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Changes in Approaches to the Analysis and Forecasting of Domestic Mechanical Engineering Within Manufacturing Industries

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ABSTRACT

Relevance: The article analyzes the relationship between the development of domestic mechanical engineering and relevant scientific schools within the framework of the concept of sustainable development. The functioning of domestic mechanical engineering is considered in the context of international associations. The following methods were applied in the study: a systems approach, functional, comparative economic, and statistical analyses, as well as the authors' methodological developments. The **scientific novelty** of the article lies in the implementation of the authors' approach to studying mechanical engineering as an interaction between scientific schools and economic and environmental factors. The **results and conclusions** of the study may be useful for decision-making within the existing economic model of the Russian Federation when forecasting, developing, and adjusting strategic programs for industry development.

Keywords: sustainable industrial development; sustainable development factor; mechanical engineering forecasting; mechanical engineering forecasting schools

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INTRODUCTION

In the current development of world economies, it is relevant to study the impact on economic life by environmental risks, including man-caused emergency situations and disasters [1, p. 7]. In this regard, the responsibility for the use of promising technologies in various spheres of the economy is inevitably increasing, which should correspond not only to the increasing pressure of the environmental factor, but also meet the requirements of competitiveness. One of the major role in solving these problems, is played by the structural branch of manufacturing industry — mechanical engineering, which determines technical and technological basic composition of fixed capital in the economy. Therefore, it is necessary to substantiate the prospects for the development of mechanical engineering and make analysis, how different scientific schools changed their points of views on this topic.[1] In view of the above, we shall explore here three interrelated issues:

- assessment of the role of domestic mechanical engineering in the economy and in the global division of labour within the framework of the theory of sustainable development;
- specific features of mechanical engineering that should be taken into account when making forecasts of its development;
- how scientific researchers made forecasting and analysed functions and features of mechanical engineering.

About forecasting in mechanical engineering and manufacturing industries

Mechanical engineering encompasses a multitude of brunches, sub-sectors and industrial sectors, specialised in machine building, as well as equipment, units, parts and components for providing technological support to the economic reproduction process.

Besides, moreover, mechanical engineering is able to ensure a sustainable innovation-driven development of the nation's economy by means of embodied technology in machine-building.

In recent years, the domestic mechanical engineering has confronted a number of challenges. The resolution of these challenges will be of paramount importance to determine Russia's position in the contemporary paradigm shift from the Global West to the Global South. The domestic mechanical engineering is either doomed to serve the domestic market as a mechanical repair-assembly hub, as it has been since the mid-1980s, or take its pivotal place in the sphere of high-technologies, investment equipment, defense products and technically sophisticated consumer goods. To have a clear idea of this issue, we shall consider how Russian mechanical engineering sector and domestic industry function as a whole within the framework of the emerging conglomerations of the Global South in comparison with the Global West (*Fig. 1*).

Referring to *Fig. 1,* the share of Gross Value Added (GVA) of mechanical engineering sectors in GDP has been higher in the G7 countries (the green curve). The sharp increase in the GVA share of BRICS countries in 2011 (the blue curve) can be attributed to South Africa's accession to the BRICS union. The GVA shares among the BRICS and the EU countries looks more stable and less volatile than among the rest of the countries in the world (the red curve).

The following analysis will consider the same indicator in the context of a specific nation. (Refer to *Fig. 2*). In this regard, among the leaders are China, Japan and Germany, as well as India and Italy, historically outperforming Russia in this parameter. In general, the country has experienced a consistent growth in the share under consideration, in contrast to more volatile growth observed in the leading countries. However, it is important to note that stability in the volume of machine-building production does not necessarily indicate constant qualitative development.

[1] We purely leave out the technical factor of forecasting mechanical engineering and then focus on the economic content of the problem.

