Rocznik Ochrona Środowiska

Volume 23	Year 2021	ISSN 1506-218X	pp. 446-457
https://doi.org/10.54740/ros.2021.030			open access
Received: 14 June 2021	Accepted: 23 July 2021		Published: 06 December 2021

Some Issues Quantifying Low-carbon of an Achievement Energy and Industry

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Abstract: In this work, for use as a unified tool within the framework of ISO 50001, a methodology for rating assessment of the processing of emissions with global pollutants is proposed, which was developed by the authors and recommended for use by state documents of the Republic of Tatarstan, Russia. It is distinguished by the absence of not transparences elements. As the initial data, the actual background concentrations (according to WMO data), the annual ceiling of greenhouse gas emissions and the maximum permissible emissions of toxic compounds, information on the characteristics of emission sources are taken for the enterprise, and as operational constants, the global warming potentials of greenhouse gases (GWP100) and officially approved values of maximum permissible concentrations of toxic compounds (MPC). The method is based on the equation (presented here at annotation in a simplified form), which gives a numerical indicator (rating) R of the efficiency of a production facility in terms of hazardous emissions into the atmosphere, taking into account greenhouse gases and energy costs arising from their removal. Currently, the technique is adapted to the energy sector; for wider adaptation to various industries, a low-carbon rating program has been drawn up for boiler houses, thermal power plants and industrial enterprises. It also meets the needs of understanding and predicting possible deviations of emission parameters from the standardized indicators. Therefore, it can serve as a tool within the framework of ISO 50001, providing objective control over the choice of means to ensure compliance with the requirements for harmful components emissions including greenhouse gases in the design and modernization of production facilities. The developed program is embedded for Russian enterprises in the shell of the '1C: Enterprise' platform – a software product for automating accounting and management at enterprises. The program can also be used in the software shell of the automated accounting of the activities of a particular organization in a one or the other country.

Keywords: global pollutants, emission sources, greenhouse gas, low-carbon achieve quantifying, energy efficiency, energy and industry

1. Introduction

In the present world, the overwhelming majority of countries are members of international organizations of the planet, solving the problem achieving of the low-carbon and energy efficiency production and consumption. Among them, a number of international organizations consider low-carbon as the most significant characteristic of a country, region, enterprise, and its achievement as the most significant goal. These are, for example, the obligations of the countries belonging to the "Group of 20" (G20), which are consumers of 80% of the world's energy resources. And the WTO member countries (162 countries plus the EU) are obliged to create conditions for fair competition, including energy saving. Finally, the States Parties to the Framework Convention on Climate Change (FCCC) at the UN (195 countries of the world plus the EU), at the 2015 Paris Conference, made a direct commitment to achieve real low-carbon production by 2030.

It can be seen that practically the entire global community is covered by the commitment to achieving low-carbon. At the same time, there are no generally accepted methods of assessing the achievement of low-carbon content in the world. Consequently, there are no ways to control and self-control the fulfillment of obligations. They did not appear during the time that has passed since the adoption of the Paris Agreement, which was characterized by the absence of specific methods and tools for implementing decisions.

The problem of the lack of criteria for a transparent quantitative assessment of the achievement of low-carbon leads to biased decisions on a global, national and local scale, from which it is necessary to have, at least, methods and tools of protection. This applies to all areas of generation and consumption of energy resources based on both fossil fuels and renewable sources. The above commitments of the G20 member countries cover the sectors of activity formed and substantiated at the 2014 Brisbane summit (Communiqué 2014), which prescribe: progress towards real low-carbon industrial production with the intensification of the implementation of an energy efficiency management system in industry; development of low-carbon power generation; improving the energy efficiency of buildings; reduction of emissions from transport and agricultural production.

Let us now turn to the document of our day – "U.S.-China Joint Statement Addressing the Climate Crisis" (U.S.-China 2021), the following areas of joint activity are highlighted:

a. Policies, measures, and technologies to decarbonize industry and power, including through circular economy, energy storage and grid reliability, CCUS, and green hydrogen;
b. Increased deployment of renewable energy;
c. Green and climate resilient agriculture;

d. Energy efficient buildings;
e. Green, low-carbon transportation;
g. Cooperation on addressing emissions from international civil aviation and maritime activities...

