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# Economic and Environmental Efficiency of the Chemical Industry in Europe in 2010-2016

*Radim Lenort[1], Joanna Baran[2], Marcin Wysokiński[2], Piotr Gołasa[2], Wioletta Bieńkowska-Gołasa[2], Magdalena Golonko[2], Norbert Chamier-Gliszczyński[3*]*

*[1]SKODA AUTO University, Czech Republic*
*[2]Warsaw University of Life Sciences, Poland*
*[3]Koszalin University of Technology, Poland*
*[*]corresponding author's e-mail: norbert.chamier-gliszczynski@tu.koszalin.pl*

## 1. Introduction

The EU is currently conducting an extremely ambitious policy to reduce climate change by limiting greenhouse gas (GHG) emissions. Work on the introduction of GHG emission reduction policy instruments began in the early 1990s. During this period, two types of solutions were considered: an emissions trading system (ETS) and carbon tax. The EC proposed introducing a carbon tax because the ETS was something new and unproven in a wider context. However, the idea was strongly opposed by both entrepreneurs and some member states that did not want to give the EU authority to introduce direct taxation (Calel, 2013).

Many years of work led to the launch of the EU ETS in 2003 (European Union, 2003). Enterprises operating in the sectors subject to these regulations receive emission allowances free of charge or have to purchase them. Only 10% of the most effective entities are entitled to obtain free allowances, with efficiency determined using special benchmarks. For the chemical industry, 17 benchmarks were determined (European Commission, 2015, p. 49). Meanwhile, purchase of allowances is associated with high costs. Considering the increasingly ambitious plans related to the EU's environmental and climatic policy (reducing the emissions of greenhouse gases by 80-95% by 2050 as compared to 1990) (European Commission, 2011), the issue of economic and environmental efficiency is becoming essential as regards both the states that set reduction objectives and enterprises whose economic results are determined by these issues. That is why it is necessary to combine the economic results of using production factors with carrying out pro-environmental tasks.

The main objective of the study is to determine the economic and environmental efficiency of the chemical industry in the EU (the fifth largest EU industry (Cefic, 2017)). In this article, chemical industry sectors in individual EU countries were adopted as objects for comparison.

The article raises the following research questions:

- Which countries in the EU have a chemical industry with the highest economic and environmental efficiency?
- Are changes occurring in the economic and environmental efficiency of the chemical industry in individual EU countries?
- What is the reason for the improvement in productivity, if such a trend is found?

## 2. Research basis

### 2.1. Chemical industry in Europe

The chemical industry is very sensitive to the current economic situation so does other elements of domestic economy (Varjan et al., 2019) it is important for economic growth and society development. In Europe, nearly 70% of sales go to other sectors of the economy, while the rest is marketed directly to consumers – this industry is considered to a linchpin of the entire economy (Centre for Industry Education Collaboration, 2018). The importance of the sector is also demonstrated by the fact that chemical products are used both by large industrial plants and individual customers in the production of everyday consumer goods, in agriculture, production and service activities producing such materials as fuels, plastics, cosmetics, fertilizers and crop protection.

Chemical production in the EU covers three product areas: base chemicals, specialty chemicals and consumer chemicals. In 2016 (latest data of Cefic, 2017), base chemicals constituted 59.2% of the total sales of chemicals in the EU. Specialty chemicals, including paints and inks, crop protection, dyes and pigments, amounted to 27.2% of the total sales of chemical industry products in the EU in 2016. Consumer chemicals accounted for 13.6% of the total sales of chemical products in the EU in 2016 (Cefic, 2017).

In 2016, the two largest producers of chemical industry products in Europe were Germany (28.7% share in total EU chemical sales) and France (13.9%). Italy (10.0%) and Netherlands (9.1%) are the next in line. Sales of chemical products in these countries accounted for 61.7% of the EU market (€ 313 billions). The share increases to 82.6% (€ 419 billions), if the Spain, the United Kingdom and Belgium are listed together with the aforementioned countries. Sales value of the remaining EU countries amounted to € 88 billions in 2016, which constituted 17.4% of the total value of sales. Among the remaining EU countries, Poland and Austria exhibited the largest sales of chemical industry products (Cefic, 2017).

