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ORIGINAL PAPER

ASSESSING MEASURES OF ENERGY EFFICIENCY IMPROVEMENT OPPORTUNITIES IN THE INDUSTRY

Aldona Kluczek

Warsaw University of Technology, Warsaw, **Poland**

ABSTRACT. **Background:** Energy efficiency has recently become one of the key aspects in the manufacturing sector. The facilities should improve their performance due to the related economic costs and the significant environmental impacts. The objective of this paper is to prove that energy efficiency of opportunities for energy savings improvements provided by the energy auditors are efficient. These opportunities represent technical actions recommended in the U.S. industrial plants over time period 2013 to 2014. Moreover, these technologies are considered as efficient ones based on energy audits results. Therefore, only ten suggested recommendations are included in the analyses.
Methods: The paper demonstrates a DEA- Slack Based Measurement approach to evaluate the energy efficiency of the recommended technical solutions. This study is built upon the results of energy audits carried out by the author with the Industrial Assessment Center`s experts at the University of Michigan.
Results: The results confirms that seven audit`s energy-effective improvements are still efficient, compared with those of the DEA-SBM method outcomes. The paper reveals inefficiencies of three industrial plants, which were considered as efficient ones examined individually in energy audit procedure. Moreover, the results are enriched with the additional analysis of input excesses and output shortfalls.
Conclusions: Based on the study of the recommended solutions in the U.S. industrial plants, more effective technologies (DMU2, 4, 5, 7, 8, 9, 10) are identified, along with the ranking of the recommended solutions used. The SBM model described in this paper allows a more accurate determination of which audit`s proposed technical improvements are energy efficient or not. Further work is required to develop a set of relative input and output variables as well as a way of variables selection using analytical methods which may make the measure more robust.

Key words: DEA, energy efficiency, SBM, technical improvements.

INTRODUCTION

Manufacturing sector has been consuming much energy at its various processes. In the U.S. according to EIA 2014, industrial sector absorb about 22% of total energy consumption [EIA 2014]. Industrial facilities use widely energy for cooling, space heating or maintaining for motors in many cases. Efforts to increase energy efficiency of these facilities and production [Koliński 2012] have gained significant traction in energy policies [Tanaka 2011]. The major energy saving opportunities are probably bound to production optimization and energy process integration within manufacturing plants and energy intensive industry (such as for example rubber [Saidur and Mekhilef 2010], casting [Noro 2014], and others). Potential energy savings could more than offset projected increases in U.S. energy consumption through 2030 [NAE 2009]. The potential energy savings or energy efficiency can be improved by a wide variety of technical actions throughout the industrial processes, including the configuration of certain technologies and processes e.g. refurbishing equipment, replacing and retiring obsolete equipment, process lines to new and state of art technologies or using heat management

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to decrease heat loss and waste energy [Tanaka 2011, Xue et al. 2015]. Further, efficiency improvements such as the adoption of many energy efficiency measures represent a driver for increasing process performance, thus energy efficient technologies.

Energy efficiency measures refer to improve processes or systems of energy using technologies in industrial plants [Trianni et al. 2016]. Currently available energy efficient and cost-effective technologies can improve energy performance efficiencies in lighting, heating, cooling, refrigeration, transportation, and other areas throughout the regional programs, even the economy [Anderson and Newell 2004, Thollander et al. 2013]. An evaluation of cost-effective performance is an essential action in identifying energy saving improvements opportunities and devising goals for assessing technical actions in terms of energy efficiency improvement. The analysis of energy intensity in industrial plants can be performed through energy audits based on the measurement of cost and energy savings under the implicit assumption that all companies are efficient [Saidur and Mekhilef 2010, Noro and Lazzarin 2014]. Arig [2011] measured and evaluated the efficiencies of manufacturing companies by using financial ratios as input and output variables. However, he did not evaluate each sector individually, which could lead to misleading conclusions due to the different structures of the sectors [Saricam, Erdumlu 2012] and company`s performance [Duzakin and Duzakin 2007].

