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Evolution of Technology and Technology Governance

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Abstract: This study is based on the concept of Kondratiev's technological waves as an analytical instrument for examining the processes of technological evolution. It aims at setting feasible indicators for this evolutionary development in order to provide a regulatory instrument for policy makers. In order to do so, the authors analyze approaches used for resource efficiency improvement in several European countries (i.e., implementation of Best Available Techniques, BAT). They emphasize that in Russia, the BAT concept is seen primarily as an industrial policy instrument. While BAT-based legislation is enforced by the environmental authorities, technological innovations making it possible to achieve performance better than that required by BAT are supported by the industrial development authorities. In the conclusions, the authors state that BAT-based solutions could be used as drivers for developing and implementing new technological solutions (innovations) and should become the basis for working out state industrial and environmental policies. The results of policies currently being developed will be assessed by the end of 2024.

Keywords: evolution of technology; technology governance; technological waves; industrial modernization; innovation; resource efficiency; Best Available Techniques; environmental policy; industrial strategy

1. Introduction

In modern society, we have become more and more dependent on technologies and their progress. In the 21st century, life cycles of technologies have tended to shorten, and many innovations of the 1990s will be forgotten very soon (if they have not been forgotten already). This is why the concept of so-called 'technological waves' has attracted the attention of not only scientists but decision-makers at various levels—sectoral, national, and international. Mankind is turning to the sixth 'technological wave', where nanotechnology, genetic engineering, membrane and quantum technologies, photonics, micromechanics, and thermonuclear energy play more and more important roles. Still, well-known (traditional) resource- and energy-intensive technologies of the fourth 'technological wave' remain important and need to be gradually modernized to improve their efficiency, to turn to using alternative energy and to reduce negative environmental impact. Circular economy principles are set to stimulate the return of recyclable resources into production processes. Civil society begins also recognizing the natural capital value, including not just mineral resources but also natural ecosystems that provide a flow of irreplaceable services and goods.

Starting from early 2000s, the United Nations have set different international development goals aimed at improving resource efficiency, ensuring proper waste management and overall fostering of innovation and modernization in industry and infrastructure. The current edition of these goals, known as Sustainable Development Goals (SDGs), was adopted by the United Nations General Assembly, and they are intended to be achieved by the year 2030 [1]. SDG9, 'Industry, Innovation and Infrastructure', and SDG12, 'Responsible Consumption and Production', have especially contributed to the fact that nowadays governments pay stronger attention to the transition of technologies to more advanced and at the same time sustainable and responsible modes of production than they did in the 1980s, before the 'Renaissance' of industrial strategy in the European Union, United States and Canada. This article aims at the analysis of governance techniques that can be used to stimulate environmental and technological modernization and to provide for favorable conditions for the development and implementation of cleaner and greener technologies.

2. Theoretical Background

2.1. The Technological Waves Concept

The technological transformation of the socio-economic system can be described as a series of changes in production methods and technological paradigms. Experts believe that the current economic system is determined by the transition of modern civilization from the industrial to the post-industrial stage, the beginning of this process is laid by the fifth technological paradigm (the fifth wave of technology) based on information and communication technologies [2,3]. In general terms, technology refers to methods, systems, and devices resulting from scientific knowledge being used for practical purposes [4]. This is a very important definition, and though technologies (chemical technology, food technology, etc.) are often described as both directions of applied science and systems used to manufacture respective products, in this article we'll speak of methods, systems, and devices used in industry for practical purposes.

In the 1920s, Nikolay Kondratiev described a 'long wave' as a rather prolonged economic cycle emerging from the implementation of innovative (for their time) technological solutions and, thus, leading to a significant period of financial wealth and stability [5]. In fact, several European scientists put forward similar ideas nearly simultaneously: Salomon de Wolff and Jacob van Gelderen were among the first authors to consider these wave-like movements or periods of certain dominant technological processes and industrial sectors [6,7]. Thus, the 'long wave' concept is recognized internationally and applied to characterize the evolution of technologies (Figure 1).