It can be seen that the two countries with the largest greenhouse gas emissions have exactly the same problems as 7 years ago before the Paris Agreement. The same applies to all other countries belonging to various world institutions aimed at achieving low-carbon and energy efficiency (Rubino M, Etheridge DM, et al. 2019, WMO Greenhouse Gas Bulletin 2019). In recent decades, only an increase in CO_2 emissions can be observed for all countries (see data on emissions by countries of the world from 1990 to 2018 by IEA – International Energy Agency CO_2 data, https://www.iea.org/).

Increasing energy efficiency in the buildings sector continues to be a one of main viable way to achieve reductions in carbon dioxide emissions. This is due to the fact that at present about a third of the energy generated in the world is spent on the energy supply of buildings and structures, which it is generated by more than three quarters by burning fossil fuel. However, on this path, the possibilities of traditional methods are close to exhaustion, and breakthrough technologies are required, and they can be found even in thermal insulation structures. At the same time, it should be borne in mind that new solutions must be checked, whether their production and / or application will lead to a greater release of greenhouse gases into the atmosphere than, for example, the generation of energy to replenish heat losses using just good thermal insulation. To do this, we must have reliable control tools - numerical criteria that would make it possible to transparently and correctly compare new technologies, for example, in this case – conventional and thermal insulation with "zero" heat loss. Today, advanced technologies that can provide a significant increase in the energy efficiency of buildings and structures, in addition to thermal insulation materials with nanoelements that provide "zero" thermal conductivity, include, for example: equipping buildings with energy storage devices based on high-temperature superconductivity (HTSC) for efficient power supply from solar and wind generators to the electrical network of a building with lighting and household electrical appliances, air conditioners, electric heaters and kitchen equipment; a radical reduction in the resistance of ventilation and air conditioning networks in buildings by means of computer profiling of shaped elements; energy efficient use of geothermal heat pumps in high latitudes.

In view of the difficult (even “crisis”, according to the joint statement of the United States and China) state of the planet, at this stage only those that reduce the release of greenhouse gases into the atmosphere should be selected from breakthrough technologies. This can be done if there is, first of all, a transparent and reliable selection tool – a numerical efficiency criterion for greenhouse gases, which would exclude any subjectivity in the technology selection process. In the transport sector, there are general prerequisites for creating such an instrument. The transport sector is both the largest consumer of energy and a source of emissions. According to 2014 IEA estimates, It accounted for about 20% of global energy consumption and about 15% of carbon emissions. Transport energy consumption could rise to 35% by 2050 if the global energy efficiency policy is not accelerated. The IEA proposes to focus primarily on heavy transport, as its impact on the environment is disproportionately high. It was assumed that the countries of the world would jointly develop techniques for effective control of fuel consumption and the impact of heavy vehicles on the environment and climate with the introduction of common approaches and coordination of national standards. Approaches were considered to reduce the impact of heavy vehicles by improving engine efficiency and performance, improving aerodynamics and tires, and increasing the use of biofuels and low-carbon fuels. However, now the transition to electric transport is becoming more and more urgent, since the generation of electricity by stationary generators has a higher fuel utilization factor than ICE. And technologies based on HTSC become breakthrough here, both for the accumulation of electricity and for replacing wheeled vehicles with the MAGLEV technology. To select from seeming successful projects, criteria for a transparent quantification of low-carbon achievement are also required.

To reduce greenhouse gas emissions in the sector of industrial and agricultural production, the world community needs to ensure a significant increase in the energy efficiency of production processes. The strategy is considered not only environmentally necessary, but also economically justified: the starting point is that production processes are accompanied by significant energy consumption.

The basis for effective cooperation is considered the agreement of the participating countries G20 in the direction of intensification of the activities of the IPEEC Working Group on Industrial Energy Management of the Global Sustainable Electricity Partnership (GSEP). Also, great hopes are pinned on the wider implementation of an energy management system based on the ISO 50001: 2011 protocol, which takes into account the diversity of industrial and technological systems in the G20 countries and is easily adaptable to the needs of any the above-identified sectors.

