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- SUMMARY -

PERFORMANCE EVALUATION OF THE ENERGY EFFICIENCY SOLUTIONS FOR END-USERS

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Content of this document

CONTENTS OF THE DOCTORAL THESIS 3

INTRODUCTION 6

STRUCTURE OF THE DOCTORAL THESIS 7

3. CRITICAL ANALYSIS OF CURRENT METHODS FOR ASSESSING ENERGY EFFICIENCY 7

➢ Deficiencies of current approaches 8

➢ Improving the methodology for evaluating energy performance 8

4. MULTICRITERIAL EVALUATION OF THE PERFORMANCE OF ENERGY EFFICIENCY INCREASE SOLUTIONS 9

➢ Development of a methodology for evaluating solutions to increase energy efficiency 9

➢ Multicriteria performance indicators 12

➢ Multicriteria evaluation method of energy efficiency solutions for users 13

5. USE OF THE PROPOSED METHOD IN ASSESSING ENERGY PERFORMANCE 20

➢ Designing sustainable development programs for energy systems for use according to the MEPEES method 20

6. VALIDATION OF THE USEFULNESS OF THE METHOD FOR ASSESSING ENERGY PERFORMANCE AND DESIGNING THE SUSTAINABLE DEVELOPMENT PROGRAM FOR FINAL CONSUMERS - CASE STUDIES 20

7. PERSONAL CONTRIBUTIONS REGARDING IMPROVING THE ENERGY PERFORMANCE ASSESSMENT METHODOLOGY 21

➢ General discussions and conclusions 21

➢ Originality and innovative contributions of the thesis 22

➢ Future research directions 24

BIBLIOGRAPHY REFERENCES 25

CONTENTS OF THE DOCTORAL THESIS

ABBREVIATIONS		9
INTRODUCTION		11
1.	Energy efficiency, a key component of current energy policies	13
1.1.	Introduction	13
1.2.	Energy consumption	14
1.3.	Major objectives of energy policies	16
1.3.1.	Improving energy efficiency	17
1.3.2.	Climate change	19
1.3.3.	Renewable energy sources	22
1.4.	Energy policies in the European Union	24
1.5.	Energy policies in Romania	27
1.6.	conclusions	30
2.	Energy performance evaluation	31
2.1.	Methodological developments for energy efficiency assessment	31
2.1.1.	Overviw	31
2.1.2.	Approaches identified in the international practices	32
2.1.3.	Evaluation methodologies used in the European Union	36
2.1.4.	Evaluation of energy performance in Romania	37
2.2.	Indicators for assessing the energy efficiency	39
2.2.1.	Introduction	39
2.2.2.	Energy intensity	41
2.2.3.	Specific energy consumption	42
2.2.4.	The potential for energy savings	43
2.2.5.	Energy efficiency indicator	44
2.2.6.	Annual unit savings in buildings	45
2.2.7.	Achieved energy savings	46
2.3.	Other indicators used in the evaluation of energy performance	46
2.3.1.	Energy consumption indicators	47
2.3.2.	Indicators of operating condition, elasticity and flexibility of the end-use energy system	48
2.3.3.	Indicators for assessing the environmental impact	52
2.3.4.	Indicators of financial evaluation of measures to increase energy efficiency	53
2.4.	Conclusions	54
3.	Critical analysis of current methods for assessing the energy efficiency	57
3.1.	Barriers in investing the energy efficiency	57
3.2.	Analysis of currently used practices	59
3.3.	Deficiencies of current approaches	62
3.3.1.	Deficiencies in the evaluation of energy investments	62
3.3.2.	Specific energy efficiency funding syncopes	64
3.4.	Improving the methodology for energy performance evaluation	66

3.4.1.	Objectives in designing an improved method to assess the energy efficiency	67
3.4.2.	General research methodology	68
3.4.3.	Holistic approach and multicriteria analysis of the energy performance	72
3.4.4.	Criteria for energy efficiency projects evaluation	74
3.5.	Conclusions	75
4.	Multicriteria evaluation of the performance of the solutions to increase energy efficiency	77
4.1.	Introduction	77
4.2.	Development of a methodology for evaluating solutions to increase energy efficiency	78
4.2.1	Objectives pursued by developing the methodology	78
4.2.2	The principles underlying the proposed methodology	79
4.2.3	Description of the proposed methodology	81
4.3.	Multicriteria performance indicators	90
4.3.1.	Propose a classification of measures to increase energy efficiency	90
4.3.2.	Synthesis of the selected indicators for evaluating the energy performance	96
4.3.3.	Weighted allocations related to evaluation criteria	108
4.3.4.	Proposing and developing complex indicators	108
4.4.	Method for multicriteria evaluation of energy efficiency solutions to end-users	120
4.4.1.	Introductory notions	120
4.4.2.	Algorithm of the proposed method	123
4.4.3.	Individual assessment of the measures to increase energy efficiency	128
4.4.4.	Proposal of a model to conceive the energy efficiency solutions	130
4.4.5.	Energy efficiency solutions evaluation	135
4.4.6	Monitoring the performance of the energy system in operation	136
4.5.	Discussions and conclusions	137
5.	Use of the proposed method in assessing energy performance	139
5.1.	Sustainable investment planning	139
5.2.	Designing sustainable development programs for energy use systems	141
5.2.1.	Computer calculation model for energy efficiency assessment	141
5.2.2	A new concept for energy sustainable development program	142
5.3.	Discussions and conclusions	146
6.	Validation of the usefulness of the energy performance assessment method and design of the sustainable development program for final consumers - Case studies	147
6.1.	Application of the MEPEES method for case study 1	147
6.1.1.	Analysis of the initial situation	148
6.1.2.	Multicriteria evaluation of the measures to increase energy efficiency	154
6.1.3.	Determining the relative performance of measures to increase energy efficiency	160
6.1.4.	Designing energy efficiency solutions	163

6.1.5.	Determining the overall performance of solutions to increase energy efficiency	166
6.2.	Sustainable development program designed according to the MEPEES method - case study 2	167
6.2.1.	Presentation of general data on the analyzed energy use systems	167
6.2.2.	Energy sustainable development program	169
6.2.3.	Financial analysis of investment projects	173
6.3	Using the MEPEES method for an industrial consumer - case study 3	177
6.3.1	Baseline situation	177
6.3.2	Determining the energy performance of the energy system	181
6.4	Conclusions	182
7.	Contributions to improve the methodology for energy performance evaluation	183
7.1.	General discussions and conclusions	183
7.2.	Originality and innovative contributions of the thesis	185
7.3	Future directions of research	187
BIBLIOGRAPHICAL REFERENCES		189
LIST OF FIGURES		201
LIST OF TABLES		203
ANNEXES		205
Annex 1- Centralization of the score allocated to multicriteria indicators for the evaluation of energy efficiency solutions		205
Annex 2.1 - Forecast of income, savings and expenditure flows for investment in the implementation of the energy sustainable development program to the end-use system - type 1		209
Annex 2.2 - Forecast of income, savings and expenditure flows for investment in the implementation of the energy sustainable development program to the end-use system - type 2		210
Annex 3.1 - Forecast of the financial flow of the investment in the execution of the energy sustainable development program to the end-use system - type 1		211
Annex 3.2 - Forecast of the financial flow of the investment in the execution of the energy sustainable development program to the end-use system - type2		212
LIST OF PUBLICATIONS		213

INTRODUCTION

The European Union (EU) strongly promotes Europe's transition to a low - carbon society and constantly updates the rules to facilitate private and public investments so needed in the transition towards clean energy [1]. Romania, as an EU Member State, has the responsability to comply with the Community environmental standards established by specific directives and to add significantly contribution in achieving the strategic objectives and European policies regarding sustainable development.

