

Towards Industrial Energy Efficiency Index

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Abstract – The study analyses factors that determine industrial energy efficiency. Composite index methodology was applied to evaluate energy utilization efficiency levels across different industrial sub-sectors. In total 12 indicators were incorporated in 3 main dimensions – economic, technical, and environmental. The first results for dimension sub-indices of the 18 main manufacturing sub-sectors in Latvia were presented and discussed. The findings of the study indicated that sector-specific disparities exist that significantly impact the energy efficiency performance of each industrial sub-sector.

Keywords – Composite index; dimensions; energy efficiency; performance indicators; sub-sectoral comparison.

Nomenclature

EEI	Energy efficiency index
I_N^+	Normalized indicator of a positive influence on energy efficiency
I_N^-	Normalized indicator of a negative influence on energy efficiency
I_{act}	Actual value of an indicator
I_{max}	Maximum value of an indicator
I_{min}	Minimum value of an indicator
I_D	Dimension sub-index
w_I	Determined weight of an indicator
w_D	Determined weight of a dimension
n_I	Number of indicators in a dimension
n_D	Number of dimensions

1. INTRODUCTION

Nowadays all companies in the industrial sector are confronted with the energy efficiency issue since manufacturing processes are highly reliable in terms of amount of energy consumed. The total energy efficiency of industry is highly dependent on the sectoral heterogeneity [1] since the technological processes and generated economic output of the produced items of sub-sectors

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differ. Therefore, in respect to industrial energy efficiency assessment it is crucial to develop a model that measures sectors separately and investigates sectoral differences [2].

When it comes to macroeconomic evaluation of energy efficiency among different sectors in the industry, the question about the choice of the most appropriate and comprehensive evaluation method arises. Numerous studies investigate energy efficiency performance levels across different sectors that include in-depth analysis of several factors of energy efficiency separately. However, when there exist many different performance indicators it might be difficult to make sub-sectoral comparisons based on different units of measurement of each indicator [3].

The goal of this study is to demonstrate the application of an innovative model for industrial energy efficiency evaluation. The composite index methodology is used to construct 3 sub-indices for each dimension of energy efficiency – economic, technical, and environmental, for 18 different manufacturing sub-sectors in Latvia. Composite indices are a common practice in the sustainability evaluation studies [3]–[5], therefore, this study aims to demonstrate that a similar approach could be used in energy efficiency research to obtain valuable findings for policymakers. This study focuses on the analysis on 12 different indicators that were incorporated in the selected dimensions of energy efficiency. Preliminary results on each dimension's sub-indices are presented and discussed

2. METHODOLOGY

Energy efficiency index (EEI) in this study is a composite measure that compares energy utilization efficiency levels among various industrial sub-sectors. The index is composed of three main energy efficiency dimensions that each consists of four explanatory indicators. The model for the composition of the EEI proceeds in several chronological stages that are illustrated in Fig. 1. The proposed model in the study is developed by using the methodological approach applied in the academic studies on sustainability evaluation [3], [4], [6], [7], as well as taking into consideration the composite index calculation practices applied in the internationally recognized reports published by the European Commission (for eco-innovation index), the United Nations (for human development index), and in relevant scientific peer-reviewed papers [5], [8].

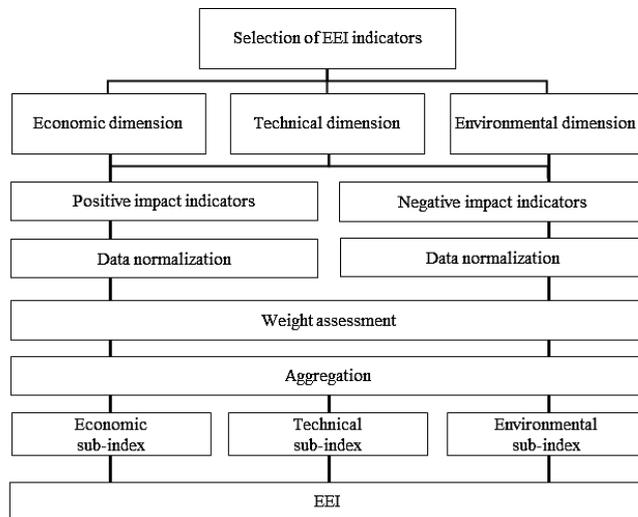


Fig. 1. Hierarchical procedure of the EEI calculation. Developed by the authors inspired by [3], [4], [6], [7].