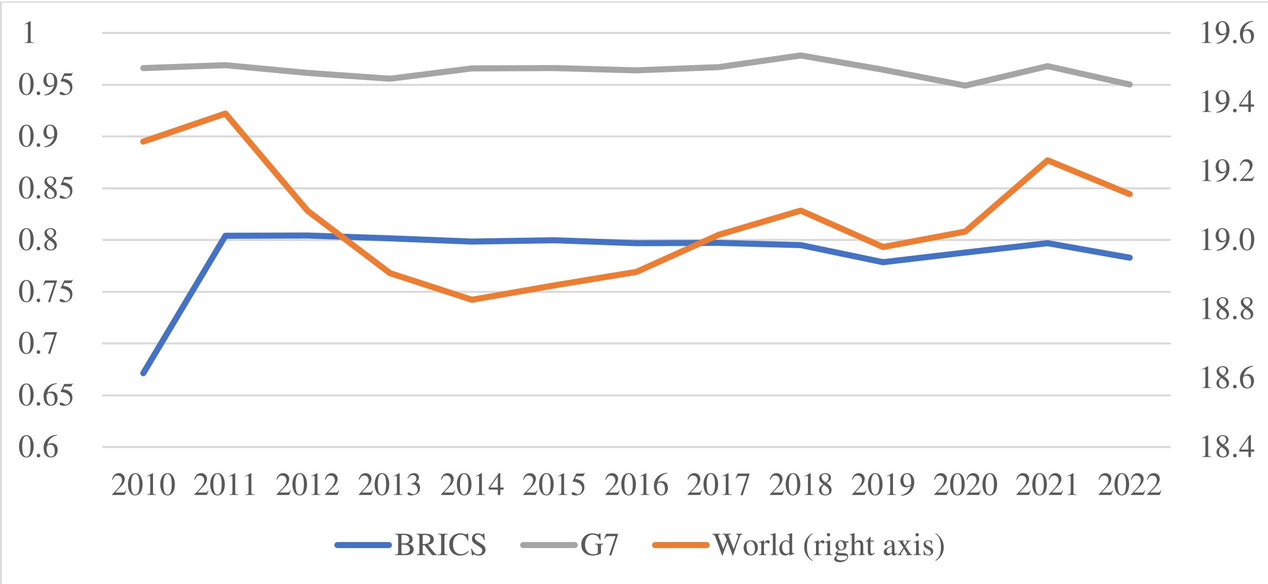

Fig. 1. **Share of Mechanical Engineering Gross Value Added (GVA) in GDP Across Country Groups, %**

Source: compiled by the authors on: URL: https://stat.unido.org/data/download?dataset=cip

Note: the right axis is the share of machine-building sector of GVA in world GDP.

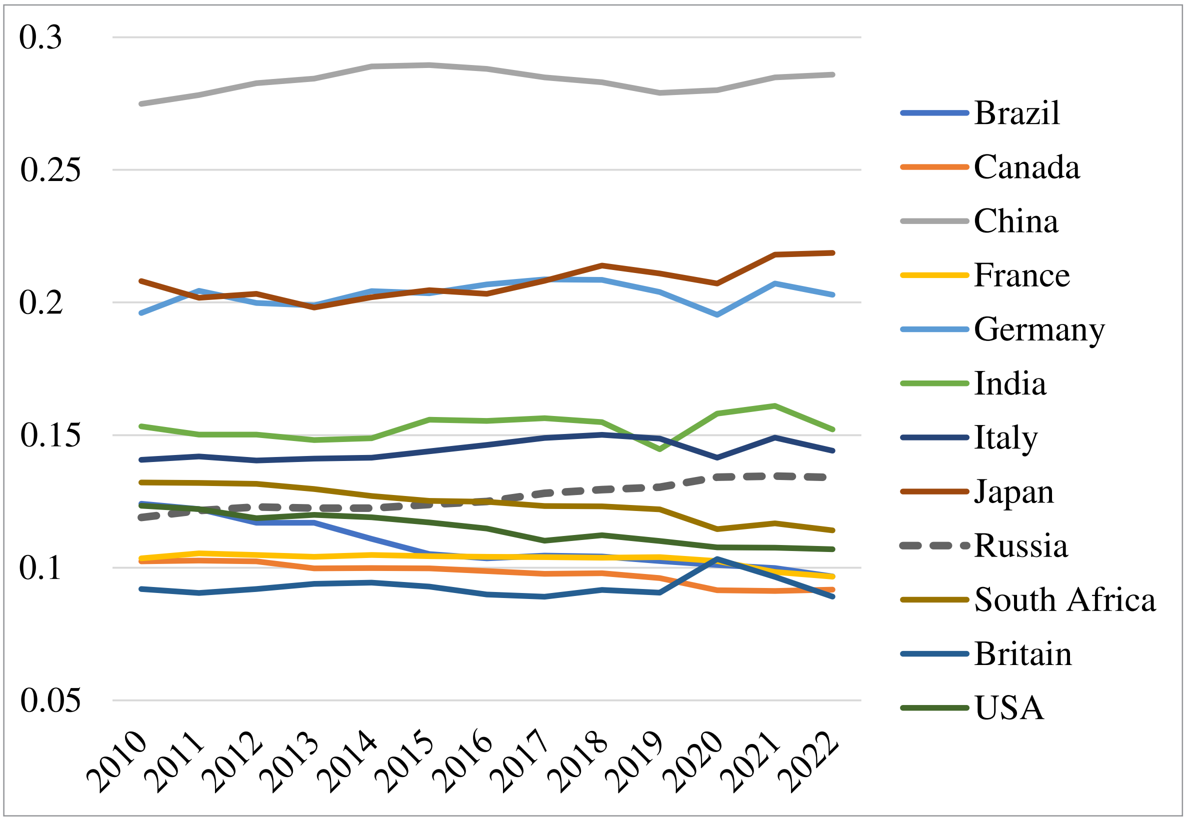

Fig. 2. **GVA share of mechanical engineering in GDP for countries, %**

Source: compiled by the authors on: URL: https://stat.unido.org/data/download?dataset=cip

In order to gain a more comprehensive idea of the state of mechanical engineering, it is important to consider not only the scale, but also the level of technological manufacturing sector. For this matter, a comprehensive analysis of the general context is necessary to assess the dynamics of share for medium and high GVA technology industry including an examination of the general volume of the sector. (Refer to *Fig. 3*).

Russia's performance here is not one of the best one: until 2020, it was in the penultimate place among the countries under consideration. Then the situation slightly improved: Russia's share keeps growing, while the share of Canada was shrinking, yet the overall situation has remained relatively unchanged. We may point to a significant progress of the United Kingdom, Italy, India, China and the USA with France, Japan and Germany among the leading nations.