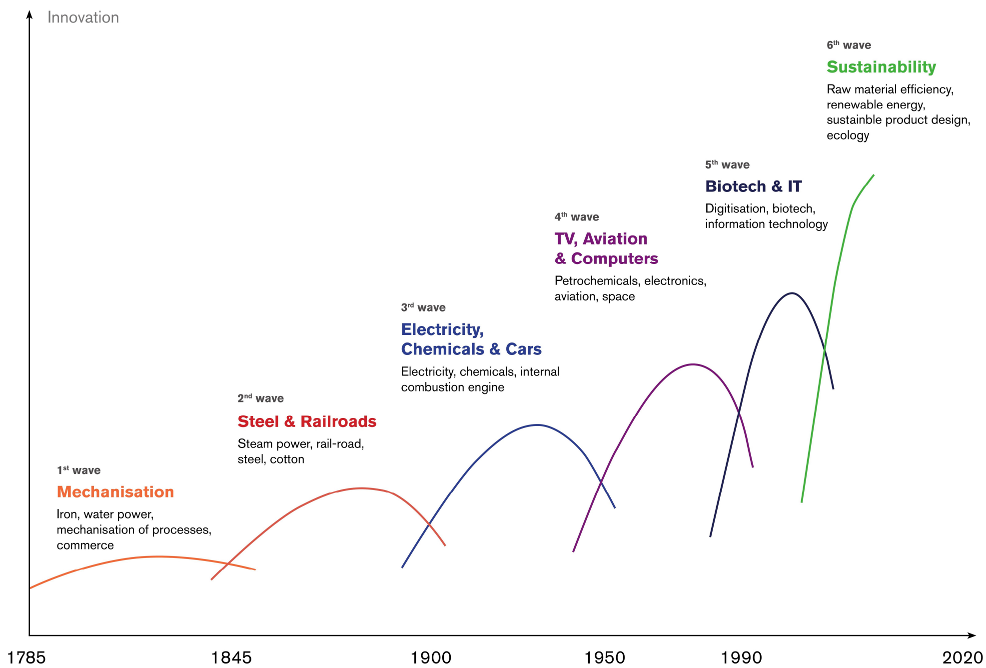

Figure 1. Technological Waves [8].

In modern history, at the beginning of the 1990s, Dmitry Lvov and Sergey Glazyev defined a 'technological paradigm' as a combination of technologies specific to a certain level of industrial development, and identified five paradigms already implemented by the world economic system. Each cycle begins with the introduction of manufacturers to a certain set of innovative solutions. The basis for subsequent technological paradigms is laid, as a rule, even during the heyday of the previous paradigm, and sometimes even at the time of the preceding one [9].

The fourth technological paradigm (wave) (1930–1985) was characterized by power engineering, machinery manufacturing, and new synthetic materials and communications equipment production, and contributed towards high-volume manufacturing of consumer commodities, weaponry, motor passenger vehicles and trucks, field engines, planes, and to the growing importance of computers and software products. Characteristic features of the fourth wave are still seen in all, even very advanced economies. Industrial sectors of the fourth wave are those consuming large amounts of natural resources (including energy).

The fifth technological paradigm is based on computer science, microelectronics, biotechnology, new types of energy sources and energy generation, genetic engineering, materials, satellite communications and space exploration. It is also a period of migration from singular 'stand-alone' companies to an intertwined electronic net of small, medium-sized and large enterprises, interacting closely in the fields of technology, product quality control, and innovation planning. A distinctive feature of the fifth wave is the enhanced role of microelectronic components. The advantage of the fifth paradigm lies in the individualization of production and consumption, an increase in production flexibility, and a strong attention to resource efficiency [10].

The origins of the sixth technological paradigm can be traced back to around 2010. Biotechnology and nanotechnology, genetic engineering, membrane and quantum technologies, photonics, micromechanics, and thermonuclear energy are becoming more and more conventional solutions. Experts expect that the synthesis of these areas will eventually lead to quantum computing and artificial intelligence, and provide access to a fundamentally new development level of governmental, societal, and economic systems. Experts predict that the sixth technological paradigm will enter the maturity phase after 2040. It is expected that a new scientific, technical and technological revolution based on achievements in the aforementioned basic technological areas will take place during 2020–2025. There are reasons for making such estimations: in 2010, the most economically developed countries had 20 % of their productive power in fourth technological paradigm, 60 % in the fifth, and about 5 % in the sixth [2]. Currently we are observing the structural reorganization of the world economy. We can try to predict the birth of a new technological paradigm out of IT and communication technologies and bioengineering with a certain measure of nano-technological solutions in well-developed economies of the 'first world', which will ultimately lead to a beneficial 'long wave' of growth. A drop in oil prices is a characteristic sign of the end of the 'delivery' period; and a new technological paradigm will grow exponentially in no small part thanks to a 'diffusion' of innovative, resource-efficient technologies and overall production energy intensity reduction.

2.2. Resource Efficiency as the Core Requirement of the Technological Evolution

Improvements in resource efficiency and reductions in environmental degradation have been drivers of new technological solutions for many decades. As emphasized by Sergei Bobylev [11], the end of the 20th century was characterized by depletion of abiotic and biotic resources (not only in materials and energy, but also clean water, air, fertile soil, and natural ecosystems), development of modern sophisticated communication tools, monitoring systems, and information processing, and formation of new knowledge on the state of the environment and environmental chemistry. These factors have become so powerful that refusing to take them into account and attempting to stay in the familiar frame of the fourth technological paradigm are fatal both for the economy and society.

In general terms, resource efficiency lies in the sustainable use of our planet's limited resources with simultaneous minimization of negative environmental impacts, thus allowing us to produce more with less raw material consumed and delivering greater value with less input [12–14].

Nowadays people realize, more and more deeply, that the wellbeing of mankind largely depends on natural capital, including ecosystems that are responsible for providing all necessary resources, goods and services: fertile soil, fresh water and clean air [15]. Still (and strangely), many of these services are consumed by humanity as if there is no limit to them [11,16]. They continue to be treated as 'free' commodities and their value is not assessed and accounted properly; that is why their depletion and pollution continues still, threatening the long-term sustainability and resilience of natural and economic systems. 'Producing more with less' becomes a kind of a motto or a core element of sustainable production in many countries and sectors of the economy.

