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POST-PANDEMIC STEEL PRODUCTION SCENARIOS FOR POLAND BASED ON FORECASTS OF ANNUAL STEEL PRODUCTION VOLUME

Bożena Gajdzik
Silesian University of Technology

Abstract:
The paper presents the results of forecasts made for the volume of steel production in Poland based on actual data for the period from 2006 to 2021 with forecasting until 2026. The actual data used for the forecasts included annual steel production volumes in Poland (crude steel) in millions of tons. Basic adaptive methods were used to forecast the volume of steel production for the next five years. When selecting the methods, the course of the trend of the studied phenomenon was taken into account. In order to estimate the level of admissibility of the adopted forecasting methods, as well as to select the best forecasts, the errors of apparent forecasts (ex post) were calculated. Errors were calculated in the work: RMSE Root Mean Square Error being the square root of the mean square error of the ex-post forecasts yt for the period 2006-2021; [illegible] as the mean value of the relative error of expired forecasts y*t (2006-2021) – this error informs about the part of the absolute error per unit of the real value of the variable yt. Optimization of the forecast values was based on the search for the minimum value of one of the above-mentioned errors, treated as an optimization criterion. In addition, the value of the point forecast (for 2022) obtained on the basis of the models used was compared with the steel production volume obtained for 3 quarters of 2022 in Poland with the forecast for the last quarter. Forecasting results obtained on the basis of the forecasting methods used, taking into account the permissible forecast errors, were considered as the basis for determining steel production scenarios for Poland until 2026. To determine the scenarios, forecast aggregation was used, and so the central forecasts were determined separately for decreasing trends and for increasing trends, based on the average values of the forecasts obtained for the period 2022-2026. The central forecasts were considered the baseline scenarios for steel production in Poland in 2022-2026 and the projected production volumes above the baseline forecasts with upward trends were considered an optimistic scenario, while the forecasted production volumes below the central scenario for downward trends were considered a pessimistic scenario for the Polish steel industry.

Key words: *steel production, Polish steel industry, forecasting, COVID-19*

INTRODUCTION

Any manufacturing company operating in an environment that has experienced two strong (acute) crisis situations in the last two decades: the global economic crisis initiated in the USA in 2008 and the global crises after the COVID-19 pandemic in 2020. Strong changes in the business environment result in the fact that companies have to verify their current production strategies. Enterprises analyze their results on an ongoing basis and forecast changes in the production volume. Taking into account the conditions created by the current economic situation and the results of the business conducted so far, in a modernly organized economy, enterprises must anticipate how to behave in the near future in order to maintain stability – resilient.

The strategy described as "resilient" has been included in the Industry 5.0 document of the European Commission [1]. The economic crisis, which intensified after trade and business restrictions introduced by national governments due to the threat of the SARS-CoV2 virus, has changed business strategies and supply chains [2, 3]. In times of crisis, companies have gained respect for the future of business. Predicting the future of business is not easy. In order to predict the future, it is necessary not only to obtain information from the past that is known and use it to forecast the future, but also to build scenarios of changes in the studied phenomenon (base and extreme scenarios: pessimistic and optimistic). To build scenarios, you need forecasts that can be made on the basis of classical (basic) econometric methods. Forecast (prediction)[1] according to the definition of the PWN online dictionary, it means: "predicting future implementations or statistical characteristics of random phenomena" [4]. Forecast is "an announcement, the anticipated effect of something, put forward on the basis of specialized research in a given field" [5]. The forecast is the results (result) of the prediction process (inference for the future) [6]. In the definition of the term "forecast" there are two factors: the first is an indication of what is to be predicted (forecasted), and the second is what methods to use to do it.

In this work, the author compiled forecasts of the total steel production volume in Poland until 2026 based on historical statistical data for the period 2006-2021. This work complements the knowledge about the Polish steel industry and steel production volumes during the COVID-19 pandemic [7, 8, 9, 10]. The compiled statistical data, models and forecasts were used by the author to determine scenarios for the volume of steel production in Poland. Scenarios are possible events of the studied phenomenon and are used in enterprise management in change management [11, 12]. Assuming the spread and direction of the forecast trend, the scenarios can be ordered into: central (basic, basic) aggregated on the basis of the averaged values of the forecasts and non-central (extreme): optimistic (increasing production trend) and pessimistic (decreasing production trend). Market analysis and forecasting the production volume according to scenarios is especially important for companies in times of crisis. The instability of the environment means that companies have to analyze it more often and set short-term strategies for action. In an economic crisis, the business risk is greater than in a period of economic stability [13].

The paper indicates that the pessimistic scenario has become realistic due to the strong impact of the COVID-19 crisis on the unfavorable situation of the Polish steel industry. The production research methodology used in the study can be used by enterprises (steel mills) to verify business strategies until 2026.

ABOUT THE IMPACT OF COVID-19 ON THE BUSINESS

The functioning of enterprises is inextricably linked with business cycles. Periods of growth (business) are followed by a crisis (economic recession, business collapse, growth slowdown, and even economic collapse) [14, 15]. On the basis of many sources, encyclopedic and scientific definitions, the crisis is a term referring to the etymology of the word "krisis" (from Greek), i.e. to a breakdown and solstice in the functioning of economies, societies, enterprises [15]. The industrial crisis is the result of the accumulation of negative phenomena in the environment of enterprises and their businesses. The causes of economic crises are different: ecological, social, economic, political, etc. [16]. The factors causing the crisis are external and internal in relation to the examined place (space) or organization. External sources of the crisis for enterprises may include barriers introduced in the financial and economic policy of the government, natural disasters, environmental disasters, epidemics, armed conflicts (wars), terrorism, cyberattacks, escalation of the level of dissatisfaction of societies with living conditions, technological revolutions and the related strong inefficiency of economies with due to the lack of reaction to technological changes and even resistance to technological progress [17]. The category of external causes also includes sharp drops in the demand for goods. The market is dynamic and demand and supply react very quickly to crisis situations [18]. The sources of internal causes of the crisis should be sought in business activity. Enterprises conduct business activity, and the management staff makes decisions taking into account the business risk [19]. Wrong business and investment decisions as well as inefficiency of management systems in enterprises may cause the accumulation of negative phenomena related to running a business and, as a result, result in a crisis. crisis, until it ends and a new reality is built. The stages of the cycle are: accumulation, initiation, contagion, transmission, new post-crisis reality [20].

At the beginning of 2020, the COVID-19 pandemic broke out, which was a sudden event in the history of mankind. The effects of the pandemic affected the whole world. In order to limit the transmission of the virus, the governments of individual EU countries have been implementing instruments to mitigate the effects of COVID in the economy (lock down) since March 2020. The COVID-19 pandemic is primarily a tragedy of many people who have lost their health and life as well as their loved ones as a result of the disease. The COVID-19 pandemic is also a crisis of households that have lost their sources of income and quality of life as a result of the restrictions introduced to limit the spread of the pandemic and reduce the number of new infections. The COVID-19 pandemic is primarily an economic (economic) crisis. In 2020, the world economy found itself in the deepest recession since World War II – according to World Bank data, global GDP decreased by 4.3% [21].

In a crisis situation, enterprises learn to manage almost anew. Crisis management is based on plans, the implementation of which is to reduce the negative impact of the crisis on the company [22]. The first form of actions taken in crisis management is about a quick reaction of the company to the negative effects of the crisis. Companies build a defence strategy in the form of an anti-crisis shield. In subsequent activities, enterprises try to understand the causes of the crisis and its course in order to introduce actions allowing it to function in the crisis [23]. The acquired knowledge is used by managers for preventive actions in the future. Preventive actions are aimed at anticipating an internal crisis situation, which are implemented, among others, by performing a threat analysis and sensitivity assessment, determining the tasks of the anti-crisis team/teams in the organization, conscious leadership in the organization, systems of coordination of

[1] Prediction can be used instead of forecast

activities, computer systems for tracking changes, autonomous change response systems [23]. Contemporary crisis management consists of the following phases: prevention, preparation, response and reconstruction [24, 25]. Crisis management with an emphasis on preventive actions is not an easy task because each crisis is different and the sources causing the crisis are difficult to predict in the global economy. Enterprises are constantly learning crisis management in the conditions in which they had to deal with a specific crisis [23, 24, 25]. In COVID-19 (in 2020), many enterprises had to face difficulties in their operations due to interruptions in the supply chain, restrictions on the professional activity of employees, a decrease in sales revenue, the need to incur additional costs due to the stricter sanitary regime, forced digitization and remote work [26, 27]. After 2020 (after severe restrictions related to COVID-19), enterprises changed their business model, introduced new products and services, changed suppliers, gained new recipients, e.g. through personalization. In global terms, the vast majority of entities have felt and still feel the negative effects of the pandemic, which led to significant structural and institutional changes [28, 29, 30, 31, 32, 33]. Digitization has helped businesses function during pandemic restrictions. Metallurgical enterprises using information and computer technologies could contact suppliers and consumers (send documents, execute orders, participate in commercial auctions, etc.) [34].

