Aggregate indicator for quantification of sustainability to increase energy efficiency of industrial processes

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Abstract. The paper is motivated by the need to provide relevant synthetic indicators, on the basis of which decision makers can evaluate and compare, the extent to which the proposed projects fall within the goals of sustainable development - economic efficiency, environmental responsibility, social solidarity, circular economy, production and responsible consumption. The case study, introduced in the paper, refers to the real and optimal thermal energy balance, made for an installation for the preparation of asphalt mixtures. The approached example took into account the perspective of multiplication and modernization of asphalt mixture preparation stations. Based on the measurements, performed "on site" and the calculations performed, the values of some indicators referring to energy performance, economic efficiency and environmental impact were obtained. The obtained indicators were aggregated in a global indicator, useful for administrative decision makers.

1 Introduction

One of the priorities of Romania's economic consolidation refers to the development and modernization, in sustainable conditions, of the road structure elements. Achieving the aforementioned objectives requires a high consumption of various resources. The energy resource is necessary in most of the construction or remediation works of the road structure sections. The basic material for the works for the construction of the road structure is the asphalt mixture. The energy used in the production stages of the asphalt mixture reaches considerable values. [1]

Energy efficiency, through the consequences of increasing its value, determines the reduction of related consumption and other resources, responding to the desires of sustainable development focused on the formulation: maximizing benefits while minimizing resource consumption and safeguarding the biodiversity of the natural environment. [2]

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The aim of the paper is to propose an aggregate indicator for energy, economic and environmental quantification, to increase the energy efficiency of processes in a plant for the preparation of asphalt mixtures. Based on the experimental data established by carrying out an energy balance and the identification of energy inefficiencies, measures to reduce losses and capitalize on secondary thermal resources are proposed and quantified. The values obtained from the calculations are visualized in a radar diagram, based on which the energy used, the environmental impact, the energy cost and the specific energy consumption are aggregated as an indicator of sustainability. By comparing the indicator of the current state with that of the state obtained after the application of measures aimed at increasing energy efficiency, one can assess the evolution towards sustainability of the explored processes.

Components of stay its preparation of asphalt mixtures [3]

Aggregate household: compartmentalized aggregate storage boxes with elements from reinforced concrete, with concrete platform.

Asphalt preparation plant: hopper of aggregates with bunkers; collector conveyor belt for transporting aggregates in the dryer; silos for storage of limestone filler; "own filler" storage silo - the fraction of dust with a grain similarity to the limestone filler, resulting from the flue gas filtration battery discharged from the dryer.

Bitumen household: **bitumen** storage tanks, thermally insulated, provided with thermal oil coil for heating and maintaining the constant temperature of the bitumen; oil heater coil for heating the thermal oil, fitted in - a transportable container equipped with a gas burner; The bitumen household is located on a retention-type concrete platform.

Ancillary installations: inclined rotary drum dryer, equipped with a gas burner with high thermal capacity; flue gas filter battery discharged from the dryer; hot material elevator; site for final sorting of hot aggregates; hot filler dispenser; mixer; prepared mixer conveyor chip; bunkers storage prepared mix; cloudy dust storage container - the fraction of fine dust resulting from the flue gas filter from the dryer. When it is discharged into the container, it is moistened with water, forming a kind of mud; control cabin.
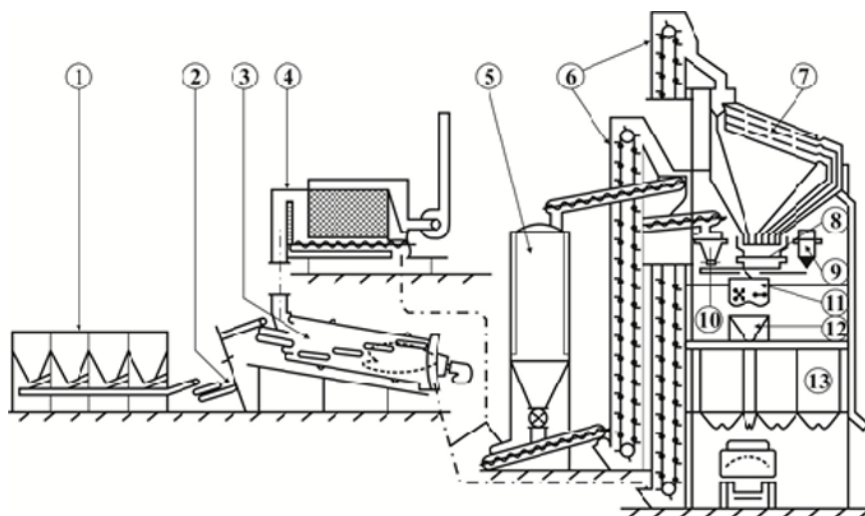