The protocol is acceptable for the development and implementation of the energy policy of any industrial enterprise in industry and agriculture, regardless of legal relations, size, climate, etc. It is an algorithm for organizing a systematic approach, first to achieving energy efficiency, and then to a constant decrease in energy consumption, with a corresponding reducing greenhouse gas emissions. The algorithm operates according to the principle: planning – executing – checking – adjusting – achieving – subsequent planning, and the ISO 50001 standard does not indicate any quantitative estimates. Each company chooses the ways to achieve the goal itself. At the same time, it requires the enterprise to demonstrate improvement in its energy efficiency indicators within the limits of the energy efficiency requirements in accordance with the energy policy of the enterprise itself. The standard specifically stipulates that it does not predetermine the description of special criteria for the level of energy efficiency, which makes it universally. However, this advantage of the protocol does not make it possible to use the achievements of the indicators as numerical criteria that would allow transparently and correctly adjusting such local actions as reducing greenhouse gas emissions and other hazardous emissions, within the framework of a regional, national and global scale. Indeed, the ISO 50001 standard can be met by businesses that produce the same products, but with different energy efficiency levels.

Meanwhile, the structure of the standard makes it possible to include in the agenda the adjustment of any variables and measured values, leading to an increase in the level of energy efficiency of the enterprise, from design and procurement of equipment to methods of documentation and reporting or for attracting specialized personnel, etc. Consequently, the achievement of indicators by enterprises according to the ISO 50001 protocol can and should be used on a national and global scale. For this their values must be further presented in form able to compare enterprises of the one industry, then – to compare industries on a regional scale, regions – nationally and countries – in globally.

2. Materials and methods

The tools for comparing enterprises, industries, regions, countries in terms of achieving low-carbon emissions should be ratings for reducing greenhouse gas emissions, which should be based on transparent adequate numerical criteria, which were mentioned earlier. This will ensure screening and timely adjustment of the movement towards reducing energy consumption and greenhouse gas emissions at the local, regional, national and global levels.

There are now many online carbon footprint calculators for businesses around the world. Further briefly consider some of them as typical low-carbon numerical identification tools. Let us the possibilities of using them as an additional tool for comparing the low-carbon ratings after establishing the level of achievement enterprises of energy efficiency indicators within the framework of the ISO 50001 protocol.

The calculator of carbon dioxide (CO_2) emissions, offered by one of the largest operating associations of energy auditors in Russia[1] is based on the conversion ratios provided in the guidelines environmental reporting by the government department UK for Environment, Food and Rural Affairs (Defra), designed for various organizations and households. The calculator gives the total CO_2 emissions from the organization's fuel and electricity consumption and from transportation by road, train, bus and airplane. Arbitrariness in the selection of conversion factors for the conversion of consumed electricity into carbon dioxide equivalent is not excluded, which can, due to the large, as a rule, consumption of electricity by enterprises, give a large error in the final value of emissions, and make it difficult to compare the results of reducing energy consumption and CO_2 emissions from different enterprises.

The possibility of using the online tool of the COMBI project ("Calculation and Implementation of the Multiple Benefits of Energy Efficiency in Europe") presented by the EU in 2018 also deserves close scrutiny. Achieving energy efficiency, in line with the Paris Agreement, has been identified as the key among the possible ways to reduce greenhouse gas emissions and address climate change. Also energy saving, in addition to directly reducing energy costs, improves air quality and the ecosystem as a whole, public health. The last with in terms of financial costs brings save another 30%, according to the Wuppertal Institute (Multiple Impacts 2020). The online tool COMBI allows to recalculate energy savings into reimbursement of investment costs and the amount of profit, according to the development models of all EU countries until 2030. To quantify the multiple impacts of the potential for additional energy savings on the economy of a country or region, the COMBI online tool uses detailed data on energy savings and investment costs of a large number of energy-related manufacturing items. Some of them could be used to create a methodology for determining the ratings of low-carbon regions and countries of the EU.

In the Republic of Tatarstan, Russia, more than 10 years ago, on the basis of recommendations contained in state documents on the state of natural resources[2] and the sanitary and epidemiological situation[3] a method was developed for direct quantitative assessments of low-carbon enterprises (Ziganshin 2019). It was used in the design of heat supply for a number of non-energy facilities. Currently, the technique has been adapted to power generation facilities. The method is fully prepared for use as an additional tool to the ISO 50001 pro-

[1] Non-profit Partnership "Interregional Alliance of Energy Auditors" https://sro150.ru/

[2] State report of the Ministry of Economic Development of the Republic of Tatarstan "On the state of natural resources and on environmental protection of the Republic of Tatarstan in 2007".

[3] State report of Rospotrebnadzor in the Republic of Tatarstan "On the sanitary and epidemiological situation in the Republic of Tatarstan in 2007".

tocol to quantitative assesment of the low-carbon achievment and to compare of enterprises industrial, generating and the construction sector.

