SUSTAINABILITY OF THE NUCLEAR POWER AS A TECHNOLOGY WITH MINIMAL RELATIVE IMPACT ON THE ECONOMIC AND ENVIRONMENTAL RESOURCES

V.I. Oussanov

*State Scientific Center Institute of Physics and Power Engineering*
1, Bondarenko Sq., Kaluga Region, Obninsk, Russia,
*E-mail: youss@ippe.rssi.ru*

ABSTRACT

The "entropy" model for quantitative assessment of the impact of the electricity generating systems is discussed in the paper. Introduction of the "entropy" notion opens an opportunity to come to a new understanding of the competitiveness of the electricity generating technologies under taking into account not only economic but also environmental resources. The criterion of the effectiveness should be formulated as production the unit of electricity under minimal dissipation of human energy and natural resources or, in another words, under minimal increase of the nooentropy in the production system. Under such wide definition, the effectiveness of a technology for electricity production becomes a very important index of the sustainability. The assessment of the "nooentropy" effectiveness of the main full-energy-chain electricity production options with normalization to natural resources of Russia has demonstrated important advantages of the nuclear power which are missed in another models of the system analysis, specifically, less impact on natural resource.

KEYWORDS: nuclear power, sustainable development, system analysis, entropy model.

## 1. INTRODUCTION

A fair observer ought to note the revelations which were made in the nuclear science for the last decades. The concept of inherent, deterministic nuclear safety for the NPPs and the nuclear fuel cycle enterprises; the principle of a radiation balance between high-level waste and natural uranium; the hazard radionuclides transmutation approach with the aim of zero radwaste release in the environment; the concept of proliferation-resistant closed fuel cycle in the area of the fissile materials protection to proliferation - this is only a very brief list of such revelations. It was a surprise and a disillusionment for the nuclear specialists when being suggested to the public opinion and to the power industry these vivid and well-founded concepts stimulated further NPPs commissioning to a very small extent, if any.

In the paper the author addresses to some aspects of an important question: what the principles of sustainability may mean to the nuclear science and engineering and when one should expect them to be taken practically in a decision making? For a technical paper like this, the way the wide problem of sustainability is posed should be specified and detailed. First of all, at the very high level of the disputes on the sustainability – the level of principle approaches – the paradigm of natural environment preservation will be followed by us instead of the opposite paradigm reducing to creation of the artificial, man-made world. Secondly, the necessity of global environment impact limitations is adopted but without discussions on difficult problems of social, demographic and economic character. Thus, the level of problem to be consider in the paper is defined by the question: how to produce a unit of electricity in the most effective, sustainable way taking into account the economic and environmental factors.

## 2. ENTROPY MODEL

The "nooentropy" notion which was introduced in [1] to characterize the irreversible changes in the environment as a quantitative measure for industry systems (including electricity production) impact. An electricity generating objects are being interpreted as a system of technological operators functioning in the multi-factor space of the human energy and natural resources. Hence, the energy production (as any other production) results in variation of numerous elementary man-made and natural factors of the environment. The distinguishing feature of nooentropy from physical entropy consist in consideration spirit energy of human beings (nooenergy or techno energy) as cause of the occurring changes instead of mechanical, chemical, etc., kind of energy in physics.

Formally, nooentropy $S(E,V)$ of the production macro system can be defined as:

$$S(E,V) = ln \int\limits_{\substack{G(p,q)<V \\ H(p,q)<E}} d^{KN} p \; d^{KN} q \tag{1}$$

where $p$, $q$ – nooenergetic and resource measures; $K$ – dimension of the multi-factor space; $N$ – number of the elementary technological operators in the system; $H, G$ – nooenergy and resource functions.

