

## MODELLING THE IMPACT OF INVESTMENTS ON ENERGY INTENSITY IN THE POLISH STEEL INDUSTRY AS A STEP TOWARDS INDUSTRY 4.0

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### Abstract

The investments affect the development of enterprises. In the perspective of Industry 4.0, if there were no impact of the COVID-19 pandemic on economies, enterprises would continue to realize strong investment strategies. Until March 2020, steel enterprises in Poland invested in new technologies, increasing efficiency in steel production. Automation of production and automation of the storage in combination with IT technology and the Internet of Things change the steel industry in Poland. The combination of operational technology (OT) with information technology (IT) is an opportunity for steel industries around the world. One of the fields of changes is energy management in steel production. Energy reduction can be achieved through active monitoring of energy consumption and an intelligent energy management system used in steel production. Realized investments until the end of 2019 in the Polish steel industry (the value of investments/ PLN million) and the energy intensity in the steel production (toe/tonne of steel) in Poland were used to build econometric models. The time series used to build econometric models covered the period from 2000 to 2019. The aim of the research was to determine whether the steel industry in Poland saves energy as investment increases, with a particular focus on the trend towards Industry 4.0 in recent years.

**Keywords:** Steel industry, Poland, investment, energy intensity, econometric model

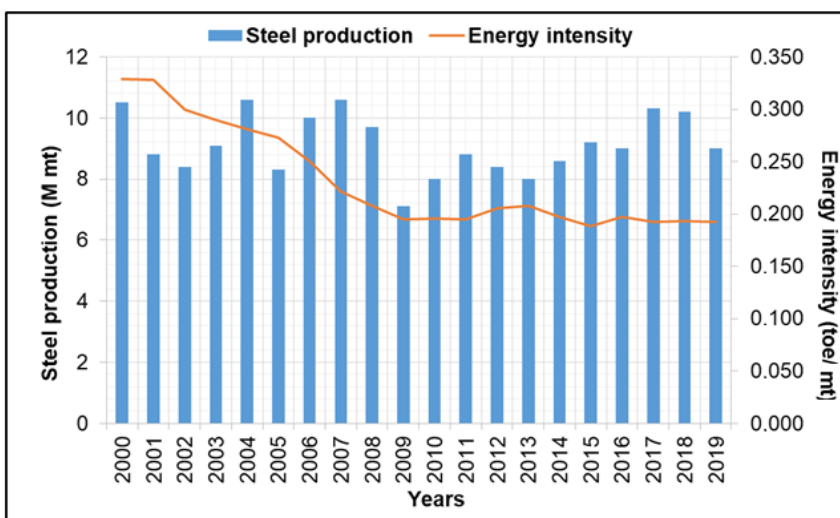
### 1. INTRODUCTION

Analysis of energy intensity is important in business management. Reducing environmental pollution and saving resources are key challenges in today's economy. On the way to sustainability, more and more enterprises are trying to use energy more efficiently. Energy efficiency reduces gas emissions and reduces production costs in the sustainability of the company. Energy efficiency is the ratio of the obtained results: goods and services to consumed energy in analyzed period. In the steel industry, energy is consumed per tonne of steel. EEI - Energy Efficiency Indicator informs about the decrease in energy consumption per unit of the product. Energy efficiency in steel industry toward Industry 4.0 is an important topic and new subject of research for scientists. Recently, this topic has been published by the authors: Wolniak et al. [1], Florens et al. [2], Johansson [3]. Energy efficiency in the Industry 4.0 can be realized through IT- integration of the production level with the planning level and further on to customers and suppliers (supply-chains). This IT integration is realized by cyber-physical-systems, the whole scenario is (in Germany) known as 'Industry 4.0' for some years now [4]. Klaus Schwab [5], founder and president of the World Economic Forum, the best known platform for the exchange of ideas and views, published a book entitled *The Fourth Industrial Revolution*, (2016), in which he points out the new changes in industry, economy, and society. The key pillars of Industry 4.0 are: IoT, big data, cloud computing, advanced simulation, autonomous systems, universal integration, augmented reality, additive manufacture and cyber security. The pillars of Industry 4.0 are described in publications: Hermann et al. [6], Erboz [7], Saniuk et al. [8]. Industry 4.0 (until the Covid-19 crisis) was heavily promoted by politicians, scientists and global capital. The changes that led to Industry 4.0 appeared in recognized companies in such industries as: automotive, clothing, shoe production and home appliances. The first initiatives also appeared in the steel industry in Poland. Steelworks in Poland use mainly rather simple automated systems in steel