The situation on a global scale, the effects of which are difficult to predict, are defined by four features that make up the acronym VUCA, derived from the military, often recalled in management, especially in 2020, dominated by the pandemic: Volatility, Uncertainty, Complexity , ambiguity (Ambiguity). The functioning of enterprises according to VUCA means that in order to find oneself in business one needs to develop the ability to adapt flexibly and courageously to unexpected events. Business strategy in a dynamic environment is based on two ways of thinking: focus on development (growth mind-set) and focus on durability (fixed mind-set) [35]. Enterprises building strategies according to VUCA should be able to function in changing conditions, but be guided by the values and vision (Vision) of their organization; should react quickly to volatility; they should develop communication skills, obtaining information from the environment, i.e. Understanding as a response to uncertainty (Uncertainty); they should develop a clear model of the company's functioning thanks to the talents of employee teams and leadership; readability of functions, responsibilities, process maps (Clarity) are needed in a collision with the complexity of reality (Complexity); should make decisions faster than other players on the market; should prefer agility as a response to the ambiguity of the environment, take advantage of opportunities whose durability is usually inversely proportional to the time of decision-making and, above all, forecast production and set strategies based on scenarios of possible events [36]. Effective crisis management is not just a matter of management strategy. Just as much depends on technological tools. In order to make the right decisions, it is necessary to efficiently supply managers with mass data. In Industry 4.0, which has been popularized since 2011, there are a number of good examples of technological solutions (pillars of Industry 4.0) that are an opportunity for the development of enterprises [37, 38, 39, 40]. Industry 4.0 technologies have facilitated communication and business implementation in a pandemic, e.g. artificial intelligence [41, 42], mobile technology and solution home office [43, 44, 45, 46]. The COVID-19 crises accelerated the digitization of industry. The impact of the post-COVID-19 crisis will be long-term. The experience of the first year of operation in the conditions of the pandemic forced changes in business. In the short and long term, enterprises must strongly change their current business strategies and model to, on the one hand, implement new technologies (politicians' emphasis on business sustainability, including hydrogen technologies, green energy, etc.), and, on the other hand, achieve "resilient ”in a dynamic market (high raw material prices, high energy prices, shortage of certain raw materials, interrupted supply chains, etc.) [47, 48]. New values are promoted by the European Commission in the concept of Industry 5.0 [1], which focuses on human-centic, sustainable and resilient values [49]. Entering Industry 5.0, it is worth looking at the current situation of various industries, including the steel industry, which employs over 6 million people in the world, and the annual global steel production in 2021 has approached almost 2 billion tonnes (1,950.5 million tonnes). In terms of steel production, Poland is ranked 19th in the world ranking (generating less than 0.5% of global steel production) (World Steel Association) [50].

THE SITUATION IN THE POLISH STEEL INDUSTRY IN THE POST-COVID PERIOD

Steel production in Poland, as well as in the world, is strongly influenced by market factors (fluctuations in supply and demand on the steel market), economic factors (business or downturn), environmental factors (stringent requirements to reduce greenhouse gas emissions, especially CO_2) and political factors.

The situation of the steel industry in the first months of 2020 changed to the disadvantage of this sector, and this was due to restrictions aimed at limiting the increase in SARS-CoV-2 virus infection. The first cases of infection were recorded in December 2019 among the inhabitants of the 11-million Chinese city of Wuhan, the first case of COVID-19 outside China was registered on January 13, 2020 in Thailand, the first European country where infections were recorded was France (January 24), in Poland, the Ministry of Health confirmed the first cases of the disease on March 4, 2020. On January 30, the World Health Organization recognized the new coronavirus as a threat of international importance [51]. The health threat has turned into a threat to economies and industries.

In the steel industry, COVID-19 has led to a decline in steel production in many countries, but globally there has been an increase. In Poland, steel production in 2020 amounted to 7.956 million tonnes, a decrease of 12.68% compared to 2019 [52]. On the other hand, in the reports of the World Steel Association, there is still a growing trend in steel production on a global scale. In 2019, the world produced 1,874.4 million tonnes (Mt) (up by 47 million tonnes compared to 2018) [50]. In 2021, the world produced 1,951 million tonnes (up 74 million tonnes compared to the previous year) [50]. In the same period, EU countries (28 countries) produced 157.5 million tonnes in 2019, 139.2 million tonnes in 2020 (28 counties) and 152.6 million tonnes in 2021 (27 countries) [53]. Thus, in EU countries, as well as in Poland, a decrease in steel production was recorded in 2020 compared to 2019. Identical trend directions appeared for apparent steel use 2019 to 2021 (Table 1).

COVID-19 restrictions have affected steel production. The Polish steel industry reduced production and introduced an economic downtime (employees do not perform work on full readiness for work and receive lower remuneration). The market situation of steel producers has deteriorated (lower financial results, lower production, lack of development prospects). The declining demand for steel led to a significant reduction in the use of production capacity (in Poland at the level of approx. 70%) [54]. The unfavourable situation in the steel industry – a decrease in production – led to the shutting down of the blast furnace in the largest steelworks in Poland. Currently (as of September 2022), another blast furnace of the largest metallurgical company in Poland is being renovated. The growing unfavourable situation for producers, employees, suppliers, customers results in the economic crisis called "COVID-19 crisis". The wrong situation is also escalating due to the higher level of steel products imports then exports. In the apparent consumption of steel products in Poland in last time, imports (foreign deliveries) constitute 70%. Other problems of Polish steel industry are related to energy intensity of industry and decarbonisation policy [55]. According to European Green Deal and Carbon Border Adjustment (CBA) changes in Polish steel industry have to be in production towards better sustainability. In the post-COVID period, the prices of energy, raw materials and carbon emissions trading increased sharply. For comparison, in 2018 the price of energy in the Polish steel industry was 0.33695 PLN /kWh, and in 2021 0.487 PLN 5/kWh of steel production in Poland [56]. In Poland, the pandemic and sanitary restrictions led in 2020 to the first drop in Gross Domestic Product in Poland since 1991. GDP in 2020 decreased by 2.8% (after an increase of 4.5% in 2019) [57].

In the second period, the average annual steel production in Poland for the last 22 years (from 2000 to 2021) amounted to 9.029 million tonnes. The lowest level of steel production volume in Poland was achieved so far in 2009, i.e. during the previous crisis, which spread from the United States to the whole world. The crisis that began in 2018 on the American real estate market and initially affected the banking sector, spread its effects to the economies of other countries. It was the biggest economic crisis in the last two decades, the effects of which were strongly felt by the global steel industry [58]. In Poland, steel production in 2009 amounted to 7.128 million tonnes and was lower than in the crisis that began after COVID-19 lockdown restrictions by 728 thousand tonnes [59, 60]. In 2020, when there were lockdown restrictions in Poland for many months, steelworks produced 7.856 million tonnes of steel [61].

Table 1

Comparison of trends of steel production (crude steel) and apparent steel use from 2018 to 2021

t	y_o	**crude steel production [million tonnes]**			***t***	y_o	**apparent steel use [million tonnes]**		
year (*y*)	2018	2019	2020	2021	year	2018	2019	2020	2021
World	1,827.0	1,874.4	1,877.5	1,951.0	World	1,711.6	1,776.9	1,784.9	1,833.7
direction of trend compared to 2018	year zero (y_o)	↑	↑	↑	direction of trend compared to 2018	year zero (y_o)	↑	↑	↑
direction of trend *y/y*	↑	↑	↑	↑	direction of trend *y/y*	↑	↑	↑	↑
EU	167.4	157.5	139.2	152.6	EU	157.4	148.1	131.0	152.8
direction of trend compared to 2018	year zero (y_o)	↓	↓	↑	direction of trend compared to 2018	year zero (y_o)	↓	↓	↑
direction of trend *y/y*	↓	↓	↓	↑	direction of trend *y/y*	↑	↓	↓	↑
Poland	10.157	8.997	7.856	8.754	Poland	14.9	13.6	12.9	15.1
direction of trend compared to 2018	year zero (y_o)	↓	↓	↓	direction of trend compared to 2018	year zero (y_o)	↓	↓	↑
direction of trend *y/y*	↓	↓	↓	↑	direction of trend *y/y*	↑	↓	↓	↑

Source: based on [50, 52, 53] 2022 WorldSteel: World Steel in Figures, p. 6. [www.worldsteel.org] and p. 15; Eurofer, European Steel in Figures 2020, p. 15 [www.eurofer.eu], Reports: Polish Steel Industry, Polish Steel Association, Katowice.

The course of the post-pandemic crisis was influenced by many factors, including the interruption of the supply chain of raw materials and the distribution network of steel products, and a sharp decline in demand for cars. Before COVID-19, the steel production pessimistic scenario meant production of less than 9 million tonnes of steel per year [7]. The optimistic production scenario in Poland was when the annual steel production exceeds 10 million tonnes of steel. In the last two decades, steel production in Poland six times reached volumes exceeding 10 million tonnes of steel produced annually, and in the last decade, such high production volumes were recorded in 2017 and 2018 (Figure 1).

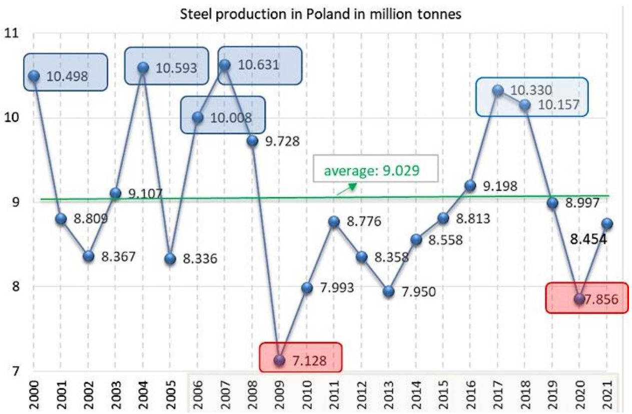

Fig. 1 The steel production in Poland from 2020 to 2021
Source: own eleboration based on data from Polish Steel Association and World Steel Association.

The period from 2006 to 2021 of the steel production volume in Poland (Fig. 1) was used for the research methodology and forecasts for the period from 2022 to 2026. In the analyzed period, from 2006 to 2021, average annual steel production amounted to 8.933 million tonnes. Forecasts of the steel production volume, which were set for 16 years (t=16). The commencement of the analysis in 2006 resulted from the completion of the restructuring of the Polish steel market (in its 2007 report, the European Commission concluded that the repair of the Polish steel industry was completed (steel plants in Poland met the viability requirements) [62]. In the analyzed period, the annual steel production in Poland very often was below 9 million tonnes of steel produced annually, i.e. below the current central (baseline) scenario, which resulted from the long-term average annual steel production in Poland After the global economic crisis in 2009, the return of the steel industry to economic activity was gradual, and as for steel – development of steel consumer markets: construction, automotive, transport, machinery, finished products made of metals, household appliances and other industries – production increased, which in 2017 and 2018 exceeded 10 million tonnes of steel produced annually in Poland.

MATERIALS AND METHODS

After a thorough analysis of the time course of the total steel production volume (Figure 1), it was found that the fluctuations in the trend courses are cyclical (repeatable). The aim of the research was a retrospective and prognostic analysis of crude steel production in Poland as a model solution for assessing changes in the volume of steel production in the Polish steel industry after the COVID-19 period. Forecasts of the steel production volume were made for the steel industry in the country, based on basic adaptation models, obtaining an additional comparative area for the assessment of trends in the studied phenomenon. The scenarios were divided into: base (central) and extreme according to the scenarios: pessimistic and optimistic based on the course of the trend. The empirical (actual) data used for the research are summarized in Table 2.
Reporting data are from the reports of the World Steel Association and the Polish Steel Association and cover the volume of steel production in Poland on an annual basis for the period from 2006 to 2021.