Nooentropy $S(E,V)$ depends of the same two parameters as physical entropy: of $E$ – nooenergy of the system and of $V$- volume of the system resources. The nooentropy change under small variations of $E$, $V$ is characterized by equation:

$$dS(E,V) = \left(\frac{\partial S}{\partial E}\right)_V dE + \left(\frac{\partial S}{\partial V}\right)_E dV \tag{2}$$

Hence, two potentials can be defined from the equation (1):

$$\frac{\partial S(E,V)}{\partial E} = \frac{1}{T} \quad , \quad \frac{\partial S(E,V)}{\partial V} = \frac{1}{R} \tag{3}$$

$T$ is a potential characterizing the "nooenergetic state" of a production system. Logically to call it technological potential of the production macro system. Since nooenergy is characteristic of the human activity, of the labor, it's for society itself to find out the method of its measurement. For the time being the most universal method is, of course, economic one.

To characterize a "resource state" of a production system (with all kinds of the resources to be taken into account) another potential has to be introduced - resource one - $R$. It ought to reflect another realities, than those reflected by the technological (economic) potential. While the technological potential characterizes the values of the mankind development, the resource one ought to characterize the values of the nature preservation. That is why it's necessary to find out another methods for the nature resources measurement then a method based on the direct monetary validation. A method of the non-monetary, relative estimation of resource expenditures in the production cycle was suggested in [1]. Later on in this paper, a procedure for justifiable converting of the natural cost to monetary form will be suggested. It will show the character of the problems arise.

The main "equation of the state" for the simplest, ideal model of technological operators can be expressed in the following mode:

$$P = \frac{T}{R} = k\frac{T}{V} \quad , \tag{4}$$

where $P$ could be interpreted as technological load of the resource; $V$ - volume of resources consumption; $k$ –constant. One can see that in case of abundant natural resources ($\frac{\Delta V}{V} \approx 0$ ) the contribution of resource factor into changes of the system state is negligible, so as only technological factors are of importance:

$$\frac{\Delta P}{P} = k\frac{\Delta T}{TP} - k\frac{T\Delta V}{V^2 P} \approx k\frac{\Delta T}{TP} = \frac{\Delta T}{T} \tag{5}$$

It looks like existing approaches to industry development are still based on same assumption of the natural resources abundance and a lack of labor resources. Actually, only a technological (economic) criteria $T$ is being taken into account, though for the most countries of the world the state of abundance of resources has long ago (and forever) gone away while a lack of labor resources is very disputable thesis. It's not excluded that in the future only $R$ will become a matter of importance but for the time being both of these potentials should be included into system analysis of the production effectiveness.

## 3. CRITERION OF COMBINED ECONOMIC AND ENVIRONMENTAL EFFECTIVENESS

Having determined a nooentropy $S$, volume of resources consumption $V$, technological potential $T$ and technological load potential $P$, one may formalize a notion of a production cycle in a manner of the thermodynamics approach. The diagram of the production process in the $P$, $V$ coordinates is illustrated at the Fig.1.