Here we come again to the concept of natural capital. Rational use of natural resources is an essential aspect of resource efficiency and also a tool to conserve natural capital. For example, specific risks associated with metals and minerals are addressed by the Raw Materials Initiative of the European Union (EU), as well as by the climate and energy policies under the Resource Efficiency Flagship; the interaction between their use and other resources is recognized [15]. Similar approaches are characteristic of Russian Federation (RF) policy in the field of rational use of mineral resources [17,18].

As societies gradually move towards sustainable materials management or a 'circular economy', with waste becoming a resource, a more efficient use of metals and minerals will result in resource consumption reduction. This will have an impact on resource efficiency via implementation of the following measures: better consideration of life-cycle impact, avoiding waste, reusing and recycling, and improving research and innovation [16].

Turning waste into a resource is a planetary challenge. It is estimated that the European Union produce a of total 2.5 bln tons of waste, 101 mln tons of which is hazardous [19]. In Russia, in 2018, the amount of waste generated reached 7.3 bln tons; this figure was growing significantly in 2010–2018. Approaches to classifying waste in the EU and the RF differ, but on average, the amount of hazardous waste formed in Russia in 2018 did not exceed 30 mln tons [17]. In the EU, around 60% of solid waste ends at landfills or at incineration installations, the rest being reused and recycled. In Russia, the share of recycled and detoxified waste reached 3.8 bln tons in 2018, but recycling as such is a significantly less developed practice than that characterizing most developed European countries.

Water is not only a significant input to economic development (industry, agriculture, energy, transport, and tourism), but a vital resource for human health; that is why its availability and quality is crucial to human health and good environmental status, while water shortage has a critical impact on the cooling of thermal and nuclear power stations and hydropower [15].

It is projected that climate change has the potential to increase water shortages as well as flood frequency and intensity. Many European and Russian river basins and water bodies have been significantly changed by land drainage, water abstraction and dams; this will eventually lead to a drop in water quality, and negative environmental and health effects.

Air quality is a matter of great concern in most densely populated and industrialized regions, both in the European Union and in the Russian Federation, since it is quite common to exceed the provisions of air quality standards and/or regulations. The list of contaminants discussed internationally includes nitrogen dioxide, ground-level ozone, and particulate matter. In Russia, within the framework of the National Project 'Ecology' ('Environment') the level of air pollution has to be significantly reduced in the 12 most-contaminated cities and industrial centers [20], and it is expected that key improvements will result from the introduction of new technologies. It is known that, despite significant efforts to reduce emissions of pollutants in the EU, current concentrations of fine particles ($PM_{2.5}$ and PM_{10}) cause 400,000 premature deaths each year in member states [21]. Other European studies show that, as it is stated in the research of M. Amann, "the number of working days lost due to air pollution induced illnesses is higher than the working days required to pay for additional pollutant abatement measures" [22].

In many countries, governments form incentives for innovation by attempting to stimulate investment into research and development and the implementation of new technologies. For example, in Australia and Brazil, direct incentives are seen as strong instruments for increasing the innovation capabilities of companies [23]. In Russia, similar incentives are made both for research institutions and for industrial companies themselves, especially for leading corporations working in such sectors as energy generation, metallurgy, and construction materials. Similarly to in Australia and Brazil, Russia supports innovations by reducing tax and favoring depreciation requirements when industries install new (for example, more energy-efficiency) equipment.

In the EU and RF, thousands of square kilometers of land are subject to annual 'land take' for industry, roads and housing [24], often 'sealing' the surface with various pavements. Many regions are characterized by irreparable soil erosion or low content of organic matter. Soil loss and contamination leads to the loss of the natural capital. Modern industrial, agricultural, energy, and transport policy reforms have provided opportunities for setting the framework, and the right incentives, for public authorities and landowners to reduce soil contamination and to increase the surface of reclaimed soils and lands [25,26].

Previous 'waves' of economic growth have contributed to increased prosperity in society, at the cost of intensive and inefficient resource use. Biodiversity and ecosystem services are still undervalued even today; waste management costs are often not included in product prices; current markets and public policies do not necessarily address competing demands on strategic resources such as land, minerals, water, biomass, and fresh air. This is why it is necessary to respond coherently, over a wide range of governmental policies, in order to deal with the expected lack of resource availability and to develop sustainably in the long run [15,22].

3. Results

3.1. 'Four Seasons' of a Technology

The invention of new technologies, and their development, improvement and replacement with innovative solutions, occurs under a combination of driving forces; still, it is possible to conditionally distinguish periods characterized by one or another driver. As it is emphasized in the theoretical background, resource efficiency is one of the key drivers, but to understand it, our societies have had to face challenges which became evident only in the 20th century (Figure 2).