Table 2
Data used to foresting of steel production in Poland [million tonnes]

t	year	crude steel
1	2006	10.008
2	2007	10.631
3	2008	9.728
4	2009	7.128
5	2010	7.993
6	2011	8.776
7	2012	8.358
8	2013	7.950
9	2014	8.558
10	2015	8.813
11	2016	9.198
12	2017	10.330
13	2018	10.157
14	2019	8.997
15	2020	7.856
16	2021	8.454

Based on these data, forecasts of steel production in Poland were made for the next five years, from 2022 to 2026.
The following designations were adopted in the forecasting:
y^* – forecast variable,
t, T – time,
n – the number of elements in the time series (length of the time series),
y_t – value of the time series (value of the forecast variable for the moment or the time: t),
y_t^* – value of an expired forecast ($l < t < n$),
y_T realisation of the variable y_t in time period: $T > n$, e.g. $T = n + 1$,
y_{T-1} – value of the variable y for a moment or a period of time $T – 1$ (i.e. the period n),
y_T^* – forecast of the variable y_t in Time: $n < T < \tau$,
y_i – value of the variable y for moment of time period: i ($i = T – k, ..., T – 1$),
τ – the last moment or period of time for which a forecast is made,
k – the smoothing constant, i.e. the number of last words of the time series taken into account

for the calculation of the mean value,
α, β, γ – forecast smoothing parameters,
l – number of weights,
w – weights used in the forecasting models (w_1, w_2, w_3).
In order to forecast the level of acceptability according to the forecasting methods used, as well as to select the best forecasts, the two most frequently determined apparent (expired – ex post) forecast errors were estimated: RMSE *and* ψ (Table 3) [63, 64, 65].

$$\text{RMSE} = \sqrt{\frac{1}{n-m}\sum_{t=m+1}^{n}(y_t - y_t^*)^2} \quad (1)$$

$$\Psi = \frac{1}{n-m}\sum_{t=m+1}^{n}\frac{|y_t - y_t^*|}{y_t} \quad (2)$$

Table 3
Description of used forecast errors in forecasting of steel production in Poland

Type of errors	Description of errors	Description of indicators
Root Mean Square Error RMSE	forecasting error informs about average deviations of forecasts from actual values in the forecast verification interval. After determining the forecast values y_t^* for each of the assumed time periods t ($t \in \overline{1,T}$), the value of the squares of the differences is estimated ($y_t - y^*_t$), and then all the values of these squares of the differences are added up and divided by the difference $n - m$	y_t – empirical value of the forecast variable, y_t^* – value of forecast, n – number of time series (numbers of element in time series), m – number of initial periods for which the ex post forecasts were realized
ψ	Average value of the relative error of expired (ex post) forecasts. The value of this error indicates the proportion of absolute error per unit of the actual value of the variable y	

Based on the literature [66, 67, 68, 69], it can be concluded that the RMSE error is more sensitive than the error ψ to unusual values of the forecast variable occurring in the series, i.e. in the case of large, though rare, forecast errors. The error value ψ is less sensitive to rare but large errors that may occur.

The measure of this error is estimated taking into account the absolute, and not, as in the case of the RMSE error, squared deviations from the true value. Optimization of the point forecast value was based on the search for the minimum value of one of the above-mentioned errors, treated as an optimization criterion.

The use of at least two prediction errors gives a greater opportunity to search for the best, optimal forecasts. Optimal parameters of the applied model were searched for in the models. If the optimal parameters of the model did not meet the expected assumptions (forecast errors were too large), the forecasting model was replaced with another one. The choice of the appropriate model was a significant problem determining the quality of the forecast in the researched area, which was the volume of steel production in Poland.

In the adopted research methodology, each of the forecasts for 2022 was additionally referred to the actual level of steel production from that period. As of the analysis date: September 30, 2022, actual data was available for three quarters, and the last quarter is the steel production volume forecast provided by the Polish Steel Association. It was finally assumed that in 2022, 8.060 million tonnes of steel (F) would be produced in Poland. The analysis was realized when the steel production figures for 2022 were not published. Now (March 2023) the Polish Steel Association published that steel production in Poland was 7.5 million tonnes, so scenarios adopted in the paper should be verified by 0.5 million tonnes down, when compared to 2022.

The following research hypothesis (RH) was adopted in the work:

RH: *After 2020, when Poland recorded a decrease in production by 12.68% due to restrictions related to COVID-19, compared to the previous year (the year preceding COVID-19), the pessimistic scenario of the steel production volume in Poland will deepen compared to the current interim production from 2000-2021 amounting to over 9 million tonnes of steel.*

FORECASTING THE VOLUME OF STEEL PRODUCTION IN POLAND

Forecasting the steel production volume started with the simplest naive method, obtaining a point forecast (ex-ante) for 2022, and ended with an advanced exponential-autoregressive model (Table 4).

Table 4
Forecasting methods used and obtained forecasts of steel production in Poland

No	Method/model		Forecasts t	Forecasts y^*_t	ψ	RMSE	Forecast error 2022*
1	Additive naive method model (for a time series around a const. value		2022	8.454	0.095	0.985	+8.92%
2A	Simple moving average model for a series formed around a constant (average) value for $k = 2$	*t*	2022	8.155	0.104	1.161	5.58%
			2023	8.305			
			2024	8.230			
			2025	8.267			
			2026	8.248			
		average	$T = 5$	8.241			
2B	Simple moving average model for a series formed around a constant (average) value for $k = 3$	*t*	2022	8.436	0.117	1.224	8.73%
			2023	8.249			
			2024	8.379			
			2025	8.355			
			2026	8.328			
		average	$T = 5$	8.349			
3A	A weighted moving average model for a series formed around a constant (average) value for $k = 3$ and weights: $w_1 = 0.20$; $w_2 = 0.15$; $w_3 = 0.65$	*t*	2022	8.473	0.090	1.048	9.12%
			2023	8.347			
			2024	8.387			
			2025	8.398			
			2026	8.386			
		average	$T = 5$	8.398			
3B	A weighted moving average model for a series formed around a constant (average) value for $k = 3$ and weights: $w_1 = 0.05$; $w_2 = 0.15$; $w_3 = 0.80$	*t*	2022	8.391	0.093	1.037	8.24%
			2023	8.374			
			2024	8.381			
			2025	8.380			
			2026	8.380			
		average	$T = 5$	8.381			
3C	A weighted moving average model for a series formed around a constant (average) value for $k = 3$ and weights: $w_1 = 0.20$; $w_2 = 0.10$, $w_3 = 0.70$	*t*	2022	8.503	0.086	1.024	9.44%
			2023	8.369			
			2024	8.399			
			2025	8.417			
			2026	8.405			
		average	$T = 5$	8.419			
4A	Single exponential smoothing Brown' model for the starting point: $G_{t(2006)} = 10.088$ million tonnes $\alpha = 0.3521$ for $\psi = 0.086$	*t*	2022	8.573	0.086	0.988	10.18%
			2023	8.615			
			2024	8.630			
			2025	8.635			
			2026	8.637			
		average	$T = 5$	8.618			
4B	Single exponential smoothing Brown' model for the starting point: $G_{t(2006)} = 10.088$ million tonnes $\alpha = 0.3822$ for RMSE = 0.986	*t*	2022	8.541	0.088	0.986	+9.85%
			2023	8.574			
			2024	8.587			
			2025	8.592			
			2026	8.593			
		average	$T = 5$	8.577			
5A	Exponential-autoregressive model for $k = 3$, $l = 2$, $\beta_1 = 0.70$, $\beta_2 = 0.20$, $\beta_3 = 0.10$, $\gamma_1 = 0.60$, $\gamma_2 = 0.40$ $\alpha = 0.3388$ for ψ	*t*	2022	8.605	0.083	0.924	+10.54%
			2023	8.735			
			2024	8.746			
			2025	8.755			
			2026	8.756			
		average	$T = 5$	8.720			
5B	Exponential-autoregressive model for $k = 3$, $l = 2$, $\beta_1 = 0.70$, $\beta_2 = 0.20$, $\beta_3 = 0.10$, $\gamma_1 = 0.60$, $\gamma_2 = 0.40$, $\alpha = 0.3564$ for RMSE	*t*	2022	8.584	0.084	0.924	+10.30%
			2023	8.713			
			2024	8.724			
			2025	8.734			
			2026	8.735			
		average	$T = 5$	8.698			
6A	Exponential-autoregressive model for $k = 2$, $l = 2$, $\beta_1 = 0.60$, $\beta_2 = 0.40$, $\gamma_1 = 0.80$, $\gamma_2 = 0.20$	*t*	2022	8.650	0.083	0.923	+10.98%
			2023	8.679			
			2024	8.698			

