Ecological-economic modeling for sustainable and safe development of high-tech industrial enterprises

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Abstract. This paper presents the concept of considering the ecological and economic component of the industrial system from two sides. The first side represents ecological and legal modeling which includes the study of exogenous and endogenous negative determinants affecting this area. The second side describes ecological and mathematical modeling which is based on the modernization and adaptation of the calculated tools for high-tech industrial enterprises to reflect the costs of environmental safety, sustainable development of production and conservation of natural resources.

1. Introduction

The technological improvement of the material and technical base of industrial enterprises, the transition of the real sector of the economy to Industry 4.0, as well as the transformation of Society 4.0 into Society 5.0 would result in the consumer attitude of the population towards nature, irrational use of mineral resources, illegal dumping of production and consumer waste garbage [1]. The chaotic desire of states to resolve environmental disasters and clarify the root causes of abnormal natural phenomena that threaten people's lives and the sustainable development of socio-economic processes on the planet give priority to the consideration of the energy, environment, and economic component at all levels of the national economy: micro-, meso-, macro-sectors.

In the modern world, environmental problems have become global. The Russian Federation is one of the countries with the worst environmental conditions. The constant human intervention in the environment makes such changes that lead to irreversible consequences in the ecological, biological and technogenic sense. Man had an impact on the environment which resulted in the emergence of an ecological and economic crisis [2].

Nowadays an actual part of the life of society, the enterprise and the state as a whole, as a regulator and supervisor compliance with environmental standards and laws become the use of energetic, ecological, and economic innovations through which the environmental impact is reduced, the use of natural resources is rationalized, a competent subsoil distribution policy is built up, materials recycling technologies are applied. Measures should be strategically sustainable, focused and necessarily correctly selected considering the anthropogenic load [3].

The study aims to simulate the flow of information on the interaction of counterparties in the field of environmental safety in the Russian Federation, to consider problems and to find solutions by
proposing mathematical tools to estimate the environmental costs of high-tech industrial enterprises. The theoretical and methodological basis of this study are the works of domestic and foreign scientists among which it should be noted: G.M. Batrakova [4], O.P. Burmatova [5], D.V. Valko [6], R.D. Garif'yanov [7], N.G. Zhavoronkova, Yu.G. Shpakovskiy [8], V.A. Kuzmin [9], N.N. Skiter [2], N.N. Sliusar [10], T.E. Eloshvili, A.V. Kutuzov [3], V.A. Tarasov, B.V. Kavalerov [11], A.B. Petrochenkov [12] etc.

2. Environmental and legal modeling to identify negative determinants in the system

Ensuring environmental safety should be considered taking into account the right of every citizen to a favorable environment, a reliable information about its condition, a compensation for damage caused to the health or the property by an environmental offense [13]. The prerogative of a healthy environment is usually referred to as social rights, but such a decrease in the value of the right in question is unreasonable because a favorable environment is a condition for the development of human life, society, and the state. Thus, the right to a favorable environment should be recognized as a special kind of the advantage requiring the priority attention from the society and the protection from the state. The resource under consideration cannot apply to either personal or social rights [13].

Figure 1 demonstrates the flow of information on the interaction of counterparties in the field of environmental safety in the Russian Federation. The model reflects the main counterparties that regulate activities in the field of environmental protection. For the convenience of modeling, the scheme contains symbols and abbreviations which will be decrypted below.

![Figure 1](image-url)

**Figure 1.** Scheme of information flows on the interaction of counterparties in the field of environmental safety.
Table 1 represents the list of abbreviations and conventions which were used in Figure 1.