Lately/Recently, all competent authorities fromdeveloped countries sustained and promoted the expanding of specific energy sustainability working methodologies.; based on the obtained results, it was possible to develop procedures, manuals or guides that were made available to stakeholders.

Due to a good international collaboration and under the auspices of organizations and agencies such as the UN, EU, IEA, etc., decision-makers in/from different countries can now use virtually the same set of indicators to measure and assess the current and future effects of energy consumption.

At EU level, energy efficiency practices are homogeneous. The European directives, methodologies and programs promoted by the European Commission (EC) in the field of energy environment combine/mix elements of international practices; these being customized at national level. Using performance indicators, similarly calculated and reported to the EC by all Member States is possible because Europe's energy systems are similar, use the same types of technologies and energy networks are interconnected.

The decision of implementing an investment regardingenergy sustainability involves several decision-makers and variouskey actors. In order to obtain a favorable decision regarding the implementation, all decision-makers should be informed of the benefits they will receive for the key actors on whose behalf they exercise their decision. The satisfaction of one interested party cannot replace the dissatisfaction of another; otherwise, a favorable decision isonly obtained by integrating compromise elements, that can sometimes be against of a solid sustainable construction of the investment project.

The purpose of the research

This paper addresses, in a concise and structured form, the current concerns in the field of energy efficiency assessment for users and provides support tools for decision-making on energy sustainability for final consumers.

The aim/main objective of the research conducted during the doctoral internship is proposing a methodology for assessing energy performance throughout the lifecycle and designing a multicriterial method for assessing energy efficiency for use facilities owned by final consumers, by attaining all decision makers and key actors requirements

All stakeholder`s evaluations will provide a common framework that facilitates decision-making on energy efficiency investments and gives accurate and complete information for monitoring performance after the implementation and during operation.

STRUCTURE OF THE DOCTORAL THESIS

The title of the doctoral thesis developed to meet this goal is named ***"Evaluating the performance of solutions to increase energy efficiency to end users"*** and is structured in seven chapters.

The first two chapters of the thesis present *the current state of knowledge.* **The first chapter** contains a summary of the current context, with the state of climate policies and commitments assumed at global, European and national level.

In the second chapter was elaborated a synthesis of current methodological developments globally identified , together with a selection of the most important energy performance indicators mentioned in recent literature that present the requirements of key actors that are involved in all phases of an energy investment.

The personal contribution is presented in chapters three, four, five and six of the thesis.

Chapter three of this paper presents a critical analysis of current methods of energy efficiency assessment and also indicatesthe main barriers in implementatingenergy efficiency investment projects, justifying in this way the need for a multicriteria analysis of energy performance in a holistic approach.

Chapter four presents a new method for multicriteria evaluation of energy efficiency solutions for end-users, based on new indicators conceived for an evaluation from the perspective of four analysis criteria (technical, ecological, financial and social). The designed method is proposed as part of a methodology for evaluating the energy performance throughout the lifecycle of an energy system.

The fifth chapter presents the advantages of using the method in planning sustainable investments and designing programs for supporting sustainable development of energy end-use systems.

The case studies presented in the **sixth chapter** confirm the usefulness of the proposed method for tertiary and industrial users.

The paper concludes with **chapter seven** where are presented the general conclusions and the future cosidered research directions

The important aspects included in the doctoral thesis are briefly presented in the following, keeping the numbering of the chapters in the thesis.

3. CRITICAL ANALYSIS OF CURRENT METHODS FOR ASSESSING ENERGY EFFICIENCY

A detailed bibliographic research was conducted in order to identify the most appropriate models for evaluating and monitoring energy performance that could be adapted to the situation in Romania.

It was found/shown that, at present, decision-makers in different countries and international bodies use virtually the same set of indicators to measure and assess the current and future effects **of energy consumption**.

The analysis of the most well-known national and international measurement and verification protocols highlighted the great similarities between them.

The differences appear in the field of applicability, the ways of acquiring the necessary information, the quality of the databases used, the mathematical models and formulations/formulas implemented, etc.

➢ Deficiencies of current approaches

The main limitations identified in the current design, implementation and operation of energy efficiency investment projects relate to the folowing:

- the current legislative framework is not adapted to ease implementation of the Energy Performance Contract and the lack of regulations on how to measure, verify and monitor performance generates distrust/mistrust in such projects;
- the language of financial evaluations is not understood/assimilated by those involved in developing the technical solution; many good projects from a technical point of view present associated risks that the financiers consider being too high;
- there are no specific working tools and mathematical models for arguing the performance and results of an investment project, this being considered a technical barrier;
- from a social perspective, energy efficiency is considered to affect the number of jobs due to the processes modernization and removal of manual labor; the restriction of comfort conditions in order to save energy; the use of technologies that have greater commercial promotion or interests for financial profits instead the interests of the beneficiary unit.

The general distrust relates to the lack of clear rules and methodologies; on the other hand, this is caused by the lack of a common language between stakeholders during execution of energy efficiency projects.

➢ Improving the methodology for evaluating energy performance

Within the doctoral thesis, a set of multicriteria and multidisciplinary key indicators were defined. These indicatorswould provide all interested parties with concrete, relevant and adequate information about the results obtained after implementingthe proposed solution. The selected indicators are found as an integral part of a methodology for evaluating the performance of solutions that increase energy efficiency designed as a continuous process starting from the design phase to monitoring the entire lifecycle of the analyzed system.

Within the proposed methodology, a heuristic method of solutions evaluating was developed to substantiate the further development of a computer based application as a "black box" type evaluation, an application that can be used by all parties involved to demonstrate on a scientific basis how they can get easy assess the level of the energy system's performance.

In order to demonstrate the usefulness of the proposed method, case studies are presented to validate the method of performance of energy efficiency solutions implemented in tertiary and industrial consumers.

➢ *The principles underlying the proposed methodology*

Sustainable development represents the way in which evolution is ensured by the congruence of economic, ecological and socio-political criteria. Sustainable development involves preserving the quality of life, assuring the conditions for protecting the environment, population and property at the same time

When referring to efficiency, the ratio between the results obtained and the efforts involved is mandatory. A measure is effective if it has the quality to produce, in good/optimal conditions (technological, ecological and socio-economically sustainable), positive effects that increase the efficiency of the analyzed system.

