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Sustainability Analysis of Manufacturing Industry

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***Abstract* – This study provides an analysis to identify the comparative sustainability of the subsectors of the manufacturing industry in Latvia. Authors assess the availability of national statistics data for the development of absolute and specific indicators, which are further used for sustainability evaluation by multi-criteria analysis, specifically the TOPSIS method. Overall eight separate indicators were used for the description of three sustainability pillars. The results provide the distribution of manufacturing sub-sectors according to their comparative sustainability, and thus the rubber and non-mineral metal manufacturing sectors and wood and wood products manufacturing are evaluated as having the lowest comparative sustainability and most appropriate for further investigation regarding the development of sector-specific energy efficiency benchmark.**

***Keywords* – Benchmarking; energy efficiency; industry comparison; TOPSIS method**

1. INTRODUCTION

The sustainability perspective tries to encompass three interrelated sustainability dimensions – economic, environmental and social aspects. In some cases a fourth additional dimension – institutional sustainability – is considered [1]. Azapagic et al. [2] argue that the use of a sustainability-based system approach might be a potential solution for various complex issues, including, energy-related problems.

Manufacturing industry is one of the cornerstones of the economy. A country's economic development strongly depends on how developed the industry is and its competiveness in the global market. Industry is also a significant resource; especially energy, consumer, and the costs of those resources directly impact its competitiveness. Therefore, the first who would gain from reduced resource and energy consumption would be the companies themselves through their increased profitability, and, sequentially, the whole national economy would gain due to decreased energy consumption and reduced GHG emissions [3]. Implementation of energy efficiency measures is widely accepted as one of the most prosperous approaches to reduce excess energy consumption, to achieve GHG emission reduction, as well as promote sustainability [4]. Simultaneous implementation of sustainability and energy efficiency in manufacturing plants is challenging [5] and sustainability requirements might be quite a complex thing to balance for the industry representatives [6]. However, to move towards sustainable development, manufacturing industries need to assess environmental impacts [7] as well as social objectives and economic efficiency [8].

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With a bottom-up approach, a detailed energy efficiency analysis and benchmarks may be produced for the production process [9]. However, a significant problem related to the manufacturing industry energy efficiency improvements is the availability of good quality data. Andersson et al. [3] note that even though benchmarking at the process or equipment level would overall provide more accurate results, the available degree of data detail is a typical limitation. In fact, researchers regularly point out to significant research limitations posed due to data quality and quantity restrictions. Cai et al. [10] note the difficulties for developing energy efficiency benchmark in the mechanical manufacturing industry. Kubule et al. [11] note the limitations regarding data on specific energy consumption in Latvia's industrial companies. Andersson et al. [12] emphasize that energy consumption for the main, as well as, support processes may vary significantly even within the limits of a single industry. In addition, they indicate problems regarding the generalization of the results without detailed bottom-up energy end-use data.

Within the National research program Energetics project EnergyPath, energy efficiency benchmarks for a particular sub-sector (or sub-sectors) of Latvian's manufacturing industry will be established. The development of national energy efficiency benchmarks will promote reduction of energy consumption by manufacturing industry and thus help the industry move towards sustainable development.

As the overall manufacturing industry consists of 23 large sub-sectors and numerous smaller sub-sectors, the first research task is to select the most relevant sector (or sectors) for in-depth research regarding the development of national-level energy efficiency benchmarks. However, such selection of a particular sector is challenging due to the complexity of the production processes involved within each of the sub-sectors, as well as because numerous different stakeholders with potentially conflicting interests are involved [2]. Moreover, [6] note that manufacturers frequently focus only on economic aspects of sustainability, or give enhanced value to environmental aspects. The interrelated effects and drawbacks between all three sustainability dimensions should be considered for the intended sector selection.

The aim of this study is to evaluate and compare Latvia's manufacturing industry sub-sectors (NACE Rev. 2 C – Manufacturing), in order to define the priority sectors for further establishment of sector-level energy efficiency benchmarks. To achieve the aim of the research, relevant indicators for all three dimensions of sustainability are compiled and contrasted by employing a multi-criteria analysis (MCA) specifically the TOPSIS method is applied.