production. Automation and modern Industrial Communication Technologies are used on selected production sections. The systems are controlling, monitoring and interacting processes in steel production. The work of blast furnaces is supervised by IT systems. The equipment in steel mills and rolling mills is partly or fully automatic. Huge progress has been made in the field of machine maintenance and management to implement Total Productive Maintenance – TPM [9]. Besides steel production in Poland, the first fully automated metallurgical warehouses are created in the southern regions in Poland. According to the PwC report [10], the metallurgical sector (respondents' opinions) until March 2020 spends around 4% of annual revenues on new investments, while expecting a 3.2% decrease in costs. In a new reality – the crisis caused by the exclusion of economies due to Covid-19 – the steel works will reduce investment expenditure. From March 2020, demand for steel is declining. This will continue throughout 2020. In 2020 worldsteel forecasts that steel demand will contract by 6.4% due to the COVID-19 crisis. Steel demand in the developed economies is expected to decline by 17.1% in 2020. In developing countries steel demand (excluding China - Chinese steel demand is expected to increase by 1.0% in 2020) is expected to fall by 11.6% in 2020. EU steel demand suffered a contraction of 5.6% in 2019 due to the sustained manufacturing recession [11]. In Poland, in March 2020, 640,000 tonnes of crude steel were produced, 30% decrease from March 2019. In the period January-March 2020, steel production amounted to 2 thousand tonnes of crude steel (decrease steel production compared to the previous year was 19%) [12]. Investments have been stopped in recent months. The topic of the study is an analysis of the correlation between investment expenditures in the Polish steel industry (sector of steel production) and energy consumption during steel production. The aim of the analysis is to determine whether energy savings are achieved during steel production in the steel industry in Poland as the value of the investment increases. The value of the investments (PLN million) – source of data: Statistics Poland – has been made real over time taking into account inflation every year. Energy intensity is expressed in the toe/tonne of steel. The time limit of the analysis is the period from 2000 to 2019. The result of the analysis are econometric models. Two models are presented in the paper: linear model and exponential model with trend.

## 2. ENERGY INTENSITY IN STEEL INDUSTRY IN POLAND IN THE PERIOD 2000-2019

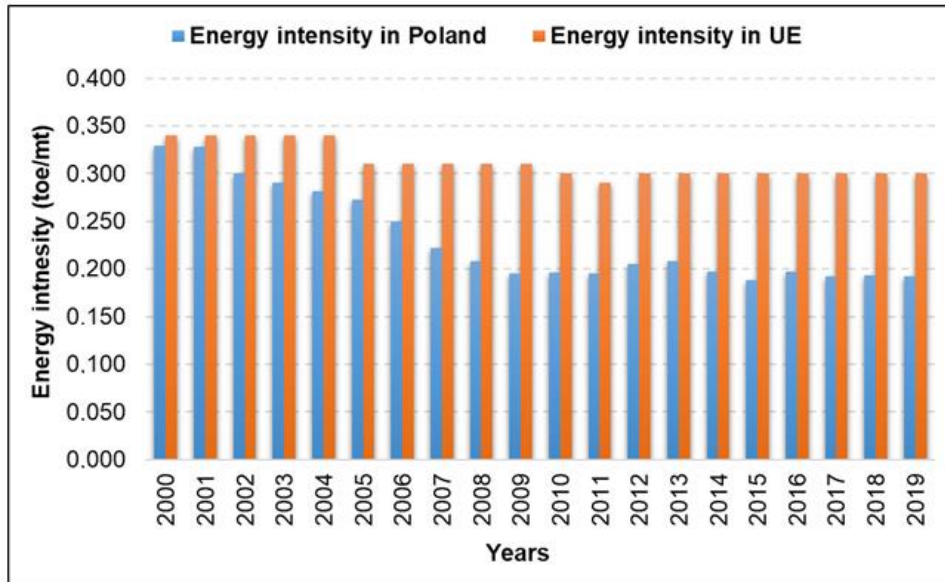
Between 2000 and 2019, the steel industry in Poland produced an average of 9.130 Mt of steel per year. Efficiency per employee was 587.8 tonnes of steel. In the trend of steel production in Poland in the analyzed time series ( $N=20$ ) there were periodic fluctuations (seasonal fluctuations) – **Figure 1**. Since 2003, companies in the sector have been using two production processes: BOF (Basic Oxygen Furnace) and EAF (Electric Arc Furnace) because OHF technology (Open Hearth Furnaces - the Siemens–Martin process) was definitively discontinued in 2002).