Fig. 1. Installation for batch production of hot asphalt mixtures: 1. dispenser, 2. conveyor, 3. dryer, 4. dust remover, 5. vertical container, 6. bucket elevator, 7. separator screen, 8. aggregate dispenser, 9. bitumen dispenser, 10. filler dispenser, 11. batch mixer, 12. chip, 13. silo for storing the mixture.

The main scheme of composition and operation of an installation for the production of hot asphalt mixtures is presented in Figure 1.

The performance of asphalt mixing plants is essentially determined by the quality and accuracy of the dosing of the components, as well as by the quality and duration of the mixing. Also, the temperature of the material in the various processing phases has a decisive role on the quality of the mixture.

During the technological process of preparation of asphalt mixtures, a series of non - conformities may occur, the probable cause of which is specified in Table 1.

Table 1. Possible non – conformities.

Name of the procedure	Name of non-compliance	Cause
Predosing aggregates	• Improper dosing	• Dosing adjustment • Defective dispensers • Conveyor with incorrect / defective belt
Drying aggregates	• Low final temperature • Improper combustion. • Improper composition and flow	• Defective combustion system • Improper fuel. • Improper operation of the dust removal system • Improper construction / operation. of the dryer
Formal sorting of aggregates	• Improper granulometry / kinds	• Improper operation of sorting equipment • Incorrect selection of sorting equipment
Final dosing of aggregates, bitumen and filler dosing	• Dosage not in accordance with the prescription	• Improper setting dispensers • Fault in dispensers
Mixing mixture composition	• Improper homogeneity. • Low temperature	• Improper operation of mixer • Improper isolation mixer

The aspects mentioned above emphasize the importance of the correct operation of the assembly and the careful and timely maintenance performed. Both the operation regime and the correctness of the operation, as well as the quality maintenance, have considerable effects on the value of the energy used. [4, 5]

2 Synthetic report on the quantitative results of the energy audit

Based on the energy audit and the energy balances, real and optimal, the quantitative and qualitative performances related to the explored processes were quantified, for the real situation and for the optimal situation (achieved following the application of the necessary measures to increase the energy efficiency). The results obtained are highlighted in tables 2 and 3, and diagrams and synthetic situations (Figures 2 and 3) [6].

By adding energy entered, useful and lost, expressed in **toe / year** to obtain the following balance real annual complex the level of firm:

Table 2. Real annually complex balance.