	α = 0.4159 for ψ		2025	8.702			
			2026	8.704			
		average	T = 5	8.687			
6B	Exponential-autoregressive model for k = 2, l = 2, β_1 = 0.60, β_2 = 0.40, γ_1 = 0.80, γ_2 = 0.20 α = 0.4852 for RMSE	t	2022	8.592	0.087	0.964	+10.38%
			2023	8.603			
			2024	8.618			
			2025	8.622			
			2026	8.624			
		average	T = 5	8.612			
7	Holt's linear model with additive trend smoothing effect for the starting point $S_1 = y_2\text{-}y_1$ α = 0.844, β = 0.0678 for ψ (forecasts for RMSE were not presented because the optimal parameters were for ψ)	t	2022	8.570	0.085	1.185	+10.15%
			2023	8.719			
			2024	8.868			
			2025	9.017			
			2026	9.166			
		average	T = 5	8.868			
8A	Holt's linear model with multiplicative trend smoothing effect for the starting point $S_1 = y_2/y_1$ with two smoothing parameters α, β; α = 0.8333, β = 0.0584 for ψ (forecasts for RMSE were not presented because the optimal parameters were for ψ	t	2022	8.607	0.097	1.207	+10.54%
			2023	8.789			
			2024	8.975			
			2025	9.165			
			2026	9.358			
		average	T = 5	8.979			
8B	Holt's linear model with multiplicative trend smoothing effect for the starting point $S_1 = y_2/y_1$ with three smoothing parameters α,β,φ, α = 0.8347, β = 0.0001, φ = 0.9951 for ψ (forecasts for RMSE were not presented)	t	2022	8.219	0.092	1.117	+6.32%
			2023	8.070			
			2024	7.923			
			2025	7.778			
			2026	7.637			
		average	T = 5	7.925			
8B	Holt's linear model with multiplicative trend smoothing effect for the starting point S_1 = 1 with three smoothing parameters α, β, φ, α = 0.2782, β = 0.0001, φ = 0.9988 for ψ (forecasts for RMSE were not presented)	t	2022	8.292	0.094	1.097	+7.14%
			2023	8.134			
			2024	7.979			
			2025	7.826			
			2026	7.677			
		average	T = 5	7.982			
9	Holt's quadratic model in additive formulation for the starting point $S_1 = y_2\text{-}y_1$ with three smoothing parameters α, β, φ, α = 0.0001, β = 0.1651, φ = 0.6115 for RMSE (forecasts for ψ were not presented because for RMSE were optimal)	t	2022	9.576	0.080	0.849	+19.59%
			2023	9.705			
			2024	9.831			
			2025	9.954			
			2026	10.076			
		average	T = 5	9.828			
10A	Brown's model double exponential smoothing for the linear, α = 0.1489 for ψ	t	2022	8.312	0.102	1.156	+7.36%
			2023	8.170			
			2024	8.028			
			2025	7.886			
			2026	7.744			
		average	T = 5	8.028			
10B	Brown's model double exponential smoothing for the linear, α = 0.3667 for RMSE	t	2022	8.287	0.103	1.156	+7.08%
			2023	8.136			
			2024	7.985			
			2025	7.834			
			2026	7.683			
		average	T = 5	7.985			
11A	Brown's model triple exponential smoothing for the quadratic, α = 0.0667 for ψ	t	2022	8.795	0.105	1.176	+12.45%
			2023	8.738			
			2024	8.680			
			2025	8.622			
			2026	8.564			
		average	T = 5	8.680			
11B	Brown's model triple exponential smoothing for the linear , α = 0.0655 for RMSE	t	2022	8.810	0.105	1.175	+12.60%
			2023	8.753			
			2024	8.696			
			2025	8.639			
			2026	8.582			
		average	T = 5	8.696			

12A’	Advanced exponential- autoregressive model for k = 3, l = 2, β_1 = 0.50, β_2 = 0.30, β_3 = 0.20, δ_1 = 0.60, δ_2 = 0.40, α = 0.3466 for ψ	t	2022	8.706	0.060	0.672	+11.56%
			2023	8.575			
			2024	8.444			
			2025	8.314			
			2026	8.183			
		average	T = 5	8.444			
12A”	Advanced exponential- autoregressive model for k = 3, l = 2, β_1 = 0.50, β_2 = 0.30, β_3 = 0.20, δ_1 = 0.60, δ_2 = 0.40, α = 0.4028 for RMSE	t	2022	8.650	0.060	0.662	+10.98%
			2023	8.502			
			2024	8.353			
			2025	8.204			
			2026	8.055			
		average	T = 5	8.353			
12B’	Advanced exponential- autoregressive model for k = 3, l = 2, β_1 = 0.60, β_2 = 0.30, β_3 = 0.10, δ_1 = 0.70, δ_2 = 0.30, α = 0.4003 for ψ	t	2022	8.633	0.060	0.662	+10.81%
			2023	8.496			
			2024	8.358			
			2025	8.221			
			2026	8.083			
		average	T = 5	8.358			
12B”	Advanced exponential- autoregressive model for k = 3, l = 2, β_1 = 0.60, β_2 = 0.30, β_3 = 0.10, δ_1 = 0.70, δ_2 = 0.30, α = 0.3979 for RMSE	t	2022	8.636	0.060	0.662	+10.84%
			2023	8.499			
			2024	8.362			
			2025	8.225			
			2026	8.088			
		average	T = 5	8.362			

** +/_ [%] to 7.7 million tonnes of steel production in 2022 (3 Q real data, 1Q estimation)*

Using the simplest method – naive (1), the point forecast (ex-ante) for 2022 was obtained, which amounted to 8.454 million tonnes. After comparing this forecast with the data for 2022 (8.06 million tonnes), the deviation was 8.92%. The next method used was the simple moving average method, which was used for k = 2 (Model 2A) and k = 3 (Model 2B). Comparing the forecast errors, a better fit of the forecasted and empirical data was obtained for the model (2A), i.e. for k = 2 than for the Model 2B, therefore the forecast trend obtained is shown in Figure 2.

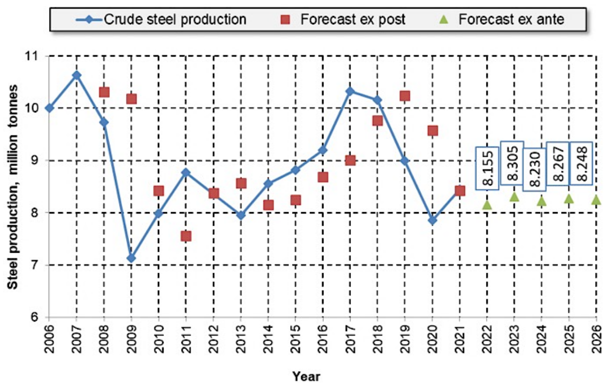

Fig. 2 Simple moving average model for a series formed around a constant (an average) value (Model 2A from Table 4): a strongly pessimistic scenario

When forecasting the volume of steel production in Poland, weights were also used in the moving average method (Model 3). When forecasting the volume of steel production, a three-fold differentiation of weights was used and three models were obtained, of which the smallest forecast errors were:ψ and RMSE were obtained in the Model 3C (Table 4), but also taking into account the adjustment of the forecast for 2022 to the actual data, the 3B Model was considered to be better. The results of improved forecasting are shown in Figure 3.

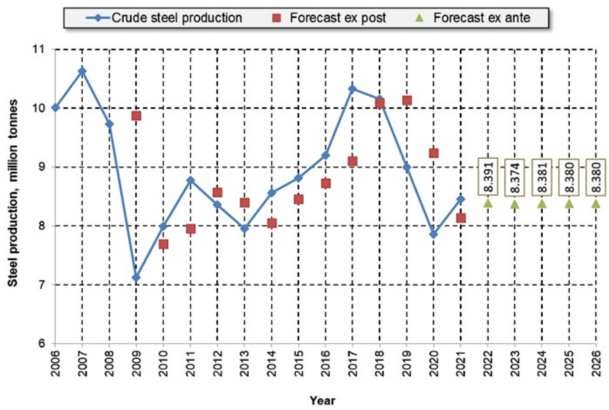

Fig. 3 Weighted moving average model for a series forming around a constant (an average) value (Model 3B): a semi-pessimistic scenario

In the presented models (Figure 2 and Figure 3), the forecasted trend of the steel production volume in Poland until 2026 will flatten, the annual forecasted steel production in Poland for model (2A) amounted to slightly 8.241 million tonnes, and in Model 3B the annual forecast amounted to slightly more than 8.361 million tonnes. In Model 2A, the forecast for 2022 compared to the actual production volume was better matched (+5.58%) than in Model 3B (8.24%).

Subsequent well-matched forecasts (ex-post) to the actual values were obtained for the exponential smoothing model using the Brown method (Models 4A and 4B). The average predictions obtained from these models (for smoothing constants α = 3.521 for the forecast error ψ and α = 0.3822 for the forecast error RMSE) are: 8.618 million tonnes (for α = 3.521 for the forecast error ψ) and

8.577 million tonnes (for α = 0.3822 for the forecast error RMSE*)*. Comparing the projected production volume with the previous models, it was found that the projected steel production volume is higher in Models 4A and 4B. The question was formulated: can the average annual steel production of approximately 8.6 million tonnes be considered an optimistic scenario for the Polish steel industry? Compared to previous models, definitely yes, but other models have yet to be checked. A good fit of the forecasts to the empirical data was also obtained for the exponential autoregressive model (Model 5A and Model 5B). Forecasts for 2022-2026 are optimistic compared to the models: 2A, 2B, 3A, 3B, 3C. The average annual volume of the forecast in the exponential-autoregressive model was 8.720 million tonnes (α = 0.3388 for ψ and 8.698 million tonnes (α = 0.3564 for RMSE) Model 5B is shown in Figure 4.

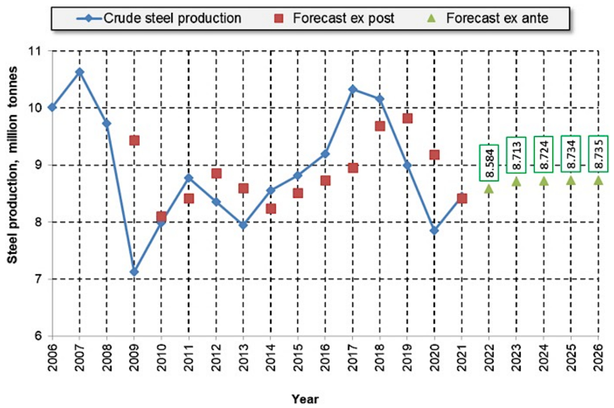

Fig. 4 Exponential-autoregressive model (Model 5B): a semi-optimistic scenario.

Optimistic forecasts were obtained for the same exponential-autoregressive model for k = 2 and weights beta 0.60 and 0.40, delta 0.80 and 0.20 (Models 6A and 6B). The average level of the forecast was 8.687 million tonnes (α = 0.3388 for ψ and 8.616 million tonnes (α = 0.3564 for RMSE). Changing the weights in this model resulted in an increase in forecast errors, hence the optimal ones were adopted. The trend of forecasts in the exponential-autoregressive model is growing, therefore the forecasts determined were considered optimistic.

