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Original Paper

Rational Distribution of Taxpayers' Money Based on a Unified Methodology for Calculating Energy Savings

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Abstract

The article presents the problem of the undetermined methodology for calculating energy savings in production processes, which is the scorecards content of the tender documents of the European Cohesion Policy for the current period until 2027. The consequence of such undetermined approach results in wrong decisions of evaluators and consequently, irrational distribution of taxpayers' money. Presented methodology is a solution that guides the user step by step and results in data that are comparable with each other. The methodology equalizes the possibilities of including companies from different sectors and prevents the creation of non-expert assessments.

Keywords

climate change, energy efficiency, tender, scoreboard, European cohesion policy

1. Introduction

The scorecards of the program documents of the European Cohesion Policy (European Commission, 2020; SVRK, 2017; MGRT, 2021a; GRS, 2020) evaluate environmental contributions from the point of view of reducing greenhouse gas emissions, saving water, using natural renewable building materials and energy savings (DZ, 2020, 2022) Inconsistencies in the monitoring of the energy savings indicator were already present in the public tenders of the 2014-2020 Program period (ARSKTRP, 2021; MKGP, 2021a, 2021b; MGRT, 2021b; SPS, 2022), and were preserved in the tenders of the Instrument for Recovery (SPIRIT, 2022a, 2022b, 2022c, 2022d) they even escalated during the calls for the Multiannual Financial Framework for the period 2021-2027 (European Commission and SVRK, 2022; European Parliament and Council, 2018). The methodology remains undefined, while the desire to reduce the impact on the environment is increasing. Thus the increase in motivation for research or unambiguous definitions of the methodology and influential parameters for calculation of energy savings in production processes (Požarnik, 2016b).

The method of calculation and argumentation is currently left to the applicants, which leads to unprofessional, incomparable estimates of energy savings (SPIRIT, 2022b) and, as a result, to an unfair allocation of points (Mohar & Požarnik, 2018). Over 15% (see Chapter 4) of very good projects are deprived of co-financing, as their evaluations are either unprofessional or incomparable with each other.

The purpose of this paper is to present a methodology for calculating energy savings of manufacturing companies, which justifies the reduction of annual energy consumption per product unit.

2. Method

The methodology presented below guides the applicant from the initial determination of the influencing parameters on the reduction of energy consumption to the final equation for calculating the reduction of annual energy consumption.

The condition for using the methodology is that the company uses production machines in production that requires electricity to operate. The field of production activities does not affect the use of the methodology. The suggested methodology is suitable for all companies (SMEs, large companies), engaged in the production of products from the metal processing industry, wood industry, rubber industry, glass industry, textile industry, food industry, pharmacy...

The methodology consists of seven steps that guide the user from determining individual factors based on machine specifications, field of application, type of product, to the calculation of total energy savings. The methodology is partly based on precisely specified calculation procedures, and partly on experiential factors, which are formed on the basis of years-long usage of certain machines or the production of certain products. Each individual step is described in more detail below.

2.1 The Basis of the Methodological Approach

The basis of the methodological approach for calculation of energy savings is the following equation:

$$i_1 = i_0 * (1 - \mu) \tag{1}$$

the following applies:

- i_0 – annual electricity consumption per product unit before investment,
- i_1 – annual electricity consumption per product unit after investment,
- μ – total electricity savings, as the sum of individual savings for individual products.

This is a general equation that applies both at the level of the entire production/plant and at the level of individual machines in the plant. The methodology further describes the process at the level of an individual machine.

The annual electricity consumption per product unit is defined as the annual electricity consumption for a specific product, divided by the number of these same products, produced per year.

$$i = \frac{E}{N} \tag{2}$$

the following applies:

- E – annual electricity consumption for a specific product,
- N – number of manufactured products per year.

2.2 Calculation of Total Electricity Savings

Electricity savings are defined as the sum of individual savings:

$$\mu = \sum_{j=1}^{k} \mu_j \tag{3}$$

the following applies:

- k –number of individual products that are manufactured on the new machine,
- μ_j – electricity saving for product j,
- j – serial number of the individual product.

In most cases, the new production machine will not produce just one product, but rather a series of different products that are not comparable to each other. Since we are interested in saving electricity per product unit, it is necessary to determine what proportion of the machine occupancy is allocated to each product. Based on data from the previous or reference production, machine occupancy factors are determined for each product.

2.3 Calculation of Electricity Savings for Each Product

The electricity saving for an individual product (μ_j) is defined as the product of the machine occupancy factor for an individual product (ρ_j) and the total electricity saving by area for an individual product ($\mu_{j,P}$).

The areas of electricity savings for each product are efficiency of drives, inclusion of digitalization, reuse of waste heat, efficiency of integrated lighting, machine speed, machine precision, machine multitasking. Not all areas are equally represented in different production processes. Therefore, in chapter 2.5 of the methodology, we calculate individual electricity savings by area based on the initial factor of electricity savings and the factor of the use and involvement of the new production machine in the existing production process. In chapter 2.4 of the methodology, the individual savings by area are added up, providing us with the total electricity savings by area for each product.

The machine occupancy factor for an individual product tells us in what proportion the individual product occupies the machine. The maximum occupancy rate of the machine is 1, which means that the machine is only used for this particular product at all times.

$$\mu_j = \rho_j \cdot \mu_{j,P} \tag{4}$$

the following applies:

- ρ_j – machine occupancy factor for an individual product,
- $\mu_{j,P}$ – total electricity savings by area for product j, as the sum of individual savings by area for product j.

2.4 Calculation of Total Electricity Savings by Area for Each Product

The total electricity savings by areas for an individual product are defined as the sum of the individual savings by area. These areas are described in the previous point of the methodology.

$$\mu_{j,P} = \sum_{n=1}^{m} \mu_{j,P,n} \tag{5}$$

the following applies:

- m – the number of areas by which individual electricity savings are calculated,

- $\mu_{j,P,n}$ – individual electricity savings for product j and area n,
- n – sequence number of the area.

2.5 Calculation of Individual Electricity Savings by Area for Each Product

The individual savings by area are defined as the product of the use and involvement factor and the initial individual savings according to the machine specifications.

$$\mu_{j,P,n} = f_{j,n} \cdot \mu_{izh,n} \tag{6}$$

the following applies:

- $f_{j,n}$ – factor of efficiency and involvement of the new production machine for product j and area n,
- $\mu_{izh,n}$ – initial individual electricity savings according to machine specifications for area n.

The introduction of the factor of efficiency and involvement of the new production machine is necessary, since the initial savings, based on the machine specifications, are not authoritative data for direct use in the formula for calculating the reduction of electricity consumption.

