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Article

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International Journal of Energy Economics and Policy

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2023, 13(1), 45-51.

Analysis and Synthesis of Alternative Solutions to Environmental Problems Associated with Large-scale Projects

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Received: 13 October 2022 **Accepted:** 08 January 2023 **DOI:** https://doi.org/10.32479/ijeep.13879

ABSTRACT

In this study the environmental problems in the large-scale project called “Ecology of the Angaro-Yenisei region” are addressed. A description of various approaches to assess the program of conservation and restoration of the Yenisei as the basis of the ecological potential of the Angaro-Yenisei region is presented. A justification is given for taking into account the uncertainty in such an assessment. The present study suggests three stages of assessment for different levels, macro-, meso- and microlevel. The estimates of the previous assessment level are the initial information for the lower level, which allows a gradually reduction of the degree of uncertainty. At the first stage, the goals of the program were developed and ranked by expert assessment methods. The second stage consisted in analyzing the National Project called “Ecology of Russia,” composed of 11 interconnected federal projects. A mathematical model of the problem of optimal project management in conditions of uncertainty is presented. At the third stage, a hybrid model of assessing a large ecological project from the logical-descriptive model created at the first stage and the mathematical model of stage 2 is considered. Similar models, in the creation of which the authors took part, were used in the assessment of large-scale railway projects. More specifically, with the help of one of them, an analysis of the development of the Asian part of the Russian Federation was carried out by the Siberian branch of the Russian Academy of Sciences. In conclusion, the need of the use of mathematical methods at various stages of assessing large-scale environmental projects from their initiation to implementation is justified.

Keywords: Environmental Problems, Angaro-Yenisei Region, Large-scale Projects, Mathematical Models
JEL Classifications: C32, C23, C51, Q40, Q45

1. INTRODUCTION

There is an aggravation of environmental problems in the world, and development is becoming an imperative with an emphasis on the preservation of a natural system as an element of the country’s national security. The need for environmental sustainability has occupied a central stage in both research and policy making discourse. Thus, investment in large-scale projects is required to be environmentally friendly. Several studies have placed emphasis on green investment and various strategies of curbing environmental degradation emanating from carbon dioxide and other Green House Gas emissions (Adedoyin et al., 2021; Mujtaba et al., 2022; Baloch et al., 2021; Agozie et al., 2022; Kolawole et al., 2022). This article addresses the environmental problems of large-scale projects not only as interregional intra-Russian or inter-sectoral, but also at a high level, according to the system paradigm of Kornai (2002). The essence of this paradigm is that large-scale projects should be considered in the “neo-classic mainstream-Marxism” bundle, however, while drawing conclusions about ways to solve environmental problems, the uncertainty of the consequences should be taken into account. In this paradigm, the traditionally used system analysis is transformed into the so-called non-system approach (Kleiner, 2004), which is notable for the breadth of the phenomena under consideration and the structure of the used research tools. The main tool of analyzing environmental problems and synthesizing alternatives to solving them in this approach are logical-heuristic models. They are based on expert assessments, whereas economic and mathematical models which use mainly statistical information become a supplement tool.

Based on the above paradigm, the article justifies the federal convalescent program called "Ecology of the Angaro-Yenisei Region (AER)." At the same time, the medical no-harm rule must be abided. That is, the cure of the current mechanism of functioning of AER of environmental ailments should be carried out without reducing the efficiency of the operating system. In this study, the environmental problems associated with the large-scale project called "Ecology of the Angaro-Yenisei region" are addressed. A description of various approaches to assess the program of conservation and restoration of the Yenisei as the basis of the ecological potential of the Angaro-Yenisei region is presented. A justification is given for taking into account the uncertainty in such an assessment. In addition, the importance of the processes taking place in the world today should be taken into account, which are the strengthening of the struggle for territories, markets and resources between world powers, their desire for leadership in the field of industrial, military and information technology.