The principles underlying the evaluation methodology [106] are the following:
A. A holistic approach;
B. Multicriteria evaluation;
C. Lifetime evaluation;
D. Incremental development;
E. Social support, safety and security.

- ***Objectives pursued by developing the methodology***

The proposed methodology aims to provide support for:
- intelligent planning of sustainable investments in energy efficiency;
- making investment decisions by providing relevant and adequate multidisciplinary information to all stakeholders;
- operating energy systems through continuous monitoring of energy performance and stressors useful in risk management;
- identifying the opportunity for new solutions to implement attaining progress in energy performance;
- extrapolating lifetime assessments and identifying recoil effects;
- monitoring the achievement of objectives and setting measures to reach the targets.

The lifetime evaluation mechanism of the system aims at preserving the performance between a minimum level (threshold) and the ideal level set as a target.

The implementation of solutions for increasing energy efficiency will take the form/represent an ongoing process that ensures new performance progress towards climate neutrality (correlated with investment capabilities).

4. MULTICRITERIAL EVALUATION OF THE PERFORMANCE OF ENERGY EFFICIENCY INCREASING SOLUTIONS

Developing a methodology for evaluating solutions to increase energy efficiency

The solutions for increasing energy efficiency are considered a combination of appropriate and timely measures that ensure progress in the overall performance of the system under study. Some measures may involve an investment effort, others may present a more efficient way of operating with a minimum of geared resources, or they may condition or may represent the foundations for further developments of the system, when the general context makes them appropriate.

The theoretical considerations that define the principles, which will underpin the decision to build energy efficiency solutions, closely relate to accessibility, speed, sustainability and efficiency, as presented in Chapter 2 where these notions are described.

The proposed methodology for evaluating solutions to increase energy efficiency involves an analysis that follows the Deming cycle [108, 109]: analyzes the system in the initial situation - defines, evaluates and builds solutions - implements - verifies implementation results - after implementation analyzes progress and performance - calls for new actions.

Assuming targets on system performance leads to continuous monitoring throughout its life. At the initial moment, based on the analysis of the existing state, are planned the solutions that can lead to the achievement of the targets; this can be attained by implementing an ideal solution that ensures that all objectives are fulfilled. However, this is very rare in reality, because the level of targets set is, in many cases, high, suggesting zero GHG emissions. Usually, ambitious final targets are achievable through a succession of solutions implemented during the lifecycle of the system, in close connection with both investment capacities and results obtained after the solution`s implementation.

In the initial planning, which may take place/happen in the design phase of a new system or the planning of modernization works for an existing system in active operation phase, an energy audit is necessary to best identify solutions to increase energy efficiency feasible in terms of efficiency at that time. Performance limits are set between a minimum level, considered a threshold, and a maximum level, called the target. The choice of the solution for implementation will be followed by the development of the technical concept, the design and approval of the financing necessary for the investment. The execution closes the first analysis cycle and opens the second one, where measurements and verifications are accomplished based on the performance obtained during the entire operation. The post-implementation situation analysis verifies whether the planned results are obtained or a corrective re-evaluation of the solution is required. It takes the place of the initial condition analysis and provides information on the requirements that are necessary to address in order to make new performance progress.

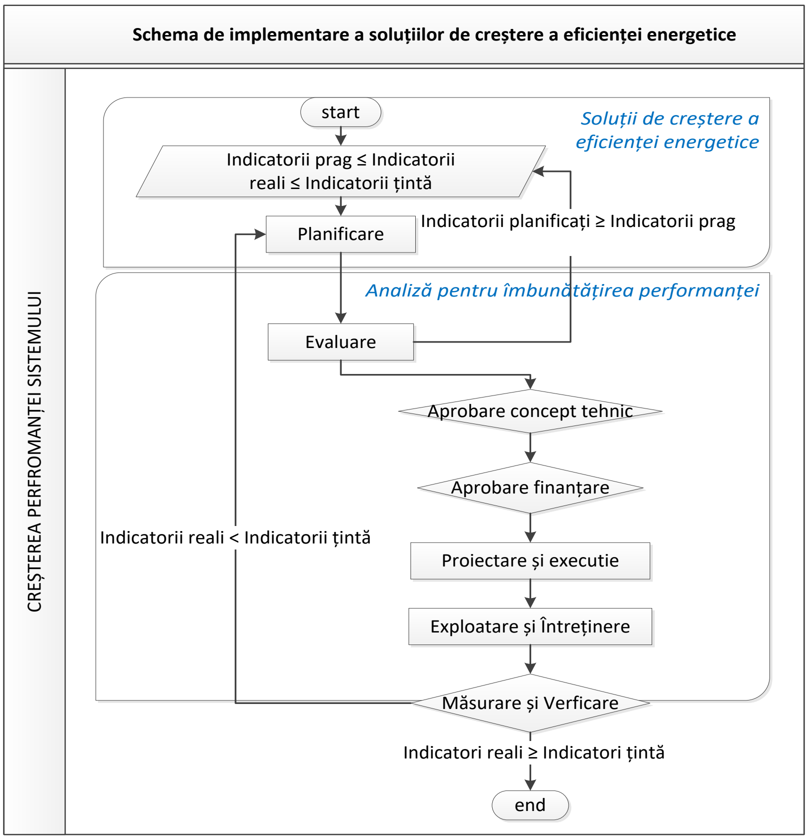

FIG. 1. Scheme for implementing solutions to increase energy efficiency throughout the life of the system

After the implementation of the first energy efficiency solution, the evaluation continues with checking the performance according to the threshold level and the target level. If the level of performance obtained is below the expected minimum, the analysis and planning will be repeated in order to eliminate the errors of the first evaluation. In the conditions of a performance superior to the threshold level, but which does not reach the set targets, the next solution to be executed is planned, reinvesting the value of the savings generated by the first implemented solution.

The moment of implementation of the second solution is given by the moment of reaching the optimal cost-efficiency feasibility. The approach can be repeated cyclically until the targets are reached, after which the evaluation only verifies the maintenance and preservation of the performance throughout the life of the system. Fig. 1 presents the scheme for the implementation of solutions to increase energy efficiency using the lifetime evaluation mechanism of the system to preserve performance between a threshold level and the ideal level set as a target.

Regarding the proposals on the methodology for evaluating the performance of solutions to increase energy efficiency throughout the life of the use system, to simplify the expression, the following abbreviation is used "LCA - MEPES methodology" (**L** ife **C** ycle **A** ssesment - **M** ulticriteria **E** valuation of the **P** erformance of **E** nergy **S** ystem).