2.1. Data Collection on Selected Indicators

Based on data availability in total 12 relevant indicators on 18 main industrial sub-sectors in Latvia were selected. Data on sub-sectors were collected and grouped according to NACE Rev. 2 classification [9]. Data were collected from Eurostat, Central Statistical Bureau of Latvia (CSB) and International Organization for Standardization (ISO) databases. All sources of the data used in the study are listed in Table 1. All the data reported in the study are for the year 2017, with an exception of data for environment protection activity from Eurostat's Community Innovation Survey (CIS) questionnaire that was collected for the latest available year. In addition, in data processing there were detected missing data on the year 2017 for the manufacture sector of computer, electronic and optical products. As a result, the values were taken for the year 2015 for the sectors. According to the performed sensitivity analysis, it did not impact the results.

2.2. Classification of the Indicators

Classification of the indicators into dimensions is commonly used in composite sustainability indices studies ([4], [10], [11]), therefore, selected indicators were grouped in three dimensions of energy efficiency – economic, technical and environmental, as presented in Table 1.

Indicators of the economic dimension reflect a sector's ability to generate sufficient economic contribution relative to the amount of energy consumed in the production process. Strong economic performance is a significant determinant for achieving higher energy efficiency [12] since the economic growth stimulate companies to invest in renewable energy technologies in order to replace the utilization of the fossil fuels [13]. Indicators identifying to the economic dimension consist of the following independent variables – value added per energy use, generated turnover per energy use, energy costs, and energy taxes per generated turnover.

Technical dimension's indicators cover both technical and structural aspects of manufacturing companies in the sectors. Access to capital, technical support, labour intensity, and sector size are some of the factors that should be considered in the concept of industrial sustainability and energy efficiency [14]. These aspects are incorporated in the technical dimension by the following variables – investment per energy use, share of ISO 50001 registered companies, share of large-sized companies, and energy use per employee.

The group of environmental indicators concern the environmental impact the sectors create as a result of their economic activity. The amount of produced greenhouse gases, including CO₂ emissions, are strongly linked with energy efficiency in the manufacturing industry [15], [16]. To measure the performance of the environmental dimension, the following independent variables were incorporated – greenhouse gas intensity, use of fossil energy resources, environment protection activity, and CO₂ productivity.

All the factors incorporated in each dimension and within the framework of the index methodology are believed to be interconnected and jointly create synergies towards the determination of the index [17].

2.3. Impact Evaluation

Each indicator is evaluated with respect to its impact on energy efficiency. Indicators are grouped in two categories depending on their positive or negative influence on energy efficiency. An indicator has a positive impact if its increasing value contributes to the improvement of energy efficiency (e.g. generated value added per unit of consumed energy). In turn, an indicator has a negative impact if its increasing value negatively deteriorates sustainable energy efficiency goals (e.g. produced greenhouse gases per generated value added) [10]. Table 1 incorporates the results from the impact evaluation.

TABLE 1. DATA SOURCES, INDICATOR CLASSIFICATION AND IMPACT EVALUATION

Dimension	Indicator	Variable	Impact	Data source
Economic	Value added per energy use	Value added/Net domestic energy use	+	[18], [19]
	Generated turnover per energy use	Turnover/Net domestic energy use	+	[18], [19]
	Energy costs	Purchases of energy products/Turnover	-	[20], [18]
	Energy taxes per generated turnover	Energy taxes/Turnover	-	[21], [18]
Technical	Investment per energy use	Gross investment in existing buildings, structures, machinery and equipment, construction and alteration of buildings/Net domestic energy use	+	[18], [19]
	Share of ISO 50001 registered companies	Number of ISO 50001 registered companies/Total number of companies	+	[22], [18]
	Share of large size companies	Number of enterprises with 250 persons or more employed /Total number of enterprises	+	[23]
	Energy use per employee	Net domestic energy use/Number of employees	-	[19], [18]
Environmental	Greenhouse gas intensity	Tons of greenhouse gases/Value added	-	[24], [18]
	Use of fossil energy resources	Fossil energy products/Total energy products	-	[25]
	Environment protection activity	Percentage of companies that reduced energy consumption or CO ₂ emissions	+	[26]
	CO ₂ productivity	Generated turnover/Tons of CO ₂ emissions	+	[18], [24]