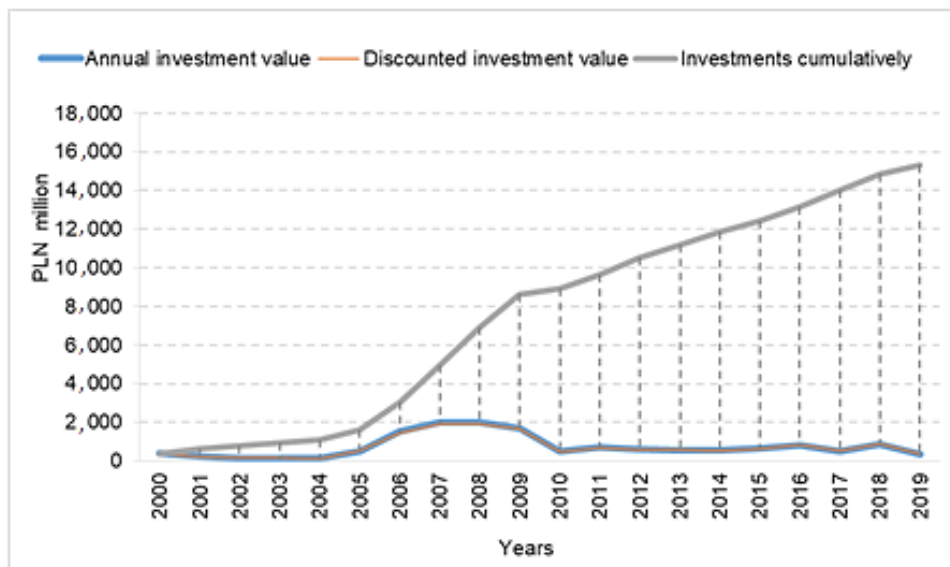
**Figure 1** Steel production and energy intensity in Poland [13]

In the period from 2000 to 2019 the average annual BOF production was 5.200 Mt, EAF 3.880 Mt of steel. Over the same period, the energy intensity was 0.2320 toe/tonne of steel. The energy intensity in Poland during the analysis period was lower than the average energy intensity in the EU. The average energy consumption in the EU was 0.3120 toe/tonne – **Figure 2**. Presented current energy consumption is an introduction to further analysis. Data on energy consumption in the Polish steel

industry are used to build econometric models (*variable y* in models) and the investment value in steel industry in Poland in the period from 2000 to 2019 is the variable *x* in the models – **Figure 3**.



**Figure 2** Energy intensity in steel industry in Poland and in the EU [13-14]



**Figure 3** Investment value in Polish steel industry [15]

### 3. METHODOLOGY AND USED EMPIRICAL DATA

The following steps have been performed in the analysis:

- 1) Obtaining empirical data
- 2) Determining Pearson's correlation coefficient
- 3) Building econometric models and their presentation

The analysis of the energy intensity according to the value of investments was carried out on the basis of empirical data. Used data is shown in **Table 1**.

**Table 1** Empirical data used in the building of econometric models [own study based on 13,15]

No.	Years	Discounted Investment Value (PLN million)	Cumulative Investment Value (PLN million)	Energy intensity (toe/tonne of steel production)
1.	2000	379	379	0.3290
2.	2001	226	618	0.3280
3.	2002	159	784	0.3000
4.	2003	164	928	0.2900
5.	2004	134	1,074	0.2810
6.	2005	523	1,609	0.2730
7.	2006	1,474	3,060	0.2500
8.	2007	1,940	4,950	0.2220
9.	2008	1,927	6,910	0.2080
10.	2009	1,651	8,622	0.1950
11.	2010	464	8,945	0.1960
12.	2011	674	9,671	0.1950
13.	2012	597	10,536	0.2050
14.	2013	575	11,206	0.2080
15.	2014	555	11,863	0.1970
16.	2015	650	12,406	0.1880
17.	2016	825	13,157	0.1970
18.	2017	541	14,041	0.1920
19.	2018	884	14,870	0.1935
20.	2019	358	15,331	0.1923

In the first step of modelling, Pearson's correlation coefficient ( $r$ ) was used. Pearson's correlation coefficient  $r$  for the impact of investments on the energy intensity was -0.90169. Pearson's correlation  $r = -0.9$  means that there is a strong negative correlation between investments and energy consumption in the Polish steel sector. The correlation result between the variables tested:  $y$  - energy consumption in steel production (steel energy intensity),  $x$  - investments in steel sector, allowed to realize the next step of research, which was the construction of econometric models. In the paper, two models were presented: linear and non-linear.