The LCA-MEPES methodology is structured in the following stages:

1. analysis of the current state or realization of the energy audit;
2. assessing measures to increase energy efficiency identified as most appropriate based on thedata extracted from the audit;
3. the decision-making phase where solutions are developed to improve the performance of the system on the basis of combined measures that are technically and economically efficient, eliminating thus the side effects of overlapping measures;
4. multicriteria evaluation of the solutions, ordering the solutions to be implemented during the life of the system until the achievement of the targeted goals;
5. monitoring the planned results attainable during the implementation of the solution;
6. continuous monitoring of the progress registered throughout the lifetime, with the resumption of the cycle of gradual solutions implementation that increase or preserve the performance of the system.
7. The LCA-MEPES methodology introduces the obligation to measure the recoil effect after the solution is implemented , at regular intervals, as a source of information and response for developping new alternatives to increase efficiency or to correct possible divergences between planning and reality. We are talking about continuous monitoring of performance, so implicitly about risk management and ensuring that the results will be maintained even if the conditions may change. For any decision-maker, this is a necessary and sufficient condition for trust and support.

A relevant contribution of this paper concerns the centralization of all important measures to increase energy efficiency to consumers, as they are available today through existing technologies on the market and timely for energy policy reasons. Therefore, the personal contribution proposes the list of the most used *classes of measures to increase energy efficiency* among final, tertiary and industrial consumers; it is summarized in table 1 of the doctoral thesis . This centralized list of measurement classes, with representative performance indicators and specification of possible geared side effects, serves technical specialists, auditors, energy managers or designers, when developing the technical concept of an energy efficiency project.

➢ Multicriteria performance indicators

➢ *Selection of indicators used to assess energy performance*

In the elaboration of the LCA-MEPES evaluation methodology, a list of multicriteria indicators was synthesized, some of them being taken from the current practices, others being new indicators developed within the proposed methodology.

This summary list brings together multidisciplinary indicators that define the reference state, technical performance, energy efficiency and environmental impact, financial performance and socio-political impact determined by the implementation of actions to improve the performance of the analyzed system.

1. Indicators for the reference situation
2. Technical performance indicators
3. Ecological indicators on energy efficiency and environmental impact
4. Financial indicators
5. Socio-political indicators
6. Indicators on system flexibility

The proposed indicators are structured according to the evaluation criterion to which they clearly respond and refer in particular to the analysis of the impact that the implemented measures generate on the energy use system of the final consumers.

➢ *Proposing and developing composite indicators*

New indicators have been defined to allow the expression of the technical, financial, ecological and socio-political dimension in assessing the energy performance of utilization systems.

- *Coefficient of performance*
- *Economic efficiency of energy conversion*
- *Energy conversion rate*
- *Technical-economic performance coefficient*
- *Settlement ratio with the network*

By determining these indicators, the level of performance obtained after the implementation of measures to increase energy efficiency compared to that of the initial situation is verified; or that related to similar systems - considered as a reference.

For a correct and relevant evaluation, depending on the characteristics of the energy systems analyzed and according to the requirements of decision makers / stakeholders, in chapter four of the doctoral thesis two lists of selected indicators are proposed to be used in the method of evaluating the performance of solutions to increase energy efficiency proposed through a personal contribution.

➢ Method for multicriteria evaluation of energy efficiency solutions for users

- *Introductory notions*

Implementing solutions to increase energy efficiency involves two major challenges: (1) designing and ordering solutions so that interventions for sustainable development can be achieved progressively, correlated with the financial capacity of the user; (2) multi-criteria assessment of performance and its monitoring throughout the life of the system.

The personal contribution to solving the problem described in the previous paragraph consists in the development of a method for multicriteria evaluation of the performance of energy efficiency solutions for users. For simplicity of expression, the name **MEPEES method** will be assigned, using the English abbreviation for « **M** ulticriterial **E** valuation of the **P** erformance of **E** nergy **E** fficiency **S** olutions».

In the elaboration of the method it was decided to use the SAW technique - Simple Additive Weighting, this being one of the most used multi-attribute decision-making techniques (MADM-multi-attribute decision-making). In specialty literature, it is used to evaluate, order and choose the best alternative of all possible scenarios [107].

The MEPEES method uses the following notations:

(1). MEE_i - measures to increase energy efficiency, feasible for the analyzed system, where $i = 1, 2, \dots n$. It is therefore considered to be identified for analysis a number of n such measures.

(2). M_{ij} - the values of the performance indicators related to measure i, with $j = 1,2, \dots k$, where k represents the number of indicators (attributes) used. The indicators selected for evaluation are multi-criteria and can be grouped into four categories, according to Table 2:

- (3). TM_{ij} with $j = 1,2, \dots t$ - technical indicators;
- (4). EM_{ij} with $j = 1,2, \dots p$ - ecological indicators;
- (5). FM_{ij} with $j = 1,2, \dots f$ - financial indicators;
- (6). SM_{ij} with $j = 1,2, \dots s$ - social indicators.

(7). n - the number of MEEs identified as feasible in the analyzed system (alternatives).

(8). E - the number of energy performance improvement solutions that can be developed based on the identified measures.

(9). k - the number of multicriteria indicators selected for evaluation (attributes), where $k = t + p + f + s$.

(10). t - number of technical indicators .

(11). p - number of ecological indicators.

(12). f - number of financial indicators.

(13). s - number of social indicators.

(14). Ψ_e - s solutions for increasing energy efficiency, where $e = 1, 2, \dots, E$.

It is considered that E solutions can be developed, of which Ψ_1 is the basic solution (elementary solution) and Ψ_E it is the ideal, or desirable, solution that includes all the measures identified as feasible for the analyzed system. Intermediate solutions, denoted $\Psi_{2, \dots (E-1)}$, they can be built by choosing the right component measures.

An adjustment factor will be used to correct any interference that may arise from the overlap of two or more measures that make up the final solution . For example, the implementation of a measure that reduces electricity consumption for lighting may reduce demand for cooling and / or increasing the demand for heat; these effects cannot be measured in practice but can be estimated by introducing this correction factor.

Designing a solution requires deciding on the measures that will make it up. To this end, a decision matrix is proposed in which energy efficiency measures are alternatives assessed on the basis of a number of k multicriteria indicators used in making decisions on choosing the best measure and ordering measures according to performance. If we analyze n measures to increase energy efficiency , denoted MEE $_{1 \dots n}$, the decision matrix, denoted by $\boldsymbol{D}$, will have the form :

$$\boldsymbol{D} = \begin{bmatrix} M_{11} & \cdots & M_{1k} \\ \vdots & \ddots & \vdots \\ M_{n1} & \cdots & M_{nk} \end{bmatrix} \tag{1}$$

where the terms M_{ij} are the technical, ecological, financial and social indicators that characterize the *measures* ; $i = 1, \dots n$, $j = 1, \dots k$.

For selecting the alternatives, among the measures that compound the solution, it is not enough just to evaluate the attributes, as this step does not provide enough information to make a decision. Because each attribute is expressed in different units of measurement and has its own optimization function, a structure must be created to allow the evaluation and comparison of attributes. To this end, a new operation is applied, by which the values of the attributes are normalized (on each column j), according to the type of optimization function (maximum / minimum).