2.4. Data Normalization

In order to transform all the indicators into a common scale, min-max data normalization is applied. Normalization stage expresses all the different units of measurement of the indicators into a common ranking unit. The values are ranked in a range from 0 to 1, where 0 being the lowest and 1 the highest grade. Indicators are normalized taking into account the results from the indicator impact evaluation. Normalization for positive impact indicators is performed using Eq. (1) and for negative impact indicators using Eq. (2).

$$I_N^+ = \frac{I_{act} - I_{min}}{I_{max} - I_{min}} ; \tag{1}$$

$$I_N^- = 1 - \frac{I_{act} - I_{min}}{I_{max} - I_{min}} , \tag{2}$$

where

I_N^+ Normalized indicator of a positive impact;

I_N^-	Normalized indicator of a negative impact;
I_{act}	Actual value of an indicator;
I_{max}	Maximum value of an indicator among the values in the sector;
I_{min}	Minimum value of an indicator among the values in the sector.

2.5. Weight Assessment

After data normalization, weights are determined for each indicator and their respective dimensions. Several weighting techniques are available such as equal weighting, expert weighting, pair-wise comparison, analytic hierarchy process (AHP), and others [6]. In this study equal weighting is applied in order to maximize the objectivity of the obtained results and emphasize the equal importance of all factors considered as stressed in various sustainability studies [4]. Equal weights are assigned to all indicators.

2.6. Aggregation

The final composition of the EEI consists of two main stages. At first, all the sub-indices of each dimension are calculated by aggregating normalized and weighted indicators according to Eq. (3). Then EEI is calculated by combining the values of each sub-index with its corresponding weight as shown in Eq. (4).

$$I_D = \sum w_I \cdot I_N^+ + \sum w \cdot I_N^-, w_I = \frac{1}{n_I}; \quad (3)$$

$$EEI = \sum w_D \cdot I_D, w_D = \frac{1}{n_D}, \quad (4)$$

where

I_D	Sub-index of a particular dimension;
w_I	Weight of an indicator;
w_D	Weight of a dimension;
n_I	Number of indicators in a dimension;
n_D	Number of dimensions.

3. RESULTS

Energy efficiency dimension sub-indices for 18 main industrial sub-sectors in Latvia have been constructed for the year 2017. Based on the most recent, publicly available data a total 12 indicators were incorporated in 3 dimensions of energy efficiency – economic, technical, and environmental. Each dimension consisted of 4 partial explanatory indicators. Table 2 summarizes the results from 3 sub-indices. It is evident that the values of dimension sub-indices differ considerably among all the sectors.

The highest average value of 0.48 was achieved in the environmental dimension sub-index, following by the technical dimension sub-index with 0.35 and the economic dimension sub-index with 0.34. The economic dimension values range from 0.03 to 1, technical dimension values range from 0.03 to 0.75, and environmental dimension values range from 0.06 to 0.72.

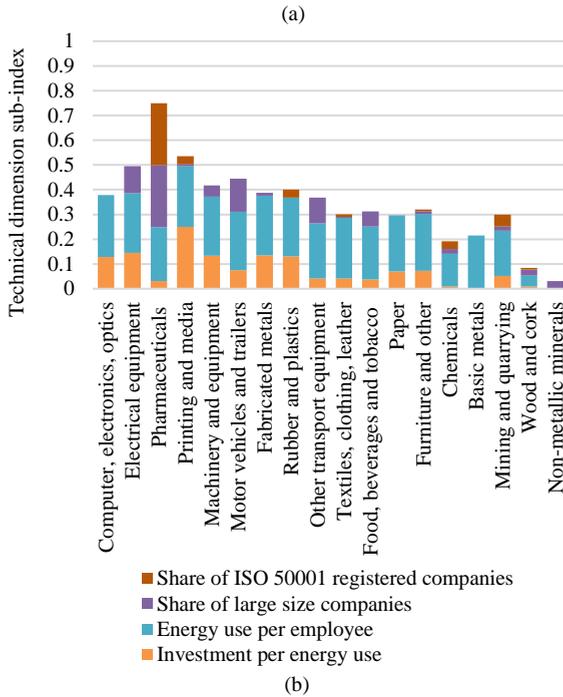
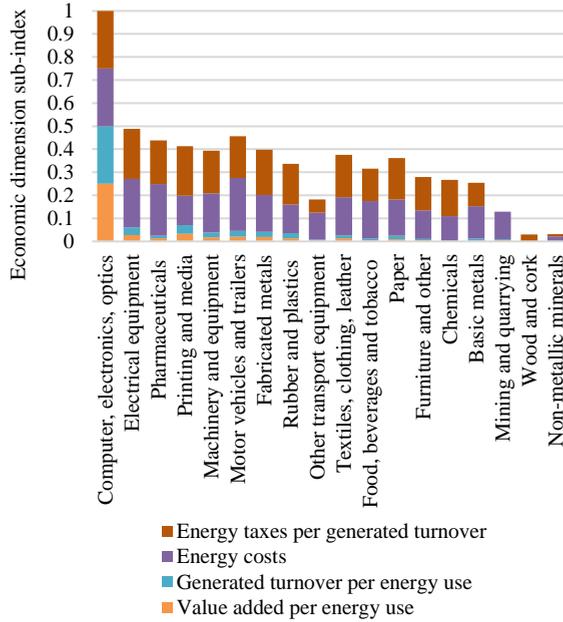
TABLE 2. RESULTS FOR ECONOMIC, TECHNICAL AND ENVIRONMENTAL DIMENSION SUB-INDICES

