Energy Efficiency Criteria of a Renewable Energy System

Intro

The Energy Transition, launched around the world, provides for the replacement of Fossil-Fuels energy systems (FFS) with Renewable Energy systems (RES). Director-General of the International Renewable Energy Agency, Adnan Z. Amin stated that the **main goal of the Energy Transition is to reduce global greenhouse gas emissions and prevent the most serious effects of climate change**. This goal is hereinafter referred to as the Main Goal. A report commissioned by the German government concluded that the size of the global market for environmentally-friendly power generation and storage was approximately €313 billion in 2011 and would exceed €1 trillion by 2025. It follows from this document that the second goal of the Energy Transition is economic growth. This goal is hereinafter referred to as the Second Goal. It is further accepted as an axiom that increasing the energy efficiency of RES contributes to the achievement of the Main Goal, and the performance of any work related to RES contributes to the achievement of the Second Goal.

Modern energy uses many types of RES. They are called "environmentally friendly" because in their work places there is practically no emission of greenhouse gases. It did not make sense to calculate the energy efficiency of RES when they were made in single copies in garages, from waste and in their free time from their main work. Moreover, all of the above has a positive impact on the environment, developed the creativity of people and improved their well-being. Therefore, their main task was to realize any RES regardless of their energy efficiency.

The Energy Transition involves the massive use of RES, which greatly increases the importance of their energy efficiency in achieving the Main Goal. Energy sciences use an **efficiency factor** (**Ef**) to evaluate the energy efficiency of RES. It shows what part of the power of the flow of energy from the environment RES converts into usable power. **Ef** takes into account all losses in all RES elements. The following are descriptions of **Ef** of several types of RES, including:

The efficiency factor of RES with solar panels (**Ef_f**) shows how much of the power of the flow of solar energy that has fallen onto the surface of the solar panel is converted into electricity. It takes into account the loss of direct conversion of light energy into electricity, as well as losses in wires, in energy storage, in a converter, etc.

The efficiency factor of RES with a wind turbine (**Ef_w**) shows how much of the power of the air flow acting on the blades of its impeller is converted into electricity. It takes into account losses of direct conversion of wind energy into mechanical energy, mechanical energy into electricity, as well as losses in wires, in energy storage, in a converter, etc.

The efficiency factor of a RES with a water wheel (**Ef_t**) shows how much of the power of the water flow acting on its impeller is converted into electricity. It takes into account losses of the direct conversion of the energy of the water flow into mechanical energy, mechanical energy into electricity, as well as losses in wires, in the energy storage, in the converter, etc.

The first thing that immediately attracts attention when familiarizing yourself with RES projects for the Energy Transition is their gigantic size with relatively low power. Windmills with towers more than 300 meters high and blades more than 100 meters long, kilometer-sized solar panels and huge platforms at sea that weigh hundreds and thousands of tons are the RES prototypes for the Energy Transition. Obviously, for the manufacture of every gram of their design, energy was expended! However, the assessment of their energy efficiency remained in the background, as if they were still made in the garage. Therefore, the appearance of the prototypes raises several practical and theoretical issues related to the achievement of the Main Goal, including:

1 question: "Will there be enough energy is generated by this RES to the producing it himself?"

2 question: “Which RES is able to quickly compensate for the energy spent on its creation from several possible for use?”.

3 question: "How to evaluate the energy cost efficiency of manufacturing RES?".

4 question: “How to evaluate the energy efficiency of converting energy received from the environment into usable energy?”

The above **Ef** does not answer these questions.

Exact answers to the questions posed above will allow humanity to immediately maximize the use of all environmental capabilities of RES in achieving the Main Goal and achieve the design parameters of the Second Goal through the development of RES production.

The lack of accurate answers to the questions posed above or the refusal to use them will force humanity to make mistakes and will not allow to use all the ecological possibilities of RES when achieving the Main Goal. However, this will make it possible to exceed the design parameters of the Second Goal due to the development of RES production, constant alterations and elimination of the consequences of environmental degradation.