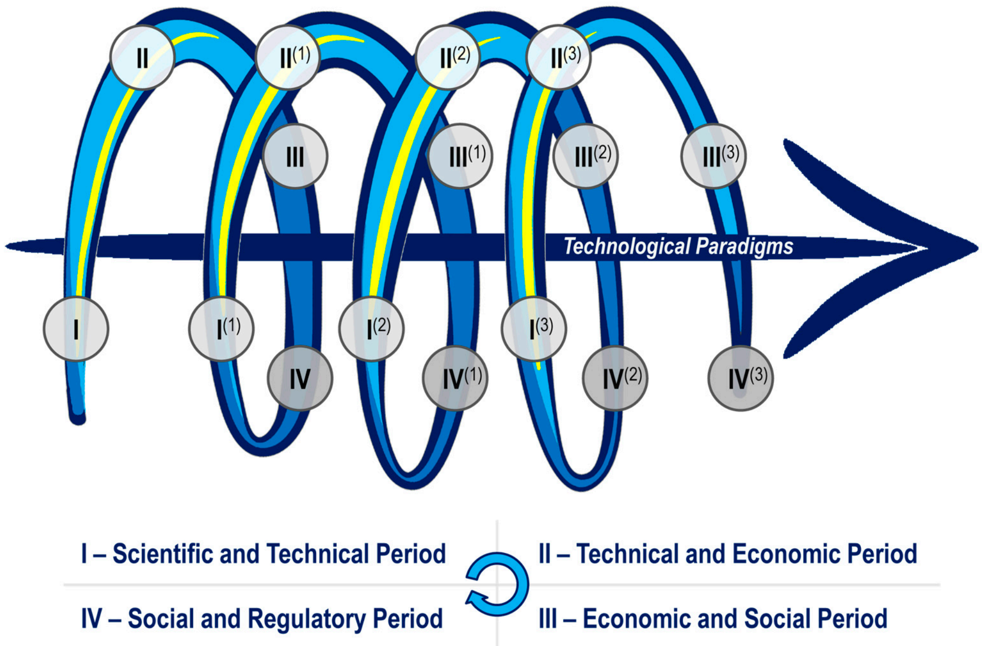

Figure 2. The concept of technological evolution. Source: Authors.

In history, the 'morning' (or 'spring') of a technology comes when there is a request for it from the society. At this stage (we call it 'scientific and technical stage') inventors or scientists discover the possibility of obtaining a new substance, material, or some other 'thing' necessary to satisfy a new need or a human curiosity. There are many examples to back up this statement: a rubber tree for indigenous peoples; the first telegraph and telephone; the first controlled nuclear reaction. At this stage, the technology should demonstrate only the ability to work to achieve the desired result. The economic benefits are not yet that important, but at the next 'technical and economic stage', business begins to show interest in the technology and the means of investing in the commercial implementation of the attractive technological process. The 'day' (or 'summer') of the technology is coming.

This is time when the technology concerned becomes more economically feasible and cost-effective. Depending on the implementation scale, it is the time when the 'presence' of this technology begins to be 'felt' by the society (its environmental impacts are often factors that make the technology become widely discussed). It is good if people appreciate and in a way 'approve' the technology. However, it often happens that technological by-products or industrial emissions and waste are perceived with hostility. Here comes the stage of active interaction (if not confrontation) between business and the society. We call it the 'economic and social stage' which represents the 'evening' (or 'fall') of the technology: further technological improvement in terms of resource efficiency is still possible, but is seriously limited by technical factors. At the same time, business is interested in increasing or maintaining the output of 'traditional' products, but this does not always suit the society. In most cases, environmental modernization approaches are suitable to alter the technology, to introduce Best Available Techniques or other regulatory instruments setting requirements for the rational use of resources and reduction of negative environmental impacts. The government intervenes and regulates the relationship between the technology and the society: the 'social-regulatory stage' is coming.

This is the 'night' (or 'winter') of the technology. In most cases, as a result, a new development round is initiated. Here we speak rather of innovative solutions than of a modernization approach. The scientific and technical stage is devoted now to the search for technical solutions that contribute to significant transformation of a known technology or its complete replacement, including taking into account the requirements developed at the social and regulatory stage of the previous cycle.

BAT is a moving target, and this is essential. An example from the Swedish pulp and paper industries during the period of 1970–2020 may illuminate this issue. In the 1970s, the permitting authorities prescribed Emission Limit Values (ELVs), mainly for typical water pollutants (Biochemical Oxygen Demand, BOD; suspended solids), acid gases (SO_2), smells (H_2S) and toxic compounds (Hg). In the 1980s, other toxic emissions were added to the prescribed ELVs, such as emissions from the bleaching of pulp (Adsorbable Organic Halogens, AOX; dioxins). In the 1990s, emissions included also other acid gases—nitrogen oxides (NO_x). After the turn of the century, waste handling regulations became more frequent. Additionally, issues like energy efficiency, greenhouse gas emissions, and risk prevention in the use of chemical products, were added, as well as requirements for the development of plans for possible closedowns of the sites. It should be noted that, during the first decades, the gradual change of priorities was a result of a learning process, which later allowed Sweden to actively participate in the development of new Integrated Pollution Prevention and Control legislation passed in the European Union in 1996 [27]. So far, we see important signs of pulp and paper production technological evolution. But revolution is quite possible, and web-based communication is one of the powerful factors that limits evolution opportunities. On the other hand, paper and cardboard re-occupy their dominant position in packaging, replacing polymers, which experienced their blossom in the 1970s and 1980s.

Innovative technologies are created by research teams, scientific groups and institutes: not necessarily closely associated with industrial companies, but often being their Research & Development (R&D) divisions. At the beginning of 2019, a review of the Organization for Economic Cooperation and Development (OECD) 'Research and Development Expenditure in Industry' was published. Expenditures on industrial research and development in many OECD member states increased during

2009–2017; chemical industry, metallurgy, and computer manufacturing are among the growth leaders; R&D investments in computer and chemical industries (considered to be drivers for fifth technological paradigm) can only be compared with those in the business services sector [28].