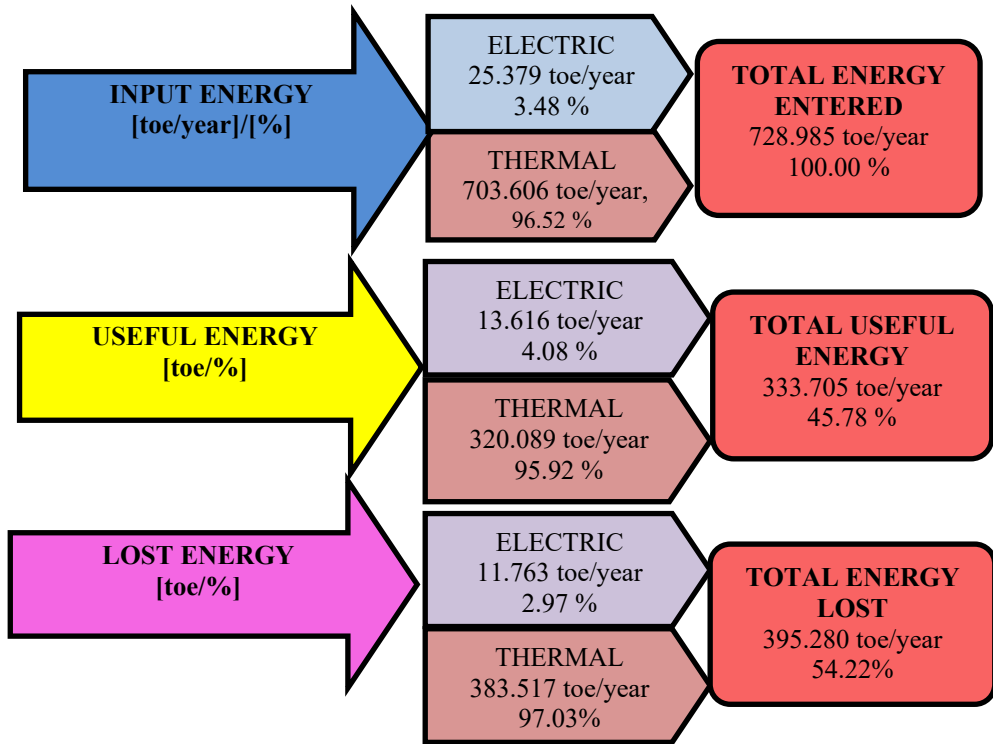| Input energy [toe/year]/[%]		Useful energy [toe/year]/[%]		Lost energy [toe/year]/[%]	
ELECTRIC	THERMAL	ELECTRIC	THERMAL	ELECTRIC	THERMAL
25.379/3.48	703.606/96.52	13.616/4.08	320.089/95.92	11.763/2.97	383.517/97.03
TOTAL ENERGY ENTERED		TOTAL USEFUL ENERGY		TOTAL ENERGY LOST	
728.985/100		333.705/45.78		395.280/54.22	

Fig. 2. Sankey diagram for the real complex annual energy balance.

   Located a summary on data obtained from achieving energy balance complex annual real:
- Total energy used annually - E_{total} = 728,985 toe
- Total thermal energy used annually - $_{Total\ thermal}E$ = 703,606 toe (96.52%)
- Total electricity used annually - $E_{total\ electricity}$ = 25,379 toe (3.48%)
- Total energy utilized useful annually - $E_{total\ useful}$ = 333,705 toe (45.78%)
- Total energy efficiency - η_{total} = 45.78%
- Total annual useful heat recovered - $E_{Useful\ thermal\ total}$ = 320.089 toe (95.92% of the total useful energy)
- Thermoenergetic efficiency - $\eta_{thermoen.}$ = 45.49%
- Total utilized useful annual $_{electricity}$ - $E_{total\ useful\ electricity}$ = 13,616 toe (4.08% of total useful energy)
- Efficiency of electricity use - $\eta_{electroen.}$ = 53.65%
- Total energy lost annually - $E_{pierd.total}$ = 394 280 toe (54.22%)
- Total heat energy lost annually - It's $_{heat\ loss.\ total}$ = 383,517 toe (97.03% of total energy lost)
- Total electricity lost annually - It's $_{electricity\ lost.\ total}$ = 11,763 toe (2.97% of total energy lost).
   Measures to reduce heat consumption
   1. The reduction of the material humidity from 5% to 3% is materialized in the reduction of the specific fuel consumption with: ΔC_{sc} = 7,345 · 10-3 - 6,044 · 10-3 = 1,301 · 10-3 m^3_N / kg material = 1,196 · 10-6 toe / kg material
At the hourly flow of material, the energy saving will be:

$$Gaze_{gas} = 195.15 \ m^3_N / h \qquad (1)$$

$$Te_{t.ep} = 0.179 \text{ tep / h} \tag{2}$$

The measure imposes additional costs related to the arrangement of a canopy over the aggregate depot

The installation of an awning for the aggregate storage ensures the fulfillment of the following objectives:

- protection of aggregates from the effect of rainwater;
- a considerable reduction in the humidity of the aggregates resulting in a reduction in the fuel consumption required for drying.