Further, Energy Efficiency Directive [EC 2012] has advocated energy audits as a way to overcome barriers to energy efficiency and facilitate implementation of energy efficiency measures in the small and medium sized firms (SMEs). It is therefore worthwhile to extend an audit method by using a non-linear measure of factors affecting production efficiency, under certain inputs and outputs. On this demand, DEA-SBM model is applied, which assesses energy efficiency of industrial plants in terms of energy-efficiency solutions apart from the effects resulting from traditional measures (energy audits). The objective of this paper is to measure and assess the energy efficiency performance of technical improvements actions in the U.S. manufacturing sector over time period 2013 to 2014. Twelve industrial plants are considered with their suggested technical improvements as decision making units (DMUs) whose efficiencies for energy-savings solutions were determined by the U.S. Industrial Assessment Center`s experts during carrying out energy audits. A DEA-Slack-Based Measure Model (DEA-SBM) model is employed in technologies recommended during energy audit to assess measures of energy efficiency improvement opportunities in the U.S. industry. Then these efficiency is benchmarked with DEA-audit`s technical efficiency scores. The benchmarking focuses on comparison of energy performance measures of processes from the energy audits to energy performance resulted from the applied SBM method.

Engineering studies identified several investments in new energy efficiency equipment, for which overall audit`s energy efficiency amounted to 1-score.

Provided audit`s information to industrial decision makers about their plant's energy performances is not enough. Energy audits of industrial plants provide important information about current energy use and opportunities for improving energy efficiency. With lower energy usage, energy saving measures are not a pressing enough issue for plant managers; instead, other attributes that come with improvements need to be emphasized. In addition, industrial mangers may not be aware that available improvements that would provide a stream of future energy savings to offset the upfront costs of those retrofits, may be inefficient. Although energy audits seem to be a relatively reliable, comprehensive method for assessment and improvement of energy performance, the prediction of the effect of modernization or upgrades on plant energy savings, is often fuzzy / vague. The author fills an information gap about getting a "confirmation" that proposed improvements are still efficient as stated during the energy audits.

The goal of the study is to prove or confirm that improvements provided by the energy auditors and examined using the SBM method are still efficient.

THEORETICAL BACKGROUND

DEA is a well-established non-parametric linear method used to evaluate the relative efficiency of comparable multiple inputs and outputs called decision making units (DMUs) [Xue et al. 2015], and to identify both inefficient DMUs and the magnitude of the efficiency. According to Charnes [1981], DMU is to be rated as fully efficient on the basis of available evidence if and only if the performances of other DMUs do not show that some of its inputs or outputs can be improved without worsening some of its other inputs or outputs. Efficiency in production units is defined as the quotient of the weighted sum divided by the weighted sum of the effects of inputs [Savič et al. 2012]. Various DEA models have been established based on a basic model modifications of C^2R model [Charnes et al. 1981] and applied in diverse industries [Jablonsky 2006, Shafiee et al. 2013], research fields [Flitsch 2012] or even used in energy efficiency analysis for the measurement of technology productivity improvement or processes and optimal allocation of resources [Grösche, 2008, Moritaa, Hirokawa, Zhu 2015]. The pros and cons of DEA as being applied to benchmark activities are identified in [Zhang et al. 2011].

In determining the variables inputs and outputs expert knowledge or accepted practices can be useful [Morita and Avkiran 2009]. Most studies about the application of DEA-based models to industrial processes measurement assume that the reduction of undesirable outputs (or inputs) and the increase of desirable outputs are proportional [Zhang et al. 2011]. In the presence of undesirable outputs, however, technologies with desirable outputs and undesirable outputs relative to less input resources should be recognized as efficient. In the extended SBM Network Data Envelopment Analysis, the input and output slacks are measured at the system level instead of at the process level giving freedom to the different processes to increase some inputs or decrease some outputs. Therefore, it leaves a room for further research related to the relationship between the overall efficiency of the system and the efficiency of its processes [Lozano 2015].

This implies that the slacks in inputs and outputs are not accounted for when recommended solutions are evaluated.