The implementation of the AER Ecology program is carried out in accordance with the Decree of the President of the Russian Federation "On the Environmental Safety Strategy of the Russian Federation for the Period until 2025" (Presidential Executive Office, 2017). This decree noted the catastrophic environmental situation in Russia. All executive bodies were instructed to understand environmental safety as part of the national security of Russia and take an active part in the implementation of state policy in the field of environmental safety at the federal, regional, municipal and industry levels.

First of all, the tasks of the AER Ecology program were set with referencing its mechanisms to time, place and resourcing. Three tasks were identified:
- Sticking to the established policy - *project* regulation of the environmental situation in AER (U1)
- Restoring the ecological potential of AER destroyed in previous years during its industrial development-*program* task (U2)
- Compromise task taking into account real resource limitations - convalescent task (U3).

The set tasks and their corresponding projects must be ranked by their degree of preference, depending on the changing characteristics of the external environment in various aspects: economic, political and military-strategic.

2. THE FIRST STAGE OF SOLVING THE PROBLEM

A group of experts from scientists of the Institute of Economics and Industrial Engineering (IEIE) of the Siberian Branch of the RAS, the Krasnoyarsk Scientific Center of the Siberian Branch of the RAS and the Siberian Transport University (STU) of Roszheldor assessed the options for the projects of the AER Ecology program in accordance with the set tasks. Expert judgments were determined by survey and interview methods, after which they were processed by computer applications developed in the STU and IEIE. Three scenarios for implementation of the tasks were considered.

1. The Optimistic scenario assumes a sustainable European-oriented development of Russia in the context of an acceptable compromise with the West
2. The Most Likely scenario involves the sustainable Chinese-oriented development of Russia
3. The Pessimistic scenario is understood as a mobilization project for the development of Russia in a military confrontation with the West.

The evaluation resulted in an evaluation matrix (Table 1).

Table 1 does not contain a dominant strategy, therefore, there is uncertainty that is proposed to be resolved using the Wald, Savage, Hurwitz and Laplace criteria (Table 2).

The analysis of Table 2 shows that task U3, to develop a convalescent AER Ecology program, is preferable by almost all the criteria.

Let us consider the strategic aspect of the result obtained. The Angaro-Yenisei region is not only the country's resource support system (Bandman, 2014), but also one of the four natural clusters of the Trans-Urals, representing the Russian civilization in the form of the humanitarian phenomenon of the Russian Asia. These clusters are located in the basins of the Ob, Lena, Yenisei and Amur rivers.

They form the ecological and assimilation potential of Siberia and the Far East. The degradation of this region is dangerous both in the short and long term, since its presence is a strategic advantage of the country in a turbulently developing competitive world of the 21st century. This article, in fact, is devoted to the preservation of this advantage. The first stage of solving the problem (the survey of a group of experts and assessment of alternatives to determining the AER Ecology program) reveals the upper level of radical

Table 1: Evaluation matrix

Tasks	Scenarios		
	1	2	3
U1	0.05	0.58	0.18
U2	0.78	0.14	0.07
U3	0.17	0.28	0.75
Probability	0.14	0.35	0.51

Table 2: Options evaluation

Tasks	Criteria by					
	Wald	Savage	Bayes	Hurwitz	Laplace	Maximax
U1						
U2						*
U3	*	*	*	*	*	

uncertainty, while the problem situation turns from unstructured to a semi-structured one (Simon, 1973).

3. THE SECOND STAGE OF SOLVING THE PROBLEM

Let us consider the differences between design and software approaches to solving complex problems. Unfortunately, domestic science and practice often do not distinguish these approaches which leads to an inadequate choice of solutions. Back in 1996, M.V. Ratz wrote about this (Rats, 1996), but the "young reformers" who advocated "Russia of the regions" were not heard. This publication was the first to draw attention to a significant difference in project and program approaches: the first, due to its holistic nature, is not at all suitable for evaluating large-scale environmental projects in which "the element of uncertainty is too large."