2. MANUFACTURING SECTOR IN LATVIA

Latvia's manufacturing industry is quite diverse, but a few industries take the lead in terms of largest turnover (NACE version 2.0 C16, C10, C25, C23), numbers of companies (C16, C14, C25, C10) and numbers of employees (C16, C10, C25, C14). These sub-sectors (C16, C10–12 and C23) are also the largest regarding total energy consumption (Fig. 1). On one hand, the generally accepted axiom implies that the greatest energy savings could be achieved by focusing on these major consumers. However, energy consumption is greatly affected by the production technologies and specifics of each industry. Hence, a more in-depth analysis can be achieved through the use of specific indicators, e.g. specific energy costs. Figure 2 presents the distribution of Latvia's manufacturing industry's sub-sectors by their specific energy costs (expressed as energy costs per total value of production). As can be seen, regarding energy expenditures, these industries rank differently with C16 and C23 being among those industries with higher share of energy expenditures to the total value of production, while C10 and C14 have significantly lower specific energy costs.

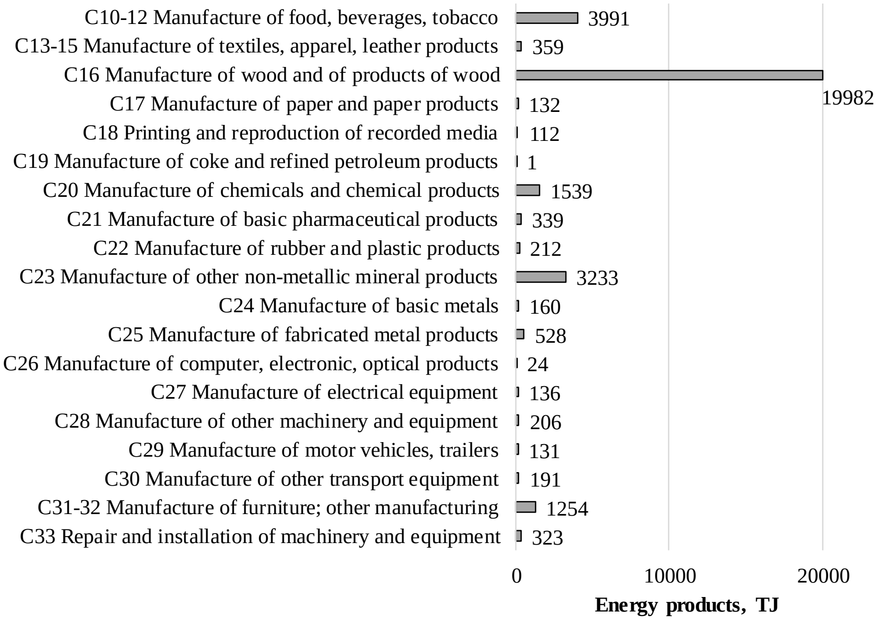

Fig. 1. Physical energy flow accounts for the use of energy resources in manufacturing subsectors 2016 (CSB: ENG200).

Considering the implementation of energy efficiency measures, some significant differences are distinguished between energy intensive and non-intensive industries. For example, energy efficiency can be examined at the overall industry sector or in separate sectors, such as energy-intensive companies or separate key areas [13]. A significant problem for the generalized definition of energy intensive industries is the differences in industrial portfolio of various countries. For example, commonly metal industry (C24) and non-metal mineral industry (C23) are considered energy intensive industries, but for Latvia's case the specific energy costs attributed to total value of production for these industries constitute only half in comparison with C16 and C33 (Fig. 2).