Therefore, it is meaningful to incorporate the input excesses and output shortfalls into DEA-based models in measuring recommended solutions performance. In this way, SBM, developed by Tone [2001] gives comprehensive approach for firm`s performance evaluation due to deals directly with input excess and output shortfall for each DMU. [Tone and Tsutsui 2010, Shafiee et al. 2013]. Efficiency is measured only by additional variables s+ and s– which measure the distance of inputs Xλ and outputs Yλ of a virtual unit from those of the unit evaluated (Xo). The numerator and the denominator of the objective function of model (2) measures the average distance of inputs and outputs, respectively, from the efficiency threshold. DMU (x_{io}, y_{ro}) is SBM-efficient unit, if p* = 1, that means $s_i*+ = 0$, $s_i*- = 0$, as no slack variables for input and output in optimal solution. It provides an efficiency score between 0 and 1. The model formula is expressed is [Tone 2002]:

minimize $p = \frac{1-\frac{1}{m}}{1+\frac{1}{s}} \frac{\sum_{i=1}^{m}(s_i^- / x_{io})}{\sum_{r=1}^{s}(s_r^+ / y_{ro})}$ subject to

(2) $\sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- = x_{io}$ i =1, 2, …, m

$\sum_{j=1}^{n} y_{ij}\lambda_j - s_r^+ = y_{ro}$ r =1, 2, …, s

$\lambda_j , s_r^+, s_i^- \geq 0$

MATERIALS AND METHODS

In order to assess energy efficiency, it is necessary to adopt a method capable of measuring energy efficiency of individual operations in manufacturing plants. Such approach is expected to yield better accuracy, when compared to traditional measures, such as energy audits. An adopted approach is based on the energy saving potentials resulted from the energy audits - recommended technical changes.

This approach - DEA-SBM - gives the possibility to compare the energy inputs / outputs for individual technical actions.

The analysis is conducted by using a DEA Frontier Software [Cooper et al. 2007]. The study is based on the assumption that proposed energy`s audit technical recommendations are efficient (score of 1).

EMPIRICAL STUDY

Manufacturing processes are influenced by raw materials, technology and equipment used, and other factors. The data used in this study was obtained from Industrial Assessment Center of the University of Michigan, within energy audits were carried out. Energy audits reports include, not limited to, the following indices: annual energy consumption, expected energy saving and costs of implementing retrofits / technologies.

The author has selected twelve most efficient technical solutions recommended during energy audits as DMUs to measure energy consumption efficiency of industrial processes for twelve industrial facilities. These solutions have represented energy saving opportunities (as shown in Table 1). Database for facilities encompassed industrial plants from manufacturing sectors consisting of fluid power valves and hose fittings, manufacturing processed milk products, metal coating, semiconductor and related device manufacturing, motor vehicle brake system manufacturing.

Table 1. The allocation of energy-efficiency improvements in twelve industrial plants in respective sector
Tabela 1. Zestawienie opłacalnych usprawnień energetycznych dla 12 zakładów przemysłowych

# of DMU	DMUs	# of industrial plants											
Energy efficiency improvements (recommendations)		1	2	3	4	5	6	7	8	9	10	11	12
1	Install a cogeneration system	☐	☒	☐	☐	☒	☐	☒	☒	☒	☒	☒	☒
2	Lower steam operating pressure	☐	☐	☐	☐	☐	☐	☒	☒	☐	☐	☐	☐
3	Install insulation on condensate return pipes	☐	☐	☐	☐	☒	☐	☐	☒	☐	☐	☐	☐
4	Replace electric heaters with gas boilers	☐	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	☐
5	Duct outside air to compressor intakes	☒	☒	☒	☐	☒	☐	☐	☐	☒	☒	☒	☐
6	Install high efficiency lighting	☒	☒	☒	☐	☒	☒	☐	☐	☐	☐	☒	☒
7	Recover air compressor waste heat	☒	☒	☐	☐	☐	☒	☐	☐	☐	☒	☐	☐
8	Reduce compressor set point pressure in compressed air system	☒	☒	☐	☐	☐	☐	☐	☐	☒	☐	☐	☐
9	Install variable speed drive (VSD) pumps	☐	☐	☐	☐	☐	☒	☐	☐	☒	☐	☐	☐
10	Use gas heaters instead of electric heaters	☐	☐	☐	☐	☐	☐	☒	☐	☐	☐	☐	☐

Source: own study

Inputs and outputs variables for determining energy efficiency found in the audit reports. Therefore, three undesirable inputs include Total investment cost (x1), Electricity consumption (x2), Gas consumption (x3) and two desirable outputs encompass potential Electricity estimated savings (x4) and Estimated gas savings (x5). Undesirable outputs (environment pollution, such as CO_2, SO_2, etc.) are ignored/discarded [Färe and Grosskopf 2004] in this study. These variables are aggregated for 12 plants in terms of recommended technical solutions for energy savings (DMU) and expressed in physical values (e.g. US$ / year, kwh / year, MMBTU / year).