It is curious to contemplate the role of nations and their corporations during the timeframe period at the very start of the current trends. For instance, between 2000 and 2010, China's share increased from 6.6 to 30.6 per cent, while the EU's share decreased from 37 to 29.9 per cent. Similarly, the USA's share fell from 29 to 19.5 per cent, and Japan's share decreased from 21 to 12.6 per cent. The Russian Federation maintained a consistent balance of share with 2.3 per cent throughout the entire period, a development that is worthy of note.[2]

When considering the index of industrial production (Refer to *Fig. 4*), with the year of 2015 noted as the base period, it is evident that Russia's industrial production indicates a steady notable progress in the context of the BRICS countries. According to the latest available statistics, in 2021 the index value for Russia was 121 per cent. In comparison, only three G7 countries performed an increase in such index in recent years (the UK had the record highest value of 109 per cent in 2021), while the other countries experienced a real decline in industrial production compared to their indexes of 2015 (Refer to *Fig*. 5).

In light of the aspects mentioned above, the following topics have been identified for the research study: firstly, our system analysis and, secondly, at least a framework forecast of mechanical engineering for the period of turbulent development in 2022–2030. However, first of all, it is important to note that machine building, as a conglomerate of economic activities, is designed to fulfil certain macroeconomic functions, namely:

- technological support for the economic reproduction process through innovation and investment activities, maintenance of existing basic technologies;
- fulfilment of household demand for technically sophisticated consumer goods;
- supply of military equipment to the Armed Forces to ensure the country's defence capability;
- technological potential for the current and future development of the national economy, capable to ensure sustainable development of the country, particularly, within the "green" trend.

Concurrently, mechanical engineering has the following inherent fundamental and largely distinct specific aspects in comparison to other industries:

- variety of manufactured products for material filling of any technology
- contradiction between flexibility and mobility of production and efficiency, between specialisation and autarky;
- mandatory accuracy of serial reproduction of assemblies, component parts and machine systems during the transition from development through innovation activities to serial production;
- high intensity and scale of inter-sectoral relations between industries;
- the acceleration and multiplicative effects;
- production of dual-use products;

[2] Study on the Competitiveness of the EU Mechanical Engineering Industry. EU 2012. FN 97615-FWC Sector Competitiveness-Mechanical Engineering. 320 p.

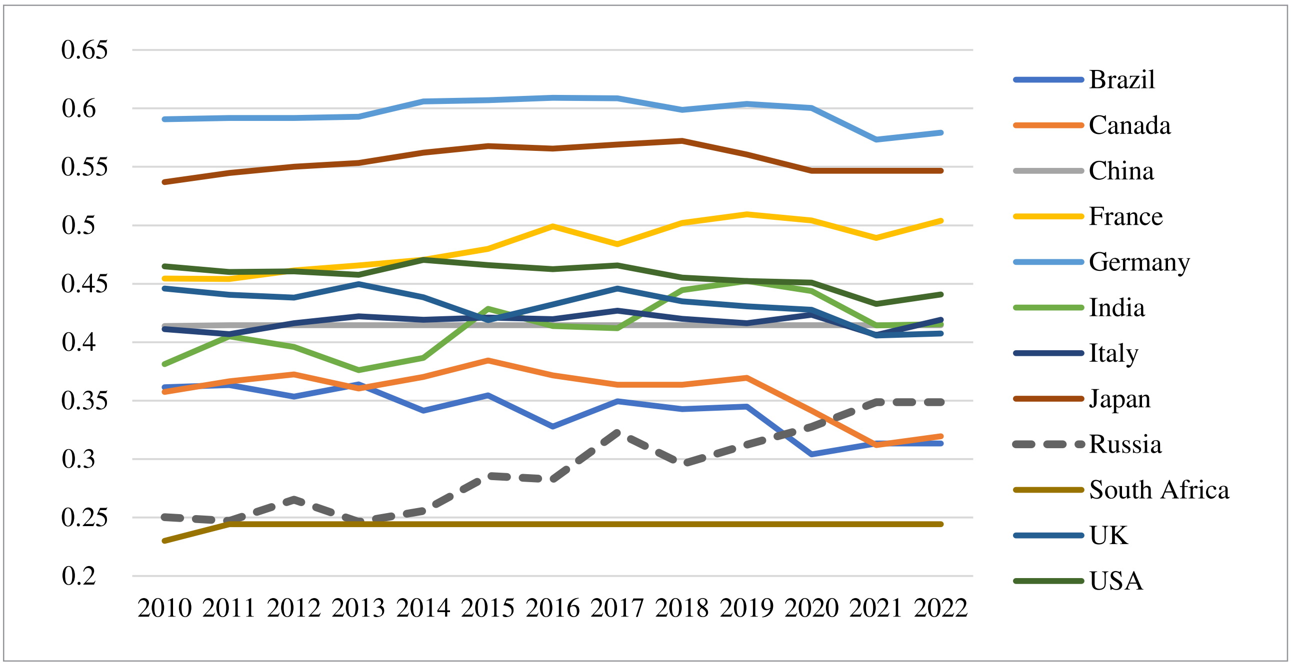

Fig. 3. **Share of Medium- and High-Tech Mechanical Engineering GVA in Total Mechanical Engineering GVA**