2.6 Determination of Initial Individual Electricity Savings ($\boldsymbol{\mu_{izh,n}}$)

The initial individual electricity savings are:

- savings due to the necessary lower total power of the new production machine or higher efficiency of the machine due to (calculation of factors based on the methods, specified in the rules on methods for determining energy savings (DZ, 2022):
  - use of energy-efficient electric motors,
  - use of frequency converters,
  - use of energy-efficient lighting on machines,
  - use of systems for utilization of waste heat from machines,
- savings due to increased machine capacity due to (factors are usually evaluated):
  - faster tool movements (working movements of the tool, tool feed movements, change of tools),
  - stronger structures with greater rigidity, reduced processing time due to:
    - larger one-time removal of material,
    - greater accuracy and, consequently, a lower number of necessary repetitions of operations,
  - more precise machine operations (processing as such and processing materials),
  - digitalization and automation of the new machine.

The initial individual electricity savings are determined by comparing specifications of the new machine with specifications of the existing machine or reference machine. The initial individual savings of electricity by area are represented by the comparison factor of the specification of the new and reference machine (Ahmad et al., 2022). In individual cases, this factor can only be determined on the basis of the machine's specifications, but in most cases it is still necessary to use a comparative assessment based on the experience of an expert in this field, since the manufacturer does not provide accurate data for all areas, or it is not possible to provide them quantitatively. The expert is the buyer or manufacturer of the new machine, and it is best that the buyer and the machine manufacturer work together to determine the savings. In this way, the "theoretical" initial individual electricity savings by area are determined, which cannot yet be directly used in the set methodology.

Since savings from different areas do not affect different production processes with the same intensity, it is necessary to add the factor of efficiency and involvement of the new production machine in the production process to the initial individual savings of electricity.

2.7 Determination of the Factor of Efficiency and Involvement of the New Production Machine ($\boldsymbol{f_n}$)

To calculate the reduction of electricity consumption per product unit, it is necessary to define the type of product. Based on the determination of the type of product, the efficiency and involvement factor of the new production machine is determined.

The importance of introducing and using the efficiency and involvement factor is shown in the following two examples:

1. <u>An example where the design capabilities of the machine are **more important** than digitalization and automation of the machine:</u>

   A product that requires many changes of different tools, and the processing operations are undemanding, will have a significantly greater impact on electricity savings due to a faster tool replacement, than due to digitalization and automation of the machine.

2. <u>An example where the design capabilities of the machine are **less important** than digitalization and automation of the machine:</u>

   A product that requires a smaller number of tool changes, processing operations and tool paths are demanding, will have a significantly smaller impact on electricity savings due to a faster tool replacement, than due to digitalization and automation of the machine. Through digitalization and automation, machining operations will be planned optimally, with minimal idle tool movements.

Based on the above, it is extremely important to determine the influencing factors as precisely as possible, which in this developed methodology are called factors of use and involvement of the new production machine. With this factor, we determine to what extent the initial individual energy savings due to the new production machine will actually be reflected in the entire production process, which is planned for the product per unit of which the annual reduction of electricity is calculated. Factors are one of the most important data that influence the accuracy of the final result of the methodology. Therefore, it is important that the total savings of electricity (μ) are divided into as many individual savings by area as possible (μ_n). This way, several efficiency and integration factors of the new production machine are determined, which are related to different areas, but the latter are significantly more elementary and easier to determine.

There are 2 different methods available when determining the factor of efficiency and involvement of a new production machine.

These are simple methods of determining the factors of efficiency and involvement of a new production machine, which are based on the assessment of the efficiency and involvement of the machine in the entire process of manufacturing the product. Since these factors are plenty (depending on a certain number of individual areas), the impact of factor error on the accuracy of the final result is significantly smaller.

2.7.1 Determination of Factors Based on Past Experience

This method is considered when the buyer's (applicant's) own experience is available based on already implemented reference projects on production machines in the existing production line.

2.7.2 Determination of Factors Based on Reference Production Machines or Production Lines

This method is used when it comes to the purchase of a completely new production machine, which means diversification of production that cannot be compared with either existing machines or implemented past processes. The method is also used in newly formed companies that are just starting with production and do not yet have their own experience in it.

Reference production machines or production lines in this case are production machines or production lines that carry out the same or similar operations and produce similar products. Reference machines or the lines must meet the minimum energy requirements.

Factors and unknowns that we determine or calculate with the given calculation procedures, are inserted into the superior equations in the methodology, which form a chain until the calculation of the final energy saving.

3. Testing the Methodology on a Case

The following case shows testing of the presented methodology on the example of production company X, which deals with metal processing.

Input data:

Company X uses a 3-axis processing machine with dimensions of the processing table 3500x2000 mm. The machine is intended for the production of 2 types of finished products. Product 1 with external dimensions 3000x1600x800 mm and product 2 with external dimensions 2000x1850x300 mm. The existing machine tool has a tool magazine with 4 different tools (alignment cutter, coarse spiral cutter ∅10 mm, coarse spiral cutter ∅6 mm and fine surface cutter ∅6 mm).

To make product 1, you need the following tools:

- Alignment cutter,
- Coarse spiral cutter ∅10 mm,
- Coarse spiral cutter ∅6 mm,
- Fine aligned milling cutter ∅6 mm,
- Fine spiral cutter ∅4 mm,
- Sinker.

To make product 2, the following tools are needed:

- Alignment cutter,

- Coarse spiral cutter ∅6 mm,
- Fine levelling cutter ∅6 mm.

Both products must be rotated 180 °along the horizontal axis y. This is done with a bridge lift, which is installed above the processing machine. The processing machine is not operating during this time.

Due to the need for more demanding operations, the company buys a new 5-axis CNC processing machine with a processing table measuring 7000x2000 mm. The new machine is equipped with a tool magazine for 12 different tools and an electric motor drive with a nominal electric power of 7.5 kW.

The annual consumption of electricity on the existing machine for processing these products is 4,000 kWh.

3.1 Calculation of Electricity Savings per Product Unit without Using the Methodology

3.1.1 Assessment of Better Utilization of the New Machine

Depending on the specifications of the old and new machine, the user estimates between 10% and 30% greater efficiency of the new machine. The average is 20% higher efficiency of the new machine, which means 20% more products produced per year. Annually, 30 pieces of product 1 and 20 pieces of product 2 are produced on the existing machine. The annual consumption of electricity on the machine for processing these products is 4,000 kWh. The annual consumption of electricity per product is 80.00 kWh/product unit. The calculation is shown in the equation below.

$$i_0 = \frac{E_0}{N_0} = \frac{4000\,kWh}{50\,pcs} = 80.00\,\frac{kWh}{piece} \tag{7}$$

the following applies:

- i_0 – annual amount of electricity consumed per product unit before the investment,
- E_0 – annual amount of electricity consumed before the investment,
- N_0 – number of manufactured products per year before the investment.