The AER Ecology program is a typical approach of this kind. After the environmental disasters of 2020 in Norilsk, the State Duma of the Russian Federation prepared the decisions on the effective compensation of environmental damage received from Norilsk Nickel and the related structures in the natural complex of the lower Yenisei. Everything was aligned with the project approach: If one caused damage to the state, localized in time and place, they should pay it as an injured party. At the same time, the question remains open: how to allocate the compensation received among other foci of man-made disasters in the country? to allocate funds to the restoration of Baikal facilities and the Angara or the Lower Volga basin? And how do you compare the current benefits of a "sensible" allocation policy with the consequences of decisions made "here and now"? The use of the design approach does not answer such questions (Charkina, 2017), due to its locality. The goals of projects, as a rule, are tightly fixed and the duration of life cycles is also finite. The duration of environmental programs of natural complexes similar to the AER, formed historically around rivers, is usually not specified, can change due to circumstances, and is almost endless. Also, the goals of environmental programs can dynamically change depending on emerging situations.

Based on rational logic, we can conclude that these approaches should be reasonably combined, but then the question "how exactly?" arises. Under the leadership of the state, as an active conductor of a nature-saving and social policy, or as a watchman state, market-efficient, but often antisocial and anti-ecological? The choice of compromise depends on the effectiveness of the mechanism of the state functioning. If this mechanism is built on a strict competitive basis, then the project approach to solve the environmental problems of such a state is more consistent with its capabilities and interests. With a weak regulated state economy, the best choice will be a programmatic approach, when the state concentrates limited resources on priority goals.

Based on this approach, at the second stage we have considered the National Project called "Ecology of Russia" (hereinafter-NPER), consisting of 11 federal projects. The presented environmental measures will be carried out in accordance with the design approach. This is based (according to the above theory) on the fact that the Russian authorities consider the country's economy to be functioning effectively, and therefore the project approach is adequate to such a condition of it. At the initial stage, we shall accept this precondition as a *basic* one and build further analysis on it.

Let us start the analysis of the NPER with its description (the project passport is in Gelrud et al., 2021). Figure 1 shows the structure and the contents of the project in accordance with (Venitsianov, 2020).

Let us transform the project structure presented in Figure 1 into the "targets-resources" system of NPER (Figure 2) and present the quantification of the target tree "from bottom to top" (Gelrud, 2018, pp. 55-57 and pp. 126-127]). In this case, let us take the data from paragraph 5 of the passport of the "Ecology" national project (Gelrud et al., 2021) and from the decree of the President of the Russian Federation "On the Strategy of Environmental Safety of