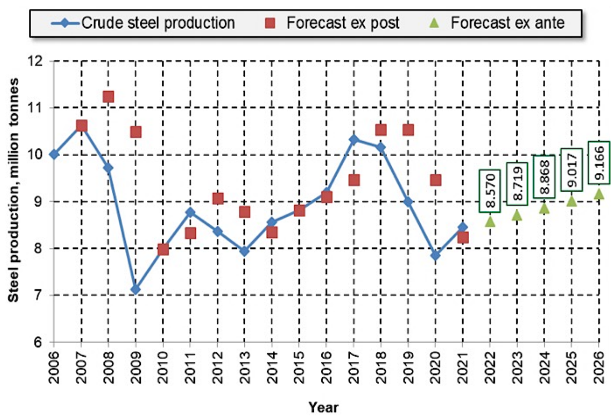

Fig. 5 Holt's linear model with additive trend (Model 7): a strongly optimistic scenario

The next models are Holt models, a linear model with an additive trend and a multiplicative trend (Model 7 and Model 8) were used. Using Holt's linear model with an additive trend ($S_1 = y_2 - y_1$) for the first time in 2025-2026, forecasts of steel production (volume) exceeding 9 million tonnes were obtained. The trend of the forecasts is increasing until 2026, and the production volumes are optimistic (Figure 5).

In the next stage, Holt's linear model with a multiplicative trend for $S_1 = 0$. The forecasting results were not presented in the study because the forecast errors were high. Another model was Holt's linear model with the effect of multiplicative trend extinction for $S_1 = y_2/y_1$. The results – forecasts – are presented in Table 4 (Model 8B). The received forecasts were classified as a strongly positive scenario, because the trend was growing, and the average annual forecast for the five-year period was 8.979 million tonnes (Figure 6.)

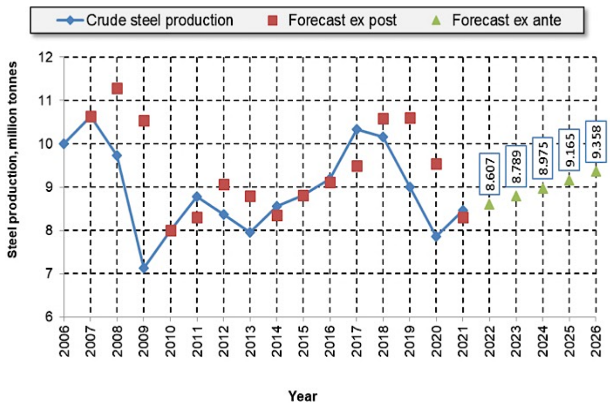

Fig. 6 Holt's linear model with multiplicative trend with two smoothing parameters (Model 8A): a strongly optimistic scenario

Using the same model, an additional parameter (smoothing constant) was introduced φ for parameters α and β. It turned out that now the trend of forecasts is strongly downward, and the obtained forecasts were considered as an undesirable scenario – very pessimistic (Model 8B in Table 4). The projected steel production will decrease (Model 8B) and in 2026 it will fall to 7.637 million tonnes (Figure 7).

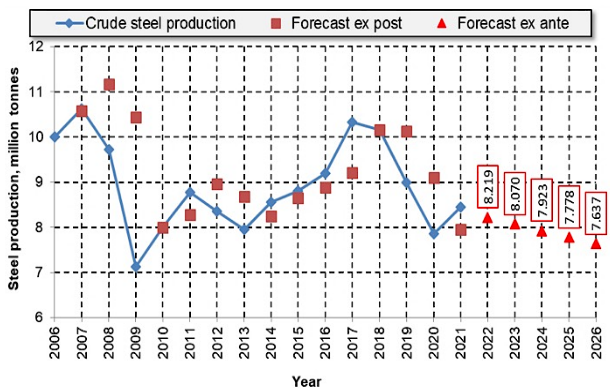

Fig. 7 Holt's linear model with multiplicative trend with three smoothing parameters (Model 8B): a strongly pessimistic scenario (downtrend)

The average annual forecast for the period 2022-2026 was 7.925 million tonnes. The publication presents the model and predictions for the smoothing constants for the error ψ (while the RMSE error was not shown as the forecasts changed slightly and the trend continued to be strongly downward). When the starting point $S_1 = 1$ was used, very low forecasts were again obtained with a downward trend until 2026, and the annual average was 7.982 million tonnes of steel produced annually in 2022-2026 (i.e. it was higher by 57 tonnes than the average forecasts obtained in Model 8B), with a fairly high RMSE error of ex-post forecasts (RMSE = 1.097).

The next segment of models are Holt square models in the additive formula for various starting points. These models gave very high forecasts for the period of 5 years. The results (forecasts) have been included in a very optimistic scenario that could have happened had it not been for the crisis caused by the effects of the COVID-19 pandemic and the war in Ukraine. If there had been no crisis, Poland would produce an average of 9.828 million tonnes per year in the coming years (until 2026). Using Holt's quadratic model in the additive formula for $S_1 = y_2 - y_1$, for the first time, the analysis performed provided a forecast of 10.076 million tonnes of steel that Polish steelworks would produce in 2026, and forecasts are also high in previous years (Model 9 in Table 4). Figure 8 shows the trend of forecasts determined using Holt's quadratic model in the additive formula for $S_1 = y_2 - y_1$.

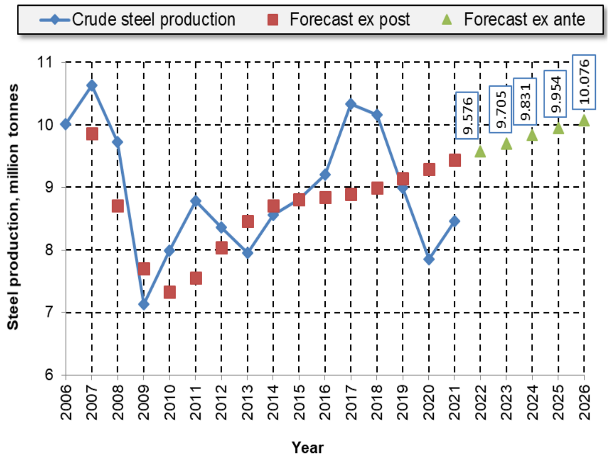

Fig. 8 Holt's quadratic model in additive formulation for $S_1 = y_2 - y_1$ (Model 9): a very strongly optimistic scenario

The presented model of ex-post forecasts had quite low forecast errors: ψ and RMSE.

The next segment of models are Brown's smoothing models: a double exponential Brown's smoothing model for a linear model (Model 10), a triple exponential Brown's smoothing model for a square model (Model 11). In Model 10 (10A and 10B – Table 4), the projected volumes of steel production in Poland until 2026 are declining (Figure 9).

Production from 8.287 million tonnes will drop to 7.683 million tonnes (Model 10B). Such a low production volume with a downward trend was classified as a strongly pessimistic scenario. Brown's triple exponential smoothing model for the quadratic model for both parameter α for the forecast error ψ as well as for the RMSE, slightly differed from the forecasts (Table 4, Models 11A and 11B). The average forecasts obtained were (Model 10A) 8.680 million tonnes of steel produced annually in Poland and (Model 11B) 8.696 million tonnes of steel produced annually in Poland until 2026.

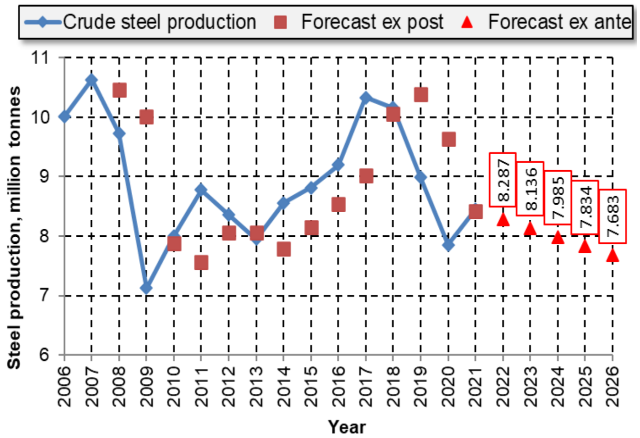

Fig. 9 Brown's double exponential smoothing model for the linear model (Model 10B): a very strongly pessimistic scenario

The last model tested was an advanced exponential autoregressive model (Model 12). In this model, the weights were selected so as to obtain the smallest forecast errors, which were among the lowest errors among all those presented in Table 4. Evaluating the received forecasts (matching the ex post forecast trend to actual data in 2006-2021) – Model 12 – an advanced model exponential autoregressive is statistically the best because forecast errors are low. The forecasting results (Model 12B') are shown in Figure 10.

The results from all the performed models are presented in Table 5, grouping the forecasts for 2022-2026 into scenarios ranging from pessimistic through baseline to optimistic.

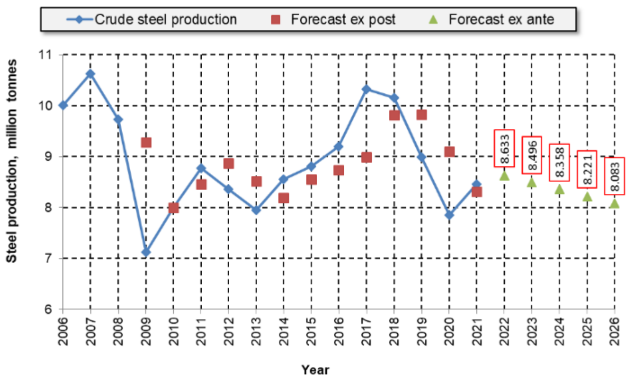

Fig. 10 Advanced exponential-autoregressive model (Model 12B'): a pessimistic scenario