Based on estimated greater efficiency, 36 pieces of product 1 and 24 pieces of product 2 will be produced on the new machine. The annual consumption of electricity per product is 66.67 kWh/product unit. The calculation is shown in the equation below.

$$i_{1,1} = \frac{E_0}{N_1} = \frac{4000\,kWh}{60\,pcs} = 66.67\,\frac{kWh}{piece} \tag{8}$$

the following applies:

- $i_{1,1}$ – the annual amount of electricity consumed per product unit after the investment, taking into account only the greater efficiency of the machine,
- N_0 – number of manufactured products per year before investment.

The estimated saving of the new machine due to higher efficiency is 13.33 kWh/product unit.

$$i_{r1} = i_0 - i_{1,1} = 80.00\,\frac{kWh}{piece} - 66.67\,\frac{kWh}{piece} = 13.33\,\frac{kWh}{piece} \tag{9}$$

the following applies:

- i_{r1} – annual savings of electricity per product unit after the investment, taking into account only the higher efficiency of the machine.

3.1.2 Electricity Savings Due to an Energy-efficient Electric Motor

The new machine has an energy-efficient electric motor. According to the rules on methods for determining energy savings (DZ, 2022), the savings of electricity per product unit due to the use of energy-efficient electric motors are 17.24 kWh/product unit.

$$PE_{el.motor} = \left(\frac{1}{\eta_{st}-0.02} - \frac{1}{\eta_{ef}}\right) \cdot P_M \cdot t_M \cdot LF \qquad (10)$$

the following applies:

- $PE_{el.motor}$ – energy savings [kWh/year] due to the use of energy-efficient electric motors,
- η_{st} – the efficiency of a standard electric motor, as determined by the table below,
- η_{ef} – the efficiency of a (new) energy-efficient electric motor (IE3 standard – premium efficiency), as determined in the Table 1 below (DZ, 2022):

Table 1. The Efficiency of Electric Motors

Rated power of the electric motor	η_{st} (standard IE1)	η_{ef} (standard IE3 – premium efficiency)
0.75	0.721	0.840
1.1	0.750	0.853
1.5	0.772	0.863
2.2	0.797	0.875
3	0.815	0.884
4	0.831	0.892
5.5	0.847	0.900
7.5	0.860	0.908
11	0.876	0.917
15	0.887	0.923
18.5	0.893	0.927
22	0.899	0.931
30	0.907	0.936
37	0.912	0.940
45	0.917	0.943
55	0.921	0.945
75	0.927	0.950
90	0.930	0.952
110	0.933	0.954

132	0.935	0.956
160	0.938	0.958
from 200 to 370	0.940	0.960

- P_M – rated electric power [kW] of the new drive electric motor,
- t_M – number of annual operating hours [h] (16 h per day, 250 days → 4000 h)
- LF – load factor, which must be determined on the basis of an analysis of the operation of the concrete drive system; for some general devices up to a power of 22 kW, standardized values can also be used, as specified in the Table 2 below (DZ, 2022):

Table 2. Load Factor (LF)

Rated power of the electric motor	Device type	Load factor (LF)	
		INDUSTRY	SERVICES
0.75-4 4.10 10-22	pumps	0.55 0.58 0.59	0.55 0.60 0.60
0.75-4 4.10 10-22	ventilators	0.53 0.56 0.59	0.60 0.65 0.65
0.75-4 4.10 10-22	air compressors	0.63 0.60 0.68	0.40 0.45 0.45
0.75-4 4.10 10-22	transport systems (conveyor belts)	0.42 0.41 0.51	0.61 0.53 0.49
0.75-4 4.10 10-22	refrigeration compressors	0.60 0.65 0.70	- - -
0.75-4 4.10 10-22	freezing technique	- - -	0.70 0.70 0.75
0.75-4	other	0.34	0.30
4.10		0.39	0.30
10-22		0.45	0.30

$$PE_{el.motor} = \left(\frac{1}{0.860-0.02} - \frac{1}{0.908}\right) \cdot 7.5 \cdot 4000 \cdot 0.39 = 1034.11\ kWh/leto \qquad (11)$$

$$i_{r2} = \frac{PE_{el.motor}}{N_1} = \frac{1034.11\ kWh}{60\ pcs} = 17.24\,\frac{kWh}{piece} \tag{12}$$

the following applies:

- i_{r2} – annual electricity savings per product unit after investment, taking into account only the use of energy-efficient electric motors.

3.1.3 Electricity Savings Due to the Use of Frequency Converters

The new machine has built-in frequency converters. According to the rules on methods for determining energy savings (DZ, 2022), the savings of electricity per product unit due to the use of a frequency converter is 25.77 kWh/product unit.

$$PE_{freq.converter} = \left(\frac{P_M}{\eta}\right) \cdot t_M \cdot LF \cdot f \tag{13}$$

the following applies:

- $PE_{freq.converter}$ – energy savings [kWh/year] due to the use of frequency converters,
- f – energy saving factor due to the installation of the frequency converter – the savings must be determined based on the analysis of the operations of the specific drive system; for simple devices, the standardized savings specified in the Table 3 can be used (DZ, 2022):

Table 3. Average Savings Factor

Type of devices	Average savings factor due to the installation of a frequency converter
pumps	0.28
ventilators	0.28
air compressors	0.12
refrigeration compressors	0.12
transport systems (conveyor belts)	0.12
other	0.12

$$PE_{freq.converter} = \left(\frac{7{,}5}{0.908}\right) \cdot 4000 \cdot 0.39 \cdot 0.12 = 1546.26\ kWh/leto \tag{14}$$

$$i_{r3} = \frac{PE_{freq.converter}}{N} = \frac{1546.26\ kWh}{60\ pcs} = 25.77\,\frac{kWh}{piece} \tag{15}$$

the following applies:

- i_{r3} – annual electricity savings per product unit after investment, taking into account only the inclusion of frequency converters.

3.1.4 Total Electricity Savings per Product Unit

All energy saving areas/parts calculated so far must be added up. The result is a total reduction in annual energy consumption per product unit.

$$i_r = i_{r1} + i_{r2} + i_{r3} = 13.33\,\frac{kWh}{piece} + 17.24\,\frac{kWh}{piece} + 25.77\,\frac{kWh}{piece} = 56.34\,\frac{kWh}{piece} \tag{16}$$

the following applies:

- i_r – annual electricity savings per product unit after investment.