The biggest allocation of energy-saving potential improvement can be attributed to process of the installation of cogeneration system (DMU 1), high efficiency lighting (DMU 6). These recommendations were proposed for plant no. 8 and no. 7 respectively. As Table 1, most energy savings can be realized in the processes of duct outside air to compressor intakes (7 DMUSs). Table 2 shows the inputs and outputs for energy efficiency improvements, which is the result of energy audits measurements.

Table 2. Input and output data for the proposed technical improvements (DMUs)
Tabela 2. Dane wejściowe/wyjściowe dla proponowanych usprawnień technologicznych (DMUs)

DMU	Proposed technical recommendations	(I)Total investment cost US[$]	(I) Electricity consumption [Kwh/yr]	(I)Gas consumption [MMBTU /yr]	(O) Electricity saving [Kwh/yr]	(O)Gas saving [MMBTU/ yr]	Overall efficiency score from energy audit reports)
1	Install a cogeneration system	1383250	17179166	551.1116	9229081	-98.3245	1
2	Replace Electric Heaters with Natural Gas boilers	94400	576000	9.989835	1146670	-18.7523	1
3	Duct outside air to compressor intakes	12850	3683971.14	0	244774.4	0	1
4	Use gas heaters instead of electric heaters	600	11173	0	10738	0	1
5	Lower steam operating pressure	10000	0	491.9561	0	10.79966	1
6	Install high efficiency lighting	111390	1224925	0	382739	0	1
7	Install Insulation on Condensate Return Pipes	3000	0	2.96364	0	2.93217	1
8	Reduce compressor set point pressure in compressed air system	2700	1524006.83	0	163022	0	1
9	Recover air compressor waste heat	1000	0	218.957	0	1.138227	1
10	Install variable speed drive (VSD) pumps	7300	123319084.8	0	490846.6	0	1

SBM-DEA RESULTS

The evaluation energy efficiency can be carried out by comparing a particular technical recommendation with other technical ”competitors” within the same group of variables.

The technical efficiency scores of ten opportunities for energy savings based on input-oriented SBM model are presented in Table 3, as the result of Formula (2). The efficiency scores (for audit`s and SBM results) are corresponded to vertically individual technologies (DMUs) in Table 3 along with the rank scale in Fig. 1. As shown in Table 3, the technical efficiency of DMUs through DEA Solver Pro 5.0 is calculated. Based on these results seven of ten DMUs are overall efficient.

The remaining inefficient DMUs (plants no. 1, 3, 6) which gained efficiency scores less than one, are comparatively inefficient as shown in Fig. 1. It also depicts the ranks of DMUs in an ascending order as follows: DMU1->DMU6->DMU3->DMU10->DMU9->DMU2->DMU8->DMU4. The lowest inefficiency score is 0.31 assigned to the DMU 1. Under the assumption of SBM model, it was found that average technical efficiency score for proposed technical solutions is 84.60%, which implies that on an average DMUs could have used 15.40% fewer resources to produce the same amount of output.

Furthermore, the emphasis on the input excess and output shortfalls is becoming significant factors that need to be focused with. In this study input-oriented model is used that has purpose to seek the input excesses that cause inefficiency without any changes in the output shortfalls. By observing input excesses in Table 4, the most inputs excess are observed in the “Electricity consumption” input with values of 7576211.8; 1395704,17; 826681,11 respectively for plant 1, 3 and 6. More input excess is seen in the input “Investment cost” for DMU 1 getting the value of 867562.85. These above values show that the capacity utilization in terms of that input requires more effort to be improved.