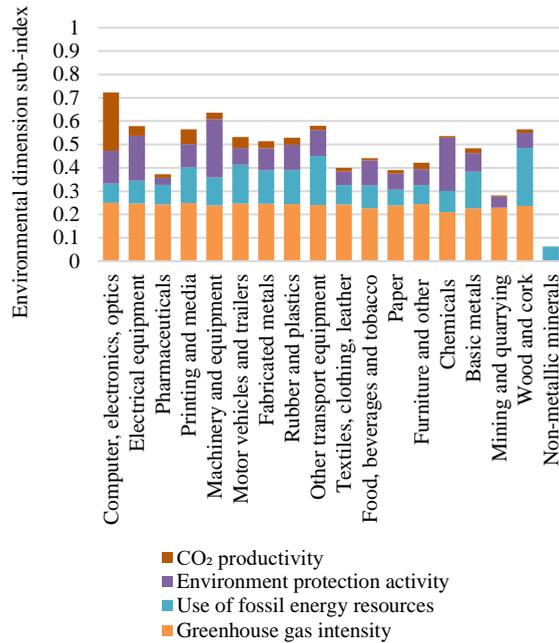
Sector	Economic dimension sub-index	Technical dimension sub-index	Environmental dimension sub-index
Computers, electronics, optics	1.00	0.38	0.72
Electrical equipment	0.49	0.50	0.58
Pharmaceuticals	0.44	0.75	0.37
Printing and media	0.41	0.54	0.56
Machinery and equipment	0.39	0.42	0.64
Motor vehicles and trailers	0.46	0.44	0.53
Fabricated metals	0.40	0.39	0.51
Rubber and plastics	0.34	0.40	0.53
Other transport equipment	0.18	0.37	0.58
Textiles, clothing, leather	0.38	0.30	0.40
Food, beverages and tobacco	0.32	0.31	0.44
Paper	0.36	0.30	0.39
Furniture and other manufacturing	0.28	0.32	0.42
Chemicals	0.27	0.19	0.54
Basic metals	0.25	0.21	0.48
Mining and quarrying	0.13	0.30	0.28
Wood and cork	0.03	0.08	0.56
Non-metallic minerals	0.03	0.03	0.06
Average	0.34	0.35	0.48

The economic dimension was the only one that reported the highest possible grade of 1 that was reached by the manufacturing sector of computer, electronic and optical products. The highest grade of 0.75 in the technical dimension sub-index was achieved by the pharmaceuticals manufacturing sector. Moreover, in the environmental dimension the computer, electronic and optical product manufacturing sector again scored highest with a value of 0.72. Fig. 2 illustrates the indicator values achieved in each dimension sub-index.

The other outstanding sectors of the economic dimension sub-index were electrical equipment manufacturing with a value of 0.49, motor vehicles manufacturing with a grade of 0.46, and the pharmaceutical product manufacturing sector with a value of 0.51

In contrast, the non-metallic minerals manufacturing sector indicated the lowest values in all the dimension sub-indices. Moreover, other underperforming sectors of the economic dimension sub-index were wood and cork manufacturing with a score of 0.03 and mining and quarrying with a score of 0.13.