The introduction of innovative solutions to the market and their implementation is largely a revolutionary process that takes place under the prevailing effect of scientific and technical factors: 'science-intensive' driving forces. The key role in the transition of the economic system to the fifth and sixth technological paradigms is played by innovative solutions; support, stimulation of innovation is becoming an integral feature of industrial policy in most world economies.

3.1.1. Regulatory Instruments of the Technological Evolution. Best Available Techniques

The impact of regulatory factors on technological development is often underestimated due to the belief that governmental regulation is characteristic of a socialist economic system. But recent history provides many examples of technological processes and products to complete their life cycle under pressure from international or national regulatory systems. Perhaps the most-known example is the prohibition of ozone-depleting substance manufacture in accordance with the Montreal Protocol of the Vienna Convention for the Protection of the Ozone Layer [29]. Let us leave to climatologists and marketing experts debates about the role of DuPont and a possible slowdown in global temperature growth due to a decrease in freon concentration in the atmospheric air, but no one could deny that the 'green light' to the market entry of a next-gen refrigerants was due to in no small part to the international regulations. At the same time, the main scientific studies were conducted during the discussion of the expected regulatory changes, their feasibility, their acceptability, and the overall readiness of certain countries to ratify the Montreal Protocol and/or not.

Another example is the concept of Best Available Techniques (BAT). This was developed almost simultaneously in Europe, America and South-East Asia, as well as in the Soviet Union. It is interesting that in the USA, Canada and Russia the term 'technology' is preferred, while the EU legislation uses another word, 'techniques'. According to the Cambridge Dictionary of English Language, a 'technique' is a way of doing something that needs skill, thought and planning [30]. It is an undeniably wider remit than 'technology', which is described in Encyclopedia Britannica as "the application of scientific knowledge to the practical aims of human life or, as it is sometimes phrased, to the change and manipulation of the human environment" [31]. This is why, speaking of Best Available Techniques, we mean both production technology, environmental protection techniques (stack gases and wastewater treatment), automation systems, and self-monitoring and management systems applied to operate an installation [16].

The essence of Best Available Techniques, regardless of how exactly the concept of BAT is described and interpreted in legislative acts, is that in order to ensure high resource efficiency and environmental performance, large enterprises of key economic sectors must use a combination of proven technological, technical and managerial solutions [32,33].

Since 1996, EU Member States have been implementing Directive 96/61/EC on Integrated Pollution Prevention and Control (IPPC), replaced in 2010 by the Industrial Emissions Directive [32]. The directives state that large installations engaged in activities covered by provisions laid in these legal acts must demonstrate compliance with BAT and obtain Integrated Environmental Permits (IEP). The list of IPPC/IED installations includes the EU's key sectors of the fourth technological paradigm: thermal power, chemical and petrochemical industries, construction materials, ferrous and non-ferrous metallurgy, the pulp and paper industry, and intensive animal husbandry. BAT Reference Documents are developed for each industry with the purpose to systematize information on the current status of a particular sector, applied technologies and technical solutions, and also (which is very important) on resource efficiency and environmental performance. From technology datasets, BAT-related solutions are selected by technical working groups while taking into account a number of criteria: these criteria are listed below (quoted) in full accordance with their description given in the EU legislation [32,33]:

1. "the use of low-waste technology;

2. the use of less hazardous substances;
3. the furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate;
4. comparable processes, facilities or methods of operation which have been tried with success on an industrial scale;
5. technological advances and changes in scientific knowledge and understanding;
6. the nature, effects and volume of the emissions concerned;
7. the commissioning dates for new or existing installations;
8. the length of time needed to introduce the best available technique;
9. the consumption and nature of raw materials (including water) used in the process and energy efficiency;
10. the need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it;
11. the need to prevent accidents and to minimize the consequences for the environment;
12. information published by public international organizations".

The BAT determination criteria are so frequently quoted by various researchers that it makes no sense to describe their features. The criteria adopted in Russia are formulated in a slightly different way, but their essence does not change from this: most of the requirements relate to ensuring resource and energy efficiency, creating closed water cycles, preventing waste generation and substance and ensuring material recycling. Both BAT concepts, European and Russian, regard primary, or 'built-in', process-oriented solutions for ensuring resource efficiency and preventing emissions as the best option. 'End-of-pipe' solutions (environmental protection techniques) receive much less attention.

The most important criteria for assessing the effectiveness of the BAT concept at the sectoral level and the level of enterprise are resource efficiency and environmental performance indicators. These indicators are systematized in BAT Reference Documents in the form of certain values, as well as in industry reviews and practical guides. Russian BAT Reference Documents were developed in 2015–2017; their application began in 2019, IEP granting process has already started being an integral aspect of Russian environmental policy [34].

BAT requirements have been applied in the EU for nearly 24 years, and about 52,000 facilities have received IEPs after clearly demonstrating BAT compliance. In Sweden, the BAT concept has been used for 50 years and has served both for environmental regulation and industrial modernization purposes [35,36].