Table 3. Energy efficiency evaluation comparison for proposed technical recommendations
Tabela 3. Porównanie wyników oceny efektywności energetycznej dla proponowanych usprawnień technologicznych

DMU	SBM Score (efficiency)	SBM rank	Energy audit`s efficiency score	Benchmark
1	0.31	10	1	inefficient
2	1	1	1	efficient
3	0.65	8	1	inefficient
4	1	1	1	efficient
5	1	1	1	efficinient
6	0.51	9	1	inefficient
7	1	1	1	efficient
8	1	1	1	efficient
9	1	1	1	efficient
10	1	1	1	efficient

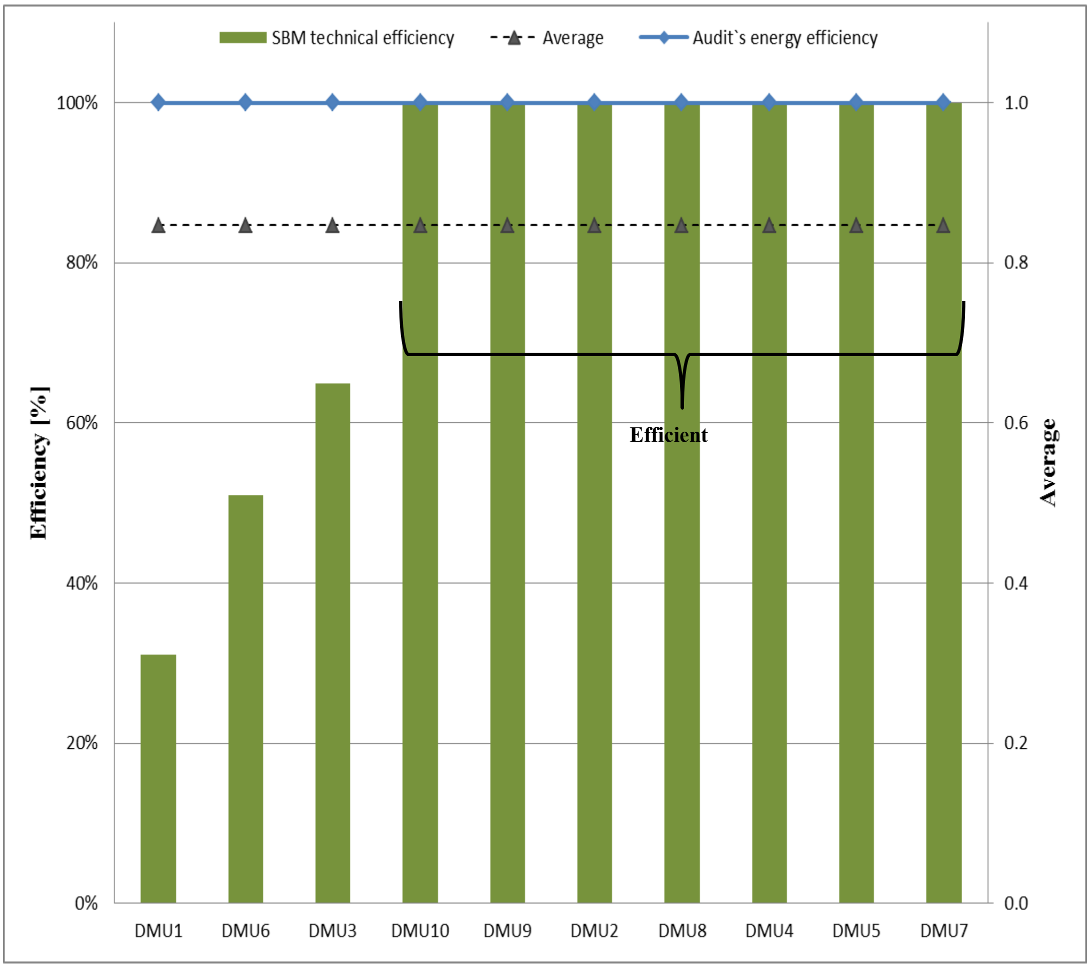

Fig. 1. The ratios of efficient and inefficient DMUs
Rys. 1. Stosunek efektywnych i nieefektywnych DMU

Table 4. Inefficiency slacks from SBM model
Tabela 4. Model SBM: Źródła nieefektywności badanych obiektów

DMU	Excess Electricity consumption S-(1)	Excess Gas consumption S-(2)	Excess Total investement S-(3)	Shortage Electricity saving S+(1)	Shortage Gas saving S+(2)
1	7576211.82	551.11	867562.85	0	98.32
2	0	0	0	0	0
3	1395704.17	0	8796	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	826681.11	0	90003.95	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0

Considering output excess only one value for DMU1 can decrease its slack in total gas. Examining the outputs excess, "Gas consumption" becomes very painful for the DMU1 whereas the rest ones get zero value in terms of efficiencies. "Electricity savings" and "Gas savings" are lacking of outputs shortage except for DMU1 which gets the highest value of 98.32 (only for gas saving).