The first of the efficiency criteria that we developed which we called **the self-reproduction coefficient** (**K_{sr}**) of RES gives the answers to questions 1 and 2. The second of the efficiency criteria that we developed, which we called **the energy efficiency coefficient** (**K_e**) of RES, is the answer to 3rd question. The third criterion of efficiency, which we called the coefficient **of total energy efficiency** (**K_{ee}**) of RES, is the answer to 4th question.

Self-reproduction of RES

Self-reproduction of RES is its ability to produce energy in an amount sufficient to product a replacement for it self. This ability is calculated through **the self-reproduction coefficient** (**K_{sr}**). We define its value as the ratio of the amount of energy generated by RES during the entire service life to the amount of energy spent on its creation and functioning during the same period. When calculating the energy spent, the energy spent on the manufacture of equipment, materials, transportation and construction works, maintenance, repair, commissioning, routine maintenance, and also the energy of the fuel, including the energy spent on its transportation. To calculate the value of **K_{sr}**, the formula is applied:

$$K_{sr} = \Sigma REn / \Sigma PEn \qquad \text{- formula 1}$$

Symbols in the formula 1:

ΣREn – the total amount of energy generated by RES during its service life;

ΣPEn – the total amount of energy spent on the creation and operation of this RES.

The value of **ΣPEn** is calculated by the formula:

$$\Sigma PEn = \Sigma PEn_1 + \Sigma Pen_2 + \Sigma Pen_3 + \ldots + \Sigma Pen_j + \ldots + \Sigma PEn_J \qquad \text{- formula 2}$$

Symbols in the formula 2:

ΣPEn_1, **ΣPEn_2**, **ΣPEn_3**, …, **ΣPEn_j**, …, **ΣPEn_J** – the total amount of energy spent on the creation and operation of this RES, including: the energy spent on the manufacture of equipment, materials, transportation and construction works, maintenance, repair, commissioning, routine maintenance, as well as fuel energy, including energy, spent on its transportation;

j – work type symbols: j = 1, 2, 3, …, j, …, J.

The **K_{sr}** value of a real RES may be less than 1: **K_{sr}** < 1. This means that during the service life up to its utilization, it produces less energy, compared with the energy spent on its creation and functioning: **ΣREn** < **ΣPEn**. Obviously, taking such a RES for an Energy Transition is unwise because it can never replace FFS. And the combined use of RES and FFS will lead to more intense environmental degradation.

The **K_{sr}** value of a real RES may be equal to 1: **K_{sr}** = 1. This means that during the service life up to its disposal, it produces as much energy as was spent on its creation and operation: **ΣREn** = **ΣPEn**. Obviously, taking such a RES for the Energy Transition is also unwise. Because it can never replace FFS, which will continue to also worsen the environment.

The **K_{sr}** value of a real RES may be more than 1 and reach 10. This means that during the service life up to its utilization, it produces up to 10 times more energy than was spent on its creation and functioning: **ΣREn** > **ΣPEn**. Obviously, this is exactly what RES needs to be used for the Energy Transition. Because it will replace FFS faster and thereby improve the environment, the greater its **K_{sr}**.

Below are examples of calculating **K_{sr}** values for various RES:

EXAMPLE 1

<u>The task:</u>

Calculate the design value of **K_{srf}** for RES_f based on the photo converter.

Initial data:

The total amount of energy that will be generated during the entire service life $\Sigma \mathbf{REn_f}$ = 4380 kWh;

The total amount of energy that will be spent on the creation and operation of this RES_f, including: the energy spent on the manufacture of equipment, materials, transportation and construction works, maintenance, repair, commissioning, maintenance, as well as fuel energy, including energy, spent on its transportation $\Sigma \mathbf{PEn_f}$ = 2738 kWh;

Solution:

$\mathbf{K_{srf}} = \Sigma \mathbf{REn_f} / \Sigma \mathbf{PEn_f} = 4380 / 2738 = 1.6$

EXAMPLE 2

The task:

Calculate the design value of $\mathbf{K_{srw}}$ for RES_w based on the wind turbine.