3.1.2. Environmental Policy, Industrial Strategy and Evolution of Best Available Techniques

It is difficult to evaluate BAT-related changes in technological processes and equipment update trends in the EU, since in most cases only qualitative descriptions by expert judgment are published for industrial sectors of the EU economy. The response to the impact—the state of the environment—is assessed by such indicators as air, natural water and soil quality, and the resource productivity of the economy (the ratio between gross domestic product (GDP) and consumption of natural resources—both extracted and imported). This information is systematized in documents and interactive databases, including Eurostat databases [37]. Russian analogues of these documents are state and regional reports on the state of the environment and some analytical materials from Federal State Statistics Service (energy intensity of GDP and the Ministry for Economic Development (reports on improving the energy efficiency of the economy).

In recent years, BAT application assessment around the world has been carried out as part of the OECD project 'Best Available Techniques for Preventing and Controlling Industrial Chemical Pollution'; the opinion of Russian experts is presented in the chapter 'Russian Experience'. This states that BAT is a tool to achieve a balance between the stimulating nature of industrial policy and the protective nature of environmental policy [36]. These policies should be harmonized, and this will require an improvement in existing legislation, development of new regulatory legal acts, the implementation of pilot projects, and the dissemination of their results in the field of an objective assessment of technological and technical solutions and development and evaluation of environmental performance enhancement programs.

Despite the universal character of the concept, each country choses its own path to BAT. For example, German experts believe that both national, and even regional, laws and levels of technological development at the time of the adoption of the EU Directive 96/61/EC were so advanced that businesses almost did not notice a change in requirements. The technological changes and development of new techniques took place mainly under the influence of scientific and technical and technical and economic factors [38]. Swedish experts emphasize the importance of well-timed requirements, and the strengthening and use of regulatory factors, to increase resource efficiency and reduce negative environmental impact [39]. Nowadays, close attention is paid to energy efficiency and emissions of greenhouse gases; problems associated with emissions of various contaminants have been solved.

The experience of Estonia shows that serious work with the regulated community is necessary: staff training is required for both enterprises and permit-granting authorities, and the formation of a national pool of BAT experts. In this republic, the new regulations made it possible not only to achieve technological modernization, but also to replace certain technological processes, in particular, in the production of organic chemicals [38].

In the Netherlands, Germany, and Sweden, government agencies stimulate the dissemination of innovative solutions and the development of fundamentally new industries or processes—those that achieve environmental performance levels that are significantly better that those required by BAT, go beyond BAT. In Europe, BAT is a matter for today, a set of minimum mandatory requirements; the state provides regulated enterprises only with information, and methodological and expert support. In some cases, when fundamental reconstruction or process updates are required, enterprises can obtain a waiver, e.g., permission for temporary operation under less strict conditions. This approach is considered possible also in the United Kingdom [40].

In the EU, voluntary agreements represent a policy instrument and a governance approach for applying new knowledge or technology to specified issues. In this case, the European Commission issues recommendations [41]. Voluntary agreements are a form of industrial self-regulation in which codes of conduct or operating constraints are formulated by associations or companies of a certain economic sector and everyone agrees to enforce them. Pure self-regulation is not very common in the EU; this is why it is often the Commission's initiative to outline the self-regulation measures [42].

Voluntary agreements are often used is Sweden and in the Netherlands [43]. The authority usually plays the traditional role of an initiator and controller, participating actively in communication with a partner, which is very important in advancing the program. In Sweden, the relationship between government and industry is characterized by building consensus more than in most other countries, which must be based on a certain degree of trust between the parties. It must also be based on the mutual ambition to find efficient and cost-effective solutions which can be considered as kinds of voluntary agreements. Several examples can illuminate this statement. Good instances are the long-term projects by leading companies to make the production and use of cement and steel carbon-dioxide-free. Agreements in forming the take-back requirements of certain product groups, after they have served out their purpose as products, can be considered as kinds of voluntary agreements. The government sets the goals, whereas the applicable sectors of business design the appropriate implementation procedures. Furthermore, in Sweden, the significant influence of applicants for integrated environmental permits (IEPs) in the decision-making process can be considered as kind of a voluntary agreement. Strong companies have traditionally had a large share of influence on the final outcome, since the applications are typically well-designed and provide the necessary bulk of information for good decisions, even though the final decisions are solely made by the governmental decision-making body [44].

Thus, governments focus their attention on introducing changes supporting the transformation of industry and technology from the achieved (current) state to the new (desired) one, which is more advanced and—in some cases—dramatically, principally different from the current state. This is why understanding how government techniques work should lead to an improved understanding of how to govern better and more effectively [45].

4. Discussion and Conclusions

4.1. Good Governance and Governance Technology

Is it possible at all to influence the evolution of technologies? Do governments have techniques to initiate or even force technological innovation, or at least modernization of technology and industry? Let us discuss these issues, considering examples from the modern history of the Russian Federation, where the environmental and technological transformation (at the initial stage—modernization) of industry has recently become one of the key priorities of national industrial policy [46]. Collaborating within the framework on projects relating to BAT and low-carbon production since the late 1990s, we will try to consider emerging the governance techniques from the international standpoint.

Internationally, policy makers and academics agree that good governance matters for economic development. Indicators used to determine how good governance is, include, as it is stated in the Recommendations of the World Bank [47]:

- "voice and accountability;
- political stability and absence of violence;
- government effectiveness;
- regulatory quality;
- rule of law;
- control of corruption".