The seven improvements proposed by auditors during at the site visit proved their effectiveness by using the SBM method. It shows that these recommended technical actions appear to have the potential to reduce their energy use and cost.

CONCLUSIONS

In this paper slacks-based measure model for DEA to measure and evaluate efficiency of technical solutions is proposed. With the help of a set of input and output variables from energy audits reports technical efficiency scores were computed.

Hence, in this study the author exams the particular recommendations that decision makers take after having an energy audit by using DEA-SBM and benchmarking those results with overall audit`s energy efficiency.

Comparing the overall audit`s energy efficiency scores for the appropriate recommendations with those of the DEA-SBM outcomes, a difference is seen: seven recommendations proposed at the site visit are efficient with values of 1, so three of them are considered as inefficient (below zero).

The goal of the study was achieved. The results confirms that seven audit`s energy-effective improvements are still efficient (DMU2, 4, 5, 7, 8, 9, 10), along with the ranking of the recommended solutions used. It was checked by comparison with the DEA-SBM outcomes. The greatest contribution to not improve the performance are DMU1, DMU3, DMU6 with their scores 0.31, 0.65, 0.52 respectively.

However, the use of these efficiency scores must be made more cautiously. The set of input and output variables selected may be made more exhaustive by adding a few more relevant variables (e.g. electricity cost) in the efficiency measurement, which may make the measure more robust. The empirical results show that efficiency measures of energy efficiency improvement opportunities are sensitive to their process characteristics, the choice estimation method, data levels. In addition, the number of technical improvements and the number of inputs and outputs used in the research affect the estimated efficiency scores or levels. On the other hand, the adding of more input, input quality indicators and production characteristics to the production model, improves the fit of model and thereby decreasing degree and dispersion of inefficiency.

Moreover, suggested improvement includes an array of possibilities for energy savings that the energy audits revealed for the twelve industrial plants. However, the array of processes should be explored more in detail before being decided upon.

Another point to measure and evaluate is that the proposed approach is advantaged by its simplicity while it can be simply extended in diverse directions.

Further work is required to develop a set of relative input and output variables as well as a way of variables selection using analytical methods which may make the measure more robust. The SBM model described in this paper allows a more accurate determination of which audit`s proposed technical improvements are energy efficient or not.

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OCENA POMIARU EFKETYWNOŚCI ENERGETYCZNEJ DZIAŁAŃ USPRAWNIAJĄCYCH PROCESY TECHNOLOGICZNE

STRESZCZENIE. **Wstęp**: Efektywność energetyczna stała się jednym z najważniejszych aspektów w sektorze wytwórczym. Zakłady przemysłowe stają przed koniecznością zmiany sposobu prowadzenia działalności gospodarczej w celu poprawy wydajności ekonomicznej i zminimalizowania negatywnego wpływu na środowisko. Celem niniejszego opracowania jest udowodnienie, że działania dotyczące poprawy efektywności energetycznej w procesach wytwórczych zaproponowane przez audytorów są efektywne energetycznie. Działania te stanowią rekomendowane przez audytorów usprawnienia technologiczne, wdrożone w amerykańskich zakładach przemysłowych w latach 2013 - 2014. Ponadto, usprawnienia te, uznane zostały za uzasadnione biznesowo pod względem kosztowo-energetycznym na podstawie wyników audytów energetycznych. W związku z tym, tylko dziesięć zaleceń poaudytowych zostało zaprezentowanych w niniejszej analizie.

Metody: Artykuł prezentuje ocenę efektywności energetycznej usprawnień technologicznych poprzez zastosowanie modelu DEA-SBM w oparciu o przeprowadzone audyty energetyczne w ramach Industrial Assessment Center przy University of Michigan.

Wyniki: Uzyskane wyniki wskazują, że siedem z dziesięciu analizowanych usprawnień technologicznych działa w sposób efektywny, co zostało zweryfikowane przy użyciu metody DEA-SBM. Ponadto, wyniki zostały wzbogacone o analizę źródeł nadefektywności oraz nieefektywności badanych obiektów.