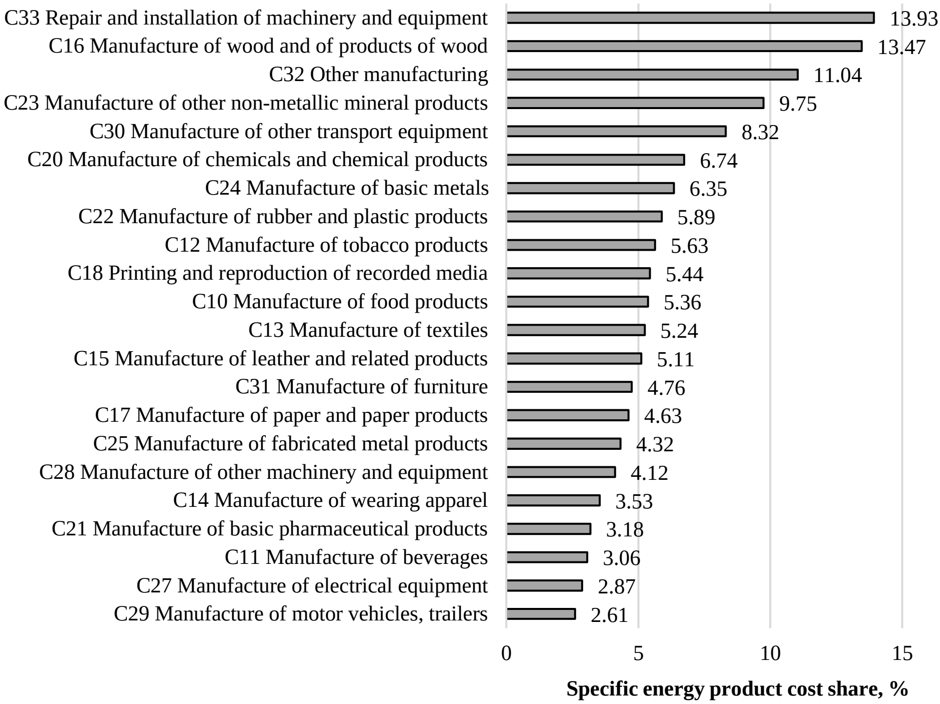

Fig. 2. Energy costs attributed to total value of production (CSB:SBG010).

3. Methods and Methodology

Sustainability analysis is a practical approach to assess these multifaceted aspects and commonly methods as life cycle analysis and environmental impact assessment are used. There have been various attempts to apply sustainability analysis in manufacturing industry related settings. Fox and Alptekin [1] used comparative sustainability analysis, including economic, ecological, social and institutional sustainability, to investigate different manufacturing distributions. Based on the results of an energy-based sustainability assessment, Kluczek [4] states that production system energy efficiency improvements have a significant impact on energy sustainability. Gbededo et al. [8] note the lack of standard holistic assessment framework to support effective decision-making for implementation of sustainable product development. As well, Kluczek [4] notes that methods that are commonly applied for assessment of the sustainability of the manufacturing industry lack in considering all three pillars of sustainability. Recently, [6] applied multi-criteria analysis to assess sustainability of an automotive industry and [14] analysed small and medium enterprises in Germany and Italy. In addition to those contributions, the current research aspires to evaluate the sustainability of whole subsectors of manufacturing at the national level.

3.1. Sustainability Dimensions

Economic sustainability is related to the profitability of the industry. “Production of goods that nobody wants to buy anymore is not economically sustainable” [1]. A more sustainable production can have an adverse effect on the costs and thus the price of the products, however it can also allow to cut costs, i.e., by the use of recycled materials [1]. Thus, it is necessary to simultaneously consider the advantages and benefit regarding all sustainability dimensions.

In the industrial context, environmental or ecological sustainability is commonly assigned to energy and resource consumption and industrial emissions. Common approaches to improve environmental sustainability of industrial production include improving specific raw material, water and energy consumption per production unit or value. Other aspects that improve the environmental sustainability can involve increasing the share of recycled or bio-based material use, use of renewable energy sources for manufacturing.

Social sustainability is related to ensuring equal opportunities, community engagement. On the other hand, a large degree of automation and low requirements for labour reduces social sustainability [1].