Source: compiled by the authors on: URL: https://stat.unido.org/data/download?dataset=cip

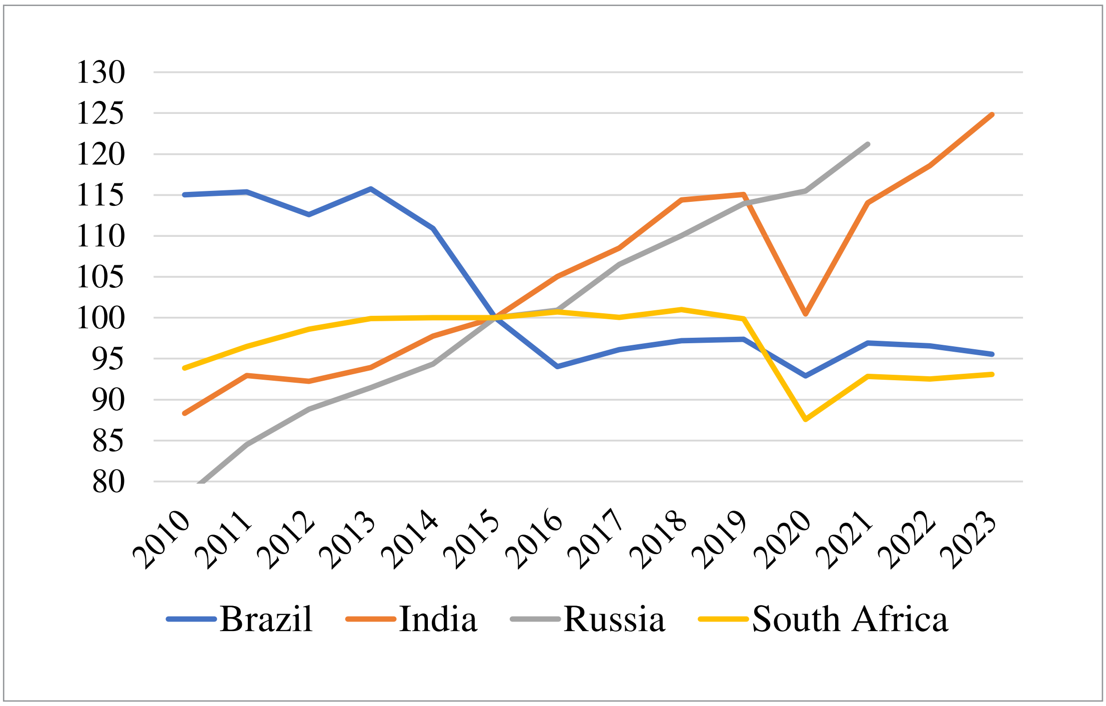

Fig. 4. **Industrial Production Index in BRICS Countries, in %**

Source: compiled by the authors on: URL: https://www.oecd-ilibrary.org/economics/data/main-economic-indicators/production-and-sales_data-00048-en

Note: 2015 г. — 100 per cent.

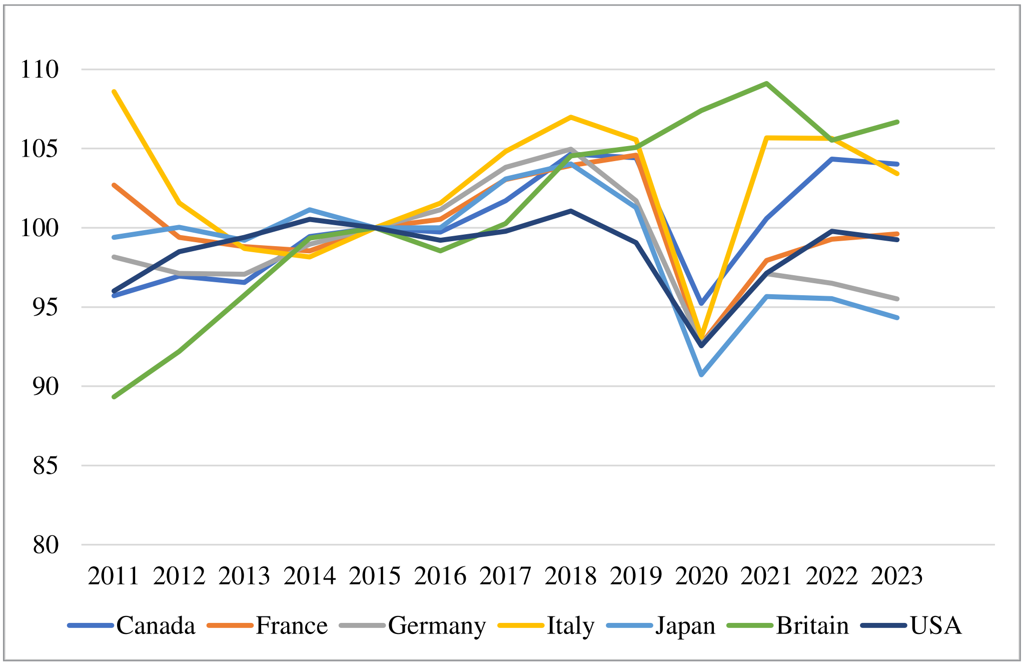

Fig. 5. **Industrial Production Index in G7 Countries, in %**

Source: compiled by the authors on: URL: https://www.oecd-ilibrary.org/economics/data/main-economic-indicators/production-and-sales_data-00048-en