The normalized values of the terms of the decision matrix **D** are denoted by $m_{ij}$and determined by the relation:

$$m_{ij} = \frac{M_{ij}}{\max\limits_{i} M_{ij}} \tag{2}$$

in case of maximization, respectively with the relation:

$$m_{ij} = \frac{\min\limits_{i} M_{ij}}{M_{ij}} \tag{3}$$

in case of minimization.

The decision matrix therefore has the attributes represented by the performance indicators defined on several evaluation criteria. The criteria, respectively the attributes, may have different importance in the decision-making process so that they are assigned weights marked with w_j, $j = 1, \dots k$. The vector of the weights of the attributes is $W = (w_1, w_2, \dots, w_k)$, in which the weights are normalized and their sum is always equal to 1:

$$\sum_{j=1}^{k} w_j = 1 \tag{4}$$

The SAW technique involves summing the attributes to obtain the final score of each alternative. In the case of decision matrix **D** , the final score of the alternative evaluation will be obtained by applying the equation:

$$PM_i = \sum_{j=1}^{k} m_{ij} * w_j \tag{5}$$

where PM_i is the performance index of measure i .

Depending on the score obtained for each alternative, it is possible to order them and choose the best alternative.

- ***proposed method***

The multi-criteria method of evaluating the performance of energy efficiency solutions involves five specific steps. Within them, the effective evaluation of the measures for increasing the energy efficiency is carried out, respectively the construction and evaluation of the solutions for preparing the program of energy efficiency improvement.. These stages are preceded by another stage in which the energy audit is performed in order to analyze the initial state of the system and the necessary data are collected to identify the appropriate measures for increasing the efficiency of the analyzed system. Following the specific evaluation stages, a continuous performance monitoring phase is proposed during the operation of the system.

The synthetic description of the steps in the structure of the MEPEES method is given/presented below.

Step 1 - The energy audit consists of:

1.1 *Initial analysis*: in this stage the data collection and the necessary measurements are performed to identify the technical condition of the analyzed system, with the determination of the parameters that describe the level of performance at the time of analysis. As a rule, this analysis is elaborated in the form of energy balance and energy audit of the building, in compliance with the methodology regulated in the legislative acts in force [60]. In the description of the initial situation, the monitoring indicators proposed in Table 4.4 will also be determined.

1.2 *Selection of measures to increase energy efficiency*: based on the results of the initial analysis, appropriate energy efficiency measures are identified, using as a guide the classification list of measures proposed in Table 4.3. Verification of the applicability of each existing class of measures in the list will allow the identification of all measures that can be taken into consideration at this time for a sustainable modernization of the system.

Step 2 - The multicriteria evaluation of the measures, using the approach presented in subchapter 4.4.1, consists of:

2.1 *Determination of the performance indicators for each* MEE_i, with $i = 1, \dots n$, as presented in Table 4.3., Obtaining the values M_{ij}.

2.2 *Establishment of thresholds and target values*: in this stage it is recommended to establish those indicators for which it is necessary to register a threshold level, as specified in the regulations in force or recommended by energy policies. In the selection of the measures that will be evaluated, it will be followed that their implementation will allow at least reaching the threshold level. Also, target values can be set for certain indicators, values that must be reached at the end of the implementation of the energy efficiency improvement program.

2.3 *Determining* ***the normalized values for each performance indicator** : the* values of the indicators M_{ij} are normalized compared to the best, maximum or minimum value depending on the optimization mode; thus the relative performance indices of the indicator are obtained, note m_{ij}. After the normalization operation, the decision matrix will be transformed as follows:

$$D' = \begin{bmatrix} m_{11} & \cdots & m_{1k} \\ \vdots & \ddots & \vdots \\ m_{n1} & \cdots & m_{nk} \end{bmatrix} \quad (6)$$

2.4 *Determination* ***of relative performance indices at the level of the analysis criterion** :* for each measure, for all defined evaluation criteria, the corresponding values m_{ij} *are added together* and a second normalization step is applied to the maximum value thus obtained (the highest value obtained by that criterion for all existing measures). This results in relative performance indices at the level of criterion x , note r_{ix}. Having defined the 4 evaluation criteria, r_{ix} are in this case composed of technical relative performance indices, r_{Ti}, ecological, r_{Ei}, financial, r_{Fi}, respectively social, r_{Si}..

These indices are determined for each measure, and the following matrix of relative performance indices can be compiled:

$$\boldsymbol{D'_{ix}} = \begin{bmatrix} r_{T1} & r_{E1} & r_{F1} & r_{S1} \\ \vdots & \vdots & \vdots & \vdots \\ r_{Tn} & r_{En} & r_{Fn} & r_{Sn} \end{bmatrix} \tag{7}$$

Depending on the category of the decision-makers involved, the evaluation criteria may have different weights related to the interest of each decision-maker. Therefore, the four evaluation criteria, considered as attributes of the matrix, are assigned weights, denoted by $w_{1,\dots 4}$, subject to the condition

$$w_1 + w_2 + w_3 + w_4 = 1. \tag{8}$$

2.5 *Determining* ***the relative performance of the measure***, *PRM* $_i$*, is* a complex indicator which orders the measures according to the performance they bring to the system from the perspective of multicriteria analysis.

For the calculation of PRM_i, the SAW technique is used, respectively the weight allocated in the evaluation to each criterion, w_x, is established and the weighted sum of the relative performance indices at the level of each *MEE* $_{i \text{ is determined.}}$ in part. The multi-criteria evaluation highlighted that each identified measure is recommended for the implementation of different performance indicators. As a result, the *PRM homogenizes the* multi-criteria indicators and shows the ranking of measures for priority for implementation from a holistic perspective.

The relative performance of the measure to increase energy efficiency, noted in PRM_i, is calculated with the relation:

$$PRM_i(r_{ix}, w_x) = \sum r_{ix} * w_x \tag{9}$$

where r_{ix} is the relative performance index of measure *i* as a function of the evaluation criterion *x* and w_x is the weight of each of the criteria used.

Relative performance is calculated for each *MEE* and it aggregates multi-criteria information on the level of performance registered based on the evaluation according to the *x* analysis criteria; Finally, the result can be summarized as a matrix of relative performances:

$$\boldsymbol{PRM(r_x, w_x)} = \begin{bmatrix} PRM_1 \\ \vdots \\ PRM_n \end{bmatrix} \tag{10}$$

Stage 3 - Designing solutions : a way of sorting and grouping the existing measures is proposed in order to develop incremental solutions that allow a progressive implementation of investments, depending on the available budget.

This decision-making stage regarding the construction of solutions uses the model of the decision tree [136, 137]. Each node of the tree indicates testing by an attribute, each branch shows the test result, and finally the classification of the measures into groups of solutions is obtained. The test attributes were considered to be quantities developed in the thesis, respectively the indicators of relative performance and relative performance of the measure.

The basic solution, the intermediate solutions and the ideal solution will be obtained. In this stage, the solutions that will be evaluated in the next stages are defined.