### 2.2. Environmental economics

The production of such huge amounts of chemical products requires a correspondingly wide variety of types of input, including energy, which depletes non-renewable energy resources. On the other hand, the industry emits GHG during production processes, thus contributing adversely to climate change. Both energy consumption and greenhouse gas emissions constitute a direct burden on the environment and cause a deterioration in the environment for future generations. Therefore, there is a need for effective use of limited resources and minimization of environmental burdens, which is currently the subject of constant research.

This issue is addressed by environmental economics, defined as the field of economic theory (Perman et al., 2003), which studies static and dynamic conditions of optimal use of natural environment resources (Fiedor, 2002). From the point of view of this paper, the most important elements of this theory are the issues related to limiting externalities, such as greenhouse gas emissions, and the proper rate of use of non-renewable resources.

## 3. Materials and methods

### 3.1. Sources for materials

The research was based on materials and secondary data from EUROSTAT. In order to determine the efficiency of the chemical industry in European countries in 2016 (the latest available data) the DEA method was used, while the Malmquist Productivity Index was used to determine changes in chemical industry productivity in 2010-2016.

### 3.2. Data envelopment analysis

The Data Envelopment Analysis (DEA) method is considered one of the non-parametric methods for testing the efficiency of objects. In 1978, the authors of the DEA method (Charnes et al., 1978), using as their base the concept of productivity formulated by Debreu and Farelland defining the measure of productivity as a quotient of a single output and single input, applied it to a multidimensional situation, i.e. one that has more than one output and more than one input (Charnes et al., 1978). Mathematically, the DEA model can be represented as follows (the presented models refer to the model known in literature as CCR and oriented towards minimizing types of input) (Charnes et. al., 1994):

Objective function:

$$\max_{u,v} \frac{\sum_{r=1}^{s} \mu_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}}, \tag{1}$$

with the following constraints:

$$\frac{\sum_{r=1}^{s} \mu_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1 \quad (j = 0, 1, ..., n), \qquad \mu_r, v_i \ge 0, \tag{2}$$

$$\frac{\mu_r}{\sum_{i=1}^{m} v_i x_{io}} \ge \varepsilon \quad \text{for} \quad r = 0, 1, ..., s, \tag{3}$$

$$\frac{v_i}{\sum_{i=1}^{m} v_i x_{io}} \ge \varepsilon \quad \text{for} \quad i = 0, 1, ..., m. \tag{4}$$

where: $s$ – number of outputs, $m$ – number of inputs, $\mu_r$ – weights determining the importance of individual outputs, $v_i$– weightsdetermining the importance of individual inputs, $y_{rj}$ – size of an $r$-type output ($r$ = 1, ..., $R$) in object $j$, $x_{ij}$ – size of an $i$-type input ($n$ = 1, ..., $N$) in object $j$, ($j$ = 1, ..., $J$).

The DEA method makes it possible to study the relationship between the level of many types of input and many types of output. In the DEA model, $m$ inputs and $s$ various outputs are reduced to individual "synthetic" input and "synthetic" output values, which are then used in the calculation of the object's efficiency index (Roll and Hayuth, 1993). In linear programming, this indicator is the objective function. In the DEA method, two variants of the objective function can be distinguished: maximization of outputs at given inputs or minimization of inputs at set outputs (Cooper et al., 2007). The optimized variables are coefficients $\mu_r$ and $v_i$, which act as weights for the amount of inputs and outputs, while the values for outputs and inputs constitute empirical data (Cooper et al., 2007). The constraint assumes that the quotient of synthetic output and synthetic input is to be less than or equal to one (without such a limitation the task would have infinitely many solutions). Input and output weights are determined in such a way that they maximize the above-mentioned relation of outputs to inputs, and their sizes can be equal to or greater than zero.