Note: 2015 – 100 per cent

- significant impact on the environment, both positive via "green" technologies and negative through increased pollution.[3]
- engineering, its products and services operate within a full innovation cycle, which includes the following:
- exploratory research;
- R&D regarding dissembled technologies;
- innovation activities that transform dissembled technologies into embodied technologies;
- mass production, market development;
- withdrawal from markets and production;

Distinctive phases to forecast machine-building include: scientific and technological (pilot studies, pre-discovery, R&D), production (innovation, serial production, market supply) and market (market operation and recycling). It is evident that within the stages of the full innovation cycle, mechanical engineering conveys the ecological function, both in its own internal functionality and in the technologies for consumers of mechanical engineering products. Furthermore, scientific research in the forecasting and analytical domain can encompass one or multiple macroeconomic functions of mechanical engineering.

Prior to the early 1960s, it was hardly possible to define precisely any forecasting technology in machine building and other manufacturing industries, with the exception of some macroeconomic technologies and sub-industries. At this current stage, we can employ a predominantly planned (non-forecast) assessment of machine-building prospects. In that time, it lacked the following important aspects:

- theory, methodology and instruments for forecasting;
- the demand for qualitative forecasts.

In the late-1950s-early 1960s, specialists started to operate with such advanced tools in mathematical economics developed as factor models, production functions, and interindus-

[3] Some authors also emphasised the importance of the trend towards miniaturisation of many types of engineering products.

try balance (ISB). The world acknowledged the concept of the role of machine-building in the technological structure of the economy and its significance in production systems and the world technological pyramid. Specialists developed algorithms for calculations, which as many people believed, would describe the relevant processes in the economy, particularly in mechanical engineering. Investment matrices developed in the USA by A. Young, L. Mally, S. Reed and R. Seaton included 75 items [2]. These matrices interconnected the advancement of machinery production with investment in fixed capital and manufacturing of product. The development of factor forecasting models in domestic science and practice is attributed to A.I. Anchishkin, and these models become an effective forecasting tool in a predominantly trendy economy [3].

As a follow-up of the aforementioned approaches, the equations of the model of inter-industry interactions by Yu.V. Yaremenko [4, p. 4] and the complex balance of equipment by V.K. Faltsman [5] were developed and used in practice. These two authors demonstrate the merging process with simultaneous divergence of planned activities and the forecasting stage in the research of machine building prospects.

SCIENTIFIC SCHOOLS OF FORECASTING MECHANICAL ENGINEERING

In 1970s-1980s, three major schools of forecasting the development of mechanical engineering emerged. Two of them were in Moscow headed by Y.V. Yaremenko and V.K. Faltsman at the Research Institute of Forecasting Economy of the Soviet Academy of Sciences [6–9], as well as by S.A. Heinman and D.M. Palterovich at The Research Institute of Economy of the Soviet Academy of Sciences. One more school was located in Novosibirsk under the guidance of A.G. Aganbegyan, E.P. Amosenok and V.A. Bazhanov at The Research Institute of Economics and Industrial Organization of the Siberian Branch of the Soviet Academy of Sciences. Their distinctive studies were complex system analysis and forecasting of machine building, not only individual sub-sectors. Experts of the Central Economic and Mathematical Institute of the Soviet Academy of Sciences under direction of V.L. Makarov and A.E. Varshavsky developed scientific and technological forecasting with special attention to machine-building sector.

Significant scientific contributions were made by Y.K. Kozlov in the field of location analysis of machine-building enterprises and by V.K. Faltsman in the field of equipment supply to the economy and complex balance of equipment. It is worth noting, that Y.K. Kozlov is among the pioneers in the field of spatial economics [10] and that he played an important role in development of organising guidelines, particularly in the research and development of machine-building [11].

The oldest school of machine-building forecasting was established at the Research Institute of Economics under the leadership of S.A. Heinman [12–14] and D.M. Palterovich [15, 16]. The characteristics of this school were distinguished by all-round interpretation of machinery as a means of production and by adoption of the normative-target approach. However, this school did not use extensive mathematical instruments for forecasting methodologies and lacked research of innovation and environmental factors in mechanical engineering. At the same time, it is noteworthy that S.A. Heinman's contributions encompassed the generalisation of predominantly all functions, factors and characteristics of the industry, while D.M. Palterovich's research delved extensively into the issues of the reproduction function of machine building.

The next in progress was the scientific school of the Institute of Economics and Forecasting of Scientific and Technological Progress founded by Y.V. Yaremenko and V.K. Faltsman. It was distinguished by the maximum integration of mechanical engineering into the production process, full mathematical and instrumental support, and the development of the genetic approach to forecasting [17].