The major challenge concerns the choice of those measures which, put together, make the most consistent contribution to improving the performance of the system, within the available budget. For selectingn the measures that compose the solutions for increasing the energy efficiency, an algorithm that uses the model of the classification and decision tree was developed, as can be seen in fig. 2.

MEE $_1$*, MEE* $_2$*, ..., MEE* $_n$

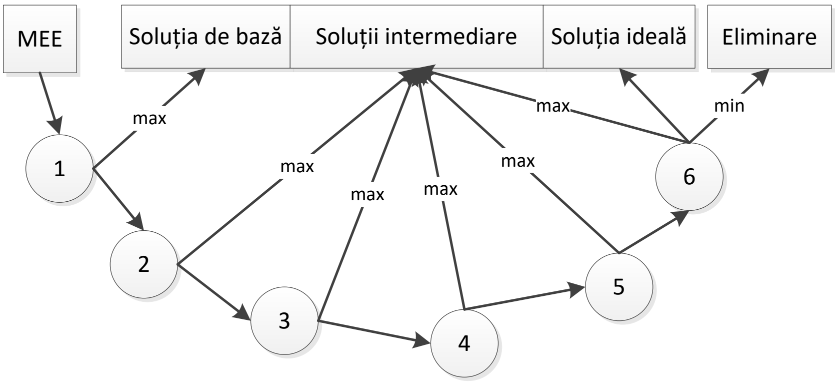

FIG. 2. Proposed classification and decision tree model for building solutions

Step 4 - Evaluate the solutions by:

4.1 *Analysis of solutions and possible interferences*: the performance indicators for each solution are calculated taking into account the side effects identified in the analysis of interferences caused by the joining of the measures that compose it. The calculation of the indicators will follow the observance of the threshold condition and, possibly, the degree of closeness to the target value set by the user.

4.2 *Determination* ***of the overall performance of the solution*** : apply all the operations described in step 2 of the evaluation of the MEE for each designed solution and thus obtain the final score of the evaluation of the solutions.

The overall performance of the Energy Efficiency Increase (*PGS*) solution is calculated by the relation:

$$PGS_e = \sum R_{ex} * w_x \tag{11}$$

where w_x is the weight of criterion x , and R_{ex} there are relative performance indices of solution e .

For each solution, the general performance indicator of the solution will be determined, the solutions being ordered ascending in order to structure the investment program; the result can be organized in the form of a matrix:

$$\boldsymbol{PGS_e(R_{ex}, w_x)} = \begin{bmatrix} PGS_1 \\ \vdots \\ PGS_E \end{bmatrix} \tag{12}$$

determination of the *PGS* involves the calculation of indicators that are largely linked to the planning phase of energy efficiency investments, so that the *PGS* essentially verifies the correctness of the planning and the necessary steps to reach the targets.

4.3 *Elaboration of the energy efficiency improvement program: depending* on the available investment budget, the solution that has the investment value closest to the budget level will be chosen for the first implementation phase. By calculating the savings obtained after the first implementation phase, the time points at which new investments can be realised in the implementation of higher score solutions are determined. Thus, the investments are staged until the complete execution of the measures that make up the ideal solution, ie the one that has the maximum final score.

Step 5 - Monitoring the performance during the operation of the system consists of:

5.1 *Determining the actual performance verification indicators*; it can start immediately after the first phase of the implementation of the energy efficiency improvement program.

5.2 *Displaying information* on the degree of performance of the planned performance, variations from the performance in the initial situation, respectively variations from the performance of similar systems considered best practices.

5.3 *Setting alerts* on monitoring system operation and real-time information on optimization possibilities to increase efficiency. The set alerts may also indicate variations in parameters that affect operational safety or security, depending on the specifics of the activities carried out within the system.

5.4 Determin***e energy system performance (PSE)*** for comparisons with similar systems or system states at different times. Apply the operations described in step 2 of the MEE evaluation for the system state at the time of analysis, evaluation based on the *indicators in Table 4.4 describing performance system*, both for the analyzed system and for those with which the comparison occurred.

Determination ***of energy system performance (PSE)*** for comparisons with similar systems or system states at different times can be done by applying the operations described in stage 2 of the MEE, based on *indicators describing system performance*, both for the analyzed system as well as for those with which the comparison is made.

To verify the level of performance achieved after implementating energy efficiency solutions, the selected monitoring indicators will be calculated, subsequently applying the operations described in the *PRM calculation stage* for each forecasted operating scenario and thus obtaining the final score of the scenario evaluation. *The performance of the energy system* (*PSE*) is calculated by using the relation below:

$$PSE_a = \sum R'_{ex} * w'_x \tag{13}$$

For each scenario, *the performance of the energy system will be determined* , the results obtained can be organized in the form of a matrix like presented below:

$$\boldsymbol{PSE_a(R'_{ax}, w'_x)} = \begin{bmatrix} PSE_a \\ \vdots \\ PSE_A \end{bmatrix} \tag{14}$$

Fig. 3 shows schematically the algorithm underlying the MEPEES method. The five successive stages of the evaluation refer to the design phase of the energy efficiency investment and the operation phase through continuous monitoring of performance under operating conditions.