Table 5

Summary forecasts of steel production in Polish steel industry

no.	t	y^*_t	y^*_t/y^*_{t-1}		no.	t	y^*_t	y^*_t/y^*_{t-1}		no.	t	y^*_t	y^*_t/y^*_{t-1}	
1	2022	8.454		↑	4A	2022	8.573		↑	8B	2022	8.219		↑
2A	2022	8.155	↓			2023	8.615		↑		2023	8.070	↓	
	2023	8.305		↑		2024	8.630		↑		2024	7.923	↓	
	2024	8.230	↓			2025	8.635		↑		2025	7.778	↓	
	2025	8.267		↑		2026	8.637		↑		2026	7.637	↓	
	2026	8.248	↓		4B	2022	8.541		↑	8C	2022	8.292	↓	
2B	2022	8.436	↓			2023	8.574		↑		2023	8.134	↓	
	2023	8.249	↓			2024	8.587		↑		2024	7.979	↓	
	2024	8.379		↑		2025	8.592		↑		2025	7.826	↓	
	2025	8.355	↓			2026	8.593		↑		2026	7.677	↓	
	2026	8.328	↓		5A	2022	8.605		↑	10A	2022	8.312	↓	
3A	2022	8.473	↓			2023	8.735		↑		2023	8.170	↓	
	2023	8.347	↓			2024	8.746		↑		2024	8.028	↓	
	2024	8.387		↑		2025	8.755		↑		2025	7.886	↓	
	2025	8.398		↑		2026	8.756		↑		2026	7.744	↓	
	2026	8.386	↓		5B	2022	8.584		↑	10B	2022	8.287	↓	
3B	2022	8.391		↑		2023	8.713		↑		2023	8.136	↓	
	2023	8.374	↓			2024	8.724		↑		2024	7.985	↓	
	2024	8.381		↑		2025	8.734		↑		2025	7.834	↓	
	2025	8.380	↓	**8.38021**		2026	8.735		↑		2026	7.683	↓	
	2026	8.380	↓	**8.37997**	6A	2022	8.650		↑	11A	2022	8.795		↑
3C	2022	8.503		↑		2023	8.679		↑		2023	8.738	↓	
	2023	8.369	↓			2024	8.698		↑		2024	8.680	↓	
	2024	8.399		↑		2025	8.702		↑		2025	8.622	↓	
	2025	8.417		↑		2026	8.704		↑		2026	8.564	↓	
	2026	8.405	↓		6B	2022	8.592		↑	11B	2022	8.810		↑
						2023	8.603		↑		2023	8.753	↓	
						2024	8.618		↑		2024	8.696	↓	
						2025	8.622		↑		2025	8.639	↓	
						2026	8.624		↑		2026	8.582	↓	
					7	2022	8.570		↑	12A'	2022	8.706		
						2023	8.719		↑		2023	8.575	↓	
						2024	8.868		↑		2024	8.444	↓	
						2025	9.017		↑		2025	8.314	↓	
						2026	9.166		↑		2026	8.183	↓	
					8A	2022	8.607		↑	12A"	2022	8.650		
						2023	8.789		↑		2023	8.502	↓	
						2024	8.975		↑		2024	8.353	↓	
						2025	9.165		↑		2025	8.204	↓	
						2026	9.358		↑		2026	8.055	↓	
					9	2022	9.576		↑	12B'	2022	8.633		
						2023	9.705		↑		2023	8.496	↓	
						2024	9.831		↑		2024	8.358	↓	
						2025	9.954		↑		2025	8.221	↓	
						2026	10.076		↑		2026	8.083	↓	
										12B"	2022	8.636		
											2023	8.499	↓	
											2024	8.362	↓	
											2025	8.225	↓	
											2026	8.088	↓	

Models with low ex post forecast errors are colored yellow.

A two-stage scenario construction method was used. The first stage consisted in taking into account the course of the forecast trend in the years 2022-2026. Decreasing trends were classified to the pessimistic scenario, and upward trends to the optimistic scenario for the forecast volume of steel production in Poland. The second stage consisted in averaging the values of annual forecasts for models with low errors (Table 6) according to the course of the trend.

Table 6

Models with low ex post forecast errors (ψ, RMSE) – ordered in according to ψ

Uptrends						Dwontrends					
No.	**Year**	**Forecast**	ψ	**RMSE**	**y*/y t=2022****	**No.**	**Year**	**Forecast**	ψ	**RMSE**	**y*/y t=2022****
9	2022	9.576	0.0803	0.8489	+19.52%	12A’	2022	8.706	0.0595	0.672	+11.56%
	2023	9.705					2023	8.575			
	2024	9.831					2024	8.444			
	2025	9.954					2025	8.314			
	2026	10.076					2026	8.183			
6A	2022	8.650	0.0832	0.923	+10.98%	12A”	2022	8.650	0.0597	0.662	+10.98%
	2023	8.679					2023	8.502			
	2024	8.698					2024	8.353			
	2025	8.702					2025	8.204			
	2026	8.704					2026	8.055			
5A	2022	8.605	0.0834	0.924	+10.52%	12B’	2022	8.633	0.0601	0.662	+10.81%
	2023	8.735					2023	8.496			
	2024	8.746					2024	8.358			
	2025	8.755					2025	8.221			
	2026	8.756					2026	8.083			
5B	2022	8.584	0.084	0.924	+10.30%	12B”	2022	8.636	0.0602	0.662	+10.84%
	2023	8.713					2023	8.499			
	2024	8.724					2024	8.362			
	2025	8.734					2025	8.225			
	2026	8.735					2026	8.088			
4A	2022	8.573	0.086	0.988	+10.18%						
	2023	8.615									
	2024	8.630									
	2025	8.635									
	2026	8.637									
6B	2022	8.592	0.087	0.964	+10.38%						
	2023	8.603									
	2024	8.618									
	2025	8.622									
	2026	8.624									
4B	2022	8.541	0.088	0.986	+9.85%						
	2023	8.574									
	2024	8.587									
	2025	8.592									
	2026	8.593									

*** t = 2022: in the work assumed that steel production in Poland in 2022 will be 8.060 million tonnes of steel (F). The analysis was realized when figures for 2022 were not published. In March 2023 the Polish Steel Association published that steel production in Poland was 7.5 million tonnes, so scenarios adopted in the paper should be verified by 0.5 million tonnes down, when compared to 2022.*

The next table (Table 7A and 7B) presents models with the smallest errors of ex-post forecasts (ψ and RMSE) forecasts of upward trends (Table 7A) and forecasts of downward trends (Table 7B).

Average forecasts from forecasts with increasing trends and forecasts with decreasing trends were calculated.

Table 7A

Forecasts of steel propduction in Poland according to uptrends

Model	2022	2023	2024	2025	2026
9	9.576	9.705	9.831	9.954	10.076
6A	8.650	8.679	8.698	8.702	8.704
5A	8.605	8.735	8.746	8.755	8.756
5B	8.584	8.713	8.724	8.734	8.735
4A	8.573	8.615	8.630	8.635	8.637
8B	8.592	8.603	8.618	8.622	8.624
4B	8.541	8.574	8.587	8.592	8.593
average	8.732	8.803	8.833	8.856	8.875

Table 7B

Forecasts of steel production in Poland according to downtrends

Model	2022	2023	2024	2025	2026
12A'	8.706	8.575	8.444	8.314	8.183
12A"	8.650	8.502	8.353	8.204	8.055
12B'	8.633	8.496	8.358	8.221	8.083
12B"	8.636	8.499	8.362	8.225	8.088
average	8.656	8.518	8.379	8.241	8.102
scenario	pessimistic				

The results from Table 7A, are shown in Figure 11, from Table 7B and Figure 12.

8,3

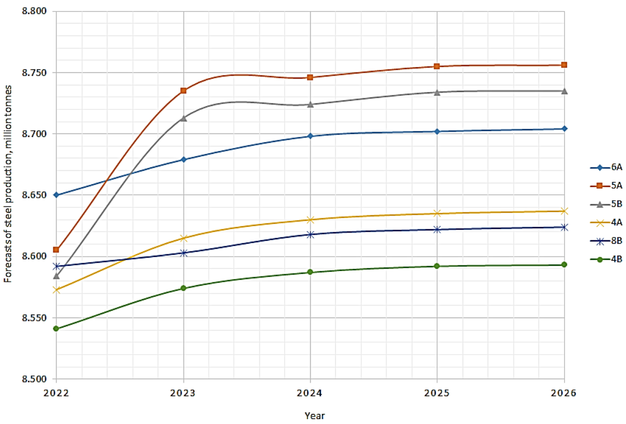

Fig. 11 Moderate optimistic scenario for steel production in Poland

Figure 11 presents moderately optimistic scenarios. Figure 11 does not include forecasts from Model 9, which were strongly optimistic due to the ongoing economic crisis resulting from the COVID-19 pandemic.

The strongly pessimistic scenario was based on forecasts obtained using the exponential autoregressive model for various weights. The resulting predictions, within this type of model, had the best fit. In this scenario, the projected volume of steel production will decrease from year to year, by an average of 100 thous. tonnes. The projected average annual steel production volume in 2023-2026 will fall from 8.518 million tonnes to 8.102 million tonnes (in the following years), the forecasted steel production for Poland will amount to: 8.518 million tonnes in 2023, 8.379 million tonnes in 2024, 2025 the forecasted production will amount to 8.241 million tonnes, and in 2026, 8.102 million tonnes of steel will be produced according to forecasts.

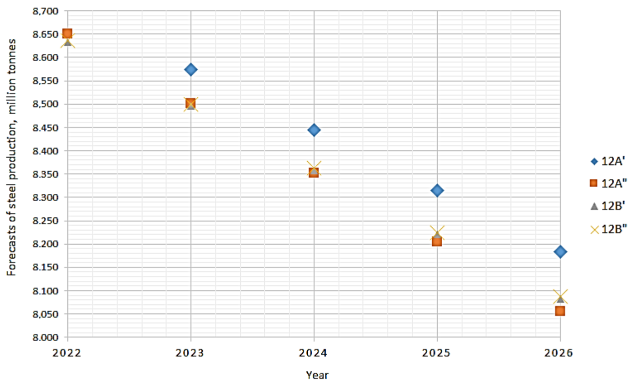

Fig. 12 Strongly pessimistic scenario for steel production in Poland

As for the averaged steel production forecast for 2022, which amounted to 8.656 (the volumes of the forecasted production obtained in the Model 12A and Model 12B were averaged), it was found that it was too high compared to the estimated actual data (2022 has already ended and the author has unconfirmed data , that the volume of steel production in Poland amounted to about 8 million tonnes). A certain limitation in recognizing the strongly pessimistic scenario as realistic for the steel industry in Poland is the fact that the forecasts discussed and presented in Figure 12 were obtained using one econometric model.

SCENARIOS FOR THE STEEL PRODUCTION IN POLAND

On the basis of various econometric models used to forecast steel production volumes for Poland, the author considered a moderately optimistic scenario as the baseline, however, not completely excluding the strongly pessimistic scenario (Figure 12). The results (forecasts) of the moderately optimistic scenario, after rejecting the forecasts obtained for model 9 (Table 7A) are presented in Table 8. Averaging the forecast values from Table 8 was considered as the baseline scenario.