### Table 1. Abbreviations and conventions used in Figure 1.

| Abbreviations     | Conventions                                                                 |
|-------------------|-----------------------------------------------------------------------------|
| Rosselkhoznadzor  | Federal Service for Veterinary and Phytosanitary Supervision                |
| Rosrybolovstvo    | Federal Agency for Fishery                                                   |
| Roshydromet       | Federal Service for Hydrometeorology and Environmental Monitoring           |
| Rosprirorodnadzor | Federal Service for Supervision of Natural Resources                        |
| Rosvodresursy     | Federal Agency for Water Resources                                           |
| Roslesxoz         | Federal Agency for Forestry                                                  |
| Rosnedra          | Federal Agency for Mineral Resources                                         |

The number of the relevant regulatory legal act (see Table 1) that controls and regulates cross-functional interaction between counterparties.

Highlighted problematic aspects in the relationship between counterparties and the functioning of the entire system (see Table 2).

We present a complete list of regulatory legal act (see Table 2) involved in the scheme (see Figure 1) [13].

### Table 2. The interpretation of the regulatory legal act used in the scheme.

| No   | Interpretation                                                                                                                                 |
|------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| 1    | - Federal Constitutional Law No. 8-FKZ (Chapter V. Relations between the Government of the Russian Federation and the President of the Russian Federation, Article 30 “Ensuring the Coordinated Functioning and Interaction of the Government of the Russian Federation and Other Government Agencies”) (dated July 3rd, 2016).<br>- Federal constitutional law of December 17th, 1997 No. 2-FKZ "On the Government of the Russian Federation.”<br>- Federal Law of the Russian Federation “Technical Regulation on Fire Safety Requirements” (as amended on July 3rd, 2016). Adopted by the State Duma on July 4th, 2008. Approved by the Federation Council on July 11th, 2008.<br>- Decree of the Government of the Russian Federation dated March 26th, 2014 No. 230 (as amended on November 12th, 2016) “On Amending Certain Acts of the Government of the Russian Federation” (as amended and supplemented, entered into force on July 1st, 2017). |
| 2    | - Federal Constitutional Law of December 17th, 1997 No. 2-FKZ (as amended on December 28th, 2016) "On the Government of the Russian Federation", Article 18 “Powers of the Government of the Russian Federation in the field of environmental management and environmental protection”. |
| 3    | - Decree of the President of the Russian Federation of May 6th, 2011 No. 590 (as amended on July 25th, 2014) "Issues of the Security Council of the Russian Federation" (together with the "Regulations on the Security Council of the Russian Federation", "Regulations on the apparatus of the Security Council of the Russian Federation".  <br>- Federal Law of December 28th, 2010 No. 390-ФЗ "On Security" and the Regulation on the Security Council of the Russian Federation. |
| 4    | Decree of the President of the Russian Federation of May 15th, 2018 No. 215 (as amended on February 26th, 2019) "On the structure of federal executive bodies" |
While compiling the flow of the information on the interaction of counterparties in the field of the environmental safety in the Russian Federation (see Figure 1), there were identified problematic aspects which solution will contribute to the further successful development of the object of study presented in the Table 3.

Table 3. Problems and solutions in the field of the environmental safety and protection.