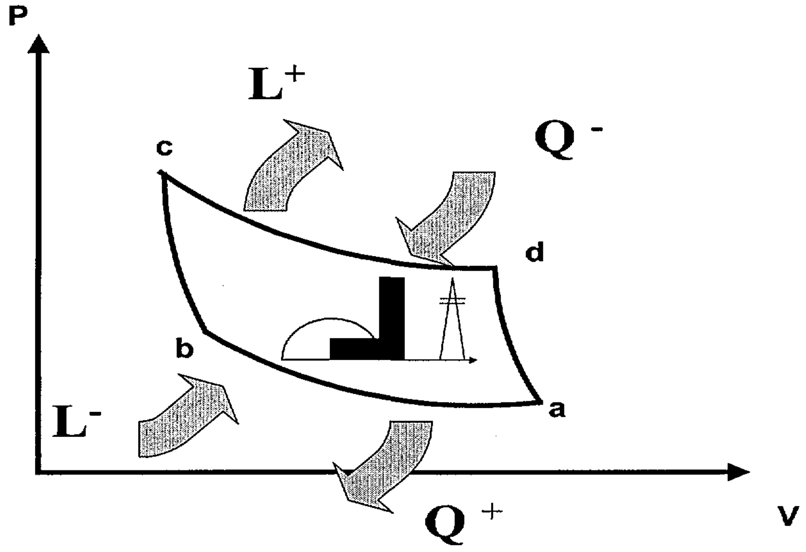



Fig.1. The diagram of the ideal production cycle

Section *a-b* of the diagram represents the stage of a resource base preparation. For the most part, these resources are being produced ($L^-$) by another enterprises and they are to be paid by the loan means of the plant ($Q^+$). The task of the following productive stage (section *b-c*) is to increase the technological potential of the plant *T* as high as possible over the technological potential of its technological surroundings. It has been shown in [1] that mainly this goal can be reached by means of increasing the personnel's qualification and specialization of the technological processes. These stage also demands a work to be done by the technological environment and, hence, investments – to be paid for this outward work. The goal of the plant creation is productive activity at the section *c-d* of the diagram. At this stage our plant runs, produces goods ($L^+$) which are to be paid by purchasers ($Q^-$). The last section *d-c* can be interpreted as the process of a plant decommissioning. The effectiveness of the ideal, closed cycle presented is defined by equations:

$$\eta_T = \frac{Q_{cd} - Q_{ab}}{Q_{cd}} = \frac{\delta Q_Z}{\delta Q}; \qquad \eta_T = 1 - \frac{T_I}{T_Z} \tag{6}$$

where $\delta Q_Z$ – a profit; $\delta Q$ – full cost; $T_Z$ - technological potential of the plant; $T_I$ - technological potential of the surroundings.

It's rather clear that the branch of industry cycle consists of the plants' cycles; production cycle of a plant consists of production cycles of its shops and so on up to production cycles of elementary operators. On the contrary, there are institutions of the consumer's type in the economics with another – reverse – type of cycles. The direct and reverse cycles are balanced in the macroeconomics.

The equation (6) expresses the philosophy of the industrial era – reaching the technological potential of enterprise as high as possible with full as possible ignoring the natural environment loses. For the time being the mankind is evidently entering another era which demands to renew the philosophy. The ideas and priorities of sustainable development declared in Rio (1992) make to look for another theoretical base for practical use in the future.

In the frameworks of the approach suggested an advancement may consist in admission that real production cycle is connected with irreversible resource loses, with waste. The effectiveness of the resource use can be characterized by the coefficient:

$$\eta_R = \frac{\delta V - \delta V_W}{\delta V} = \frac{\delta V_Z}{\delta V} \tag{7}$$

where $\delta V$ – resources involved in the cycle; $\delta V_W$ - waste; $\delta V_Z$ – usefully used resources or ecologically clean resources returned to the environment.

To aggregate both (6) and (7) equations let's address again to the nooentropy notion. As a result of the production cycle completion there are some special-purposed, positive changes in the environment $\delta S_Z$ and full changes $\delta S$. It's naturally to define generalized effectiveness of the productive cycle as:

$$\eta = \frac{\delta S_Z}{\delta S} \tag{8}$$

Taking into account equation (2) for $\delta S$ one comes to definition of both economic and environment effectiveness of the productive cycle $\eta$:

$$\eta = \frac{\dfrac{dQ_Z}{Q} + \dfrac{dV_Z}{V}}{\dfrac{dQ}{Q} + \dfrac{dV}{V}} \tag{9}$$

Introduction of the generalized "nooentropy" notion opens an opportunity to come to a new understanding of the competitiveness of the electricity generating technologies under taking into account not only economic but also environmental impact. The criterion of the effectiveness should be formulated as production the unit of electricity under minimal dissipation of human energy and natural resources or, in another words, under minimal increase of the nooentropy in the production system. A very important feature of the equation (9) is a relative character of the material and financial expenses in the production process, i.e. both of them are related to the corresponding potentials: material – to the resource potential of the nature, financial – to the nooenergetic potential of the society.

Under such wide definition, the effectiveness of a technology for electricity production becomes a very important index of the sustainability criterion in the energy sector of an economy.