The solution of the objective function by means of linear programming makes it possible to determine the efficiency curve on which all of the most effective units of the studied group are located. Graphical presentation of the efficiency curve is possible for the following models: 1 input and 1 output, 2 inputs and 1 output or 1 input and 2 outputs. For multidimensional models, the equivalent of the curve is several interconnected fragments of different hyperplanes. Objects are considered to be technically effective, if they are on the efficiency curve (their efficiency index is 1, which in a model focused on minimizing inputs means that there is no more favorable combination of inputs that allows the enterprise (sector/country) to achieve the same outputs). Meanwhile, if they are outside the efficiency curve, they are technically ineffective (their efficiency index is less than 1, which means that there is a more effective combination of inputs that allows the same outputs to be achieved). The efficiency of an object is measured in relation to other objects from the studied group and takes values from the interval (0, 1). In the DEA method, analysis objects are so-called Decision-Making Units (DMU), which may be enterprises, sectors and/or countries (Charnes et. al., 1994). The subject of the analysis is the efficiency with which a given DMU transforms its inputs into outputs.

### 3.3. Malmquist Productivity Index

In turn, the structure of the Malmquist Productivity Index (MPI) is based on the principle of comparing the relation of several inputs to several results of a given object at different moments in time (Baran and Wysokiński, 2016). The MPI for a given object is the product of the index of changes in technical efficiency (*EFCH*, the technical efficiency is defined as the relation of the outputs obtained from given inputs against the possible maximum outputs obtained with given inputs) and the index of technological progress (*TECH*, the technological progress is defined as changes in manufacturing technology in the considered period) according to the following formula (Färe et al., 1994):

$$M(y_{t+1}, x_{t+1}, y_t, x_t) = \underbrace{\frac{D^t(y_{t+1}, x_{t+1})}{D^t(y_t, x_t)}}_{EFCH^{t+1}} \cdot \underbrace{\left[\frac{D^t(y_{t+1}, x_{t+1})}{D^{t+1}(y_{t+1}, x_{t+1})} \cdot \frac{D^t(y_t, x_t)}{D^{t+1}(y_t, x_t)}\right]^{\frac{1}{2}}}_{TECH^{t+1}} \quad (5)$$

where: $D^t(y_{t+1}, x_{t+1})$ means efficiency using the technology of year $t$ for data from the year $t+1$, $D^t(y_t, x_t)$ is the unit's efficiency in period $t$ using the technology available at that time and data from the period $t$, $D^{t+1}(y_{t+1}, x_{t+1})$ shows the unit's efficiency for the period $t+1$, and $D^{t+1}(y_t, x_t)$ means efficiency using the technology of year $t+1$ for data from the year $t$.

For a MPI value greater than 1, it is assumed that in the audited period, from $t$ to $t$+1, there was an increase in productivity. Meanwhile, when the value of the MPI is lower than 1, it indicates a decrease in productivity, with a value equal to 1 indicating that efficiency is maintained at the same level. A similar interpretation of the indicators is applied to *EFCH* and *TECH* (Coelli et al., 2005).

The decomposition of this index can be specified as follows (Cooper et al., 2007):

$$EFCH(P) = \frac{\frac{BD}{BP_2}}{\frac{AC}{AP_1}}, TECH = \sqrt{\frac{AC}{AE} \cdot \frac{BF}{BD}}, \text{ so } MPI = \frac{AP_1}{BP_2}\sqrt{\frac{BF}{AC} \cdot \frac{BD}{AE}}, \quad (6)$$

## 4. Results and discussion

In order to determine the economic and environmental efficiency and changes in productivity over time in the chemical industry sector in individual European countries, the DEA method and the MPI, with a focus on minimising inputs, were used. Based on subject literature, a set of variables was defined for these models. The production size is usually assumed as its volume, i.e. a set of manufactured products, expressed either in physical units or in constant prices. In this study, the production value of the chemical industry was assumed as the production volume (output). The variables explaining the production volume, according to economic theory, are three production factors: labour, objectified work (capital) and land. In reference to the above, the present research assumed the number of employees as the measure of the labour factor (input 1). In non-agricultural enterprises, the land factor generally does not play a significant role. Therefore, it is often omitted or replaced by the consumption of materials and energy – in the research the consumption of energy was assumed as the input (input 2). $CO_2$ emissions were assumed as the environmental input (input 3).

The following variables were adopted for the calculated models:

- output $y_1$ – production value (one thousand Euro),
- input $x_1$ – number of employees (number of persons employed),
- input $x_2$ – energy consumption (one thousand tonnes of oil equivalent),
- input $x_3$ – $CO_2$ emissions (tonnes).