The amount of energy consumed annually per product unit after investment is represented by the equation below:

$$i_1 = i_0 - i_r = 80\,\frac{kWh}{piece} - 56.34\,\frac{kWh}{piece} = 23.66\,\frac{kWh}{piece} \tag{17}$$

the following applies:

- i_1 – annual amount of electricity consumed per product unit after investment.

Following the result, by replacing the existing machine company X will reduce the annual energy consumption per product unit by 70.4%.

$$\mu = \frac{i_r}{i_0} = \frac{56.34\,\frac{kWh}{piece}}{80\,\frac{kWh}{piece}} = 0.704 \rightarrow 70.4\ \% \tag{18}$$

the following applies:

- μ – reduction of annual energy consumption per product unit.

3.2 Calculation of Electricity Savings per Product Unit Using the Methodology

3.2.1 The Basis of the Methodological Approach

The energy consumed per product unit after the investment (i_1) is calculated by multiplying the energy consumed per product unit before the investment (i_0) by the difference between 1 and the proportion of the reduction in annual energy consumption per product unit (μ). The share of reduction in annual energy consumption per product unit is calculated in point 2 of the methodology, where it is named as electricity savings (see Chapter 3.2.2).

$$i_1 = i_0 \cdot (1 - \mu) \tag{19}$$

$$i_1 = 80.00\,\frac{kWh}{piece} \cdot (1 - 0.5812) = 33.50\,\frac{kWh}{piece} \tag{20}$$

$$i_0 = \frac{E_0}{N_0} = \frac{4000\,kWh}{50\,pcs} = 80.00\,\frac{kWh}{piece} \tag{21}$$

3.2.2 Calculation of Total Electricity Savings

Electricity savings are defined as the sum of individual savings. Electricity savings mean the proportion of reduction in annual electricity consumption per product unit. Individual savings for each product are calculated in point 3 of the methodology (see Chapter 3.2.3).

$$\mu = \sum_{j=1}^{k} \mu_j \tag{22}$$

$$\boldsymbol{\mu} = \sum_{j=1}^{2} \mu_j = 0.4649 + 0.1162 = 0.5812 \ \rightarrow \mathbf{58.12}\ \% \tag{23}$$

3.2.3 Calculation of Electricity Savings for Each Product

The electricity savings for each product are calculated as the product of the machine occupancy factor for each product (ρ_j) and the total electricity saving by area for each product ($\mu_{j,P}$), which are calculated in Chapter 3.2.4.

$$\mu_j = \rho_j \cdot \mu_{j,P} \tag{24}$$

The machine occupancy factor is determined by the company on the basis of data from production. The machine occupancy factor for product 1 (ρ_1) means the proportion of working time that was dedicated to processing products 1, the machine occupancy factor for product 2 (ρ_2) means the proportion of working time that was dedicated to processing products 2. The company determined the following factor from the collected data:

$\rho_1 = 0.75$

$\rho_2 = 0.25$

$$\boldsymbol{\mu_1} = \rho_1 \cdot \mu_{1,P} = 0.75 \cdot 0{,}6199 = \mathbf{0.4649} \tag{25}$$

$$\boldsymbol{\mu_2} = \rho_2 \cdot \mu_{2,P} = 0.25 \cdot 0.4649 = \mathbf{0.1162} \tag{26}$$

3.2.4 Calculation of Total Electricity Savings by Area for Each Product

To calculate the total electricity savings by area for an individual product, we need individual savings by area ($\mu_{j,P,n}$), which are calculated in Chapter 3.2.5.

$$\mu_{j,P} = \sum_{n=1}^{m} \mu_{j,P,n} \tag{27}$$

$$\boldsymbol{\mu_{1,P}} = \sum_{n=1}^{6} \mu_{1,P,n} = 0.2155 + 0.0644 + 0.1 + 0.12 + 0.05 + 0.07 = \mathbf{0.6199} \tag{28}$$

$$\boldsymbol{\mu_{2,P}} = \sum_{n=1}^{6} \mu_{2,P,n} = 0.2155 + 0.0644 + 0.01 + 0.04 + 0.025 + 0.02 = \mathbf{0.4649} \tag{29}$$

the following applies:

$\mu_{1,P}$ - total electricity savings by area for product 1,

- $\mu_{2,P}$ - total electricity savings by area for product 2.

For companies X, we select the following areas:

- $n = 1$ – area of influence of drive efficiency: energy-efficient electric motors,
- $n = 2$ – area of influence of the drive efficiency: frequency converters,
- $n = 3$ – area of influence of the machine's multitasking,
- $n = 4$ – area of influence of the machine's digitalization,
- $n = 5$ – area of influence of the machine's accuracy,
- $n = 6$ – area of influence of processing speed.

Areas 1 and 2 are the same as defined in the calculation of electricity savings without using the methodology; all other areas make up the total estimated savings due to better machine utilization, which is used in the calculation without using the methodology. We will evaluate the impact of the listed areas with additional factors.

3.2.5 Calculation of Individual Electricity Savings by Area for Each Product

To calculate individual electricity savings by area, we need the factor of efficiency and involvement of the new production machine for each product ($f_{j,n}$) and the initial individual electricity savings ($\mu_{izh,n}$). The unknowns are defined in the next 2 points of the methodology (see Chapter 3.2.6 and 3.2.7).

$$\mu_{j,P,n} = f_{j,n} \cdot \mu_{izh,n} \tag{30}$$

We insert the calculated parameters in points 6 and 7 (see Chapter 3.2.6 and 3.2.7) into the equation and calculate individual electricity savings by area for each product.