## 4. LONG-TERM ENVIRONMENTAL POLICY AND MECHANISMS OF ITS IMPLEMENTATION

The construction of an algorithm for the evaluation of the coefficient of the real plant efficiency (9) is, undoubtedly, a challenging problem. But for the simplest model of the plant considered above the necessary formula can be easily derived. Actually, the volume of nooenergy and natural resources in the abstract space introduced is a product of the corresponding attributes:

$$Q = q_1 \cdot q_2 \cdot q_i \ldots q_I, \qquad V = v_1 \cdot v_2 \cdot v_i \ldots v_I. \tag{10}$$

Then the full relative cost of the goods (electricity) production both for material resources $\delta v$ and financial $\delta q$ impacts are:

$$\delta v = \frac{\delta V}{V} = \sum_i \frac{\delta V_i}{V_i} \quad ; \quad \delta q = \frac{\delta Q}{Q} = \sum \frac{\delta q_i}{Q_i} \tag{11}$$

where $i$ – current index of a factor impacted in the result of production cycle realization; $\delta v_i$, $(\delta q_i)$ – ecological (financial) annual impact over the $i$ factor (health impact, bio-spherical pollution, natural resources exhaustion, cost, etc.); $V_i$, $(Q_i)$ – annual quota of the $i$ factor admissible consumption in the global system.

When estimating effectiveness $\eta$ of electricity production options with the same goal function $\delta S_Z$ (production of equal amount of kWhs), equation (9) becomes more simple because of reducing to comparing of only full relative cost $\delta S = \delta v + \delta q$. The less $\delta S$ – the better estimation of the alternative.

Being very simple, equations (11), nevertheless, reveal a new understanding of a reasonable environmental strategy. Such strategy must be based not only on a long-term economic planning but ecological planning as well. While forecasting and planning the indices $Q_i$ of an economic development is routine practice for today, the planning of the annual environmental quotas $V_i$ for the period of projection is rather new procedure which will demand joint efforts by the environmentalists, biologists, geologists and other specialists from the earth science. The equations (11) give an opportunity to compare and harmonize relative costs made by the human beings and by the nature under the process of electricity production..

In the analysis made, main pathways of impacts were taken into account: impacts on resources of the labor, renewable and nonrenewable resources of Russia geosphere. The necessary data were taken from national and international published materials and databases. A small portion of the global limits (quotas) used in the study are shown in the Table 1. The annual rates of the nonrenewable resources consumption were calculated proceeded from supposition of their steady exhaustion in a century. (By the way, as a rule, this rates appeared to be very near to the real figures of the annual consumption of the most raw materials significant for the study.) In respect of renewable resources it was supposed, that the probable increase in the rate of electricity production in the future won't be accompanied by the same increasing of the resource quotas in the electricity sector.

TABLE 1. SOME ANNUAL LIMITS (QUOTAS) OF NATURAL RESOURCES CONSUMPTION BY THE ELECTRICITY SECTOR USED IN THE STUDY

| Geosphere | Type of environmental impact | Annual impact limit (quota) |
|---|---|---|
| Atmosphere | GHG release, t $CO_2$ | $4.82 \cdot 10^8$ |
| | Wind power potential, GW | $1.6 \cdot 10^3$ |
| Hydrosphere | Irreversible fresh waster consumption, $m^3$ | $3.5 \cdot 10^{10}$ |
| | Water power potential, GW | $2.3 \cdot 10^2$ |
| Lithosphere (organic) | Coal combustion, t | $2.0 \cdot 10^9$ |
| | Gas combustion, t | $4.9 \cdot 10^{11}$ |
| | Oil combustion, t | $8 \cdot 10^7$ |
| Lithosphere (non-organic) | Iron use | $5 \cdot 10^7$ |
| | Uranium-235, t | $2.0 \cdot 10^4$ |
| | Uranium-238, t | $1.0 \cdot 10^6$ |
| Land | Land use, $km^2$ | $6.8 \cdot 10^5$ |

As for the ecological limitations and constraints, it's not excluded that the Convention on Climate Change is a beginning of the new era of global and regional limitations on the biosphere contamination and pollution. These limitations give a definite base for the component of relative cost connected with greenhouse gases (GHG) releases. Besides the established limits on greenhouse gases emissions, which are becoming the object of the international low, the recommendations on the heat release global limits and national regulation on chemical and radioactive releases were used in the course of the work to determine the values $V_i$.