In the first stage of the study, the DEA method was calculated. The average economic and environmental efficiency of the chemical industry in Europe was quite high, with the efficiency index at 0.70 in 2016. Out of 27 analysed sectors of the chemical industry in individual European countries, 10 were considered fully efficient (the DEA efficiency ratio was 1). Countries with a chemical industry characterised as fully efficient include Belgium, Denmark, Germany, Estonia, Ireland, France, Italy, Malta, Netherlands, and Austria. The chemical industry in Romania and Bulgaria proved to be the least economically and environmentally efficient (see Figure 1).

In the second stage of studies, an analysis of changes in the productivity of the chemical industry in individual European countries in the years 2010-2016 was performed. As part of this stage, answers were also sought to the question of what had a greater impact on the change in productivity – improvement in technical efficiency in the industry or technological progress?

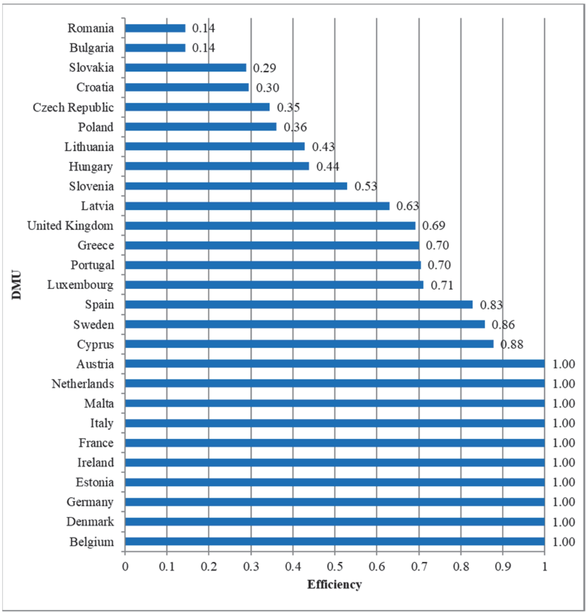


**Fig. 1.** Technical and environmental efficiency of the chemical industry in EU countries in 2016

In the analysed period, the chemical industry in Europe improved its annual productivity by 5% (see Table 1, row MPI and column Average). It is worth noting, however, that the improvement was still decreasing in the analysed period: from 16% in 2010/2011 to -2% in 2015/2016 (see Table 1). The conducted analyses make it possible to state that, in the period 2010/2011-2012/2013, technological progress had a greater impact on improving the chemical industry's productivity. The average annual *TECH* index was 1.32. In turn, the rate of efficiency change in the same period was below 1, which indicates that in the given period the chemical industry in Europe reported a deterioration in efficiency, and an improvement in this area was only noted from 2013/2014 to 2014/2015. The average annual *EFCH* index was 1.58 in the period, so technical efficiency had a greater impact on improving the chemical industry's productivity in the given period. The decline in productivity in 2015/2016 was due to a decline in both indices.

**Table 1.** Average annual values of the MPI, changes in technical efficiency (*EFCH*) and technological progress (*TECH*) in the chemical industry as a whole in Europe in the period 2010-2016

| Index | 2010/ 2011 | 2011/ 2012 | 2012/ 2013 | 2013/ 2014 | 2014/ 2015 | 2015/ 2016 | Average |
|---|---|---|---|---|---|---|---|
| EFCH | 0.97 | 0.79 | 0.81 | 1.06 | 2.07 | 0.99 | 1.11 |
| TECH | 1.20 | 1.50 | 1.26 | 0.99 | 0.59 | 0.99 | 1.09 |
| MPI | 1.16 | 1.14 | 1.01 | 1.04 | 1.00 | 0.98 | 1.05 |

However, the situation of the chemical industry varies depending on the country. Research results indicate that in 2010-2016 the chemical industry improved its productivity in 20 European countries (see Table 2). Countries that experienced deterioration in the chemical industry's productivity are France, Cyprus, Lithuania, Slovakia, and United Kingdom. In Germany and Luxembourg, on the other hand, neither improvement, nor deterioration in the productivity of the chemical industry has been observed. Technological progress (*TECH*), in all countries (except Cyprus) was at a level 1 or above 1.However, this average annual improvement was approx. 9%, while improvement in technical efficiency (*EFCH)* was 11%, although the index was lower than 1 in Spain, France, Cyprus, and United Kingdom.