$$\mu_{1,P,1} = f_{1,1} \cdot \mu_{izh,1} = 1 \cdot 0.2155 = 0.2155 \tag{31}$$

$$\mu_{1,P,2} = f_{1,2} \cdot \mu_{izh,2} = 0.2 \cdot 0.3221 = 0.0644 \tag{32}$$

$$\mu_{1,P,3} = f_{1,3} \cdot \mu_{izh,3} = 1 \cdot 0.10 = 0.1 \tag{33}$$

$$\mu_{1,P,4} = f_{1,4} \cdot \mu_{izh,4} = 0.3 \cdot 0.40 = 0.12 \tag{34}$$

$$\mu_{1,P,5} = f_{1,5} \cdot \mu_{izh,5} = 0.1 \cdot 0.50 = 0.05 \tag{35}$$

$$\mu_{1,P,6} = f_{1,6} \cdot \mu_{izh,6} = 0.7 \cdot 0.10 = 0.07 \tag{36}$$

$$\mu_{2,P,1} = f_{2,1} \cdot \mu_{izh,1} = 1 \cdot 0.2155 = 0.2155 \tag{37}$$

$$\mu_{2,P,2} = f_{2,2} \cdot \mu_{izh,2} = 0.2 \cdot 0.3221 = 0.0644 \tag{38}$$

$$\mu_{2,P,3} = f_{2,3} \cdot \mu_{izh,3} = 1 \cdot 0.10 = 0.1 \tag{39}$$

$$\mu_{2,P,4} = f_{2,4} \cdot \mu_{izh,4} = 0.1 \cdot 0.40 = 0.04 \tag{40}$$

$$\mu_{2,P,5} = f_{2,5} \cdot \mu_{izh,5} = 0.05 \cdot 0.50 = 0.025 \tag{41}$$

$$\mu_{2,P,6} = f_{2,6} \cdot \mu_{izh,6} = 0.2 \cdot 0.10 = 0.02 \tag{42}$$

3.2.6 Determination of Initial Individual Electricity Savings ($\boldsymbol{\mu_{izh,n}}$)

The initial individual electricity savings are determined from the specifications of the new machine and the collected data from the real environment. If individual savings for certain areas cannot be determined directly, we estimate them based on the specifications of the new and existing machine.

<u>Initial individual savings for area 1:</u>

For area 1, the initial individual savings are the same as calculated in step 2 of the calculation of electricity savings per product unit without using the methodology (see Chapter 3.1.2).

$$i_{r2} = 17.24 \frac{kWh}{piece}$$

$$\boldsymbol{\mu_{izh,1}} = \frac{i_{r2}}{i_0} = \frac{17.24 \frac{kWh}{piece}}{80 \frac{kWh}{piece}} = 0.2155 \rightarrow \mathbf{21.55}\ \% \tag{43}$$

<u>Initial individual savings for area 2:</u>

For area 2, the initial individual savings are the same as calculated in step 3 of the calculation of electricity savings per product unit without using the methodology (see Chapter 3.1.3).

$$i_{r3} = 25.77 \frac{kWh}{piece}$$

$$\boldsymbol{\mu_{izh,2}} = \frac{i_{r3}}{i_0} = \frac{25.77 \frac{kWh}{piece}}{80 \frac{kWh}{piece}} = 0.3221 \rightarrow \mathbf{32.21}\ \% \tag{44}$$

<u>Initial individual savings for area 3:</u>

The new machine enables multi-tasking due to the larger processing table, which enables 2 different workpieces to be clamped on the table. The table has separate beds in 2 parts, which means that it can be divided into two parts of different sizes, which depend on the dimensions of the workpieces. The separation of the table means that during the processing of the workpiece on one part of the table, deformations are not transmitted or the other part of the table does not shake. In the specific case of company X, this means that while processing product 1 on one part of the table, the operator can rotate and re-clamp product 2 on the other part of the table. As already said, rotating the workpieces in this case is necessary due to the size of the workpieces. The same applies when removing the finished workpiece from the table and clamping a new blank. The machine thus has no gray phases and is constantly in the working cycle. On the existing machine, the idle state due to the rotation of the workpieces on the table represents 10% of the working time. It follows that the initial individual savings due to the multitasking of the new machine amount to 0.10 or 10%.

$\boldsymbol{\mu_{izh,3}} = 0.10 \rightarrow \mathbf{10}$ %

Initial individual savings for area 4:

The new machine is more digitalized than the existing machine. The software makes it possible to optimize the working paths of the tool to achieve higher quality and a shorter processing time. The tool is calibrated automatically, as is the determination of the initial point or initial points of the coordinate system of the workpiece. The setting of the number of revolutions of the spindle and the feed rate takes place through the real-time measurement of the load on the tool and the correction of the parameters, which is consistent with the digital library. The digital library contains the specifications of each tool and the range of permissible parameter values (number of revolutions, feed speed, maximum material removal, permitted types of materials for processing).

Based on the comparison of the specifications of the new and existing machine and the data collected so far on processing on the existing machine, the company estimates the saving of electricity due to the digitalization of the new machine at 0.4 or 40%.

$\boldsymbol{\mu_{izh,4}} = 0.40 \rightarrow \mathbf{40}$ %

Initial individual savings for area 5:

Due to a greater rigidity of the individual parts of the machine, the new machine ensures greater processing accuracy than the existing machine. The individual parts were designed on the basis of numerical simulations with which the development engineers achieved the optimal shape of components to achieve maximum rigidity of the entire system. The tool feed technology is significantly more accurate due to a more precisely manufactured components that make up the feed mechanism (spindle, nut, sensors).

The processing accuracy is specified in the machine specification:

- Processing accuracy of the existing machine: $\pm$0,05 mm,
- Processing accuracy of the new machine: $\pm$0,01 mm.

With the required accuracy of $\pm$0.05 mm, the company had to repeat the same operation 2 times on the existing machine. This will no longer be necessary on the new one. The processing time to achieve the required accuracy will be cut in half, so the initial individual saving due to the processing accuracy is 0.50 or 50%.

$\boldsymbol{\mu_{izh,5}} = 0.50 \rightarrow \mathbf{50}$ %

Initial individual savings for area 6:

In general, all speeds are on average 10% higher than the speed of the existing machine. From this, the company concludes that the savings due to a higher processing speed will be 0.10 or 10 %. The larger tool magazine in the new machine significantly contributes to the higher speed of the machine, because of which it is not necessary to manually change individual tools in the magazine.

$\boldsymbol{\mu_{izh,6}} = 0.10 \ \rightarrow \mathbf{10}$ %

Once we have determined all initial savings for each area, we also determine the efficiency and involvement factors of the new production machine for each area.

3.2.7 Determination of the Efficiency Factor and Involvement of the New Production Machine ($\boldsymbol{f_n}$)

Company X has many years of experience in its field, it therefore decides to determine factors based on past experience.

Determination of factors based on past experience:

Product 1:

Area 1: The energy efficiency of electric motors affects energy savings all the time while the machine is running. Thus the efficiency and involvement factor in this area will be 1.

$\boldsymbol{f_{1,1} = 1}$

Area 2: The impact of the use of frequency converters has a greater effect on energy savings with frequent changes in the speed of the motor drive. In case 1 and 2, it concerns larger workpieces, which are processed at constant machine revolutions 80% of the time, in which optimal engine performance was achieved even on the existing machine via built-in reducers and multipliers. The efficiency and involvement factor in this area is therefore 0.2.

$\boldsymbol{f_{1,2} = 0.2}$

Area 3: The impact of multitasking already covers the involvement of only 10% of the working time, both products benefit from the advantage of the new machine, so the efficiency and involvement factor is 1 in this area as well.