High regulatory quality—the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development—is essential to achieve longer-term objectives in the environmental and technological transformation of Russian industry.

In Slavic languages and technocratic post-Soviet counties, there is a definite tendency to prefer the term 'technology' while discussing 'techniques'. This is true not only for Best Available Techniques, called technologies in Russian, Belorussian, and Ukrainian, but for many other cases—political technologies, training technologies, and governance technologies. However, people speaking Romance languages sometimes also replace 'approaches', 'methods', and 'techniques' by a more technocratic term— 'technology' [48].

Considering this tendency, we will be using the 'governance technology' syntagma to describe the approaches applied to lead the processes of governance undertaken by the government of a state over a system (an industry and its technological state), through laws, norms, and other requirements. In accordance with a statement made in the research of M. Hufty, this relates to "the processes of interaction and decision-making among the actors involved in a collective problem that lead to the creation, reinforcement, or reproduction of social norms and institutions" [49].

Nowadays, two Russian authorities aim at a fundamental change of national industry, applying governance technologies to push industry from the current state to the desired one—innovative, competitive, resource- and energy-efficient and environmentally friendly.

The Ministry for Natural Resources and Environment and its supervisory authority (the Federal Supervisory Natural Resources Management Service or Rosprirodnadzor) develop and supervise implementation of the national environmental policy (officially described as the national policy in the field of environmental safety). The Ministry for Industry and Trade develops and supports implementation of the national industrial policy aimed at boosting productivity, by backing businesses to apply innovative technologies and create new products, improving their competitiveness, and investing in research, skills, and infrastructure.

Cleaner (greener) growth is the challenge reflecting the international trend, and both the environmental and industrial policies recognize this fact. Thus, we have two interrelated governance wings that need to be harmonized to achieve objectives of the environmental and industrial policies.

4.2. Governance Technology Used by Environmental Authorities

Rosprirodnadzor helps to push industry towards better environmental performance by influencing the main production processes (and production technologies) applied, using specific governance technology based on Integrated Environmental Permits (Figure 3). The European experience shows that Best Available Techniques (as requirements being gradually made more stringent) have been serving as effective instruments of national environmental policies for at least two decades. In Russia, the first results of the BAT-based environmental regulation will not be possible to assess before 2025, when all installations obliged to demonstrate compliance with BAT requirements will have obtain IEPs. The first installations were granted Integrated Environmental Permits in 2019. To receive permits, seven of sixteen installations had to develop so called Environmental Performance Enhancement Programs (EPEP). These programs aim at achieving BAT requirements (BAT-associated Emission Levels, BAT-AELs) and must be implemented by non-conforming installations for a maximum of seven years. Draft EPEPs are assessed by BAT experts [50] and approved by the Inter-Departmental Commission before being submitted to Rosprirodnadzor. The final decision on BAT-AELs and other environmental requirements are set by Rosprirodnadzor, the government body officially authorized to grant IEPs and monitor compliance.

Figure 3. Governing environmental modernization of Russian industry: technologies and instruments applied by the environmental authorities. Source: Authors.

We have already discussed the role of BAT-expert society in the development and implementation of Best Available Techniques in Russia, and in 2015–2020 we can conclude that our hypothesis has been proven by practice. In Russia, the information exchange process applied to identify BAT and to work out Reference Documents on Best Available Techniques (BREFs) is governed by the Ministry for Industry and Trade; the Russian BAT Bureau collaborates with national and international stakeholders coordinating development of BREFs as documents of the national standardization system.

BAT experts take a leading part in working out and reviewing BREFs, run research projects implemented jointly with pilot industries, support the Inter-Departmental Commission (managed by the Ministry for Industry and Trade, Minpromtorg) in assessing draft EPEPs, and facilitate the decision-making process of Rosprirodnadzor in granting IEPs and setting BAT-AELs. In addition, BAT experts play a crucial role in training practitioners and students and publicizing the concept of Best Available Techniques, both in Russia and in other countries.

4.3. Governance Technology Used by the Ministry for Industry and Trade

It is not a surprise that Minpromtorg aims at making Russian industry more competitive and strong, and at implementing innovations reflecting the priorities of the fifth and sixth technological waves. Along with fostering principal transformation and innovative changes, Minpromtorg continues looking for opportunities to modernize traditional heavy industry (such as coal, steel, and non-ferrous metal production), forming the core of the fourth technological wave.

Here we agree with R. Garcia, R. Calantone (authors publishing their articles in the Journal of Open Innovation) and H. Chesbrough, who emphasize "modernization as universal historical and institutional phenomenon representing a special complex of modernization—a system of economic, social, state, legal, scientific and technological institutions of a country or a geo-economic region into a more modern concrete-historical form" [51,52].

Industrial modernization is a continuous and open-ended process, but modernization is replaced by innovation when a technology reaches its limits to improvement. Innovation is the creation of a new way of doing something, whether the development of a new product or the invention of a new philosophy or theoretical approach to a problem. Innovation plays a key role in the technological progress; by nature, it is more revolutionary than evolutionary.