Figure 1: NPER structure

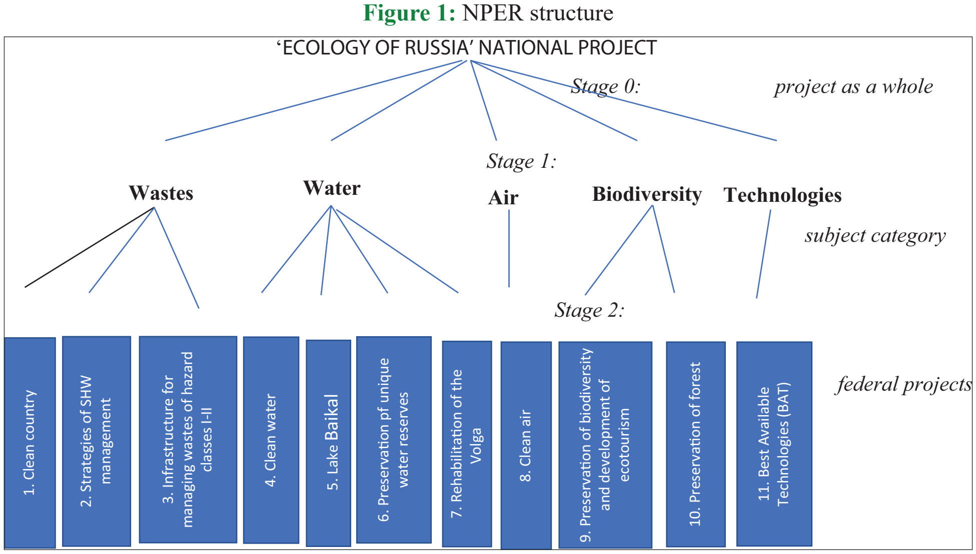
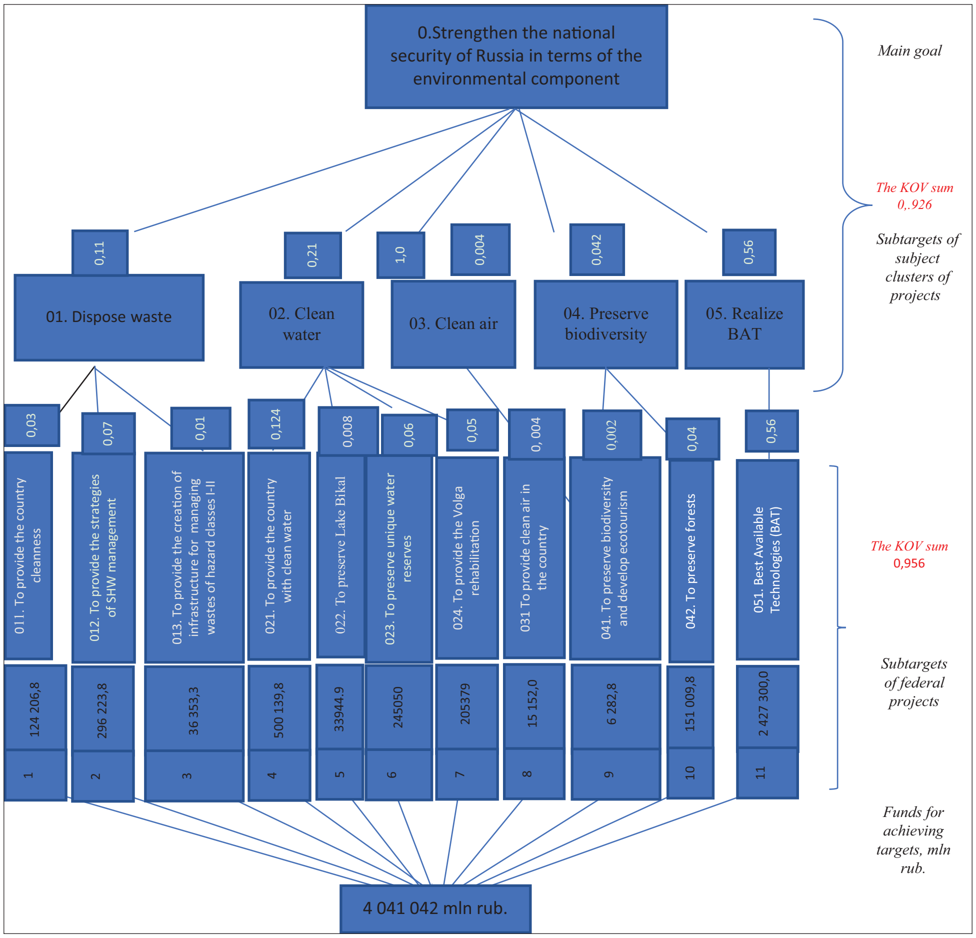


Figure 2: The "target-recourses" system of NEPR



the Russian Federation for the Period until 2025" (Presidential Executive Office, 2017).

In the 11 NPER projects under consideration, there is clearly no Yenisei project, as it was done for the Volga and Lake Baikal. If the costs of the Yenisei project are included in the costs of projects 4 and 6 from the "Water" subject area (Figure 1), then the size of the share intended for AER and Yenisei is unclear.

Table 3 contains data from the NPER passport on the expenditures intended for the implementation of the program for each year (V_i). In this project implementation, all work is shifted to the right within the full reserves, the so-called "late plan" is obtained (Gelrud, 2018), which provides investment dynamics that minimize the amount of discounted costs (V^D_{min}).

$$V^D_{min} = \sum_{i=1}^{6} \frac{V_i}{(1+r)^i} = 2\ 505\ 179{,}56,$$

where *r* is the discount rate stated for the project and equal to 13%.[1]

If all the work of the NPER is delivered in the early time of their completion, then we will get a distribution of funds that maximizes the amount of discounted costs (V^D_{max}) (Table 4).

$$V^D_{max} = \sum_{i=1}^{6} \frac{V_i}{(1+r)^i} = 2\ 858\ 456{,}17.$$

The project with late work completion means a tense plan with the work having no time reserves for maneuvering and a high degree of risk of disruption of the expenditure plan in full. Whereas the plan with work carried out early implies the minimum degree of risk of non-fulfillment of the project targets. Thus, you can formulate a project cost management problem that has the following mathematical model.