| № | Name                                           | Essence of the problem                                           | Possible solution                                                                                                                                                                                                 |
|---|------------------------------------------------|------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| I | Disposal, storage and utilization of waste     | Landfill overcrowding                                             | To minimize the space the waste occupies, it is necessary to install autonomous pressing plants operating on solar batteries. The operation of the press is based on a chain transmission without using the principles of hydraulics, and the maintenance of the installation is reduced only to the annual lubrication of the door locking mechanism. A wireless warning system allows you to automatically monitor the level of container fullness, giving additional opportunities to improve the logistics of the process [4]. |
| II| Digitalization of environmental safety         | Reducing the environmental risks by preventing natural and man-made emergencies | Prevention and liquidation of emergency situations due to the use of remote monitoring systems for emergency situations, including space monitoring; systems for informing the public about the threat of occurrence and rules of conduct in emergency situations; introduction of robotic systems; introduction of innovative technologies for an early detection of the sources of the technological accidents and the natural disasters [8]. |
| III| Use of cardboard as a structural material      | Production of goods by means of the rational use of the raw materials | Furniture and interior items - armchairs, sofas, etc. - are manufactured with using digital cutting of sheet materials. Such furniture is used in many coworking spaces, and you can make it by sending files with drawings to any manufacturer with suitable machines. It is also important that the flexibility of these technologies makes them optimal for small businesses [14]. |
| IV | Optimization of mathematical tools in environmental and economic modeling of industrial entities | Outdated calculation mechanisms for calculating the environmental costs | Development and improvement of the calculation base when calculating costs for ecology and environmental safety, taking into account the digital vector of industrial development [16]. |
The problems listed in the Table 3 are the most significant since at the moment, almost 100% of the landfills in the Russian Federation are filled up but garbage must be disposed, recycled and utilized somewhere. Also, by preventing and eliminating the emergencies by using the remote monitoring of the adverse events occurrence, including space observation, it is possible to reduce the number of atomic disasters and emissions of the harmful substances into the atmosphere. The use of cardboard reduces the amount of carbon dioxide emissions into the environment, so it contributes to the rejection of plastics. It is worth noting that cardboard and paper are renewable raw materials and are considered more environmentally friendly packaging in comparison with plastic packaging. The considered problems amount only a small part of the number of environmental problems in our time [4, 7, 10].

Problems related to environmental safety urgently require all social and state institutions to constantly pay attention to them in order to prevent and to eliminate dangerous environmental situations in time. At present, the state is not making full use of its real opportunities to reduce the burden on nature, prevent environmental damage and protect its own natural interests. The activities of government institutions and civil society in the field of environmental safety require further improvement and optimization [9].

3. Ecological and economic modeling for the modernization of computational mathematical tools

Having analyzed the main problems of the environmental and economic part in the activities of industrial enterprises, society and government agencies, it is necessary to consider in detail the fourth paragraph (see Table 3) and propose solutions to the identified problem, namely the lack of adaptive and improved calculation mechanisms for calculating the cost share for ecological, sustainable and safe development of high-tech entities of the real sector of the economy [14].

Based on the concept considered in the works of Prof. Yu.A. Vasiliev, the "environmental" costs of an industrial enterprise are divided into capital and current [15]. We modify the formula considering the modern socio-economic approach and present the author’s calculation tools, including future costs for environmental safety of subjects of the real sector of the economy:

\[ Tec = \sum_{k=1}^{n} (C_{es} + C_{ues} + F_{es}) \]  

where

Tec – Total Environmental Costs;
CAPes – Capital Costs of the Industrial Enterprise’s Ecological Safety;
CURes – Current Costs of the Industrial Enterprise’s Ecological Safety;
Fes – Future Costs of the Industrial Enterprise’s Ecological Safety.

We detail the terms of (1) introducing the components of capital costs for the environmental safety of industrial entities [15]:

\[ Tec = \sum_{k=1}^{n} (C_{onf} + C_{ftpc} + C_{frpc} + C_{fapp} + P_{rs} + P_{rw} + P_{n} + P_{v} + P_{rs} + O_{Capes}) \]  

where

Tec – Capital Costs of the Industrial Enterprise’s Ecological Safety;
CONtf – Constructing Treatment Facilities;
CFTpc – Constructing the Facilities for the Treatment of Production and Consumption Waste;
CFRpc – Constructing the Facilities for the Recycling of Production and Consumption Waste;
CFapp – Constructing the Facilities for the Air Protection from Pollution;
Prs – Soil Protection and Rehabilitation;
P RW – Wastewater Protection and Rehabilitation;
Pn – Noise Protection;
Pv – Vibration Protection;
Prs – Radiation Safety Protection;
OCAPEs – Other Capital Costs of Ecological Safety.
Let's introduce the components of current costs for the environmental safety of industrial entities [15]:

\[ C_{URes} = \sum_{k=1}^{n} (C_{URmef} + C_{URoef} + C_{URref} + C_{URciw} + C_{URiws} + C_{URrt} + C_{URref} + C_{URiw} + C_{URciw} + C_{URiws} + C_{URrt} + C_{URref} + C_{URiw}) \]

where

- \( C_{URes} \) – Current Costs of the Industrial Enterprise's Ecological Safety;
- \( C_{URmef} \) – Current Costs of the Maintenance of Ecological Facilities;
- \( C_{URoef} \) – Current Costs of the Operation of Ecological Facilities;
- \( C_{URref} \) – Current Costs of the Repair of Ecological Facilities;
- \( C_{URciw} \) – Current Costs of the Industrial Waste Collecting;
- \( C_{URiws} \) – Current Costs of the Industrial Waste Storage;
- \( C_{URrt} \) – Current Costs of the Industrial Waste Recycling and Treatment;
- \( C_{URiuw} \) – Current Costs of the Industrial Waste Utilization;
- \( C_{URiwd} \) – Current Costs of the Industrial Waste Disposal;
- \( C_{URceh} \) – Current Costs of Controlling over Environmental Hazard;
- \( C_{URpf} \) – Current Costs of Pollution Fee;
- \( OCU_{Res} \) – Other Current Costs of Ecological Safety.

The formula (1) presents the third term, namely, the future environmental costs, when calculating it, the authors propose to use the formula (4):

\[ F_{es} = \sum_{k=1}^{n} (F_{r} + F_{dif} + O_{Fes}) \]

where

- \( F_{es} \) – Future Costs of the Industrial Enterprise's Ecological Safety;
- \( F_{r} \) – Future Renaturation Costs;
- \( F_{dif} \) – Future Costs of Dismantling the Items of Fixed Assets;
- \( O_{Fes} \) – Other Future Costs of Ecological Safety.

High-tech industrial enterprises must lay the value of the estimated obligation to restore the ecological system during the acquisition, creation, modernization, or reconstruction of fixed assets potentially hazardous to the environment [11]. The authors propose the following settlement mechanism for finding the initial value of the estimated obligation to restore the natural environment:

\[ IC_{eores} = IC_{fa} * k_{rr} \]

The Initial Cost of the Estimated Obligation to Restore the Ecological System \( IC_{eores} \) = Initial Cost of Fixed Assets \( IC_{fa} \) * Cost Ratio to Restore the Natural Resources in the Occupied Area \( k_{rr} \) – Remediation Cost Ratio.

The cost ratio to restore the natural resources in the occupied area depends on the multifactor model which includes the accounting and environmental policies of the industrial entity, the activity of the enterprise and its type, as well as the uncertainty in the timing of the fulfillment of the estimated obligation and the amount of claims thereon [1].

4. Conclusion

The current state of the environmental safety of the Russian Federation under the current conditions results into the impact of a combination of factors – anthropogenic, technogenic, political, economic, social, moral-psychological, legal, insufficient readiness of the authorities to conduct an environmentally-oriented economic and social policy, low efficiency of environmental activities of law enforcement agencies, a number of external environmental threats, dangers and risks [5].

The Russian Federation has basically formed and operates the mechanism for ensuring national security and environmental safety as its component. It is based on legislative, executive and judicial authorities, state, public and other organizations and associations, citizens, as well as legislation regulating relations in the field of environmental safety [6].
It is also worth noting that the emergence of new risks and threats arising from the transition to new management mechanisms that are based on the widespread introduction of the modern digital technologies [16] requires fundamental comprehensive research aimed at identifying and optimizing a new modernized calculation base for accounting for revenue and expenditure from the application at high-tech industrial enterprises of a safe environmental policy for the sustainable development of the company. The transition to the digital economy is making fundamental changes in the field of ecology, public administration, the system of relations between the state and society, as well as energy, energy consumption and energy savings [17]. The future work might be related to implementing the model developed to the energy sector of the national economy, while using waste as an alternative source of energy, which would lead to significant contribution in energy savings [18].

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