## 5. Conclusion

As of 1st January 2013, the third stage of EU ETS came into force (European Union, 2009) which covered the chemical industry. As a result, operating costs increased significantly. The operating principles of this system mean that the issues of energy and emission efficiency (related to setting benchmarks for particular branches of the economy and granting free emission rights) are beginning to play a major role in the economic calculation. The European chemical industry, bearing the costs of the fight for climate stability, is becoming increasingly less competitive with non-EU producers not subject to similar regulations. As the presented research has shown, enterprises are trying to adapt to the emerging situation and improve theirefficiency and productivity. This is particularly evident in the EU countries that are the leadingproducers in the chemical industry, i.e. Germany, France, Italy, and the Netherlands. Under the conducted analysis, these countries achieved the highest economic and environmental efficiency ratios.

**Table 2.** Average annual valuesof the Malmquist index, changes in technical efficiency and technological progress in the chemical industry in individual European countries in the period 2010-2016

| Country | EFCH | TECH | MPI |
|---|---|---|---|
| Belgium | 1.00 | 1.03 | 1.03 |
| Bulgaria | 1.18 | 1.10 | 1.04 |
| Czech Republic | 1.15 | 1.16 | 1.01 |
| Denmark | 1.49 | 1.19 | 1.06 |
| Germany | 1.00 | 1.00 | 1.00 |
| Estonia | 1.38 | 1.10 | 1.18 |
| Ireland | 1.17 | 1.18 | 1.27 |
| Greece | 1.13 | 1.24 | 1.16 |
| Spain | 0.99 | 1.02 | 1.01 |
| France | 0.97 | 1.00 | 0.97 |
| Croatia | 1.12 | 1.11 | 1.01 |
| Italy | 1.02 | 1.02 | 1.04 |
| Cyprus | 0.90 | 0.94 | 0.83 |
| Latvia | 1.15 | 1.07 | 1.08 |
| Lithuania | 1.07 | 1.10 | 0.98 |
| Luxembourg | 1.11 | 1.02 | 1.00 |
| Hungary | 1.14 | 1.14 | 1.01 |
| Malta | 1.12 | 1.00 | 1.11 |
| Netherlands | 1.01 | 1.02 | 1.03 |
| Austria | 1.05 | 1.04 | 1.01 |
| Poland | 1.06 | 1.04 | 1.05 |
| Portugal | 1.15 | 1.16 | 1.04 |
| Romania | 1.28 | 1.10 | 1.08 |
| Slovenia | 1.17 | 1.12 | 1.02 |
| Slovakia | 1.04 | 1.11 | 0.96 |
| Sweden | 1.26 | 1.23 | 1.03 |
| United Kingdom | 0.97 | 1.02 | 0.99 |
| Average | 1.11 | 1.09 | 1.05 |
| Max | 1.49 | 1.24 | 1.67 |
| Min | 0.90 | 0.94 | 0.83 |

Note: a greyed field indicates an improvement of the given indicator

Considering the tightening EU climate policy, it seems that the best approach to monitoring efficiency is a comprehensive approach to both economic and environmental aspects. The conducted studies present such an approach and make it possible to indicate countries with the highest economic and environmental efficiency of the chemical industry (Belgium, Denmark, Germany, Estonia, Ireland, France,Italy, Malta,the Netherlands, and Austria), as well as thosethat have most improved their productivity in the analysed period (Ireland, Estonia, Greece, Malta). Technological progress was the source of improvement in productivity of the chemicalindustry in the period 2010/2011-2012/2013. But technicalefficiencyhad agreaterimpact on improving the chemicalindustry'sproductivityin the period 2013/2014-2014/2015. The conducted studies and adopted research methods made it possible to accomplish the research goal and to obtain answers to the research questions posed.

The obtained results provide the foundation for further in-depth studies, in which it is necessary to identify the main factors that have had an impact on the economic and environmental efficiency of the chemical industry in individual EU countries which could be realised with methods of prediction market (Czwajda et al., 2019). In future research, the identification might be realised with design thinking methodology (Kostrzewski, 2018).