Quite recently, up to the 1990s, some technologists were still trying to modernize the vertical upward drawing of glass known as Émile Fourcault technology, while the float process was invented by Alastair Pilkington in the 1950s. In the 1970s, the float method of glass making revolutionized the industry, and the evolution of the vertical upward drawing technology ended after a more than 60-year dominance all over the world (is this not a long wave?). Nowadays, practitioners argue that opportunities to improve the energy efficiency of glass production lay not in the production technology but in changing the attitude to glass and glass products, in introducing multi-layer materials providing for the high energy efficiency of various constructions—industrial buildings, shopping centers, houses, etc.

Returning to the industrial policy of the Russian Federation, we have to emphasize that the current modernization process is catalyzed by such concepts as resource efficiency, greener growth, and the circular economy. It is evident then that innovation is more desirable than modernization, but both paradigms will coexist to gradually move Russian industry from its current state to the new one—more efficient, competitive, and environmentally and socially responsible. Minpromtorg helps to push industry towards a new, modernized and more innovative state by influencing the main production processes (and production technologies) applied, using its specific governance technology based on green financing, support for energy efficiency enhancement of industrial production, and digitalization and implementation of innovative technologies. With regards to the interrelatedness of environmental and industrial policy, formation and implementation of new environmental industrial policy in Russia, 'green' solutions play a very special role (Figure 4).

Since industrial modernization is seen as environmental and technological at the same time, Best Available Techniques form the necessary basis for setting minimum requirements for industries seeking the support of Minpromtorg. All energy efficiency and green production initiatives are assessed by experts using BAT requirements as 'measurement units': only projects achieving BAT or going beyond BAT can gain support, rendered first of all via the Industrial Development Fund.

The Fund is a state institution created in 2014 by the Ministry for Industry and Trade of the Russian Federation, with a goal to increase the competitiveness of Russian industry over implementation of governmental policies for import substitution and export enhancement [53]. The main idea lies in providing targeted loans to companies operating within Russian borders and implementing industrial technological project on a competitive basis.

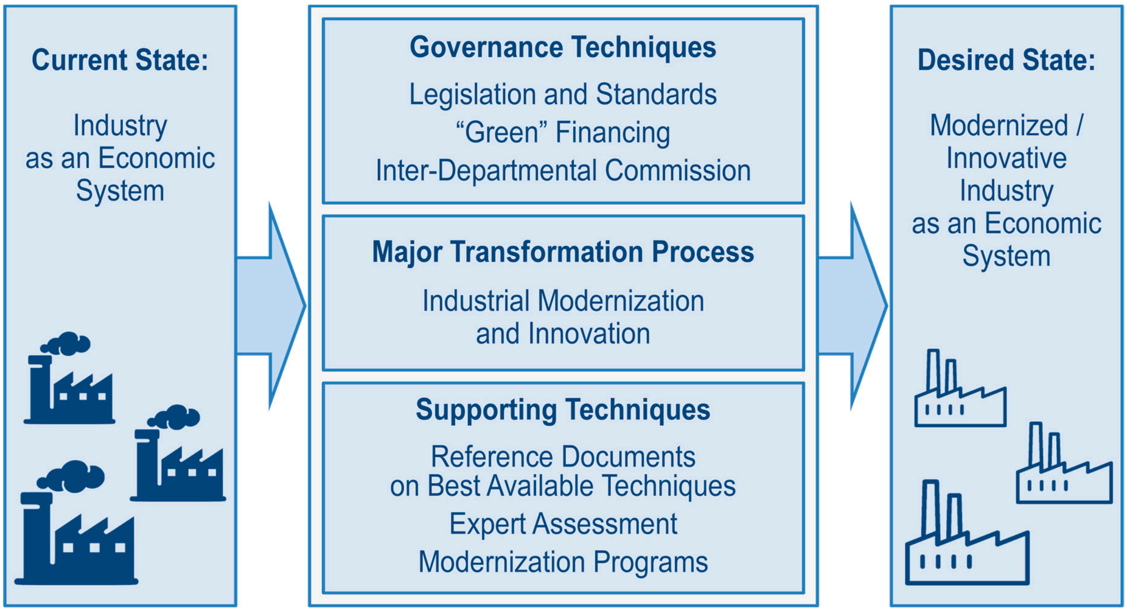

Figure 4. Governing industrial modernization in Russia: technologies and instruments applied by the ministry for Industry and Trade. Source: Authors.

Thus, governance technologies are applied by the authorities to initiate the transfer of the industry, as an integral part of the economic system, from the current state to the new one—more advanced, applying innovative solutions, resource- and energy-efficient, and environmentally friendly. Solutions that can help to build a circular economy and to introduce technologies of the fifth and sixth technological waves are fostered by the ministries authorized in such fields as environmental and industrial policy, digitalization, education and science.

The key roles are played by the Ministry for Natural Resources and Environment, developing environmental policy, and its supervisory body—Rosprirodnadzor, a new governance technology based on granting Integrated Environmental Permits and checking compliance of regulated installations to improve the environmental performance of industry and reduce adverse environmental impacts. The Ministry for Industry and Trade applies its governance technologies, supportive by their nature, and stimulates industries to introduce modern resource-efficient and environmentally friendly technologies.

Do these authorities influence the evolution of technologies? Do they have techniques to initiate or to force technological innovation or at least modernization of technology and industry? At minimum, they act as factors contributing towards technological progress or at least preventing businesses from doing business as usual and resisting from the necessary technological changes, both evolutionary and revolutionary.

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