Let option k of the realization of the project is characterized by the dynamics of expenditure V^t_k in period *t* and the options in Tables 3 and 4 correspond to the extreme options which have the minimum (V^D_{min}) and maximum V^D_{max} total discounted costs. Other options of expenditures have the subtotals of costs from (V^D_{min}) to (V^D_{max}) and consequently non-zero time reserve amounts (T^k).

Let also $\sum_i V^t_k = Q$; T^p_t, T^n_i are early and late timings of events *i* of the work schedule; T^k_t are values of the timing of events *i* of expenditure option *k*.

$$T^k = \sum_i (T^n_i - T^k_i).$$

1 Such discount rate is a weighted average cost of capital (WACC).

Table 3: Expenditures according to the late plan

Years	2019	2020	2021	2022	2023	2024
V_i (mln rub.)	221 533,3	528 693,7	659 196,4	892 258,9	889 565,5	849 794,2

Table 4: Expenditures according to the early plan

Years	2019	2020	2021	2022	2023	2024
V_i (mln rub.)	865 023,50	899 325,10	850 544,60	622 541,90	502 410,50	301 196,40

T^k corresponds to the risk of failure to fulfill the project implementation plan (the maximum time reserve T^k corresponds to the minimum risk of failure to meet the deadlines). In the task, it is necessary to determine the implementation of the project and the corresponding amounts of its financing by years, at which a minimum of discounted costs is achieved at a given degree of risk or a minimum of risk for an acceptable amount of discounted investments.

Thus, it is necessary to find:

$$x_k = \begin{cases} 1, \text{ if } k \text{ option of the project is invested in,} \\ 0, \text{ otherwise.} \end{cases}$$

Under the following limitations:

$$T_t^p \leq T_t^k \leq T_i^n, \quad (1)$$

$$\sum_i \sum_{k=1}^{n} V_k^t . x_k = Q. \quad (2)$$

Target functions:

Minimizing the amount of discounted costs:

$$F_1 = \sum_{t=0}^{T} \left(\sum_{k=1}^{n} x_k . V_k^t \right) (1+r)^{-t} \to min; \quad (3)$$

Minimizing the risk:

$$F_2 = \left(\sum_{k=1}^{n} x_k . T^k \right) \to max. \quad (4)$$

This task is proposed to be solved by the method of successive concessions which consists in the following: first we solve problem (1)-(3) without criterion (4). As a result we get solution $\{x_k(1)\}$, which corresponds to the minimum of target function $F^1{}_1$ and a value of the second criterion $F^1{}_2$, most likely not a maximum one. We increase the first criterion by 5%, $F^2{}_1 = 1{,}05F^1{}_1$ an introduct the additional limitation:

$$\sum_{t=0}^{T} \left(\sum_{k=1}^{n} x_k . V_k^t \right) (1+r)^{-t} \leq F_1^2. \quad (5)$$

Next we solve problem (1)–(2) with the additional limitation (5) and target function (4). We get solution $\{x_k(2)\}$ with the value of target function $F^2{}_1 \geq F^1{}_1$, and the second function $F^2{}_2 \leq F^1{}_2$. Making this step-by-step process N times, we get a set of solutions $\{x_k(1)\}$, $\{x_k(2)\}$,…, $\{x_k(N)\}$ with the corresponding values of the target functions.

Each solution of this sequence is Pareto-optimal, and can be accepted for implementation. In this orderly sequence, each subsequent option has a larger cost and a lower risk of project delays. This target statement provides a compromise choice of the amount of investment in the project which is V_k^t.