Table 8

Forecasts steel production volumes for Poland in the moderately optimistic scenario

Model	2022	2023	2024	2025	2026
6A	8.650	8.679	8.698	8.702	8.704
5A	8.605	8.735	8.746	8.755	8.756
5B	8.584	8.713	8.724	8.734	8.735
4A	8.573	8.615	8.630	8.635	8.637
8B	8.592	8.603	8.618	8.622	8.624
4B	8.541	8.574	8.587	8.592	8.593
average	8.591	8.653	8.667	8.673	8.675
scenario	basic				

Forecasts from Model 9 were classified as a strongly optimistic scenario (Table 9). However, a certain limitation was adopted for this scenario, resulting, for example, from the current situation in the steel sector in Poland and the economic situation (high inflation, high energy prices, reduced production volume in integrated steelworks due to the shutdown of blast furnaces, shortages of raw materials, increasing environmental protection costs, etc.). In this scenario, the forecast for 2022 is strongly overestimated compared to the actual steel production, which was around 8 million tonnes for the whole of 2022. However, it can be assumed that the high forecast of steel production in 2022 would be realistic if not for the economic problems after the COVID-19 pandemic and the war in Ukraine. The post-covid crisis is characterized by high inflation, rising prices of raw materials, energy and fuels, shortages of raw materials, etc.

Table 9
Forecasts steel production volumes for Poland in the strongly optimistic scenario

Model	2022	2023	2024	2025	2026
9	9.576	9.705	9.831	9.954	10.076
scenario	strongly optimistic *				

** during up demand on steel.*

The results of the forecasts of the steel production volume in Poland, broken down into three key scenarios, are presented in Figure 13. The baseline scenario is a moderately optimistic scenario obtained on the basis of averaged forecasts from the models presented in Table 8, the pessimistic scenario is obtained from averaged forecasts with decreasing trends (Table 7B) , and the strongly optimistic scenario are the forecasts from Model 9 (Table 9).
Summing up the research, it was assumed that in a situation of post-pandemic economic crisis, Polish steelworks will reduce steel production, if the demand for steel increases and the war in Ukraine ends, production will increase, i.e. a moderately optimistic scenario will become realistic, in which the total annual steel production will not exceed however, 9 million tonnes of steel. However, if the demand for steel increased sharply, e.g. the reconstruction of the infrastructure after the end of the war in Ukraine, steel mills in Poland are able to produce up to 10 million tons of steel per year (despite the reduction of production capacity in Cracow – complete exclusion of the blast furnace from the process). All three forecast trends obtained according to the moderately optimistic scenario, the pessimistic scenario and the strongly optimistic scenario are presented in the last figure (Figure 13).

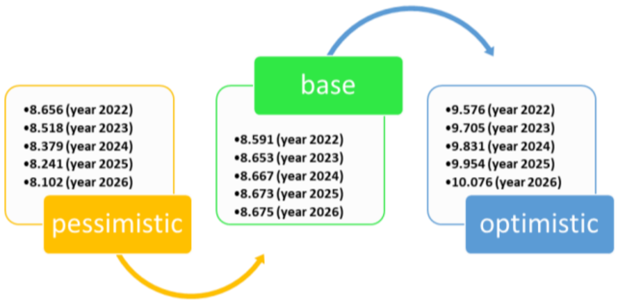

Fig. 13 Scenarios of seel production volumes for Poland [mln tonnes]

DISCUSSION

The global steel sector contributes significantly to economic development. With the development of the Industry 4.0 concept, it has been recognised as capable of transforming production processes towards smart manufacturing [71, 72, 73, 74]. The transformation of the steel industry towards smart manufacturing began with a delay, as it was only half a decade after the initiation of the Industry 4.0 concept [75, 76]. The first investments in steel mills that could be considered, in line with the idea of Industry 4.0, in scientific publications appeared in scientific databases in 2016. Among the first publications were those presenting the use of autonomous technologies for product quality control during ongoing metallurgical processes [77, 78, 79, 80]. The full automation of metallurgical processes was becoming a necessity, if only because of the high risk for employees, who had to work at very high temperatures and come into contact with other risks to their health and life [81, 82].
Along with automation, IT technologies were entering the steel mills. Digitalisation was a prerequisite for the introduction of smart solutions in steel mills [73, 83], as well as in other industries [84]. The digitalisation of the steel sector in Europe was made possible by EU programmes dedicated to the steel industry [85]. By the end of the second decade of the current century, steel mills had already initiated changes that were bringing the steel industry closer to smart steelmaking [86]. On this path to Industry 4.0, however, energy cost issues arose. When investing in Industry 4.0, steel mills had to invest in technologies to reduce energy intensity[87, 88]. Reducing energy intensity was accompanied by innovations that reduced resource intensity [89]. The development of Industry 4.0 in the steel industry required sustainability [90]. The EU prepared dedicated programmes for the steel industry to reduce CO_2 emissions [85].
Strong and solid environmental laws , in place in EU countries, have forced steel mills to invest in technologies that reduce emissions, while at the same time investing in technologies that build smart manufacturing at different levels of improvement [91, 92, 93, 94, 95, 96]. Had it not been for the business constraints caused by the COVID-19 pandemic [8, 9, 10], which disrupted supply chains, steel mills could have continued to invest in smart manufacturing unhindered but, after the COVID experience, relied on securing supply chains. Trust built up over years in the supply chain in a pandemic has not helped companies to ensure stability of supply [97]. The Industry 5.0 concept relies on technological support in supply chains [98]. Knowledge transfer in chains and networks must improve cooperation and coopetition [99], and IT systems must anticipate even the most unexpected situations through insightful analysis of various symptoms of changes in the companies' environment [98].
After the pandemic, many countries around the world had stunted economies. In 2021, the war in Ukraine caused EU countries to have high inflation. Eurostat reported that at the end of 2022, inflation in the EU (Eurozone) was 9.2% and in the EU as a whole over 11% [100]. The largest contributor to price increases was energy, which reduced production in the steel sector, which is highly energy-intensive [101, 102]. In Poland, almost 50 per cent of steel is tipped in EAF technology, and the other half in BOF technology [98]. There is also very high inflation in Poland, in December 2022 it was 16.6 per cent (year-on-year) GUS (General Statistical Office in Poland:

tradingeconomics.com). Employment has an impact on volume of the steel production (problem of generation gap) [103] and a value of human capital. The economic calculus has forced steel mills in Poland to shut down some of their technology, the capacity of which, it can be assumed, will not be put into operation soon. The war in Ukraine has been recognised as creeping, meaning that it will extend over time and is characterised by irregularity of actions, contrary to international law [104]. The timing of the war reinforces the effects of the post-pandemic crisis, which has developed into a global economic crisis. The pessimistic scenario for the Polish steel sector, which the author determined on the basis of steel production volume forecasts, is realistic in the ongoing economic crisis. Steel mills in Poland should take into account the forecasts set out by the author in planning production and refreshing their operational strategies.

CONCLUSION

The forecasts of the steel production volume for Poland are, like all forecasts, subject to error, but they may constitute illustrative knowledge about the situation on the Polish steel market. The forecasts presented by the author in Table 4 were made using different models, which increases their usefulness. Steel companies and industry organizations can use the compiled forecasts (Table 4) for production planning (setting steel production strategies), grouping prepared forecasts according to their own scenarios, which decision-makers will set on the basis of the situation in their enterprises. The author, taking into account the post-covid crisis, is in favor of a pessimistic scenario with a downward trend in production (blue line in Figure 13) or under a low-optimistic scenario (green line in Figure 13). Scenarios are projections of production volume, taking into account either unfavorable or favorable situation on the steel market. Today it is difficult to predict what will happen in 5 years, because the environment is highly dynamic and even labile. The post-COVID-19 events that slowed economic growth are called the "black swan". The SARS-CoV-2 virus pandemic has become a challenge for all countries. As a result of the disruption of the supply chain and reduced demand, there was a crisis. This crisis caused the largest drop in demand for steel since the global financial crisis in 2008. In the context of the current crisis, governments are changing their current policies and introducing saving programs, e.g. in terms of energy consumption. The results of the programs are yet to be seen. However, if the highly optimistic scenario (orange line in Figure 13) comes true, the Polish steel industry has technological potential (production capacity) that will have to be used to again produce, on average, well over 9 million tons of steel per year, and even 10 million tonnes. Such a situation with the production of over 10 million tons of steel produced annually was in the Polish steel industry in 2000, 2004, 2006, 2007, 2017, 2018 (World Steel). According to the earlier scenarios and post-restructuring analyzes prepared by the author, the Polish steel industry has the conditions and resources (production capacity) to produce an annual average production volume of over 9 million tonnes of steel, as a baseline scenario. In a crisis, steel production always declines. Forecasts made by the author during the COVID-19 pandemic indicated that in 2020, 7.891 million tonnes of steel would be produced in Poland, and the actual volume was 7.856 million tonnes, so the author's forecasts were quite accurate. The author hopes that the forecasts presented in this publication will also be realistic scenarios. Of course, forecasting is subject to error. but it is worth considering several scenarios for the Polish steel industry.

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REFERENCES

[1] Industry 5.0. Towards a sustainable, human-centric and resilient. Brief Policy of European Commission. European Commission, Brussel, January 2021.

[2] N.N. Belanova, A.M. Kuznetsova, "State support mechanisms for business in the context of coronavirus pandemia", *Lecture Notes in Networks and Systems*, Vol. 139, pp. 288-295, 2021.

[3] N. Akbulaev, I. Mammadov, V. Aliyev, "Economic impact of COVID-19", Sylwan, 164(5), pp. 17-25, 2020.

[4] Dictionary of PWN (Polish Scientific Publishing House), Warsaw, keyword: Forecast (in Polish: Prognoza)

[5] Dictionary of modern Polish language (in Polish: Słownik współczesnego języka polskiego). Publisher: WILGA, Warsaw, Poland, 1996.

[6] Z. Pawłowski, *Econometrics* (in Polish: Ekonometria), Publisher: PWN, Warsaw 1966. p. 121.

[7] B. Gajdzik, R. Gawlik, S. Skoczypiec, "Forecasting-Scenario-Heuristic method proposal for assessment of feasibility of steel production scenarios in Poland – Managerial implications for production engineering", *Archives of Civil and Mechanical Engineering*, Vol. 18 No. 4, pp. 1651-1660, 2018.

[8] B. Gajdzik, "Polish crude steel production in pandemic year of 2020 compared to previous five years", *Metalurgija*, Vol. 61, No. 1, pp.137-140, 2022.