In the same time-frame period, the scientific school of the Institute of Economics and Industrial Production Organisation of the Siberian Branch of the Soviet Academy of Sciences was founded under the leadership of academician A. G. Aganbegyan and his partners in science E.P. Amosenok and V.A. Bazhanov [18–20]. This school played a distinguished role in application of extensively input-output model tools aimed at the resolution of significant major economic challenges and tasks for the development of Siberia and the Far East. In addition, the school provided a robust foundation in political and economic substantiation of its research work.

A bit later, another scientific school, directed by V. L. Makarov and A. E. Varshavsky [21], who subsequently developed the research work ideas of A. I. Anchishkin on scientific and technological forecasting [22]. The school pinned a significant emphasis on the continuity of the complete innovation cycle, development of methods and instruments for scientific and technological forecasting [22].

Since the late 19th century, the necessity to envisage environmental and climatic factors for economic activities was always a fundamental reason for alterations in industrial production, with the objective to safeguard ecology and public health. Currently, this fact has been recognised as a mandatory item of the global agenda for sustainable development, which makes it possible to solve a number of problems from different spheres in an integrative way — economic, social and environmental.

The Russian economic model can be characterised as environmentally intensive. At present, the process of optimising environmental-economic relations is at the initial stage aimed to make an ecologically balanced economy. Today's urgent part of the agenda is the concept of "double dividends", which refers to the simultaneous achievement of high performance indicators in the economy and environmental friendliness of products and production technologies. In this regard, it is clear, that the ecologically balanced economy requires consideration of the sustainable development factor in the forecasting of industrial production.

In the context of Russian practice, three stages (or directions) of greening policy in industrial process could be determined:

1. Introduction of the quotas mechanism for greenhouse gas emissions within the framework of the Kyoto Protocol (1997).

2. Introduction of the system of payment for harmful environmental impact (1998).

3. Implementation of the model of the best available technology to reduce waste, discharges and emissions (2014).

It is hard to overstate the role of industry in mitigating the negative effects of production activities, including:

- introduction of modern, advanced technologies aimed to preserve resources and reduce production waste;
- industrial collaboration aimed to optimise utilisation of resources and the circularity of raw materials and waste streams;
- optimising the sectoral structure of production, avoiding nature-intensive high-waste production;
- development and production of new types of long-life-cycle products, suitable for the production re-cycling after wear and tear;
- enhancement of environmental-friendly production by means of introduction of efficient systems for capturing harmful substances and hazardous waste utilisation;
- development of "ecological engineering" within the framework of the ecological engineering industry.

The abovementioned directions will contribute to solution of various local objectives. Their combined application could be used in modern approaches to develop mechanical engineering.

ORGANISATIONAL ASPECTS OF FORECASTING

Nowadays, a system of forecasting centres and a hierarchical structure of forecasts is operating in Russia, primarily providing scientific and technological forecasts with a special focus on ecological factor.

In the contemporary world, the USA takes priority in this sphere, involving such national entities as the RAND Corporation, The Massachusetts Institute of Technology (MIT), Department of Energy, Management Association, Hudson Institute, Council of Economic Advisers, Board of Governors of the Federal Reserve System, Industrial Research Council, Stanford University, Harvard University. In the PRC, the Academy of Sciences deals with such issues.

In Russia, it was N.I. Komkov, who pioneered and carried out the most outstanding research work in this area. He supplemented the functional "what to do" with "how to do" relating not only to machine building, but also to the sequence of the industrial process: "extractive industry →processing industry →manufacturing industry" [23, 24].

The peculiarities of mechanical engineering started to study within the framework of the following investment industries:

- investment engineering;
- metallurgy;
- construction;
- production of synthetic materials.

This approach was used furthermore during the development of the Comprehensive scientific and technical programmes in the 1970s-1980s and partly within the framework of the Programme of fostering mechanical engineering (1984).

The comprehensive targeted programme to foster machine tool construction occurred in the period of 1983–1985. The programme's fundamental elements were outlined in the Decree No. 773 of the Council of Ministers of the USSR dated August 7, 1985, "On measures to radically improve the technical level, quality of machine-building products and the development of machine-building as the basis of scientific and technological progress in the 12th five-year period with the perspective up to the year of 2000[4]".

[4] URL: https://docs.cntd.ru/document/765705293

The idea of the programme, which coincidentally commenced during the perestroika period, stated that the rise of machine building would serve as the catalyst for boosting technical and technological level of production and labour productivity to foster the economy. For this purpose, following 1985, the volume of capital investments in machine-building was doubled. However, this did not yield any considerable effect: the technological "stuffing" of investments lacked a strong support by innovative technology. In reality, technological capabilities remained status quo.

The much-anticipated acceleration in machine-building development did not work out, and the planned 1.5-fold increase by 2000 (compared to 1985) did not work out too, due to the gap between R&D and production activity. The national programme of machine-building recovery was not consistent within the framework of the stages of the full innovation cycle. It lacked specific target points and specific measures. Thus, by the end of the 1980s, due to the change of the vector of functioning of the domestic economy, the programme became obsolete and it was deactualised.

Almost in the same time-frame period, a different academic discipline, Environmental engineering, emerged in the West, as a reaction to the public concern about water and air pollution and other environmental problems. In the 1970s, the term "environmental engineering" replaced "sanitary engineering", since the focus of the discipline expanded to include the reduction of air, water and soil pollution [25]. In the USSR, the term "ecological engineering" appeared a few decades earlier, with the adoption of the Order of the People's Commissar of the USSR for Chemical Industry No. 153 dated April 22, 1944 "On Arrangement of production of electrostatic precipitator equipment required for completion of gas cleaning plants".