But how will the resulting investment dynamics affect meeting environmental requirements for the NPER by the end of the project life cycle? This happens differently if the benefits of the project are assessed by the concept of "antifragility" introduced by Taleb (2012). Indeed, if the function of benefits (results) from annual investments has a quadratic form, elementary calculations made according to Taleb (2012). using the example of a plan with a minimum cost amount (Table 3) result in:

$[M(\overline{V_i})]^2$ = 453 611 679 049,00.

Mean:

$M(\overline{V_i^2})$ = 512 122 805 162,44.

Difference between these values 512122805162,44–453611679049,00 = 58511126113,44 corresponds to the hidden benefit from the antifragility of the obtained dynamics of financing NEPR.

These differences can be calculated for all the distribution options and introduced into the model as a third target function.

The introduction of the "antifragility" indicator allows for obtaining an assessment of the allocative effectiveness of the distribution of annual NPER funds with a technical approach. Despite all the advantages of such numerical assessments of environmental programs, qualitative analysis of the problem remains an important component of a systemic assessment. The above is a systematic description of the synthesis of various methods for assessing the program of conservation and restoration of the nature of the Yenisei as the basis of the ecological and assimilation potential of AER. The results obtained must be considered with great caution, since the problem of accounting for uncertainty has many aspects, and we analyzed its special case in the conditions of the paradigm of Kornai.

4. THE THIRD STAGE OF SOLVING THE PROBLEM

Above, at the first two stages of solving the problem, the results of experiments obtained through verbal and digital system models using the example of NPER were considered. The third stage discussed below is to a certain extent hypothetical. This is explained as follows. From the initial text of the article, one may logically conclude that the third stage should contain a description of a hybrid model for assessing environmental projects, consisting of a logical-heuristic model created on the basis of expert information, and an economic-mathematical model describing the results of experiments using it. The authors participated in the creation of similar models that were used in the assessment of large-scale railway projects, but unfortunately, the specifics of environmental programs were not taken into account in these projects. We are talking about Optimization Interregional Intersectoral Models (OIIM), which were tested to varying degrees when solving macroeconomic problems in the planned and market economies (Grandberg, 2007; Kuleshov et al., 2014).

When using one of the OIIM options, a medical-ecological-economic model (MEEM) was developed, which allowed analyzing the development of the Asian part of the Russian Federation (Lamin et al., 2012). Currently, the authors are improving the above models focusing on the creation of a hybrid model which should provide a comprehensive assessment of large-scale environmental projects. The main difficulty in creating such a model is to find a universal method of accounting for the uncertainty factor. The authors of this article have advanced in their research only in particular cases. Finding a universal method is carried out using Big Data technology. Today it is difficult to predict the outcome of this search; therefore, the third step of solving the problem should be called hypothetical for now.

5. CONCLUSION AND POLICY RECOMMENDATION

Due to the centuries-old large-scale industrial development without proper environmental restrictions, the pristine natural system of AER has now been thoroughly destroyed in all its parts, starting with the upper Yenisei (Angarsk, Usolye-Sibirskoye), its middle part (Lower Priangarye and Lake Baikal), the lower reach (Norilsk), and the situation is on the verge of disaster. In Russia such an understanding is declared, but practically very little is done. This article discusses possible strategies to solve the environmental problem in AER in the scenarios-contrasts of Russia's development between 2023 and 2040 and provides mathematical models and methods for choosing a reasonable and effective solution. To aid policymaking, this study identified three stages of assessment of large-scale projects for different levels, macro-, meso- and microlevel. At the first stage, the goals of the program were developed and ranked by expert assessment methods. The second stage consisted in analyzing the National Project called "Ecology of Russia," composed of 11 interconnected federal projects. A mathematical model of the problem of optimal project management in conditions of uncertainty is presented. At the third stage, a hybrid model of assessing a large ecological project from the logical-descriptive model created at the first stage and the mathematical model of stage 2 is considered.

However, this study is limited to the analysis of few selected projects. Further studies can consider large number of projects to further verify the viability of the findings of this study.

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