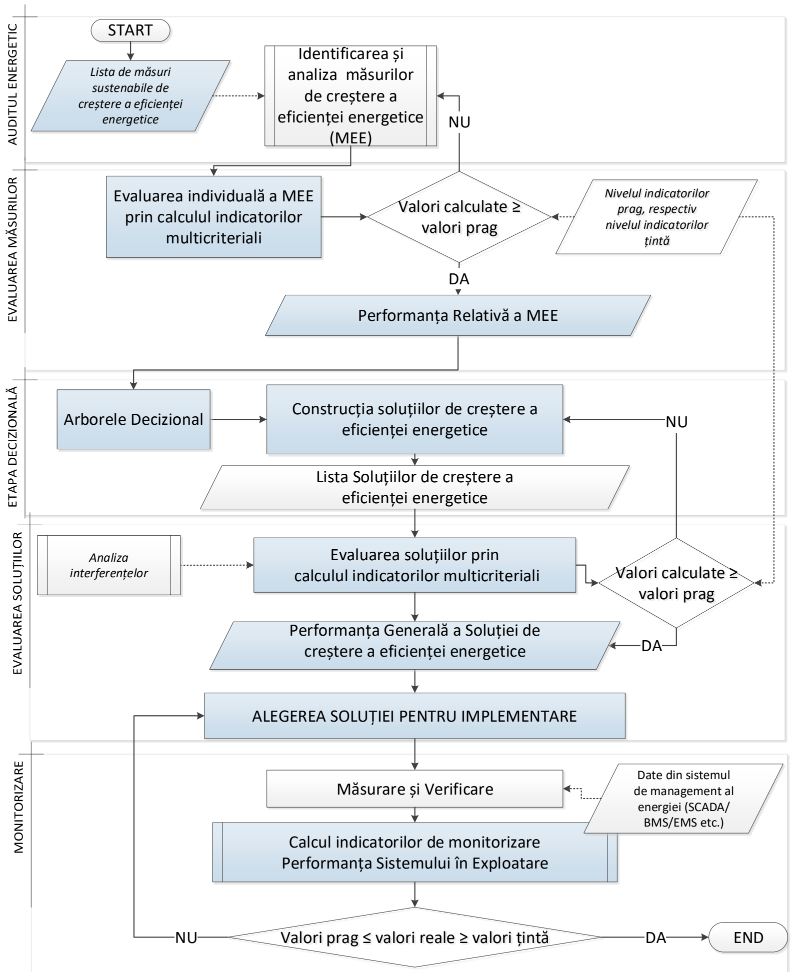

FIG. 3. Logic diagram describing the MEPEES method

- New developments introduced by the MEPEES method

The MEPEES method uses the following elements newly developed in the doctoral thesis, which can be considered as useful **databases** in assessing energy efficiency in users:
(1) the list of sustainable measures to increase energy efficiency
(2) indicative list of side effects of implementing energy efficiency measures
(3) the list of multicriteria performance indicators
(4) list of monitoring indicators.

calculation and analysis models developed through the personal contribution in the doctoral thesis are applied within the method, namely:
(5) the calculation of the relative performance of the measure,
(6) selection of measures for the construction of solutions using the decision tree,
(7) the overall performance calculation model of the solution,
(8) choosing the optimal solution for implementation and development of the energy efficiency improvement program,
(9) continuous monitoring of system performance and identification of optimal scenarios for maintaining system performance in operation (by determining system performance in operation).

5. USE OF THE PROPOSED METHOD IN ASSESSING ENERGY PERFORMANCE

➢ Design of sustainable development programs for energy systems for use according to the MEPEES method

The methodological developments presented in the thesis will allow the beneficiaries to prepare the technically and financially adequate energy investment projects in order to be presented to third party investors.

As can be seen from FIG. 4, the programs are correlated with the financial capacity of the beneficiary and present, correctly and adequately, the way in which the energy savings generated after implementation will materialize in cash flows to ensure the liquidity necessary to repay the loans or credits committed.

Financiers and investors will be able to verify the sustainability of the investment and during the credit / loan period will have to face the results of the evaluation during the monitoring period with the planned ones.

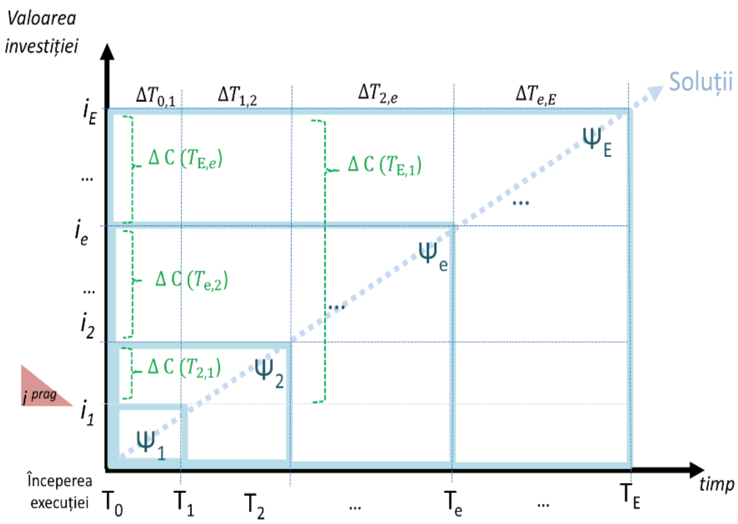

FIG. 4. Timing of investments in the execution of solutions

6. VALIDATION OF THE USEFULNESS OF THE METHOD FOR ASSESSING ENERGY PERFORMANCE AND DESIGNING THE SUSTAINABLE DEVELOPMENT PROGRAM FOR FINAL CONSUMERS - CASE STUDIES

In order to validate the usefulness of the energy performance assessment method and the advantages of a sustainable development program designed using the MEPEES method, chapter six of the thesis presents case studies based on information from real energy systems, with data related to real consumers processed in the technical studies and energy balances in which the author of this paper was involved.

For the case studies, 3 types of final consumers were chosen: public administrative building, private commercial building (offices) and private industrial consumer.

The results of the simulations from the case studies led to the determination of the indicators proposed in the thesis and the design of sustainable development programs for each energy use system analyzed.

The comparison of the programs that resulted using the MEPEES method for the two systems highlighted the fact that the maximum level of performance attainable by modernizing a system is different from that of a similar system. The differences that occur are influenced by the possibilities of installing the modern technologies available, the conditioning of space and functionality being the main causes.

7. CONTRIBUTIONS REGARDING IMPROVING THE ENERGY PERFORMANCE ASSESSMENT METHODOLOGY

➢ General discussions and conclusions

Energy constraints bring to the fore the issue of how to assess investment opportunity and sustainability, so that the taken measures at the microeconomic level support the achievement of macroeconomic objectives.

This paper addresses, in a concise and structured form, the current concerns in the field of energy efficiency assessment for users and support tools that are proposed in decision-making on energy management actions for final consumers.

A methodology for evaluating the lifetime energy performance of an energy use system (LCA-MEPES) has been developed. The proposed methodology presents an organized and results-oriented way of working, essential both in the planning and design phase of solutions to increase energy efficiency, and in the phases of their implementation and operation of the modernized system.

This methodology proposes a multi-criteria assessment method (MEPEES) developed to take the form of a support tool in decision-making on the planning and operation of energy efficiency projects. The method processes, as input information, data about the energy use system and data that measures the satisfaction degree of the deciders interests for the execution of performance improvement solutions.

The mathematical processing operated in the evaluation method provides, in an objective manner, relevant and sufficient information for all the actors involved. With the help of this method, all known alternatives at the time of the analysis and the possible side effects are verified, ordering the alternatives according to the performance, being evaluated from a multidisciplinary perspective.

New energy performance indicators have been developed on the basis of which a complex indicator has been defined, called energy system performance (PSE), which includes multidisciplinary information on the interaction of the analyzed system with the user and the grid to which it is connected.

The purpose of multicriteria evaluation of solutions to increase energy efficiency, according to the MEPEES method, refers to identifying the level of performance that can be attributed to an energy system from a technical, ecological, financial and social perspective. Improving energy performance is achieved through affordable investments, which correct technical deficiencies or align the system with the latest technological developments designed to ensure decarbonization or reduction of greenhouse gas emissions, without compromising comfort and socio-economic benefits.

In essence, the MEPES methodology proposes a detailed and complete analysis of the energy use system, throughout its life, starting from the identification and evaluation of its maximum potential for performance improvement. The planning phase identifies all measures to increase energy efficiency that can be implemented under the conditions allowed by the structure, condition and position of the system, so that the definition of the ideal solution will lead to the achievement of ambitious targets. Once analyzed, MEEs are selected for the design of a series of solutions that, through successive implementation conditioned by financial affordability, allow continuous progress to the desired level; then the system is monitored during economic operation and the appropriate action is taken to preserve the performance achieved.