2. Reducing shutdown times during the technological process leads to the reduction of heat loss by accumulation. These losses are caused by the need to cool the dryer drum to avoid thermal stresses. The value of heat loss is estimated at:

$$\Delta e_{accumulation} = 15960 \text{ MJ / h} = 414.72 \text{ m}^3_N \text{ / h} = 0.381 \text{ toe / h} \tag{3}$$

The measure does not impose additional costs.

3. Maintaining the bitumen temperature at $150\ ^0$ C during dryer shutdown periods reduces energy consumption by:

$$Te_{tep}. = 1.78 \cdot 10^{-6} \text{ toe / kg bitumen} = 0.02 \text{ toe / h} \tag{4}$$

The measure does not impose additional costs.

TOTAL ACHIEVABLE SAVINGS - 0.579 toe / h

NECESSARY INVESTMENTS - ASSESSED VALUE = 1,000,000

The average annual operation duration of the asphalt mixture installation, resulting from statistics is 390 hours / year.

Considering 390 hours / year, the average annual operating time, results in annual savings, achievable due to the reduction of energy consumption, amounting to 0.579 x 390 = 225.81 toe / year.

Estimating the price of a toe at 1772 lei / toe results in an annual saving of 225.81 x 1772 = 400 135 lei.

The payback period is estimated at 1,000,000 / 400 135 = 2,499 years ≈ 2.5 years.

The implementation of the recommended measures leads to the reduction of energy losses and to the reduction of the environmental impact.

By adding energy entered, useful and lost, expressed in **toe / year** to obtain the following balance optimal annually complex the level of firm:

Table 3. Optimal annually complex balance.

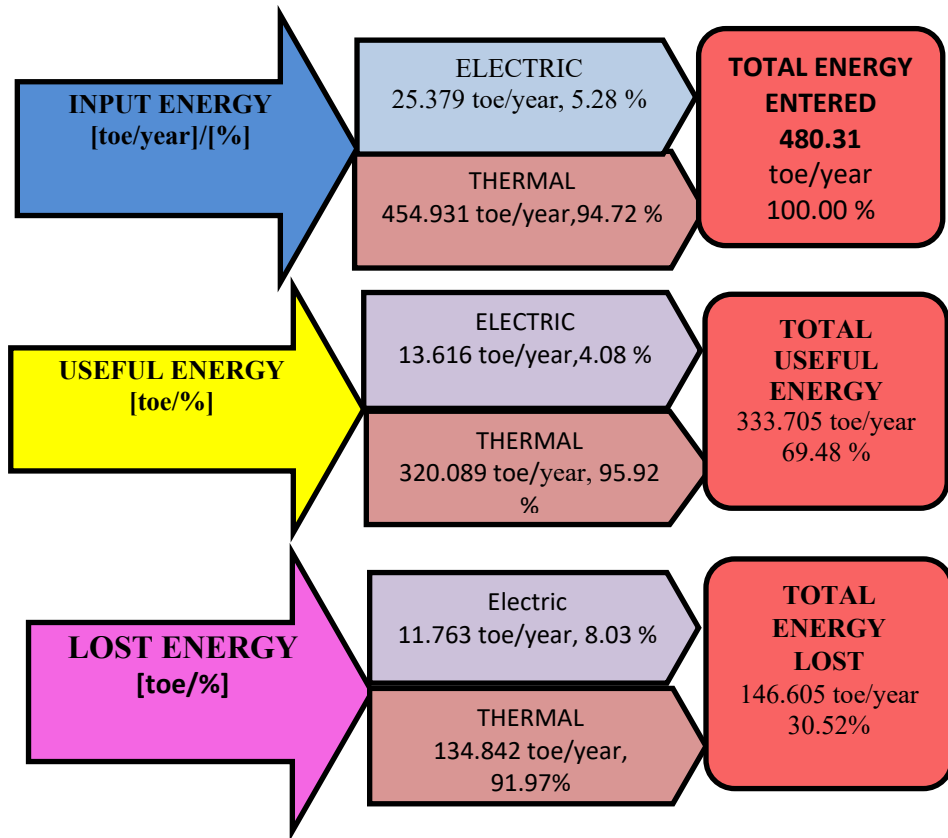| Input energy [toe/year]/[%]		Useful energy [toe/year]/[%]		Lost energy [toe/year]/[%]	
ELECTRIC	THERMAL	ELECTRIC	THERMAL	ELECTRIC	THERMAL
25.379/5.28	454.931/94.72	13.616/4.08	320.089/95.92	11.763/8.03	134.842/91.97
TOTAL ENERGY ENTERED		TOTAL USEFUL ENERGY		TOTAL ENERGY LOST	
480.31/100		333.705/69.48		146.605/30.52	