Institutional sustainability, which is concerned with ethics [1], highly values rational and purposeful use of resources, in ways that bring more benefits to the society as a whole while simultaneously reducing the environmental impact, thus ensuring an ethical approach to production and consumption system *per se*.

3.2. Multi-Criteria Decision Analysis

One of the common approaches for simultaneous consideration of multifaceted aspects of any field, including sustainability, is the use of multi-criteria decision analysis. This method facilitates the inclusion of various category factors into a standardized evaluation framework.

Multi-criteria analysis has been applied for various decision-making problems. Weigel et al. [15] apply MCA for the assessment of four alternative steel production technologies. They also apply a sensitivity analysis to assess whether the obtained results would significantly change if different stakeholder perspectives were used for assignment of MCA weights. Vanaga et al. [16] apply MCA to select the thermodynamically best alternatives for the energy efficiency improvement of buildings.

With the use of multi-criteria decision analysis and particularly the TOPSIS method (Technique for Order of Preference by Similarity to Ideal Solution), the assessment alternatives are evaluated in respect to an ideal best and critically worst potential case. The equations and application of the TOPSIS method has been described in-detail in numerous articles, i.e. [17].

3.3. Indicator Selection and Data Acquisition

The aim of the research is to evaluate the subsectors of the manufacturing industry by accounting for all dimensions of sustainability. Based on a literature analysis, a set of relevant indicators was established.

Stamford and Azapagic [18] use a set of 36 sustainability indicators that cover all of the three main aspects of sustainability for assessment of UK electricity decarbonisation scenarios. The same set of indicators are also integrated into their developed sustainability assessment approach called DESIRES [2]. Within this method, the authors offer an approach that includes a life cycle-based evaluation of each of the three sustainability dimensions in combination with multiple attribute decision analysis. The use of multiple attribute decision analysis to combine the results for the individual evaluations of the three sustainability dimensions, ensures that stakeholders and decision makers may comprehend the incorporated information more easily [2]. Fox and Alptekin [1] suggest indicators as sales, price, cost (economic dimension), inputs, processes, reuse (environmental dimension), participation, ownership, engagement (social dimension).

Based on the mentioned examples regarding the indicators typically applied for sustainability analysis, the authors devised a list of indicators applicable particularly to the manufacturing industry's sustainability analysis considering also the sub-sector level data availability for Latvia's manufacturing industry. In order to cover the widest range of indicators, the national statistical databases regarding energy consumption, CO_2 emissions, economic statistics and employment were used. As our analysis is based on publicly available statistical data collected by the National Statistics Bureau and reported as well to Eurostat, the developed method should be applicable for all EU countries where national statistics are collected by the same methodologies. The list of the selected indicators and their affiliation to a particular sustainability dimension are presented in Table 1.

TABLE 1. SELECTED INDICATORS ACCORDING TO THE THREE SUSTAINABILITY DIMENSIONS

Economic dimension	Environmental dimension	Social dimension
Category weight: 0.33	Category weight: 0.33	Category weight: 0.33
Turnover, million EUR Share of added value from total manufacturing industry, % Energy costs to total production value, % Gross investments into tangible goods, million EUR	Carbon dioxide emissions (CO_2), thousand t Energy consumption, TJ	Number of employees Share of employees in large size companies, %

The selected economic and environmental absolute indicators are quite self-explanatory. They characterize the profitability or the capacity of each manufacturing industry's subsector, i.e. the turnover and the share of added value from total manufacturing industry, or the impact on environment through emitted carbon dioxide and energy consumption *per se*. In addition, several specific indicators were developed based on the reasoning set out hereafter.

The total energy consumption is an absolute indicator, which can describe the total capacity of each manufacturing sub-sector, however an additional economic indicator – energy cost share – can be as a proxy for efficient use of energy resources (Fig. 2). If a sub-sector's energy cost share is high, this is an indication of the need to implement energy efficiency measures or consider energy source change.