So, the analysis of the methods shows next. The simple and transparent methods can give a significant error due to taking into account a small number of factors, and the inaccuracy of the results of complicated methods that take into account many factors is due to the impossibility of their correct inclusion due to the need to supplement with forecast data, but forecasts are often not justified. At the same time, our proposed methodology use just real data can give transparent and reliable results on low-carbon and toxic emissions of enterprises, but so far it has not been tested at the global, national and/or regional levels.

3. Results and discussion

Thus, today it is impossible to find ready-made and tested methods of quantitative assessment of the approach of energy and industrial production in the world to low-carbon content. It seems reasonable enough to use the proposed at this work methodology with its testing in the pilot region, necessary adjustments and further dissemination of experience. Let us dwell in more detail on the discussion of the design equations and properties of the proposed method for quantitative assessments of low-carbon energy and industry.

The methodology is based on equations (1, 2), which give weighted average numerical indicators R, η_{COMP} of the efficiency of generating enterprises for the emission of toxic ingredients and greenhouse gases, and taking into account the energy costs that may arise during CCS.

$$R = C_u \cdot \eta_{COMP} = C_u \cdot EER \cdot T_1 = C_u \cdot EER \cdot (T_1/T_2) \cdot T_2; \quad (1)$$

$$\eta_{COMP} = \frac{EER \cdot V}{\tau_0 \cdot W} \left(\frac{\sum_{i=1}^{m} (BC_i \cdot GWP_{i100}) \cdot \prod_{i=1}^{m} \left(2 - \frac{C_{iAAU}}{C_{ib}}\right)}{\sum_{i=1}^{m} (C_{iAAU} \cdot GWP_{i100})} + \frac{\sum_{j=1}^{n} \text{ПДК}_j \cdot \prod_{j=1}^{n} \left(2 - \frac{C_{je}}{C_{jb}}\right)}{\sum_{j=1}^{n} C_{je}} \right) =$$

$$= EER \left(\frac{\sum_{i=1}^{m} (BC_i \cdot GWP_{i100})}{\sum_{i=1}^{m} (C_{iAAU} \cdot GWP_{i100})} \prod_{i=1}^{m} \left(2 - \frac{C_{iAAU}}{C_{ib}}\right) + \frac{\sum_{j=1}^{n} \text{ПДК}_j}{\sum_{j=1}^{n} C_{je}} \prod_{j=1}^{n} \left(2 - \frac{C_{je}}{C_{jb}}\right) \right) \times$$

$$\times \frac{100\pi H^2}{\tau_0 \cdot W} \left\{ H + D\left[w_0^r \left(1{,}239 - 0{,}147\ u_m^r\right) - 0{,}514 \right] \frac{(\rho_{ar} - \rho)}{(\rho_{ar} - \rho_e)} \right\}. \quad (2)$$

In equations (1, 2):
W, m^3/s – emission intensity,
τ_0, s – time scale, s,
τ_1, $T_1 = \tau_1/\tau_0$ – time, s, and dimensionless time parameter, of filling the control volume of the expert assessment V, m^3 with greenhouse gases,
$\tau_2 = V/W_a$, $T_2 = V/(\tau_0 W_a)$ – time, s, and dimensionless time parameter, of filling the control volume of the expert assessment V, m^3 by the emission,
C_{ib}, C_{iAAU}, BC_i, GWP_{i100} – the initial and maximum permissible in terms of carbon credits, and the background concentration, mg/m^3, and the global warming potential of the i-th type of emitted greenhouse gases,
M_{AAU}, t CO_2-eq/year – permissible mass emission of greenhouse gases equal in value to the AAU (Assigned Amount Unit) carbon credits,
C_{jb} mg/m^3, C_{je} mg/m^3, MPC_j, mg/m^3 – initial, final and maximum permissible concentration of the j-th type of toxic substances in emissions,
ρ, ρ_e – density of combustion products at the outlet from the pipe, kg/m^3, calculated (at a calculated temperature t_a) and benchmarking (at the temperature $t_e = 150°C$),
ρ_{ar} – density of atmospheric air, kg/m^3,
w^r_e, u^r_m – dimensionless velocities of the jet and wind at the cross section of the pipe mouth with height H, m, and diameter D, m,
C_u – capacity utilization.