Fig. 3. Sankey diagram for the optimal complex annual energy balance**.**

Summary statement on data obtained for energy balance after implementation of the proposed measures to increase energy efficiency

- Total energy used annually - E_{total} = 480.31 toe
- Total thermal energy used annually - $_{Total\ thermal}E$ = 454,931 toe (94.72%)
- Total electricity used annually - $E_{total\ electricity}$ = 25,379 toe (5.28%)
- Total energy utilized useful annually - $E_{total\ useful}$ = 333,705 toe (69.48%)
- Total energy efficiency - η_{total} = 69.48%
- Total annual useful heat recovered - $E_{Useful\ thermal\ total}$ = 320.089 toe (95.92% of the total useful energy)
- Thermoenergetic efficiency - $\eta_{thermoen.}$ = 73.35%
- Total utilized useful annual electricity - $E_{total\ useful\ electricity}$ = 13,616 toe (4.08% of total useful energy)
- Efficiency of electricity use - $\eta_{electroen.}$ = 53.65%
- Total energy lost annually - $E_{pierd.total}$ = 146 605 toe (30.52%)
- Total heat energy lost annually - It's $_{heat\ loss.\ total}$ = 134,842 toe (91.97% of total energy lost)
- Total electricity lost annually - It's $_{electricity\ lost.\ total}$ = 11,763 toe (8.03% of total energy lost).

The increase in efficiencies, following the application of energy loss reduction measures, is represented in Figure 4.
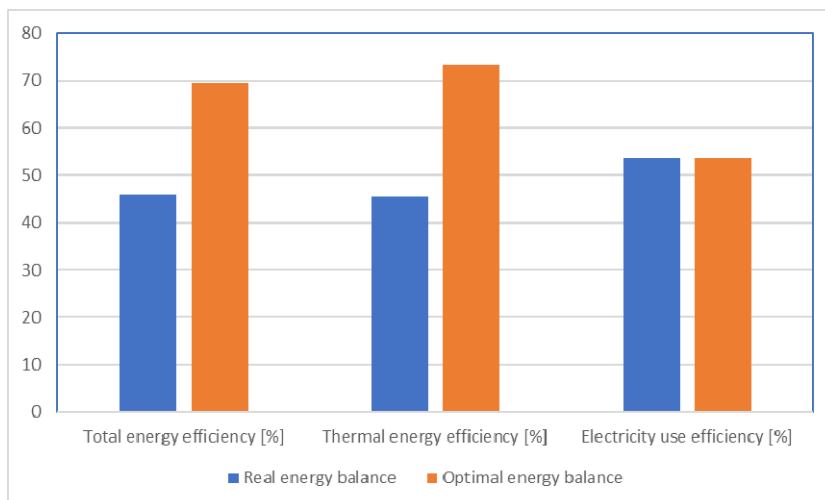
Fig.4. Variation of efficiencies, following the application of measures to reduce energy losses.

3 Proposal of an aggregate indicator for estimating the sustainability of increasing energy efficiency

The proposed indicator must quantify the synergistic effect of the whole:
- ENERGY USED - SYMBOL *E*
- ECONOMIC COST - SYMBOL *C*
- ENVIRONMENTAL IMPACT - SYMBOL *I*
- SPECIFIC ENERGY CONSUMPTION - SYMBOL *S*
Performing the following calculations:
- the sum of the energies used on the company outline, taken from the synthetic summary table of the complex energy balance for the company outline;
- the amount of energy savings achievable by applying the proposed measures;
- determination of the CO_2 footprint related to the energy used;
- specific energy consumption,
- the values shown in Table 4 resulted.

Table 4. The values of the energy indicators after the application of the saving measure.