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**Abstract**

Based on the Data Envelopment Analysis method and the Malmquist Productivity Index, the article specifies the economic and environmental efficiency and its changes in the chemical industry in individual EU countries from 2010 to 2016. The following have been adopted as variables in the model: 1 output (production value) and 3 types of input (number of employees, energy consumption, $CO_2$ emissions). The countries where the chemical sector obtained the highest economic and environmental efficiency were: Belgium, Denmark, Germany, Estonia, Ireland, France, Italy, Malta, the Netherlands, and Austria. The chemical industry in Romania and Bulgaria proved to be the least economically and environmentally efficient. As part of the research, it was indicated that both technological progress and the change in technical efficiency had impact on the improvement in productivity in the chemical industry in EU. In the analysed period, the chemical industry in Europe improved its annual productivity by 5%. It is worth noting that the improvement was still decreasing in the analysed period: from 16% in 2010/2011 to -2% in 2015/2016. The conducted analyses make it possible to state that, in the period 2010/2011-2012/2013, technological progress had a greater impact on improving the chemical industry's productivity. In turn, the technical efficiency had a greater impact on improving the chemical industry's productivity in the period 2013/2014-2014/2015. The decline in productivity in 2015/2016 was due to a decline in both indicators. However, the situation of the chemical industry varies depending on the country. Research results indicate that in 2010-2016 the chemical industry improved its productivity in 20 European countries. Countries that experienced slowdown in the chemical industry's productivity are France, Cyprus, Lithuania, Slovakia, and United Kingdom. In Germany and Luxembourg, on the other hand, neither improvement, nor deterioration in the productivity of the chemical industry has been observed.

**Keywords:**
efficiency, environment, chemical industry, Europe

## Efektywność ekonomiczno-środowiskowa przemysłu chemicznego w Europie w latach 2010-2016

**Streszczenie**

W artykule bazując na metodzie Data Envelopment Analysis i Malmquist Productivity Index określono efektywność ekonomiczno-środowiskową i jej zmiany w przemyśle chemicznym w poszczególnych krajach UE w latach 2010-2016. Do modelu przyjęto jako zmienne: 1 efekt (wartość produkcji), 3 nakłady (liczba zatrudnionych, zużycie energii, emisja $CO_2$). Krajami, gdzie sektor chemiczny odnotował najwyższą efektywność ekonomiczno-środowiskową były Belgia, Dania, Niemcy, Estonia, Irlandia, Francja, Włochy, Malta, Holandia i Austria. Najmniej efektywny pod względem ekonomiczno-środowiskowym okazał się przemysł chemiczny w Rumunii i Bułgarii. W ramach badań wskazano, że zarówno postęp technologiczny, jak i zmiana wydajności technicznej miały wpływ na poprawę wydajności w przemyśle chemicznym w UE. Przemysł chemiczny w EU w badanym okresie poprawiał swoją produktywność średniorocznie na poziomie 5%. Warto jednak zauważyć, że poprawa uległa zmniejszeniu w analizowanym okresie z 16% w 2010/2011 do -2% w 2015/2016. Przeprowadzone analizy pozwalają stwierdzić, że w okresie 2010/2011-2012/2013 postęp technologiczny miał większy wpływ na poprawę produktywności przemysłu chemicznego z kolei na wydajność techniczną w okresie 2013/2014-2014/2015. Ograniczenie produktywności w latach 2015/2016 było spowodowane spadkiem obu wskaźników. Sytuacja przemysłu chemicznego jest jednak zróżnicowana w zależności od kraju. Wyniki badań wskazują, że w latach 2010-2016 w 20 krajach Europy przemysł chemiczny poprawił swoją produktywność. Kraje, które odnotowały pogorszenie produktywności przemysłu chemicznego to Francja, Cypr, Litwa, Słowacja i Wielka Brytania. Z kolei w Niemczech i Luksemburgu nie odnotowano ani poprawy, ani pogorszenia produktywności przemysłu chemicznego.

**Słowa kluczowe:**
efektywność, środowisko, przemysł chemiczny, Europa