In order to consider the social dimension of sustainability, the authors consider the total number of employees and the share of large companies per sub-sector. The necessary data are acquired from enterprise economic statistics database, thus partly these indicators could be assumed as socio-economic, not strictly economic ones. However, as mentioned before, a wide evaluation of the manufacturing industry is restricted due to data availability, thus we choose to convey the social dimension aspects at least partly, to ensure a broader look at sustainability.

As mentioned in Chapter 2, Latvia's manufacturing industry is quite diverse; however, the top leading subsectors are far in front of others. In order to assess whether most of the sector's employees work in the large size companies or SMEs, we develop a specific indicator – share of employees in large size companies. This is an important sector characterization, especially for future policy planning, as in the coming years energy efficiency incentives will be directed more towards SMEs rather than large size companies. Additionally, for the development of sector-wide energy efficiency benchmark, it may be more desirable for the sector to be smaller and less fragmented to allow better communication with businesses and data acquisition.

In order for the energy efficiency benchmark method to have a greater effect, the choice of the sector should be based not only on the specific energy consumption, but also on the willingness of the sector to change – flexibility, so it is not profitable to choose a sector that is firmly tied to certain technologies and does not want to invest in technology change.

By analysing the Central Statistical Bureau's (CSB) information on structural business indicators in various manufacturing sub-sectors, it is possible to compare companies' investment in building construction or investment in equipment with company turnover (Fig. 3). It can be seen that these indicators correlate very well, which indicates a close relationship between company investments and the company's economic performance, or the company's capacity. Meanwhile, companies' investments in land and investments in existing buildings and construction correlate less (R^2 = 0.72 and R^2 = 0.12 respectively in 2016) with total turnover and output value.

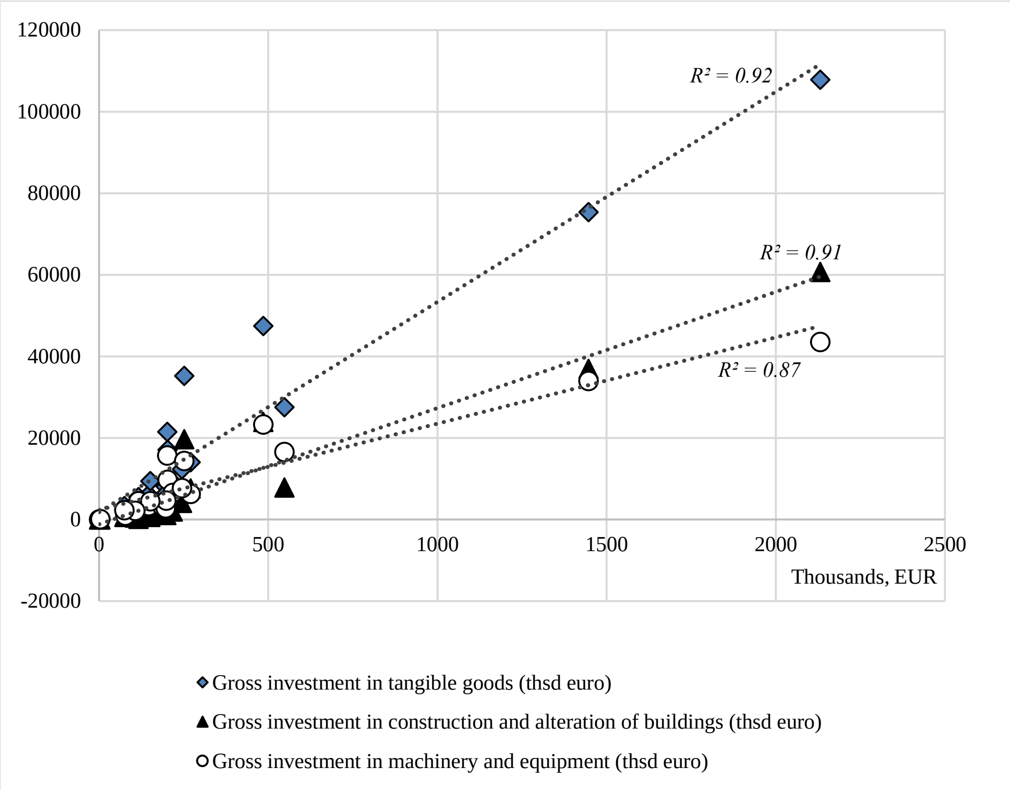

Fig. 3. Regression between sector turnover and investments into tangible goods.