The values of w^r_e, u^r_m are obtained by scaling the real velocity of the jet exit from the pipe w_e, calculated at the reference temperature $t_e = 150°C$, and the velocity of the wind um, according to the minimum admissible (for reasons of stability of the result of a numerical experiment) jet exit velocity $w = 1$ m/s and calm speed $u_{calm} = 1$ m/s. Formula (2) is valid under the following restrictions on the speed of the jet and the wind speed: $w_0 \geq 1$ m/s; 1 m/s $< u_m <$ 7 m/s; $u_m/w_0 < 3$.

The estimated parameter *EER* was obtained from a comparison of energy costs for removing from emissions and from a reference gas mixture of CO_2 and H_2O with a decrease in their concentrations to the actual background content in an unpolluted atmosphere. An analysis of the energy consumption of possible methods for removing CO_2 and H_2O showed that it is convenient to take condensation at atmospheric pressure as a calculation method. The energy consumption $E^{dn}_{a\,H_2O} + E^{dn}_{a\,CO_2}$ for removing the heat of condensation of CO_2 and H_2O from emissions is divided to the total energy consumption E_a for cooling the emissions, taking into account the condensation of the CO_2 and H_2O contained in them:

$$EER = 1 - \frac{E_{aH_2O}^{dn} + E_{aCO_2}^{dn}}{1{,}1E_a} \tag{3}$$

Ultimately, the *EER* parameter characterizes the efficiency of systems in terms of the type of fuel used and the method of its combustion, regardless of the performance of the systems. For facilities that use hydrocarbon gases and do not use any technologies that lead to a change in CO_2 and / or H_2O emissions (for example, steam injection into the furnace to suppress NO_x, etc.), the value of the parameter changes insignificantly and is usually within the range 0.55...0.60. The *EER* value will change significantly during the combustion of artifical gases and/or hydrogen fuel.

Dimensionless numerical indicators R and η_{COMP} allow you to numerically compare production facilities for the emission of toxic pollutants and greenhouse gases. The complex indicator of the efficiency of energy generation and cleaning of emissions η_{COMP} in the presence of greenhouse gases in them is the product of:

$$\eta_{COMP} = EER \times \mathrm{T}_1 = EER \times (\mathrm{T}_1/\mathrm{T}_2) \times \mathrm{T}_2 \tag{4}$$

The *EER* factor determined by (3) takes into account the energy costs for a hypothetical return of the atmosphere quality in order to avoid possible climate changes on a global scale. This condition is realized through the energy-ecological rating coefficient of perfection of the *EER* systems, which represents the efficiency of the systems under consideration in the form of a dimensionless energy consumption for the restoration of the quality of the environment.

The next factor ($\mathrm{T}_1/\mathrm{T}_2$), nominally represents the ratio of dimensionless times of filling the control volume of the expert assessment V, m^3 with polluting components T_1 and emission T_2. In essence, this is a weighted average ceiling norm (the maximum acceptable in terms of the requirements for limiting greenhouse gas emissions and the maximum permissible according to the hygienic standards of harmful effects):

$$\frac{\mathrm{T}_1}{\mathrm{T}_2} = \frac{\sum_{i=1}^{m}\left(BC_i \cdot GWP_{i100}\right)}{\sum_{i=1}^{m}\left(C_{iAAU} \cdot GWP_{i100}\right)} \prod_{i=1}^{m}\left(2 - \frac{C_{ie}}{C_{ib}}\right) + \frac{\sum_{j=1}^{n} \text{ПДК}_j}{\sum_{j=1}^{n} C_{je}} \prod_{j=1}^{n}\left(2 - \frac{C_{je}}{C_{jb}}\right) \tag{5}$$

In the first term of expression (5), as the final concentration of the greenhouse pollutant, the maximum acceptable carbon allowances concentrations C_{iAAU}, mg/m^3, of greenhouse gases emitted are used, normalized using the global warming potentials GWP_{i100} to the equivalent CO_2 emission, mg CO_2-eq/m^3, in form $\sum_{i=1}^{m}\left(C_{iAAU} \cdot GWP_{i100}\right)$.