Initial data:

The total amount of energy that will be generated during the entire service life $\Sigma \mathbf{REn_w}$ = 2891 kWh;

The total amount of energy that will be spent on the creation and operation of this RESf, including: the energy spent on the manufacture of equipment, materials, transportation and construction works, maintenance, repair, commissioning, maintenance, as well as fuel energy, including energy, spent on its transportation $\Sigma \mathbf{PEn_w}$ = 2950 kWh;

Solution:

$\mathbf{K_{srw}} = \Sigma \mathbf{REn_w} / \Sigma \mathbf{PEn_w} = 2891 / 2950 = 0.98$

EXAMPLE 3

The task:

Calculate the design value of $\mathbf{K_{srt}}$ for RES_t based on the water wheel.

Initial data:

The total amount of energy that will be generated during the entire service life $\Sigma \mathbf{REn_t}$ = 24966 kWh;

The total amount of energy that will be spent on the creation and operation of this RESf, including: the energy spent on the manufacture of equipment, materials, transportation and construction works, maintenance, repair, commissioning, maintenance, as well as fuel energy, including energy, spent on its transportation $\Sigma \mathbf{PEn_t}$ = 7802 kWh;

Solution:

$\mathbf{K_{srt}} = \Sigma \mathbf{REn_t} / \Sigma \mathbf{PEn_t} = 24966 / 7802 = 3.2$

Examples 1, 2, and 3 show that the best is a water-wheel-based RES_t at $\mathbf{K_{srt}}$ = 3.2, and the worst is a wind-driven RES_w at $\mathbf{K_{srw}}$ = 0.98. In addition, they show that the use of a windmill should be abandoned because it will not even generate the energy that was spent on its manufacture.

Energy Efficiency of RES

Energy efficiency of RES is its ability to rationally use the energy spent on its creation and functioning. This ability is determined through the value of **the energy efficiency coefficient** ($\mathbf{K_e}$). We define it as the quotient of dividing the difference between the amount of energy generated by RES during its service life and the amount of energy spent on the creation and functioning of this RES to the amount of energy spent on the creation and functioning of this RES. Thus, the calculation of $\mathbf{K_e}$ is based on the same values that were used above in formula 1 when calculating the value of $\mathbf{K_{sr}}$:

$$\mathbf{K_e} = (\Sigma \mathbf{REn} - \Sigma \mathbf{PEn}) / \Sigma \mathbf{PEn} \qquad \text{- formula 3}$$

Symbols in the formula 3 - see above.

Below are examples of calculating $\mathbf{K_e}$ values for various RES:

EXAMPLE 4

The task:
Calculate the design value of $\mathbf{K_{ef}}$ for RES_f based on the photo converter.

Initial data - see above Example 1.

Solution:
$\mathbf{K_{ef}} = (\Sigma \mathbf{REn_f} - \Sigma \mathbf{PEn_f}) / \Sigma \mathbf{PEn_f} = (4380 – 2738) / 2738 = 0.6$

EXAMPLE 5

The task:
Calculate $\mathbf{K_{ew}}$ design value for RES_w based on a wind turbine.

Initial data - see above Example 2.

Solution:
$\mathbf{K_{ew}} = (\Sigma \mathbf{REn_w} - \Sigma \mathbf{PEn_w}) / \Sigma \mathbf{PEn_w} = (2891 – 2950) / 2950 = -0.02$

EXAMPLE 6

The task:
Calculate the design value of $\mathbf{K_{et}}$ for RES_t based on the water wheel.

Initial data - see above Example 3.

Solution:
$\mathbf{K_{et}} = (\Sigma \mathbf{REn_t} - \Sigma \mathbf{PEn_t}) / \Sigma \mathbf{PEn_t} = (24966 – 7802) / 7802 = 2.2$

Examples 4, 5 and 6 show the same result as examples 1, 2 and 3 showed above: the best is a water-wheel based RES_t at $\mathbf{K_{et}} = 2.2$, and the worst is a wind-driven RES_w at $\mathbf{K_{ew}} = -0.02$. They also show that the use of a windmill should be abandoned due to the negative value of energy efficiency.