Another potential way to account for the flexibility of the sub-sector could be to account for its innovative activity share. According to information from the CSB on the number of innovatively active enterprises in industry, and specifically in manufacturing, there is a larger share of innovative active companies than among the service industries. There is also a higher percentage of innovative enterprises in the large-size company category, which is probably due to the availability of more financial resources for large enterprises to support innovation; as well as they are more prone to exploring opportunities for growth and development. However, these data are not available at the manufacturing sub-sector level, which limits the use of this indicator in the present study. Another limiting consideration regarding the statistics on company innovation activities is that this general definition of innovation activities does not differentiate between product development and energy efficiency innovations. Some companies might be positive about implementing product development innovations, while, due to lower awareness regarding energy issues, their engagement in energy efficiency might not be as active. A broader exploration of this issue is one of the potential future studies towards understanding how to implement energy efficiency policies in Latvia more successfully.

All three types of sustainability dimensions were attributed with an identical summary weight share (0.33). The ideal and negative ideal solutions for TOPSIS matrix were selected according to the following reasoning:

- Higher environmental sustainability (the ideal solution) is for lower energy consumption and CO_2 emissions;
- Higher environmental sustainability corresponds to lower specific energy costs;
- To select a sector with significant contribution to the economy, for turnover and share of added value the ideal solution is higher values;
- To select a sector that seeks to invest in equipment replacement and factory improvements for gross capital expenditure in tangible assets the ideal solution is higher values;
- To select a sector with larger SME share (in order to promote energy efficiency developments in SMEs) for the share of large size companies and share of employees in large size companies, the ideal solution is lower values.

As the research aims to identify the sectors which would gain more from in-depth energy benchmarking and efficiency improvements, for most economic indicators, higher values are attributed to better performance. In contrast, higher environmental performance is attributed to lower CO_2 emission levels.

4. RESULTS

Based on the previously defined data availability for indicator development, the authors derived eight indicators that are related to the three assessed sustainability dimensions and the values of which are presented in Table 2. The indicator weights within each sub-category were evenly divided, e.g. each of both indicators in environmental dimension accounts for 0.165 of the global weights. The assessed alternatives are manufacturing industry sub-sectors, where data are available for separate sectors or sector groups where data is available only at such a level.

The results of applying multi-criteria analysis by the means of TOPSIS analysis are presented in Fig. 4. Overall, the three sub-sector groups with the worst sustainability ratings are for rubber and non-mineral metal manufacturing sectors (C22–C23), chemical manufacturing (C20) and pharmaceutical production (C21), which is mainly due to fossil energy resource consumption and thus higher CO_2 emissions. Wood and wood products industry (C16–18) has the highest and thus the best results in turnover and number of employee's criteria that contribute to the higher score for this sector. However, the wood and wood products industry has also the highest overall energy consumption, which draws the overall result down. Although the overall energy consumption is the highest in the wood and wood product industry, most of the used primary energy sources are biomass based, therefore CO_2 emissions are not as high as those for rubber and non-mineral metal manufacturing sector.