GENERAL EQUILIBRIUM MODELLING UNDER THE DOUBLE DIVIDEND HYPOTHESIS

Nowadays, the mathematical apparatus operating to forecast in the field of sustainable industrial production is mainly focused on models that are based on the impact of the energy sector on the long-term goal of making the climate neutral. Such models test the possibility of a so-called "double dividend" — the positive environmental and economic effects of mitigation policies to change the climate through environmental taxes and their reallocation. The objective is to ensure a transition cost-effectively to carbon-free technologies.

The environmental aspects in economic system analyses are completely evaluated by Computable General Equilibrium (CGE) models. Currently, these models have become a staple tool for analysing the economy-wide ramifications of environmental policy, including environmental taxes, resource allocation, and income of diverse economic agents.

CGE models are originated from the traditional "input-output" model developed by V. Leontiev in 1953, which is based on the method of estimating exogenous shocks under certain restrictive assumptions, such as fixed technology [26].

In 1968, V. Aysard with co-authors put forward a methodology with more alternatives for decision-making industrial policy based on "input-output" tables [27]. Later, in 1970, A. W. Kneese and colleagues used a similar "input-output" approach to develop environmental policy [28].

The aforementioned models are based on the assumption that environmental impact or the use of resources are proportional to output (similar to the assumption of fixed coefficients in the traditional "input-output" model). Therefore, they do not admit technical changes following an exogenous shock. These and some other limitations made researchers to develop more sophisticated methods.

Johansen's model (1960) became the first empirical model of general equilibrium without the assumption of fixed coefficients of "input-output" analysis [29]. Nowadays and already for several decades, CGE models for analysing the double dividend hypothesis have been extensively developed and applied worldwide.

Dynamic general equilibrium (DGE) models make another class that can take into account factors related to sustainable development policies. These models tend not to disaggregate data by sectors, but take into account the dynamics of the modelled variables over time, which allows obtaining the results in the form of a trend graph.

Practically, CGE models work well in the period of stability in economy, however, they are not effective in the crisis period.[5] Nevertheless, it is important to note, that from the point of view of forecasting and economic analysis these models serve to give an adequate response to the criticism of the use of econometric approach for solving applied problems to justify the directions of economic policy, since they are based on the theory of the real business cycle and try to simulate changes in the behaviour of economic agents to various shocks of macroeconomic nature [30].

NEW INPUTS IN FORECASTING MACHINE BUILDING IN THE FRAMEWORK OF MANUFACTURING INDUSTRIES

Structural and technological stagnation in the 1980s prompted changes in approaches to forecasting mechanical engineering, including:

- consideration of the dominance of demand in foreign and domestic markets;
- active allocations of the financial factor and overestimated role of international differentiation of labour;
- maximum consideration of export-import flows of machinery;
- determination of a new position of the Russian Federation in the world technological pyramid.

From 1990 through 2010, the following changes took place:

- shifting from forecasting of large industry aggregates and complexes to corporate forecasting;

[5] URL: https://infraeconomy.com/tpost/ibbeh40zm1-intervyu-s-aleksandrom-shirovim

- shifting the focus to spatial development and regional economy;
- separation of machine-building into a regular type of economic activity, beyond the full innovation cycle or scientific and technological forecasting;
- acceptance of the hypothesis that there are no restrictions on entry into the world markets of technologies, machinery and equipment;
- global adoption of the sustainable development factor in production processes at the level of international legal documents[6] and change of approaches to forecasting with regard to the sustainable development factor (environmental factor) in the practice of Western countries;
- understanding of the need to develop the ecological engineering industry[7] in Russia;
- adoption of the declaration of the necessity to develop the ecological engineering industry in Russia at the level of federal goal-setting documents.

Consequently, the following changes took place:

- decay of activity of the leading scientific schools of machine building forecasting and their integration into scientific schools of macroeconomic research;
- development of branch schools in accordance with the demand of corporations and authorities;
- Russia, much later than Western countries experienced transition to the implementation of sustainable development policy in industrial sectors, harmonisation of national legislation with the norms of international law, as well as taking into account the environmental factor (sustainable development factor) in the forecasting of production processes.[8]

CHANGING THE MODEL OF FUNCTIONING OF THE DOMESTIC MACHINE-BUILDING INDUSTRY

In the 2020s, the development of approaches to machine building forecasting started with:

- consideration of mechanical engineering as a sequence of technologically interrelated industries and productions;
- taking into account real financial constraints;
- restoration of the full innovation cycle for key machine-building industries;
- transition to the implementation of sustainable development policy in industrial sectors, including mechanical engineering.

In this area, the scientific research works by I. E. Frolov and his followers are of considerable interest: the peculiarities of the forecast approaches of the 2020s were organically taken into account [31–33].

