not narrow in 2000–2012.

Introducing the capacity load factor into the decomposition analysis allows to reflect technological energy efficiency improvement more adequately. This factor plays an especially significant role in business cycles as well as in economic development phases based mainly on spare capacity load (as it happened in Russia in 2000–2008). With this factor considered, the contribution of the technological factor to Russia's energy savings improvement over 2000–2012, estimated before, is halved.

In those sectors of economy, where energy efficiency policies were most actively implemented (public and housing sector), significant energy efficiency improvement was achieved. As energy efficiency policies are still weak for industry and transport, their contribution to energy savings was limited, and those sectors are first targets for additional policies. As the federal energy efficiency program was only started in 2011, results of the analysis show that it allowed to put the technology factor at the forefront.

Pilot application of the energy efficiency and energy savings accounting system in Russia and energy consumption growth decomposition analysis have shown that: (1) its creation is possible even using a noncomprehensive statistical base; and (2) it provides nontrivial results and shows that impressive GDP energy intensity decline in 2000–2012 was mostly driven by structural factors with limited contribution of technological ones which failed in bridging the technological gap with advanced economies. Facing slowing economic growth in years to come, the federal policy to improve energy efficiency is to be focused on providing incentives for a more dynamic penetration of energy-efficient technologies to improve the Russian economy, competitiveness, and energy security.

## Appendix

**Table 1** List of 15 sectors and of 44 subsectors

| Sector number | Subsector number | Name of the sector or subsector | Activity indicator |
|---|---|---|---|
| 1 | 1 | Electricity generation | Electricity production |
| 2 | | Heat generation | Heat production |
| | 2 | Heat generation by cogeneration plants | Heat production |
| | 3 | Heat generation by boilers | Heat production |
| | 4 | Oil refineries | Primary oil refined |
| 3 | 5 | Gas processing | Gas processed |
| 4 | 6 | Coal treatment | Coal treated |
| 5 | 7 | Own use | Electricity production |
| 6 | 8 | Transmission and distribution losses | Primary energy production |
| 7 | | Industry | Industrial production index |
| 8 | 9 | Oil production | Oil production (tones) |
| | 10 | Gas production | Gas production ($m^3$) |
| | 11 | Coal production | Coal production (tones) |
| | 12 | Iron ore | Iron ore production (tones) |
| | 13 | Iron ore agglomerate | Iron ore agglomerate production (tones) |
| | 14 | Iron ore pellets | Iron ore pellets production (tones) |
| | 15 | Coke | Coke production (tones) |
| | 16 | Pig iron | Pig iron production (tones) |
| | 17 | Open-hearth steel | Open-hearth steel production (tones) |
| | 18 | Basic oxygen steel | Basic oxygen steel production (tones) |
| | 19 | Electric steel | Electric steel production (tones) |
| | 20 | Rolled ferrous metals products | Rolled ferrous metals products production (tones) |
| | 21 | Electro ferroalloys | Electro ferroalloys production (tones) |
| | 22 | Synthetic ammonia | Synthetic ammonia production (tones) |
| | 23 | Fertilizers | Fertilizers production (tones) |
| | 24 | Synthetic rubber | Synthetic rubber (tones) |
| | 25 | Pulp | Pulp production (tones) |
| | 26 | Paper | Paper production (tones) |
| | 27 | Cardboard | Cardboard production (tones) |
| | 28 | Cement and clinker | Cement and clinker production (tones) |
| | 29 | Aluminum | Aluminum production (tones) |
| | 30 | Meat | Meat production (tones) |
| | 31 | Bread | Bread production (tones) |
| | 32 | Other | Other manufacturing industry production index |
| 9 | 33 | Construction | Construction production index |
| 10 | 34 | Agriculture | Agriculture production index |
| 11 | | Transport | Sum of freight and passenger turnover |
| | 35 | Railroad | Railroad transport work (gross -t-km) |
| | 36 | Pipeline | Pipeline transport work |
| | 37 | Motor vehicles | Number of motor vehicles |
| | 38 | Other transport | Other transport sum of freight and passenger turnover |

**Table 1** (continued)

| Sector number | Subsector number | Name of the sector or subsector | Activity indicator |
|---|---|---|---|
| 12 | 39 | Municipal utilities | Population |
| 13 | 40 | Commercial | Commercial floor space |
| 14 | | Residential | Residential floor space |
| | 41 | Space heating | Residential floor space |
| | 42 | Domestic hot water, DHW | Population |
| | 43 | Other residential needs | Population |
| 15 | 44 | Non-energy use | Manufacturing industry production index |

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