The exercise made by the author regarding construction of the global system of constraints has shown that global environmental policy as an important component of sustainable development is only on the stage of a giving rise, leaving alone the mechanisms of its practical implementation. From this point of view a lot of technical decisions suggested by the nuclear engineers and directed for the environment preservation leaves behind the realities of decision making. The entropy model helps to understand that only a legalized system of global health and environment regulation can be a reliable base for an inculcation of the advanced energy technologies.

## 5. PRELIMINARY RESULTS

The results of the relative environmental cost $\delta v$ calculations (without the human health measures) in accordance with equation (11) made for the full-energy-chains of the main electricity production options with normalization to natural resources of Russia are shown in Table 2. One may note irregularity of relative environmental cost component in respect of different geo-sphere impact, which even in totality gains a hundred and more times. It means that some technologies are ecologically less expensive then other ones and, hence, more competitive from this point of view. It follows from the Table 2 that the most promising at the existing levels of the natural resource and ecological limitations are nuclear and solar fuel cycles, the most expensive for the nature – oil and coal fuel cycles.

The "matrix of relative environmental impacts" of the table 2 gives an opportunity to understand attractive and weak sides of the energy options under consideration. For example, the most important pathways of contribution to environmental cost for the organic fuel burning technologies are greenhouse gases releases, air and fresh water chemical contamination, exhaustion of fuel resource. The role of the greenhouse gases release component is domineering in this class of options with reservation of only oil and biomass burning cycles. The calculations made show that comparatively small oil resource of Russia $V_{oil}$ converts the fuel resource component of the oil electricity generating option into the important contributor to the relative ecological cost. The land use has become the critical component of the environmental cost for the biomass burning option.

TABLE 2. IMPACTS RELATED TO LIMITS OF ANNUAL NATURAL RESOURCES CONSUMPTION OF RUSSIA BY THE MAIN OPTION OF ELECTRICITY GENERATION OF kWh (A CENTURY FORECAST)