$\boldsymbol{f_{1,3} = 1}$

Area 4: The impact of digitalization is only apparent in demanding tool paths, where path optimization and smart setting of machine parameters are required. For product 1, the company assesses the essential importance of digitalization at 30% of processing. The efficiency and involvement factor in this area is therefore 0.3.

$\boldsymbol{f_{1,4} = 0.3}$

Area 5: The accuracy of the machine affects electricity savings only in processing, where the required accuracy is ± 0.05 mm. This represents only 10% of the total processing for product 1, so the efficiency and involvement factor in this area is 0.1.

$\boldsymbol{f_{1,5} = 0.1}$

Area 6: The biggest contribution to the speed of the machine comes from the larger tool magazine (approx. 80 %), the rest is represented by the actual higher feed speeds and speeds of the dead paths of the tool. For product 1, on the existing machine, due to the small tool magazine, manual replacement of

2 tools in the magazine is required, area 6 therefore has a greater impact here. The company estimates that the efficiency and involvement factor in this area is 0.7.

$\boldsymbol{f_{1,6} = 0.7}$

Product 2:

Area 1: The energy efficiency of the electric motors affects energy savings all the time while the machine is running. The efficiency and involvement factor in this area will therefore be 1.

$\boldsymbol{f_{2,1} = 1}$

Area 2: The impact of the use of frequency converters has a greater effect on energy savings with frequent changes in the speed of the motor drive. In case 1 and 2, it concerns larger workpieces, which are processed at constant machine revolutions 80% of the time, in which optimal engine performance was achieved even on the existing machine via built-in reducers and multipliers. The efficiency and involvement factor in this area is therefore 0.2.

$\boldsymbol{f_{2,2} = 0.2}$

Area 3: The impact of multitasking already covers the involvement of only 10% of the working time, both products benefit from the advantage of the new machine, so the efficiency and involvement factor is 1 in this area as well.

$\boldsymbol{f_{2,3} = 1}$

Area 4: The impact of digitalization is only apparent in demanding tool paths, where path optimization and smart setting of machine parameters are required. For product 2, the company assesses the essential importance of digitalization at 10% of processing. The efficiency and involvement factor in this area is therefore 0.1.

$\boldsymbol{f_{2,4} = 0.1}$

Area 5: The accuracy of the machine affects the electricity savings only in processing, where the required accuracy is ± 0.05 mm. This represents only 5% of the total processing for product 2, the efficiency and involvement factor in this area is therefore 0.05.

$\boldsymbol{f_{2,5} = 0.05}$

Area 6: With product 2 on the existing machine, manual tool change in the magazine is not required, as only 4 tools are required for processing. Area 6 therefore has a significantly smaller impact here than in case of product 1. The company estimates that the efficiency and involvement factor in this area is 0.2.

$\boldsymbol{f_{2,6} = 0.2}$

4. Results

When dealing with the results, a comparison of the calculated electricity savings per product unit without using the methodology (see Chapter 3.1) and the calculated electricity savings per product unit using the methodology (see Chapter 3.2) is shown.

The comparison shows a 12.28 % deviation of the results, which is called the unfairness factor (ω). In the calculation of electricity savings without the used methodology, the result was a 70.4 % reduction in electricity consumption (μ_{BM}), while in the calculation with the used methodology, it was 58.12 % (μ_{ZM}) (see Figure 1). The unfairness factor can be crucial in the project evaluation and the deciding factor as to whether an application will be approved or rejected.

$$\omega = \mu_{BM} - \mu_{ZM} = 0.1228 \rightarrow 12.28\ \% \tag{45}$$

the following applies:

- ω – factor of unfairness (irrationality),
- μ_{BM} – reduction of the annual energy consumption per product unit after calculation without using the methodology,
- μ_{ZM} – reduction of the annual energy consumption per product unit after calculation with using the methodology.

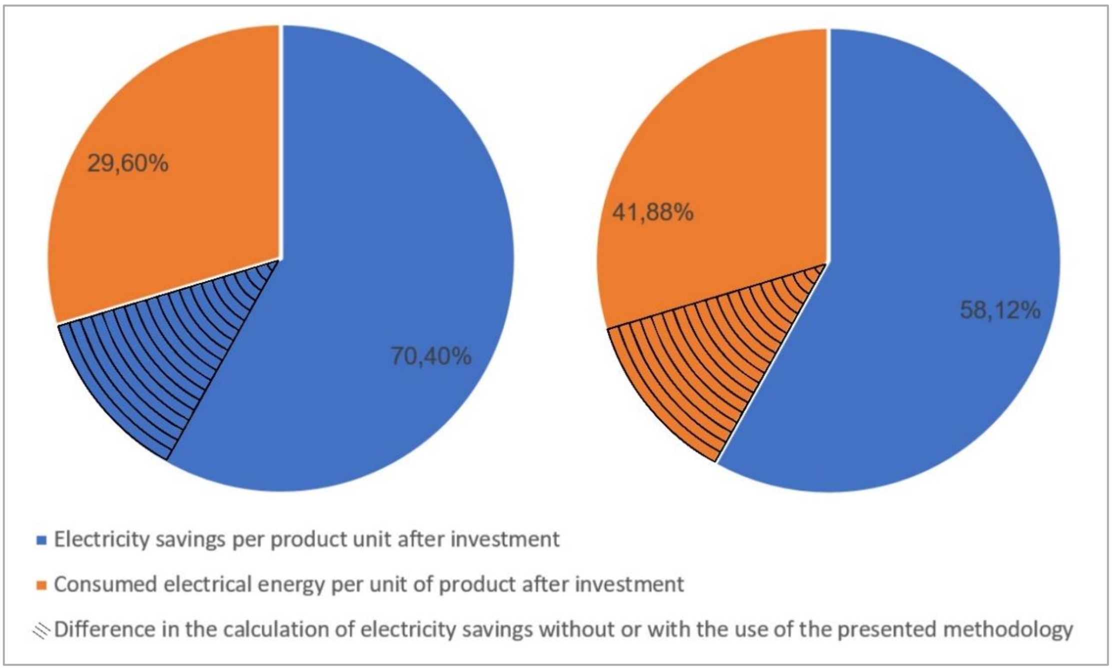


Figure 1. Calculated Electricity Savings without (Left) and by Using the Methodology (Right)

If we look at the unfairness factor from a broader perspective, we can claim that 12.28% of the awarded projects were irrationally evaluated. Based on the number of published tenders that required the calculation of energy savings, and based on the amount of funds tendered, we can determine how efficient the state has been in distributing taxpayers' money. In 2022, 208,445,027 EUR were available in the Republic of Slovenia (Q) (SPS, 2022; SPIRIT, 2022a, 2022b, 2022c, 2022d). Due to sub-optimally assessed projects, which is the result of not using the presented energy savings calculation methodology, 12.28% of ineligible projects were approved (see Figure 2). This means that the state irrationally spent EUR 25,597,049 in 2022.

$$Q_{IR} = \omega \cdot Q = 0.1228 \cdot 208{,}445{,}027\ EUR = 25{,}597{,}049\ EUR \tag{46}$$

the following applies:

- Q_{IR} – irrationally spent funds in the year 2022,
- Q – total funds available.