Currently, the use of CGE- and DGE-models to analyse the possibility of double dividends is quite a common practice all over the world. For example, there is a predictive dynamic general equilibrium model that is sufficiently detailed to consider the main areas of reform of climate change strategy discussed in the EU.[9] The model is disaggregated by sectors, which in their turn are divided by the degrees of environmental impact into energy sources — "dirty" (greenhouse gas emitting) and "clean" (non-polluting). It also takes into account the reduction of emission of greenhouse gas by means of carbon taxes or government restrictions. The results of modelling present the magnitude of the costs of transitioning to a net zero-emissions economy.

[6] In 2015, the UN General Assembly adopted the Resolution "Transforming the World. The 2030 Agenda for Sustainable Development". It implied an increase in global resource efficiency in consumption and production systems. At the same time, economic growth should not lead to environmental degradation.

[7] The branches of ecological engineering are those whose main activities are the design, production and maintenance of machines, technological equipment and components for them, used to prevent and reduce the negative impact (influence) on human health and the environment.

[8] Regarding the concept of extended producer responsibility, Russia began to implement such legislative regulation only 25 years after the emergence of the concept of extended producer responsibility in the West.

[9] URL: https://economy-finance.ec.europa.eu/publications/e-quest-multi-region-sectoral-dynamic-general-equilibrium-model-energy-model-description-and_en

The research work of J.V. Gonzalez [34] is of considerable interest from the point of view of studying the prevalence of such models: the author analysed 69 different CGE- and DGE-models of different regions of the world, mostly the models of the USA, Canada and EU countries.[10] The author also found out that the developed models achieve double dividend in 55 per cent of cases. The rest of the models, which he studied, indicated that the environmental dividend can be almost always achieved, while the economic dividend is still an ambiguous issue that requires further study.

In Russia, the use of both types of models is not as widespread as abroad [35–37]. Nevertheless, it is in demand from the management of the Federal apparatus.

For example, the Bank of Russia actively uses the model, which was developed by N. Turdiyeva in 2024,[11] for analysis of the consequences of our country's climate policy. The specific part of the model regards the integration of climate and trade policy within the framework of universal equilibrium. The author believes, that active domestic climate policy would refrain the carbon intensity of Russian GDP from growing and increasing the physical risks of climate change. A necessary measure to reduce them would be the development of 'green' industries in the domestic economy, including export-oriented industries.

Currently, the transition to the implementation of sustainable development policy in industrial sectors in Russia proceeds in several directions. Firstly, based on the fact, that the State is striving for the transition to the sixth technological model, the consideration of various factors of sustainable development is an integral part of industrial policy. Such criteria as 'sustainability' and 'efficiency' have become key factors in the design, production and operation of machinery and equipment.

[10] URL: https://www.researchgate.net/publication/321305017

[11] URL: https://cbr.ru/StaticHtml/File/158735/wp_125.pdf

Sustainability in mechanical engineering requires minimising the negative impact on the environment during production and operation of machinery and equipment by means of reduction of harmful substances emission and noise levels. It also requires using resource- and energy-saving technologies and environmentally friendly materials. Environmental aspects in the new paradigm in the development of machinery and equipment need to be taken into account within the framework of the full life cycle: from prospecting research of the production up to its utilisation. Modern technologies and innovative materials in production contribute to higher efficiency in mechanical engineering.

Secondly, the Government takes legislative measures to develop a new sub-sector of ecological engineering to produce equipment that helps preventing harmful effects on human health and the environment.[12] As of the end of 2022, the national ecological engineering included nearly 250 enterprises.[13]

It is important to point out, that the sustainability factor in mechanical engineering contributes not only to clean-up environment, but also to economic and social benefits. Efficient use of resources and reduction of raw material costs lead to effective balance of financial performance of enterprises. Thus, environmental aspects become an integral part of the development strategy of the mechanical engineering industry.

Currently, experts developed an algorithm for the field of agricultural production. The algorithm is based on the assessment of the impact of machine technologies on three main components of the natural environment: atmospheric air, hydrosphere and soil, with the possibility of predicting changes in the sustainable state

[12] Order of the Government of the Russian Federation of June 6, 2020 No. 1512-r (ed. 21.10.2024) "On Approval of the Consolidated Strategy for the Development of the Manufacturing Industry of the Russian Federation up to 2030 and for the period up to 2035". URL: https://bazanpa.ru/

[13] Ibid.

of the natural environment depending on the applied technical and technological solutions [38]. Naturally, the results of such approaches will be taken into consideration for decision-making on the development of certain types of production in mechanical engineering.

CONCLUSIONS

The basic issues of development of mechanical engineering, except for market and environmental factors within the framework of the sustainable development concept, have been studied earlier. This industry in Russia has been maintaining its position in the markets since 2000, with only exceptions related to the relocation of people and cargo. Recently there was a need to set up a system of forecasting the development of mechanical engineering in view of technological and environmental factors. At the same time, the existing strategies should take into account the impact of technologies on the environment.

The objective to reach the UN Sustainable Development Goals encourages countries to develop new diagnostic and monitoring tools to assess their own performance. Nowadays international organisations already use the UN Industrial Development Organisation's (UNIDO) indicators: Industrial Competitiveness Index (CIP) and the Inclusive and Sustainable Industrial Competitiveness Index (ISCIP), which include social and environmental indicators. In this regard, the sub-branch of environmental engineering will be paid a strong focus, so that it would have a decent status in the engineering complex of the Russian Federation.

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