The reason the same result mentioned above is a strict mathematical relationship between the values of $\mathbf{K_e}$ and $\mathbf{K_{sr}}$, which is represented by the formula:

$\mathbf{K_e} = \mathbf{K_{sr}} - 1$ - formula 4.

Conventions in the formula 4 - see above.

Total Energy Efficiency of RES

The total energy efficiency of RES is its ability to efficiently convert the energy received from the environment into usable energy in combination with the rational use of the energy spent on its creation and functioning. This ability is determined through the value of the **coefficient of total energy efficiency** ($\mathbf{K_{ee}}$). We calculate it as the product of the **Ef** value (see above) of the RES under consideration and its $\mathbf{K_e}$ value by the formula:

$\mathbf{K_{ee}} = \mathbf{Ef} * \mathbf{K_e}$ - formula 5

Conventions in the formula 5 - see above.

The examples of choosing the best RES project for the Energy Transition through Kee from several of the submitted projects are below:

EXAMPLE 7

The task:
Choose the best RES_f project with photo panel through a $\mathbf{K_{eef}}$ value from the RES_{f1}, RES_{f2}, RES_{f3}, RES_{f4} and RES_{f5} projects.

Initial data:
RES_{f1} – $\mathbf{Ef_{f1}} = 0.119$, $\mathbf{K_{ef1}} = 4.8$;
RES_{f2} – $\mathbf{Ef_{f2}} = 0.142$, $\mathbf{K_{ef2}} = 3.01$;
RES_{f3} – $\mathbf{Ef_{f3}} = 0.167$, $\mathbf{K_{ef3}} = 0.6$;
RES_{f4} – $\mathbf{Ef_{f4}} = 0.219$, $\mathbf{K_{ef4}} = 2.55$;
RES_{f5} – $\mathbf{Ef_{f5}} = 0.192$, $\mathbf{K_{ef5}} = 6.5$.

Calculation:
$K_{eef1} = Ef_{f1} * K_{ef1} = 0.119 * 4.8 = 0.571$;
$K_{eef2} = Ef_{f2} * K_{ef2} = 0.142 * 3.01 = 0.428$;
$K_{eef3} = Ef_{f3} * K_{ef3} = 0.167 * 0.6 = 0.1$;
$K_{eef5} = Ef_{f4} * K_{ef4} = 0.219 * 2.55 = 0.557$;
$K_{eef4} = Ef_{f5} * K_{ef5} = 0.192 * 6.5 = 1.248$.

Solution:
The best project is RES_{f5}, in which $K_{eef5} = 1.248$.

EXAMPLE 8

The task:
Choose the best RES_w project with a windmill through a K_{eew} value from the RES_{w1}, RES_{w2}, RES_{w3}, RES_{w4} and RES_{w5} projects.

Initial data:
RES_{w1} – $Ef_{w1} = 0.303$, $K_{ew1} = 5.34$;
RES_{w2} – $Ef_{w2} = 0.494$, $K_{ew2} = 6.13$;
RES_{w3} – $Ef_{w3} = 0.363$, $K_{ew3} = 2.67$;
RES_{w4} – $Ef_{w4} = 0.427$, $K_{ew4} = 1.4$;
RES_{w5} – $Ef_{w5} = 0.563$, $K_{ew5} = -0.02$.

Calculation:
$K_{eew1} = Ef_{w1} * K_{ew1} = 0.303 * 5.34 = 1.616$;
$K_{eew2} = Ef_{w2} * K_{ew2} = 0.494 * 6.13 = 3.026$;
$K_{eew3} = Ef_{w3} * K_{ew3} = 0.363 * 2.67 = 0.97$;
$K_{eew4} = Ef_{w4} * K_{ew4} = 0.427 * 1.4 = 0.598$;
$K_{eew5} = Ef_{w5} * K_{ew5} = 0.563 * (-0.02) = -0.011$.