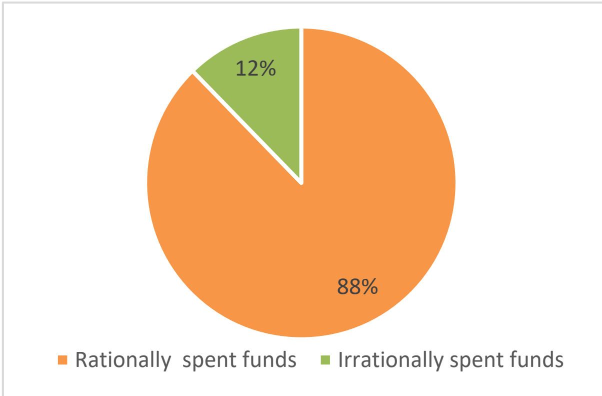


Figure 2. Irrational and Rational Usage of Taxpayers' Money

Figure 3 shows a comparison of the accuracy of the final result with and without using the described methodology. The surface of the coloured area represents the results. The smaller the area, the more accurate the final results. In both cases, the error in determining the initial savings is assumed to be ±10 % and the error in determining the efficiency and involvement factor is ±20 %. In the first case (left on the Figure 3), the factor of efficiency and involvement is not taken into account, so the actual error can be significantly greater than ±20 %.

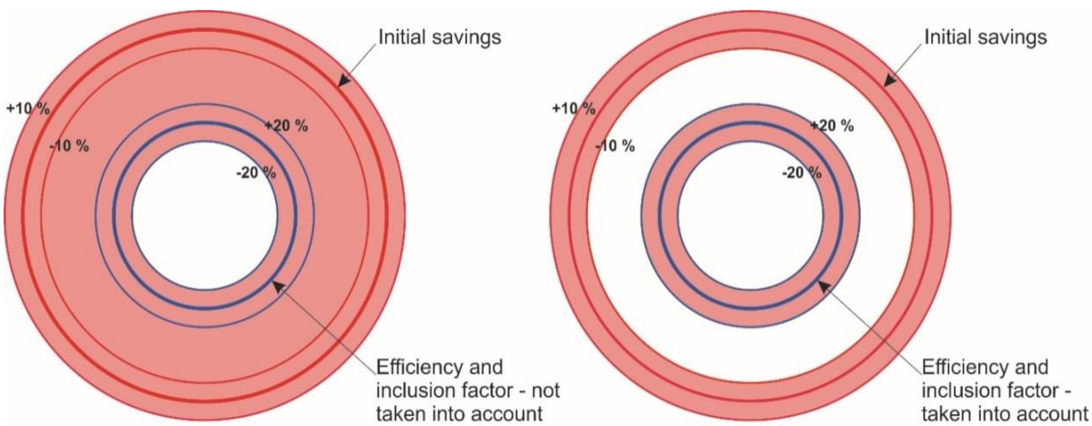


Figure 3. Field of Results without (Left) and Using the Methodology (Right)

5. Discussion

By analysing the results, we determined the connections between individual factors and assessed their influence on the accuracy of the calculation.

The Rules on Methods for Determining Energy Savings and the Act on Efficient Use of Energy already specify methods for determining energy savings (DZ, 2020, 2022; Požarnik et al., 2016b). These methods do not take into account the actual situation in the production in question. For a more accurate calculation and to obtain results that will be comparable with each other, it is necessary to define at least 3 different areas of use of the production machine and take into account the additional efficiency and involvement factor that defines each area.

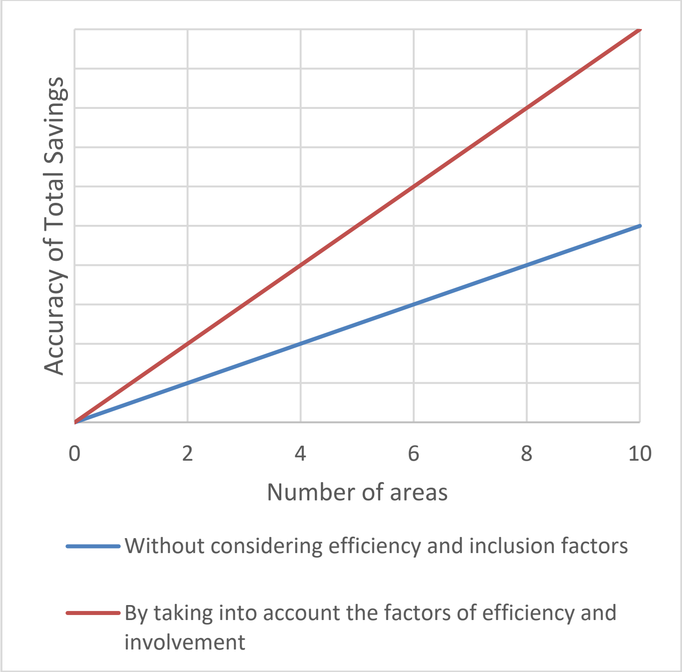
In the presented example, the same company was presented with the same investment, except that in the calculation without using the methodology, the total savings of electricity are estimated on the basis of better utilization of the machine. This assessment is divided into 4 new areas, which enables more accurate assessments of factors that are more elementary and easier to determine in this case if calculating by using the methodology. All areas, including the use of energy-efficient electric motors and frequency converters, which are used in the calculation without using the methodology, are multiplied by factors that assess the real impact of the area in relation to the specific product and conditions on the machine. An experience factor is added, which is determined on the basis of experience and knowledge of the process with which the company deals with the machine. The most important influencing factor in the presented methodology is the factor of efficiency and involvement of the new production machine.

We do not claim that the results of the methodology are completely accurate, as experiential factors are included, but the results of the methodology are significantly more accurate and comparable to each other than if the presented methodology were not taken into account when calculating the energy savings.