The C_{iAAU} value is determined by M_{AAU}, t CO_2-eq/year. This is the emission ceiling (permissible mass emission) of greenhouse gases equal in value to the *AAU* (Assigned Amount Unit) carbon quota. The corresponding maximum permissible carbon emissions concentration of C_{iAAU} GWP_{i100}, mg CO_2-eq/m^3, can be approximated through the second emission consumption *W* of the source as 101.5 M_{AAU}/W. In the future, instead of M_{AAU}, it is necessary use the current limits on the greenhouse gases, which, apparently, will be adopted soon.

In any case, greenhouse gas control measures are intended to ensure that the existing background concentration *BC* is not exceeded by a certain amount. Therefore, to characterize the change in the quality of the atmosphere due to the emission of a greenhouse pollutant, as the concentration scale is take the sum of the background concentrations of the emitted gases B_{Ci}, which, in terms of mg CO_2-eq, has the form $\sum_{i=1}^{m}\left(BC_i \cdot GWP_{i100}\right)$. An analogue of the maximum permissible emission of MPE, here is the intensity of greenhouse gas emissions, which corresponds to the value of a carbon quota of the type AAU $W\sum_{i=1}^{n}\left(C_{iAAU} \cdot GWP_{i100}\right)$. Taking this into account, the time τ_1 for filling the control volume of the expert assessment V with greenhouse gases from zero to their background concentrations (in terms of mg CO_2-eq) will be:

$$\tau_1 = \left(V\sum_{i=1}^{n} BC_i \cdot GWP_{i100}\right) \Bigg/ \left(W\sum_{i=1}^{n} C_{iAAU} \cdot GWP_{i100}\right), \qquad (6)$$

and at dimensionless form:

$$\mathrm{T}_1 = \left(V\sum_{i=1}^{n} BC_i \cdot GWP_{i100}\right) \Bigg/ \left(\tau_0 W\sum_{i=1}^{n} C_{iAAU} \cdot GWP_{i100}\right). \qquad (6a)$$

In expressions (6, 6a), the value of the control volume of the air space around the emission source V, m^3, for expert assessment of the intensity of atmospheric pollution, is determined by the formula:

$$V = 100\pi H^2 \left\{ H + D\left[\mathrm{w}_0^{\mathrm{r}} \left(1{,}239 - 0{,}147\ \mathrm{u}_{\mathrm{m}}^{\mathrm{r}}\right) - 0{,}514 \right] \frac{(\rho_{ar} - \rho)}{(\rho_{ar} - \rho_e)} \right\}. \quad (7)$$

Formula (7) was obtained on the basis of numerical experiments by the author of this article (Ziganshin & Sivkov 2016). It is a refinement to a formula similar in structure (Berlyand & Genikhovich 1971, Berlyand & Kiselev 1972), which was the basis for the first Russian normative method for dispersing pollutants OND-86, on the basis of which programs of the type UPRZA "Ecolog" and its modern improved version of the UPRZA "Eco Center" were further developed. The main refinement according to formula (7) consists in determining the effective emission height, taking into account the height of the emission plume rise above the source, which makes it possible to more accurately reflect the differences in emission sources along the height, the diameter of the mouth the pipe and by the rate of release into the atmosphere.

The proposed technique is relatively simple and fairly transparent. Calculations performed for generating enterprises (without of nuclear and hydropower) show the possibility of easy adaptation of the methodology to local conditions, for example, when working with underutilized capacities, when using hydrogen fuel and / or alternative energy sources. At present, a calculation program has been drawn up according to the proposed methodology, which is embedded in the software product for automating the activities of Russian enterprises "1C: Enterprise". Similar software are available at EU enterprises.

4. Conclusion

The versatility of the methodology proposed in this paper allows joint to ISO 50001, complementing the local results of the enterprise with a universal rating on greenhouse gases, showing true achievements in the direction of low-carbon. According to the ratings of enterprises, the rating of the region is easily assembled, and according to it – the national rating. The practice of collecting data according to this scheme has been tested around the world with ozone-depleting and greenhouse gases, and it works well. But today there are no methods with the ability to generalize results at all levels of activity – local (enterprise or region), national (state or region) and global. For example, for one of the most powerful COMBI systems, it is possible to obtain data only for regions and EU countries based on long-term forecasts for EU countries. Therefore, in the COMBI system, it is fundamentally impossible to work with enterprises, and, therefore, it is impossible to work with ISO 50001. The method proposed in this work provides transparent numerical criteria that allow you to correctly determine the low-carbon of the breakthrough technology and compare them with traditional ones, providing reliable tools for monitoring the achievement of low-carbon by enterprises, regions and states.

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