Solution:
The best project is RES_{w2}, in which $K_{eew2} = 3.026$.

EXAMPLE 9

The task:
Choose the best RES_t project with water wheel through a K_{eet} value from the RES_{t1}, RES_{t2}, RES_{t3}, RES_{t4} and RES_{t5} projects.

Initial data:
RES_{t1} – $Ef_{t1} = 0.298$, $K_{et1} = 3.97$;
RES_{t2} – $Ef_{t2} = 0.416$, $K_{et2} = 4.29$;
RES_{t3} – $Ef_{t3} = 0.671$, $K_{et3} = 5.22$;
RES_{t4} – $Ef_{t4} = 0.54$, $K_{et4} = 2.84$;
RES_{t5} – $Ef_{t5} = 0.808$, $K_{et5} = 3.72$.

Calculation:
$K_{eet1} = Ef_{t1} * K_{et1} = 0.298 * 3.97 = 1.181$;
$K_{eet2} = Ef_{t2} * K_{et2} = 0.416 * 4.29 = 1.783$;
$K_{eet3} = Ef_{t3} * K_{et3} = 0.671 * 5.22 = 3.501$;
$K_{eet4} = Ef_{t4} * K_{et4} = 0.54 * 2.84 = 1.534$;
$K_{eet5} = Ef_{t5} * K_{et5} = 0.808 * 3.72 = 3.004$.

Solution:
The best project is RES_{t3}, in which $K_{eet3} = 3.501$.

EXAMPLE 10

The task:
Choose the best RES project by K_{ee} value from those presented in examples 7, 8 and 9.

Initial data:
RES_{f5} – $\mathbf{K_{eef5}}$ = 1.248;
RES_{w2} – $\mathbf{K_{eew2}}$ = 3.026;
RES_{t3} – $\mathbf{K_{eet3}}$ = 3.501.

Solution:
The best project is RES_{t3}, in which $\mathbf{K_{eet3}}$ = 3,501.

Findings

1. Our proposed calculation formulas and algorithms for their application, which determine the energy efficiency of any RES, are extremely simple; contain technical parameters and operations that are available for measurement, registration, storage and use. Obviously, their use does not require large expenditures, the creation of special equipment and provides the achievement of the Main Goal. Therefore, compliance with the criteria proposed above should be a prerequisite for choosing RES for the Energy Transition.

2. The proposed formulas and algorithms do not contain economic parameters and therefore do not directly affect the achievement of the Second Goal. Therefore, the hope that the business will voluntarily use them to the detriment of profit is in vain.

3. It follows from the above that any project on the use of RES in the framework of the Energy Transition should be checked by the Regulator for compliance with the criteria proposed above in order to achieve the Main Goal.

4. The Energy Transition is global. The damage to the environment that may result from failure to comply with the above criteria will be global. Therefore, there must be global control over its implementation, for example, under the auspices of the United Nations. Its purpose may be to prohibit the mass use of RES, which have the value of the self-reproduction coefficient is less, for example, 2.

5. This article is to inform all interested people about the global danger of the Energy Transition without the control we have proposed.

Ending

The above information is part of the Noologistic Control Technology (NCT) of large-scale industrial facilities. It complements the previously published articles "Noologistic Control Technology", "Boxed software of the Noologistic Control System for multidimensional branch facilities" and «Choosing the best systems based on Renewable Energy in Energy Transition process». The word "Noologistic" in the NCT name comes from the ancient Greek words **νόος** - noo (reasonable) and **λογιτσιχη** - logistics (the art of counting).

We published in this article a description of **the energy efficiency coefficient** ($\mathbf{K_e}$) and **the total energy efficiency coefficient** ($\mathbf{K_{ee}}$), as well as the algorithms for their application for the first time in the world. The purpose of the publication is to inform participants of Energy Transition about the criteria that provide them with the opportunity to design and choose the most energy-efficient RES.
We will publish in the future the technology of choosing the most environmentally efficient RES, first on the emission of greenhouse gases, and then on the generalized environmental impact.

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