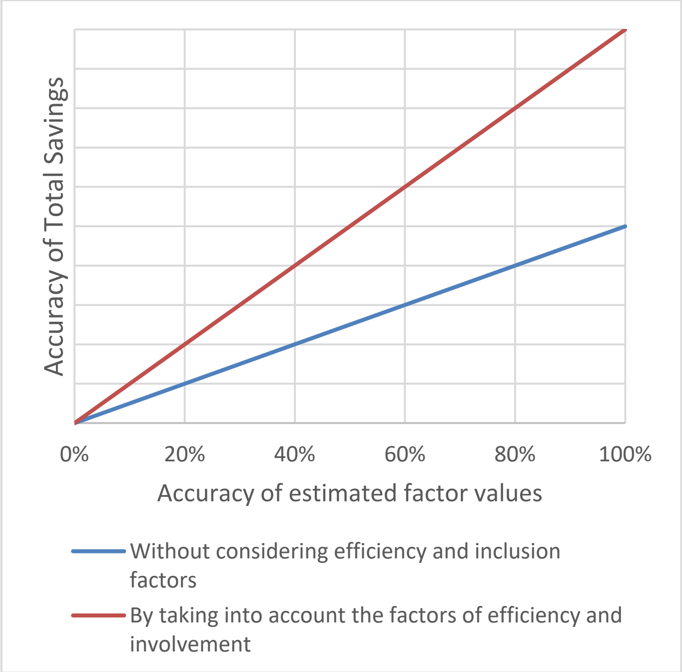
The advantage of the methodology is a separate monitoring of the influence of the areas for each product that will be processed on the machine. In this way, a more precise analysis of individual processes, which are necessary for the production of an individual product, is added to the calculation process.

The same applies to determining the number of areas in which the new production machine affects the overall energy savings. The more we determine these areas, the more elementary and simpler is the determination of the individual efficiency factor and involvement of the new production machine.

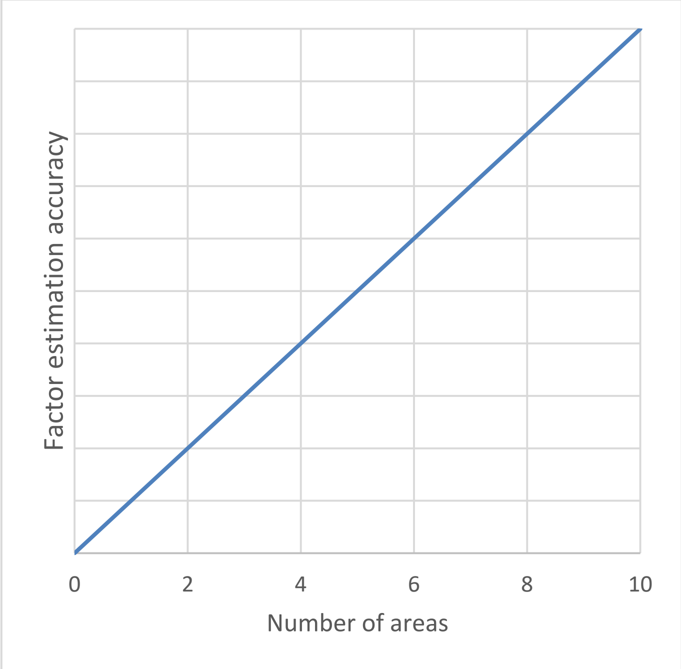
The relationship between the number of areas, the accuracy of the estimated factor values and the accuracy of the total savings is shown in the following graphs.



Graph 1. The Effect of the Number of Fields on the Accuracy of the Total Saving



Graph 2. The Impact of Estimated Values on the Accuracy of Total Savings



Graph 3. Correlation of Factor Estimation Accuracy and Number of Domains

By using the methodology, we get more accurate values of energy savings and more comparable results for different types of production facilities. In this way, we enable a fair distribution of the points from the scorecard of each tender and, in general, a more rational assessment of the applications submitted to the tender.

6. Conclusion

The share of irrationally spent money is significantly too large and must decrease for a successful functioning and development of the Republic of Slovenia in the future. We are convinced that the same applies to any EU member state or for the entire EU area.

The field of results of the presented methodology is significantly smaller than the field of results of undefined and vague methodologies. The use of a uniform methodology for calculating energy savings is absolutely necessary for correct decisions of evaluators and the rational distribution of money.

From the research examples it is clear that:

- without using the methodology: larger field of results → less accurate results,
- with using the methodology: smaller field of results → more accurate results.

We argue, that the only acceptable proof of the investment's contribution to energy efficiency with the developed methodology is presented in this paper, as it enables reproducibility of measurements and monitoring of results. Only in this way will the European Cohesion Policy, the EU's main investment policy, achieve the set goals of The European Green Deal by 2030 (European Commission, 2020).

Due to the non-use of a uniform methodology for calculating energy savings, 12.28 % of submitted projects were irrationally assessed. In 2022, EUR 208 million were available from this area. The value represents the tendered funds of tenders that required the calculation of energy savings. Due to irrationally assessed projects, the state irrationally spent EUR 25 million in 2022, which means that the efficiency of the state in distributing taxpayers' money was extremely low.

The basis for comparable final results is the same calculation methodology. Each methodology contains factors (Mohar et al., 2015) that are evaluated during the calculation itself. Estimation errors have less impact on the accuracy of the final results if they are used in the same methodology.

The developed methodology for calculating the reduction in annual electricity consumption per unit of product, service and process consists of 7 points. The first 5 points are calculated, while the last 2 are experiential and are based on experience and collected data from production activities.

Obtained results are more accurate and, what is essential, comparable with each other. Only by using the same methodology for all companies, we can obtain comparable results and correctly evaluate applications submitted to public tenders.

More accurate and mutually comparable results lead to a fair distribution of points from the scorecards of tenders and, consequently, a rational distribution of taxpayers' money, which is the goal of this article.

The weakness of the methodology remains the assessment of the value of certain factors that appear in the calculation. This cannot be avoided without preliminary measurements, on the basis of which algorithms are designed to determine individual factors.

Meaningful further research is aimed at gathering data and defining precise procedures to determine initial production machine savings as well as efficiency and involvement factors. The development of accurate determination procedures requires field measurements of parameters, processing of collected data, smart data linking and definition of algorithms for determining individual factors (Požarnik et al., 2017). For accurate results that predict the real situation after the inclusion of new production machines, this is the only real solution. At this point, artificial intelligence functionalities must be included in the methodology in the analysis of a large amount of data that is obtained from production through machine vision.

Research in this area makes sense, because in this way the state will save a lot of taxpayers' money, which will be spent on more meaningful, profitable, and beneficial purposes for people.

All reference documents listed in Slovenian are harmonized with the European policy and approved by the European Parliament, as the Republic of Slovenia is a full member of the European Union. The provisions and instructions in the documents apply to the entire European Union.

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