(c)

Fig. 2. Results for the a) economic, b) technical, c) environmental dimension sub-indices of EEI.

The results of the economic dimension sub-index suggest that producing more sophisticated or lightweight end products constitutes to higher energy utilization efficiency levels. However, manufacture of primary products and raw materials are associated with lower energy efficiency. This result is explained by the sectors' ability to generate sufficient economic value relative to the amount of energy consumed. The more a sector's economic activity contributes to the industry's gross domestic product and generated value added, the more justified are the amounts of energy consumed.

When analysing indicator values of the economic dimension in more detail, it can be observed that for the economic dimension a crucial role is for the indicators of energy expenses that is measured by the purchases of energy products and energy taxes per turnover. For most of the sectors, these indicator values contributed the most to the economic dimension sub-index. The competitive advantage of computer, electronic and optical products manufacturing sector is that in addition to high values in these indicators, it also reported equally high values for generated turnover and value added per energy use indicators. As a result, ranking the sector ranks substantially higher compared to other sectors.

For the technical dimension, energy use per employee and investment made per energy use played a significant role in contributing to the overall value of the sub-index. The pharmaceuticals manufacturing sector stood out with the highest sub-index value that was achieved thanks to a higher share of large-sized companies and ISO 50001 registered companies in a sector compared to the others.

In the environment dimension, the use of fossil energy resources and greenhouse gas intensity indicator values were the most significant determinants of the overall value of the sub-index. The manufacturing sector of computer, electronic and optical products proved to be an absolute

leader in the environment dimension due to higher CO₂ productivity compared to other sectors. Wood and cork manufacturing sector achieved high overall environment dimension sub-index value, however, it indicated underperforming results of the economic and technical dimension sub-indices.

At the current stage of the study, descriptive analysis of the obtained dimension sub-indices in each sector was executed and dominant relationships among the sectors was examined. Based on the normalized sum of partial indices, the sector naïve ranking appears in Table 2. Based on Pareto efficiency it is possible to distinguish between two groups, namely the 5 first sectors that are non-dominated and the rest 13 sectors that are dominated by the leading sectors such as computer, electronics, optics manufacturing or the electrical equipment manufacturing. In other words, if the weights are assigned to economic, technical and environmental dimensions, none of the sectors belonging to the second group would outrank any one of the first group sectors. On the other hand, among the first five, we are not able to rank unless we assign weights. Further analysis is required to come up with a factor that could adequately rank the sectors on their overall energy efficiency. Thus, the final Energy Efficiency Index (EEI) has not yet been obtained and the next methodological step that consist of the aggregation of each dimension's sub-index will be performed in further research.

4. CONCLUSIONS

The findings of the study reported that energy efficiency levels of each dimension appear to be different among the 18 sub-sectors of the manufacturing industry. The differences are observed in all three dimensions of energy efficiency – economic, technical, and environmental. The results revealed that knowledge-intensive sectors that produce more complex and sophisticated products such as computer, electronics, optics manufacturing, electrical equipment manufacturing, and pharmaceuticals manufacturing are associated with higher economic dimension sub-index values of energy efficiency. However, primary manufacturing sectors that produce industrial raw materials such as non-metallic minerals manufacturing, wood and cork manufacturing, mining and quarrying are associated with lower energy efficiency levels in most of the representative dimensions.

The proposed model combines various indicators of industrial energy efficiency into a common scale, therefore allowing to easily identify sub-sectoral differences in each dimension of energy efficiency. The model could be calibrated and used as a tool for policymakers to develop sector specific legislation and requirements related to energy management practices. As a result, more efficient policy instruments could be developed in order to increase the industry engagement towards the implementation of the energy efficiency activities [27].

Further research will focus on incorporating all the dimensions in one final Energy Efficiency Index (EEI) to obtain final numbers of energy efficiency levels for all sectors reviewed in this study. To investigate dynamics and evolution of EEI and its dimension sub-indices over time, the index could be constructed for different time periods. It would allow to identify those sub-sectors that showed improvements towards energy efficiency goals [28]. Moreover, in further research additional indicators could be added for each dimension to increase the explanatory power of each dimension's sub-index. In addition, further research could experiment with the application of different weighting techniques and included indicators in order to validate the overall model.

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