| Type of electricity option | | IMPACT | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Atmosphere | | Hydrosphere | | Land | | Lithosphere (organic) | | Lithosphere (nonorganic) | | Total |
| | | Specific | Relative | Specific | Relative | Specific | Relative | Specific | Relative | Specific | Relative | With GHG / without |
| Coal | | 1000 g.$CO_2$ | $1.25\cdot10^{-12}$ | $6.0\cdot10^{-3}$ $m^3$ (2) | $1.7\cdot10^{-13}$ | $5.6\cdot10^{-10}$ $km^2$ | $8.3\cdot10^{-16}$ | $5.7\cdot10^{-4}$ t.c.e.(4) | $2.8\cdot10^{-13}$ | $8.1\cdot10^{-7}$ t.s.s.(5) | $1.6\cdot10^{-15}$ | $1.7\cdot10^{-12}$ / $4.5\cdot10^{-13}$ |
| Natural gas | | 668 g.$CO_2$ | $9.0\cdot10^{-13}$ | $4.1\cdot10^{-3}$ $m^3$ (2) | $1.2\cdot10^{-13}$ | $6.0\cdot10^{-10}$ | $8.8\cdot10^{-16}$ | $5\cdot10^{-4}$ t.c.e | $2.4\cdot10^{-13}$ | $1.6\cdot10^{-7}$ t.s.s.(5) | $3.2\cdot10^{-15}$ | $1.2\cdot10^{-12}$ / $3.6\cdot10^{-13}$ |
| Oil | | 780 g.$CO_2$ | $1.0\cdot10^{-12}$ | $5.1\cdot10^{-3}$ $m^3$(2) | $1.4\cdot10^{-13}$ | $5.3\cdot10^{-10}$ $km^2$ | $7.5\cdot10^{-16}$ | $5\cdot10^{-4}$ t.c.e | $3.8\cdot10^{-12}$ | $6.0\cdot10^{-7}$ t.s.s.(5) | $1.1\cdot10^{-15}$ | $4.9\cdot10^{-12}$ / $3.9\cdot10^{-12}$ |
| Hydro | | 17 g.$CO_2$ | $2.3\cdot10^{-14}$ | $8.3\cdot10^{6}$ J(3) | $8.1\cdot10^{-14}$ ? | $3.8\cdot10^{-9}$ $km^2$ | $7.7\cdot10^{-15}$ | $3.7\cdot10^{-6}$ t.c.e | $1.8\cdot10^{-15}$ | $9.1\cdot10^{-7}$ t.s.s.(5) | $1.8\cdot10^{-15}$ | $1.2\cdot10^{-13}$ / $9.2\cdot10^{-14}$ |
| Wind | | $1.8\cdot10^{7}$ J.(joule)(1) | $7.7\cdot10^{-14}$ ? | $1.0\cdot10^{-3}$ $m^3$(2) | $3.0\cdot10^{-14}$ | $0.9\cdot10^{-9}$ $km^2$ | $3.0\cdot10^{-14}$ | $3.8\cdot10^{-6}$ t.c.e | $1.9\cdot10^{-15}$ | $4.3\cdot10^{-7}$ t.s.s.(5) | $8.6\cdot10^{-15}$ | $7.7\cdot10^{-14}$ / $6.0\cdot10^{-14}$ |
| Solar (PV) | | 100 g.$CO_2$ | $1.4\cdot10^{-13}$ | $2.0\cdot10^{-3}$ $m^3$(2) | $6.0\cdot10^{-14}$ | $5.0\cdot10^{-9}$ $km^2$ | $1.4\cdot10^{-14}$ | $1.0\cdot10^{-6}$ t.c.e | $5.0\cdot10^{-15}$ | $1.0\cdot10^{-7}$ t.s.s.(5) | $2.0\cdot10^{-14}$ | $2.4\cdot10^{-13}$ / $9.9\cdot10^{-14}$ |
| Biomass | | 70 | $9.5\cdot10^{-14}$ | $4.0\cdot10^{-3}$ $m^3$(2) | $1.2\cdot10^{-13}$ | $8.0\cdot10^{-7}$ $km^2$ | $1.0\cdot10^{-12}$ | $4.0\cdot10^{-6}$ t.c.e | $2.0\cdot10^{-15}$ | $3.0\cdot10^{-7}$ t.s.s.(5) | $5.0\cdot10^{-16}$ | $1.1\cdot10^{-12}$ / $1.0\cdot10^{-12}$ |
| Nuclear | Open | 10 g.$CO_2$ | $1.4\cdot10^{-14}$ | $1.5\cdot10^{-3}$ $m^3$(2) | $4.3\cdot10^{-14}$ | $4.6\cdot10^{-10}$ $km^2$ | $6.7\cdot10^{-16}$ | $4.0\cdot10^{-6}$ t.c.e | $2.0\cdot10^{-15}$ | $3\cdot10^{-8}$ t.n.u.(6) | $4.6\cdot10^{-14}$ | $1.1\cdot10^{-13}$ / $9.2\cdot10^{-14}$ |
| | Closed | 10 g.$CO_2$ | $1.4\cdot10^{-14}$ | $1.4\cdot10^{-3}$ $m^3$(2) | $3.8\cdot10^{-14}$ | $3.5\cdot10^{-10}$ $km^2$ | $5.2\cdot10^{-16}$ | $4.0\cdot10^{-6}$ t.c.e | $2.0\cdot10^{-15}$ | $2\cdot10^{-7}$ t.s.s.(5) | $4.0\cdot10^{-15}$ | $5.8\cdot10^{-14}$ / $4.4\cdot10^{-14}$ |

(1) – wind energy needed for kWh electricity production;
(2) – liquid LLW;
(3) – hydro-energy for kWh electricity production;
(4) – t.c.e. – tons of coal equivalent
(5) – t.s.s. –tons of stainless steel
(6) – t.n.u. – tons of natural uranium

The Table 2 demonstrates rather low level of the relative environmental cost received for the nuclear fuel cycle. The main components of this result are: low greenhouse gases and chemical releases, low fresh water contamination, low land use, low consumption of the organic raw materials. The additional advantage of the closed nuclear fuel cycle is a low "power resource" component, which is not so small for the open nuclear fuel cycle in a century forecast. In the whole, it can be concluded from the Table 2 that under normal operation the center of the nuclear fuel cycle environmental impact is displaced to the domain of non-organic resources while other cycles impact biosphere more directly. It's a conclusion of paramount importance for the sustainability principle realization since it shows that only the nuclear technology can open for the power production a really new "resource niche", different from the biosphere resource.