The evaluation method proposed in this thesis is intended to be a theoretical and applied development that would substantiate the foundations of a computer application, useful in making decisions on energy management in a system to users. The application can take the form of an evaluation module that can either work independently or communicate bidirectionally with the energy management and control systems (EMS, BMS, SCADA) installed within the evaluated system.

➢ Originality and innovative contributions of the thesis

The personal contribution is presented in four chapters of this paper; the innovative ideas formulated by the author are contained in chapters 3, 4 and 5, and their correctness is demonstrated in chapter 6 by the three case studies.

The first important contribution is to identify and critically analyze current methods of assessing energy efficiency. The weaknesses of the current methodologies are presented and a series of new indicators are proposed to allow the multicriteria analysis.

The second significant contribution concerns the development of an original methodology for evaluating the energy performance throughout the life of the system, called LCA-MEPES. In the description of this methodology, presented in Chapter 4, there are some innovative elements that have not been used so far in assessing energy performance.

First, the methodology sets the purpose of assessing energy performance in terms of the sustainability of energy systems, according to the European Green Pact; it proposes a new approach in the field of energy, that of sustainability, being imposed the target of climate neutrality by 2050 in the conditions of a sustainable economy, with the decoupling of economic growth from the use of resources and in conditions of social equity. The LCA-MEPES methodology introduces for the first time a complex multicriteria analysis, which aims to meet the main European priorities set out in the Green Pact: the use of sustainable technologies (technical criterion) to ensure climate neutrality (ecological criterion) through a transformation of society and Europe's economy towards a cost-effective (financial criterion), fair and socially balanced (socio-political criterion).

Secondly, the methodological development proposed in this paper is a useful working tool in investment planning to increase energy efficiency. The synthesis of all possible actions to improve performance, with the classes of measures to increase energy efficiency, requires a thorough analysis in the design and planning of investments in a sustainable system.

The third novelty brought by LCA-MEPES is the list of key indicators proposed for performance evaluation, which provide in addition to current practices information on overall performance, energy flexibility, ability to respond to occupant needs and economic and financial profitability. . In this way, energy use systems will be able to generate information for operating optimization scenarios and, at the same time, be able to prepare for their integration into smart grids with a role in increasing SEN flexibility. For theaccuracy of the evaluation, in LCA-MEPES key indicators are proposed synthesized according to the relevance of the recent specialized literature; they are based on measurable parameters and data from relevant sources. New complex indicators developed providing a simultaneous response to multiple technical, environmental, financial and social requirements.

The fourth element of novelty concerns the proposal of a continuous evaluation throughout the life cycle of the use system. The performance indicators proposed measure the impact on the entire lifetime, and the evaluation process is built in a continuous form, with defined stages in both planning and operation phases. In essence, the purpose of the evaluation is to ensure the sustainability of the system by reaching an optimal level of performance and maintaining it at all levels of operation.

Its own contribution is also found in combining current practices with new developments that lead to convergence towards a better, a more correct, complex and relevant evaluation of investment projects. to streamline decision-making, both in planning and operation. 11 important points have been integrated that improve the current approach, proposing a sustainability-oriented one.

Compared to current practices, the MEPES method presented in this paper introduces (1) the verification of compliance with the standards and norms in force, on the multidisciplinary areas with which the system intersects, so that performance is defined according to a regulated minimum level and if the system does not comply with the standards in force. It recommended (2) to verify the positioning of the performance level in relation to other similar systems by consulting and extracting relevant data from comparative analyzes with similar systems available in the recent literature.

The method involves (3) identifying all applicable energy efficiency measures by consulting the database with the classes of sustainable measures to increase efficiency in energy systems. Within the MEPES method, several evaluation stages were developed, namely (4) the individual evaluation of the MEE, (5) the decision-making stage of the solutions and (6) their multicriteria evaluation. In the construction of the solutions, the most appropriate measures will be selected and (7) the side effects generated by the overlapping of the measures or the interactions with other systems or subsystems will be eliminated, in an evaluation that is intended to be as exhaustive as possible. This method established that (8) it is important that performance is assessed on the basis of a threshold level, established on the basis of compliance with standards and in relation to similar systems, as well as on the basis of the desired ideal level, called the target.

In the evaluation (9), key multi-criteria indicators were defined which advocate an overall assessment of the sustainability of the system. With the evaluation of the solutions implemented during operation, the recoil effects will be calculated (10) and new measures will be determined for the corrections necessary to reach the planned parameters. For sustainability reasons, the methodology proposes that (11) performance evaluation be carried out throughout the life of the system, with the planning, evaluation and implementation of new incremental solutions to ensure performance increases until the targets are reached; then, the evaluation continues to ensure the maintenance of the achieved performance and the readjustment to the energy policies of the moment, by redefining a new target level, if necessary.

➢ Future directions of research

The objectives pursued by creating the method for evaluating solutions that increase energy efficiency refer to the theoretical and applied substantiation of the elements that will facilitate the development of IT applications (software) useful in designing, analyzing and conducting energy efficiency investment projects. Given that the method uses complex data and a large volume of multidisciplinary information contained in the evaluation, it is obvious that the development of a software application is a natural and extremely useful desideratum. The processing of data in dedicated computer applications will allow their storage throughout the operation. The operations of calculating the indicators and those of verifying the threshold values or target values can be performed throughout the life of the system by querying them. It will also be possible to allow the import of data from external databases, periodically updated and validated, and the export of information for monitoring and control systems.

The way of managing the performance in operation and the risks will be the subject of further developments, the thesis being limited to the development of the performance evaluation method in the design phase of the sustainable development program and to the development of the lifetime performance evaluation methodology of the system. Analysis models comprising methods for risk management and sensitivity analyzes will be developed in other future research.

Concerns are currently being raised about the development and testing of holistic concepts for integrating energy consumers and prosumers into SEN. The current efforts refer to the creation of optimization models that simultaneously satisfy the operational conditions, production limitations, reduction of carbon emissions and maximization of profit / benefits. Within these initiatives for designing optimization models, genetic algorithms are used, optimization, with the definition of a programming problem. The holistic approach underlying MEPEES can be supported in defining it with *PSE* as an indicator that can be integrated into such an optimization algorithm.

Future research aims to use the developments made in this paper to design, test and demonstrate an innovative application for real-time energy management and control in prosumers; it will be developed according to the LCA-MEPES, the MEPEES evaluation method presented and the models presented for investment planning in increasing energy efficiency and those for continuous monitoring in the operating phase of the energy system. The computer application will use self-learning algorithms to optimize both energy use according to local production and local storage of green energy, while maintaining the system at an optimal level of performance with improved comfort for residents.

Monitoring and control of energy by smart metering to the place of consumption is the subject of the latest innovative developments. Current research concerns new affordable solutions for monitoring and controlling decomposed consumption per internal consumer for automatic energy demand response commands [32].

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