Name	Current values	Values after single application of measures to increase the energy efficiency	Reduction factor	Discount percentage
ENERGY [MWh / year]	8500	5585	0.657	34.3
MEDIUM IMPACT [tCO2/MWh]	5960	3915	0.6568	34.32
ENERGY COST [thousand lei]	4080	2681	0.6571	34.29
SPECIFIC ENERGY CONSUMPTION [MJ/ton]x10	3250	2420	0.7446	25.54

Based on the data mentioned in the table, a diagram was built (Figure 5) which cumulatively visualizes the synergistic effect of the specified quantities.
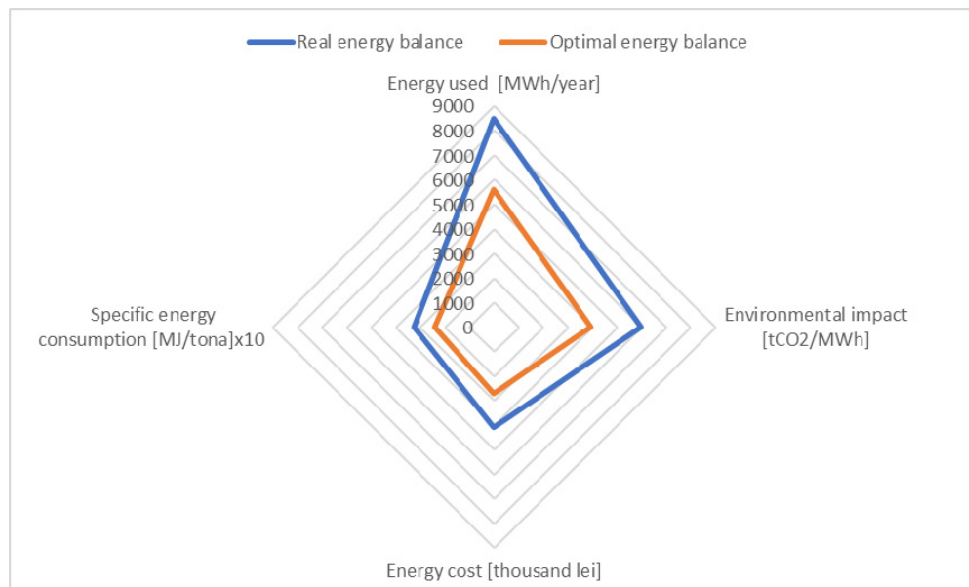

Fig.5. Diagram for calculating the integrated sustainability indicator.

By planning the two surfaces, the values were obtained:

$A_{large} = 28.16 \text{ cm}^2$; $A_{small} = 12.60 \text{ cm}^2$, the surfaces quantifying the cumulative effect of the components: energy-environment-cost- specific consumption.

Assimilating the values of the surface areas with the indicator ***E CIS***, it is possible to establish:

- the reduction factor of the ***E CIS*** indicator by decreasing the energy used:

$$F_{red. \, E \, CIS} = A_{small} / A_{large} = 0.328 \tag{5}$$

- percentage reduction of the ***E CIS*** indicator by applying the proposed technical-organizational measures:

$$R_{proc. \, It \, CIS} = [(A_{large} - A_{small}) / A_{sea}] \times 100 = 55.26 \, \% \tag{6}$$

4 Conclusions

The usefulness of the indicator consists in assembling some components of sustainable development: economic component, ecological responsibility, energy efficiency, also tangenting social solidarity by facilitating the obtaining of cheaper products.

The validation of the validity of the proposed indicator also results by comparing the value of the percentage reduction $R_{proc. \, It \, is \, the \, CIS}$ with the increase of the total energy efficiency, following the application of the proposed technical and organizational measures.

Total energy efficiency for the real balance (table 2) - $_{real} \eta = 45.78\%$, and the total energy efficiency for the optimal balance (table 3) - $_{optimal} \eta = 69.48\%$.

The percentage increase of the total energy efficiency, following the application of the proposed measures, amounts to $\Delta \eta = 51.77\%$, a value close to the percentage reduction of the proposed aggregate indicator.

8

The major advantage of the indicator lies in the concentration of information of a different nature, offering decision makers a significant and useful comparison value, without going into the specific details of the diversity of the evaluated objective.

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