Wnioski: W oparciu o powyższe badania dotyczące usprawnień technologicznych w amerykańskich zakładach przemysłowych, wyszczególniono siedem efektywnych energetycznie technologii (DMU2, 4, 5, 7, 8, 9, 10). To potwierdza, że usprawnienia zaproponowane podczas audytów energetycznych są nadal efektywne. Przedstawiony w artykule sposób pomiaru narzędzi realizacji poprawy efektywności energetycznej pozwoli na bardziej precyzyjne określenie czy rodzaj zaproponowanych usprawnień technologicznych jest efektywny energetycznie czy też nie.
Dalszych prac wymaga opracowanie zestawu istotnych zmiennych wejściowych i wyjściowych oraz sposobu wyboru wskaźników przy pomocy metod analitycznych, co może przynieść bardziej wiarygodne wyniki.

Słowa kluczowe: metoda DEA, efektywność energetyczna, nieradialny model SBM, usprawnienia technologiczne.

BEWERTUNG DER ENERGETISCHEN EFFEKTIVITÄT DER TECHNOLOGISCHE PROZESSE VERVOLLKOMMNENDEN AKTIVITÄTEN

ZUSAMMENFASSUNG. Einleitung: Die energetische Effektivität wurde zu einem der wichtigsten Aspekte im erzeugenden Sektor. Industrielle Einrichtungen stehen vor der Notwendigkeit der Veränderung ihrer wirtschaftlichen Betätigung zwecks der Verbesserung ihrer ökonomischen Effizienz und der Reduzierung ihrer negativen Beeinflussung der Umwelt. Das Ziel der vorliegenden Bearbeitung ist es, die von den Auditoren vorgeschlagenen, die energetische Effektivität innerhalb der Erzeugungsprozesse verbessernden Aktivitäten als energetisch effektiv auszuweisen. Diese Aktivitäten gelten als die von den Auditoren empfohlenen, technologischen Innovationen, die in amerikanischen Industriebetrieben in den Jahren 2013-2014 eingeführt wurden. Darüber hinaus wurden die Verbesserungen hinsichtlich der energetischen Kosten aufgrund der Ergebnisse von energetischen Audits als wirtschaftlich begründet festgelegt. Im Zusammenhang damit wurden zehn aus den betreffenden Audits resultierende Empfehlungen innerhalb der vorliegenden Analyse dargestellt.
Methoden: Der Artikel projiziert eine Bewertung der energetischen Effektivität technologischer Innovationen durch die Anwendung des DEA-SBM-Modells und auf Grund der energetischen Audits, die im Rahmen des Industrial Assessment Centers an der University of Michigan durchgeführt wurden.
Ergebnisse: Die erzielten Ergebnisse weisen darauf hin, dass sieben von zehn betrachteten, technologischen Verbesserungen sich effektiv auswirken, was unter der Anwendung der DEA-SBM-Methode verifiziert wurde. Darüber hinaus wurden die Ergebnisse um die Analyse der Quellen des unter- und übereffektiven Verhaltens bei den betrachteten Objekten bereichert.
Fazit: Anhand der betreffenden Forschungen hinsichtlich der technologischen Innovationen, die in den amerikanischen Industriebetrieben eingeführt wurden, wählte man sieben energetisch effektive Technologien (DMU 2, 4, 5, 7, 8, 9, 10) aus. Dies bestätigt den Sachverhalt, dass die während der energetischen Audits empfohlenen Verbesserungen weiterhin als effektiv gelten. Das im Artikel projizierte Verfahren zur Bewertung der die Verbesserung der energetischen Effektivität bewirkenden Tools ermöglicht eine mehr präzise Feststellung, ob die Art der vorgeschlagenen technologischen Innovationen energetisch sehr effektiv oder weniger effektiv zu sein vermag. Weiterer Arbeiten bedarf die Ausarbeitung der Sätze von relevanten Eingangs- und Ausgangsdaten sowie der Art und Weise der Auswahl von Kennziffern anhand von analytischen Methoden, was gegebenenfalls mehr glaubwürdige Ergebnisse mit sich bringen kann.

Codewörter: DEA-Methode, energetische Effektivität, nicht radiales SBM-Modell, technologische Innovationen

Aldona Kluczek
Institute of Organization of Production Systems
Faculty of Production Engineering
Warsaw University of Technology
02-524 Warsaw, **Poland**
email: a.kluczek@wip.pw.edu.pl