An assessment of the relative health impacts was made in the same manner and then included into the "matrix of relative environmental impacts". In accordance with (11) the very same algorithm was also can be used for the calculations of the "economic relative impact" - $\delta q$. In the most aggregated approach the components of the impact are the costs of a kWh in every specific electricity option under consideration related to the nooenergy potential of the power branch (the sum of money circulating in the electricity sector). Assuming that equal human and nature relative cost should be paid in money also equally one comes to monetary validation of the absolute environmental cost connected with the given electricity option *i*:

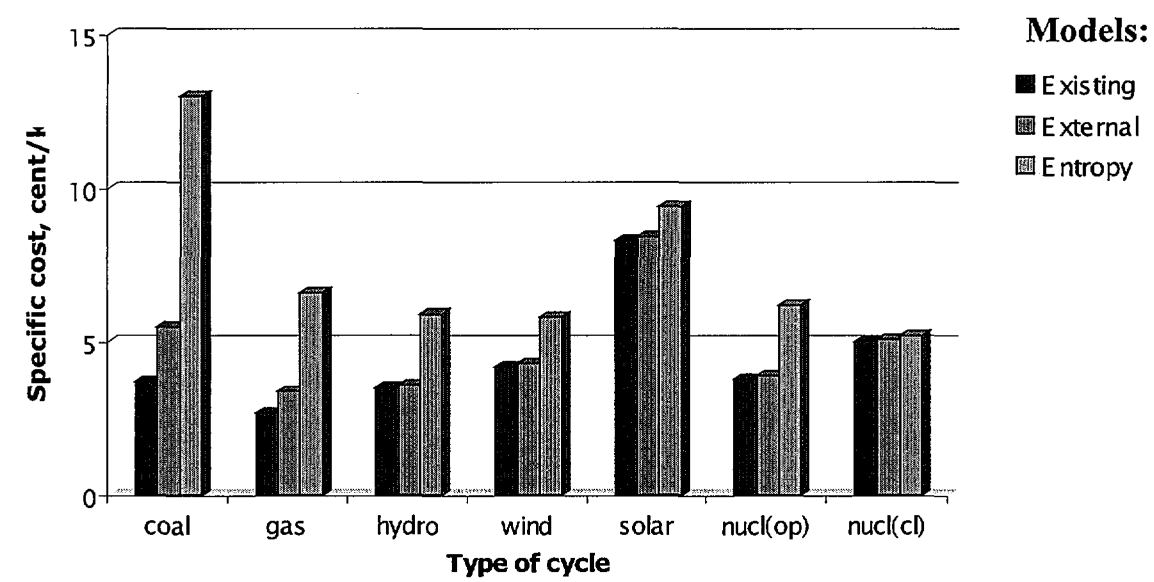
$$\delta c^V_j = \delta c^E_j \, (\delta v_j / \delta q_j) \ , \tag{12}$$

where $\delta c^E_j$ – specific electricity cost in j option; $\delta c^V_j$ – additional environmental cost in *j* option.

Projections of the electricity cost by the end of the first quarter of this century (by the year 2025) made in three different scenarios are presented in the Fig.2. The existing market economic practice continuation is postulated in the first scenario. The electricity cost data for the case were taken by the author from [2] where they were received with the use of the global energy model code (GEM-10). The second scenario is based on the assumption of the external cost adding to the inner cost of the electricity production in Russia (external model [3]). The third scenario is an attempt to take into account both economic and environmental cost of the electricity production in the frameworks of the entropy model. The results presented in the Fig.2 worth discussing.