TABLE 2. APPLIED INDICATORS AND THEIR VALUES

	C10–C12	C13–C15	C16–C18	C20	C21	C22–C23	C24–C25	C27	C28	C29–C30	C31–C33
Carbon dioxide emissions (CO_2) kg/EUR production value	0.09	0.05	0.05	0.11	0.07	0.95	0.03	0.03	0.03	0.02	0.04
Energy consumption, MJ/ EUR production value	2.50	1.42	8.46	7.01	2.08	5.31	1.09	0.69	1.03	1.21	2.97
Turnover, million euro	1717	258	2451	218	188	688	626	197	199	259	573
Gross investment in tangible goods, million EUR	89.4	9.0	130	9.1	5.0	68.8	29.5	8.0	6.5	13.0	50.8
Share of added value from total manufacturing industry, %	20.9	4.7	26.3	2.3	3.3	9.9	8.8	2.8	2.8	3.5	9.8
Energy costs to total production value, %	5.0	4.3	12.3	6.7	3.2	8.6	4.6	2.9	4.1	5.0	9.3
Number of employees (thousands)	23.9	12.6	30.0	2.8	2.1	8.7	11.7	2.8	3.5	3.9	15.4
Share of employees in large-size companies, %	0.3	0.1	0.2	0.1	0.8	0.2	0.1	0.6	0.2	0.4	0.2
Multi-criteria evaluation results	0.81	0.65	0.68	0.53	0.50	0.34	0.68	0.56	0.61	0.59	0.67

The best sustainability evaluation in the current approach is for the food and drinks manufacturing sector group (C10–12). This sector has a relatively high turnover and contributes a large extent to the manufacturing industry's added value, as well it has relatively low CO_2 emissions and energy consumption, which puts it ahead of the other sectors.

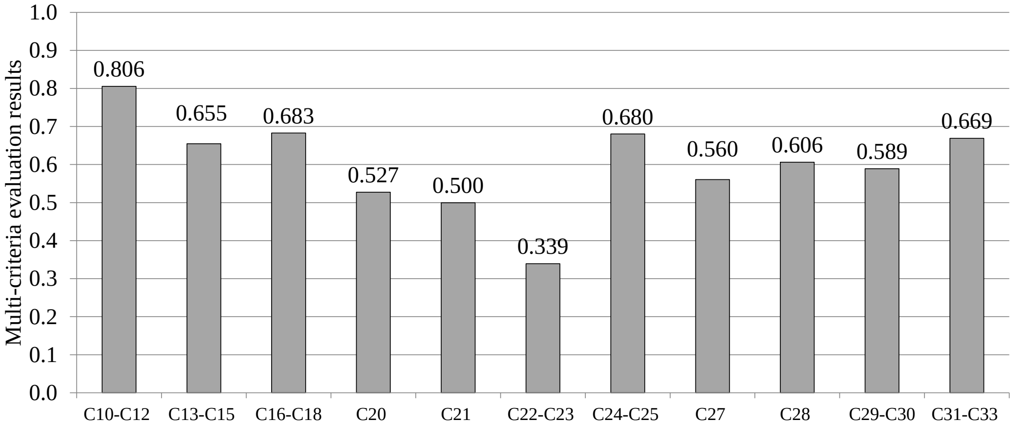

Fig. 4. Results of multi-criteria evaluation.

Based on the evaluation results, the most appropriate sector for development of a sector wide energy benchmark would be non-metallic mineral production sub-sector because it could provide the highest improvement of energy efficiency and CO_2 reduction. As well, wood and wood products sub-sector could also contribute to significant energy efficiency improvements as it is known from the energy statistics that this sector are responsible for the highest energy consumption share, however the CO_2 reduction potential is lower as the sector already uses biomass to a large extent.

5. Conclusions

Even though the data availability at single sub-sector level leads to the necessity to evaluate groups of sub-sectors, the evaluation results clearly indicate main manufacturing industry sub-sector groups that have the lowest sustainability evaluation based on the applied framework, and thus would gain significantly from the development of sector-wide energy efficiency benchmark. These sectors are rubber and non-mineral metal manufacturing sectors (C22–C23), wood and wood products manufacturing (C16–C18).

This assessment of the industry's compliance to the principles of sustainable development demonstrates the need to carefully assess the overall impact of industry rather than just taking economic benefits into account. It is necessary to reassess those industries which on the one hand are able to produce high economic performance, but the achievement of this performance is based on the exploitation of the environmental dimension and inefficient use of resources. Implementation of energy efficiency measures is a basic, however very significant opportunity for improvement of the overall sustainability performance of the manufacturing industry, and should be further pursued, e.g., through the development of sector adjusted energy efficiency benchmarks.

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