#### 4. PRESENTATION OF OBTAINED ECONOMETRIC MODELS

Obtained models:

1) Linear model (formula 1)

$$y = -8.589 \cdot 10^{-6}x + 0.295 \quad (1)$$

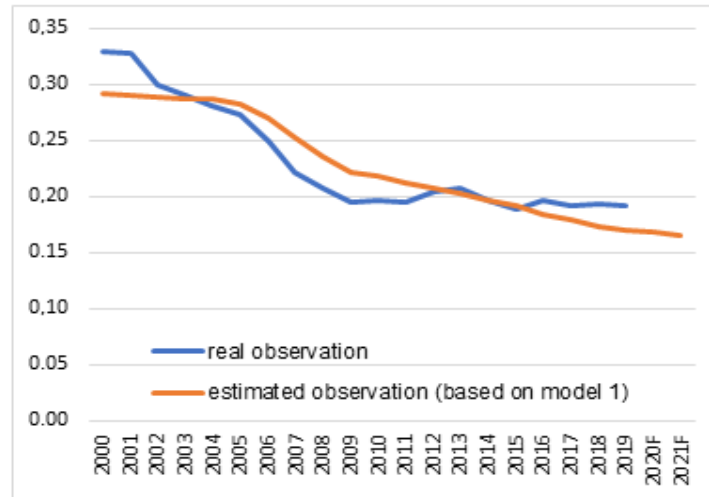
where:

$y$  – steel energy intensity (toe/ 1 tonne)

$x$  – investments (PLN million)

Coefficient determination for this model was  $R^2 = 0.8281$ . Coefficient determination is high, which means the model is good fitted. Obtained model informs that realized investments in the steel industry in Poland in

the period from 2000 to 2019 affect energy consumption in steel production in the sector. **Figure 4** shows trends for real and estimated steel energy intensity in Polish steel industry.



**Figure 4** Model 1: steel energy intensity in Poland [own study]

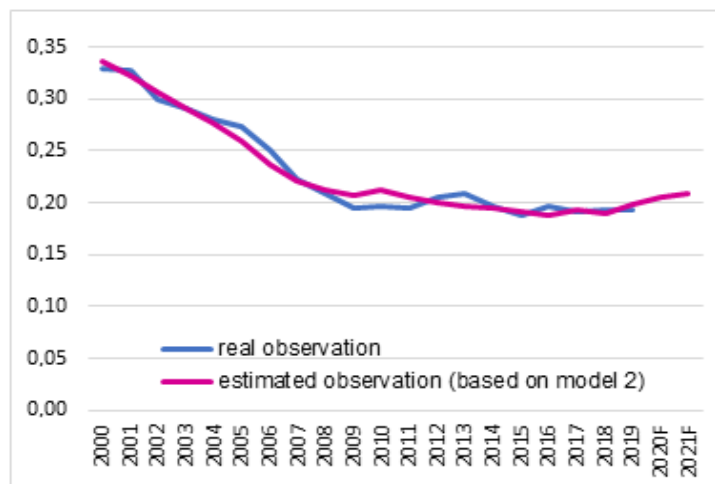
2) Exponential model with trend (formula 2)

$$y = -1.2 \cdot 10^{-5}x - 0.019t + 0.001 t^2 + 0.360 \quad (2)$$

where:

- $y$  – steel energy intensity (toe/1tonne)
- $x$  – investments (PLN million)
- $t$  – time (years)

This model is better than first model ( $R^2 = 0.9713$ ), the model explains 97% variability energy intensity through investments in steel production in Poland. The model is statistically significant. Obtained model informs that increasing investments in the steel industry in Poland by a unit in the following year will result in a decrease in unit energy consumption of  $-1.2 \cdot 10^{-5}$  toe/tonne of steel for other unchanged factors. In each following year energy saving will be of 0.019 for other unchanged factors. **Figure 5** shows trends for real and estimated steel energy intensity in Polish steel industry.



**Figure 5** Model 2: steel energy intensity in Poland [own study]

## 5. CONCLUSION

The obtained models show that the increase in investment expenditures contributes to the decrease in energy consumption in the Polish steel sector. Based on the obtained models, it can be assumed that in the following years the increase in investment expenditures in the steel industry in Poland will affect energy savings. The situation of reducing steel production, together with the decrease in steel demand during the Covid-19 pandemic, has a negative impact on the conclusion. Economic crisis disrupts steel production trend (such situation was in period 2009-2010). Strong fluctuations in the trend of steel production make it difficult to perform the econometric analyses and build statistic models. The decline in steel production during the Covid-19 crisis can be expected to reduce energy consumption in the steel industry, but unfortunately also to a decline in investment expenditures. The expansion strategies realized until March 2020 in the steel industry in Poland are being replaced by cost-cutting strategies during the period of Covid-19.

## ACKNOWLEDGEMENTS

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