First of all, a relative assessment of the environmental impact of the different electricity technologies in the entropy model turned out to be not radically biased as compared to fundamental conceptions formed by "ExternE" study in spite of significant specificity of Russia and the model itself. Use of oil and coal fuel cycle leads to the highest environmental impact; gas fuel cycle takes approximately intermediate position; nuclear, solar, wind and mountain hydro can be considered as rather ecologically clean options of electricity generation.

**Fig.2. Comparison of electricity cost in combined economic and environmental models**



At the same time the environmental cost of electricity production in the entropy model has appeared to be three-four times more than the external cost for the identical conditions. Thus, if to proceed from the supposition that relative expenditures of the nature should be paid in money equally with the "energetic" expenditures of the human society then the entropy model recommends to increase the cost of the coal and oil electricity (up to 4 times), the cost of the gas electricity (up to 2 times), etc. Hence, the high economic indices of the most effective traditional energy options can be partly explained by the unpaid exploitation of the natural environment. The Fig.2 demonstrates that the closed nuclear cycle is the most competitive and stable option under transition to more "fair" relations of the electricity production systems with the environment. The positions of the wind and solar options under such transition also become better.

Coming to the final remarks, it is necessary to mention that sustainability of the nuclear power is a relative notion. The entropy model indicates some historical, structural, regional and other features which effect its understanding. Historically, the coal electricity was rather sustainable in the last century when much weaker technological potential were involved in the electricity production sector on the one hand and nobody spoke of the GHG global limitations – on the other hand. Structurally, it follows from the approach developed that there are more sustainable and less sustainable kinds of the human activity in themselves. Banking, tourism, culture, education and other institutions mostly based on human activity than on natural resources consumption are more environmentally sustainable than industrial enterprises which are being converted to the "outcasts" of the prosperous societies. Regionally, at the given moment the situation with the technological and resource potentials of the different countries and regions of the world differ to a great extent. So, if not the international cooperation which could help to spread the technological potential created in the industrially developed countries all over the world, one could not even mention the nuclear, wind, solar as sustainable options for many of them.

## 6. CONCLUSION

It is shown in the paper that some general lows of the macro system behavior in the nature and in the society have the features of similarity. Basing on this understanding, the entropy model of energy production is developed. A criterion of both economic and environmental effectiveness is suggested: it is a minimal labor and resource dissipation (minimal techno entropy increase) under production of a unit of electricity.

The quantitative definitions for the technological and resource potentials are introduced. They give an opportunity to separate and to compare technological expenditures of the society from the expenditures of the nature made in the process of electricity production. A reasonable long-term strategy of energy production answering the principles of co-evolution of the man and the natural environment might consist in minimization the full cost of electricity including technological expenditures and expenditures of the nature.

The method used in the paper clearly demonstrates that realization of the environmentally sustainable strategy is impossible without a legalized system of long-term global health and environment regulations and planning. From this point of view the Convention on Climate Change is one of the first but not the last step on a way to global limitations of the environmental impacts. Accordingly, Kyoto mechanisms have a potential for wider application than only for greenhouses gas release limitations – they can help to convert the decision making into a procedure much more sensitive to technologies of the environment preservation than it is nowadays.

In the frameworks of the methodology discussed the nuclear fuel cycle has appeared to be the most competitive energy option for the development in the first part of this century taking into account both technological and environmental conditions of Russia.

The author gratefully acknowledges the helpful discussions of L. Belyaev, H. Inhaber, V. Kagramanian, O. Marchenko, Z. Nikodem, S. Subbotin, M. Troianov.

## REFERENCE

[1]. V. OUSSANOV "Benefits of Nuclear Power to Lowering Ecological cost of Energy Production", Proc. Int. Conf. on Future Nuclear Systems GLOBAL'99, Jackson Hole, Wyoming, Aug.30 – Sep.2, (1999).

[2]. L. BELYAEV, O. MARCHENKO, et al. "The World Power and Transition to Sustainable Development", Nauka, Novosibirsk, 2000, p.269.

[3]. Externalities of Energy, Extern E Report, Rep. EUR-16522, EC, Brussels (1995).