[9] B. Gajdzik, R. Wolniak, "*Sensitivity of the steel sector to economic crises. Impact of the Covid-19 crisis on steel production in Poland*", [in:] Cyber-physical systems solutions to pandemic challenges. Eds. Tushar Semwal and Faiz Iqbal. Wydawca: Boca Raton: CRC Press-Taylor & Francis Group, pp. 27-41, 2022, p-ISBN: 978-1-032-03037-1e-ISBN: 978-1-003-18638-0.

[10] B. Gajdzik, R. Wolniak, "Influence of the COVID-19 crisis on steel production in Poland compared to the financial crisis of 2009 and to boom periods in the market", *Resources*, Vol. 10 , No. 1, pp.1-17 (art. no. 4), 2021, doi: 10.3390/resources10010004.

[11] G. Gierszewska, M. Romanowska, *Strategic analysis of the enterprise* (in Polish: Analiza strategiczna przedsiębiorstwa), Polish Economic Publishing House (Polskie Wydawnictwo Ekonomiczne), Warsaw, pp. 49-53, 2004.

[12] E. Urbanowska-Sojkin, P. Banaszyk, H. Witczak, *Strategic management in the enterprise* (in Polish: Zarządzanie strategiczne przedsiębiorstwem), PWE Polish Economic Publishing House: Warsaw, p. 41, 2007.

[13] S. Taneja, M.G.Pryor, S. Sewell, A.M. Recuero, “Strategic crisis management: A basis for Reneval and crisis Prevention”, *Journal of Management Policy and Practices*, Vol. 15(1), pp.78-85, 2014.

[14] Dictionary of Polish language (in Polish: Słownik języka polskiego, PWN -Polish Scientific Publishing House: Warsaw, online: https://sjp.pwn.pl/sjp/kryzys;2565070.html.

[15] W. Kopaliński, Słownik wyrazów obcych i zwrotów obcojęzycznych, Publishing House RYTM, Poland, 2007.

[16] M. Adamczyk M. *Współczesny kryzys finansowy – przyczyny i konsekwencje dla gospodarki światowej*. Publisher: Uniwersytet Gdański, Gdańsk, Poland, pp. 3-6, 2012.

[17] K.J. Engemann, *The Routledge Companion to Risk. Crisis and Security*, Routledge, New York, 2018.

[18] A. Khorram-Manesh, *Handbook of Disaster and Emergency Management*. Institute of Clinical Sciences. Gothenburg, 2017.

[19] N. Roubini, S. Mihm, *Economics of the crisis* (in Polish: Ekonomia kryzysu). Publishing House Wolters Kluwer Poland, Warsaw, 2011.

[20] P. Komorowski, Przebieg kryzysu gospodarczego w wymiarze cyklu życia. Publisher OW SGH, Warsaw, Poland, p. 281, 2013.

[21] World Bank, Global economic prospects., online https://www.worldbank.org/en/publication/global-economic-prospects (30.04.2021).

[22] Crisis management, Cambridge Business English Dictionary , Cambridge University Press, [online] https://dictionary.cambridge.org/pl/dictionary/english/crisis-management [2020-10-01].

[23] W. Lidwa, *Management in crisis situation* (in Polish: Zarządzanie w sytuacjach kryzysowych), Publisher Akademia Obrony Narodowej, Warsaw, Poland, p. 37, 2010.

[24] H. Hamidovic, An introduction to crisis management. *ISACA Journal*, 5, pp. 1-4, 2012.

[25] Y. Kitamura, S. Karkour, Y.Ichisugi, N. Itsubo, “Evaluation of the Economic. Environmental and Social Impacts of the COVID-19 Pandemic on the Japanese Tourism Industry”, *Sustainability* MDPI, 12, 10302, 2020.

[26] N.N. Belanova, A.M. Kuznetsova, “State support mechanisms for business in the context of coronavirus pandemic”, Lecture Notes in Networks and Systems, 139, pp.288-295, 2021.

[27] B. Gajdzik, “Steel production in Poland with pessimistic forecasts in COVID-19 crisis”, *Metalurgija*, Vol. 60, No. 1-2, pp. 169-172, 2021, UDC – UDK 669.18:62.001.6:338.45:02:438=111

[28] B. Gajdzik, “Steel production, consumption and foreign trade in Poland in crises: the financial crisis 2008-2009 and the COVID-19 crisis – first half of 2020”, *Metalurgija*, Vol 60, No. 1-2, pp.173-176, 2021.

[29] C. Sapriel, “Effective Crisis Management: Tools and Best Practice for the New Millennium”, *Journal of Communication Management*, Vol. 7, No. 4, pp. 348-355, 2010.

[30] K.S. Zamoum, Crisis management: A historical and conceptual approach for a better understanding of today's crises. In Crisis Management Theory & Practice. Edited by Kattarina Holla, Michal Titko and Jozef Ristvej. London: IntechOpen Limited, pp. 203-217, 2018.

[31] H. Hamidovic, “An introduction to crisis management”, *ISACA Journal*., 5. 1-4, 2012.

[32] C. Lionis, E. Petelos, “Challenges, priorities and tasks for the generalists at the time of COVID-19 pandemic”, *European Journal of General Practice*, Vol. 26, No. 1, pp. 104-105, 2020.

[33] M. Javaid, A. Haleem, R.P. Singh, MIU Haq, A. Raina, R. Suman, “ Industry 5.0: Potential Applications in COVID-19”, *Journal of Industrial Integration and Management-Innovation and Entrepreneurship*, Vol. 5 (4), pp. 507-530, 2020, doi: 10.1142/S2424862220500220.

[34] B. Gajdzik, Towards Industry 4.0 versus the COVID-19 crisis - the use of selected technologies (ICT) in business [in:] Cyber-physical systems solutions to pandemic challenges. Eds. Tushar Semwal and Faiz Iqbal. Publisher: Boca Raton: CRC Press-Taylor & Francis Group, 2022, pp. 53-70.

[35] VUCA from: Warrner Bennis, Leadership theories, 1987 (Sawan, R., Leadership in the VUCA World, https://www.linkedin.com/pulse/leadership-vuca-world-robin-sawan, (8.Aug. 2020)

[36] J. Dyktus, *Pandemia – katalizator wielkich zmian gospodarczych i społecznych*, [in:] Ekonomiczne skutki pandemii (eds) J. Błach. B. Barszczowska. Akademia WSB, Dabrowa Górnicza, 2021, pp.27-52.

[37] K. Schwab, The Fourth Industrial Revolution. World Economic Forum. January 11th, 2016.

[38] C. Senn, The nine pillars of Industry 4.0, [online:] https://www.idashboards.com/ blog/ 2019/07/31/the-pillars-of-industry-4-0/ (2019-02-07).

[39] M. Hermann, T. Pentek, B. Otto, “Design Principles for Industrie 4.0 Scenarios. A literature review”, Working Paper No. 01. Technische Universität Dortmund Fakultät Maschinenbau, 2015 [online:]http://www.iim.mb.tu-dortmund.de/cms/de/forschung/Arbeitsberichte/Design Principles-for-Industrie-4_0-Scenarios.pdf.

[40] H. Kagermann, W. Wahlster and J. Helbig. eds. Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0, Working Group 2013; Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution. VDI-Nachrichten. April 2011.

[41] S. Obeidat, How Artificial Intelligence Is Helping Fight The COVID-19 Pandemic. https://www.entrepreneur.com/article/348368 (05.12.2020).

[42] W. Naudé, Artificial Intelligence against COVID-19: An Early Review. https://towardsdatascience. com/artificial-intelligence-against-covid-19-an-early-review-92a83 60edaba?gi=3a7f01bf4326. (05.12.2020).

[43] H. Fadinger, J. Schymik J., The costs and benefits of home office during the COVID-19pandemic: Evidence from infections and an input-outputmodel for Germany. [in:] Covid Economics Vetted and Real-Time Papers”. Ch. Wyplosz, Graduate Institute Geneva and The Centre for Economic Policy Research (CEPR), 2020.

[44] L.T.D. Siqueira, dos Santos A.P., R.L.F. Silva, P.A.M. Moreira, da Silva Vitor J., Ribeiro V.V. Vocal “Self-Perception of Home Office Workers During the COVID-19 Pandemic”, *Journal of Voice* 2020.

[45] H.M. Von Gaudecker, R. Holler, L. Janys, B. Siflinger, Ch. Zimpelmann, Labour apply in the Early Stages of the COVID-19 Pandemic: Empirical Evidence on Hours. Home Office. and Expectations. “Institute of Labor Economics”. IZA DP 13158/2020.

[46] M. Winarsih Indriastuti, K. Fuad, “Impact of covid-19 on digital transformation and sustainability in small and medium enterprises (SMEs): a conceptual framework”, *Advances in Intelligent Systems and Computing*,1194 AISC, pp. 471-476, 2021.

[47] Energy Revolution: A Global Outlook. Drax 2018.

[48] Green Deal: https://www.goldmansachs.com/insights/pages/paving-the-way-for-the-european-green-deal.html. (10.2020).

[49] S. Grabowska, S. Saniuk, B. Gajdzik, "Industry 5.0: improving humanization and sustainability of Industry 4.0", *Scientometrics* 2022, https://doi.org/10.1007/s11192-022-04370-1
[50] World Steel in Figures 2022, Report of World Steel Association (2022).
[51] WHO Infection prevention and control during health care when novel coronavirus disease (COVID-19) is suspected or confirmed external icon. WHO. Retrieved from: https://www.who.int/publications/i/item/WHO-2019-nCoV-IPC-2020.4, access data: 29th June 2020.
[52] Polish steel industry. Report 2022. Publisher: Polish Steel Association. Katowice. Poland.
[53] Eurofer European Steel in Figures 2020, p. 15 [www.eurofer.eu].
[54] Sytuacja w przemyśle stalowym i w gospodarce narodowej popyt, podaż, prognozy. March 2020. Polish Steel Association, Katowice, Poland.
[55] J. Steinhoff, *Transformacja polskiej energetyki jako konsekwencja European Green Deal* [in:] Ekonomiczne skutki pandemii (eds) J. Błach, B. Barszczowska. Akademia WSB. Dabrowa Górnicza, pp. 251-270, 2021.
[56] S. Dzienniak, M. Zagórska M., *Droga energia przyczyną niskiej konkurencyjności polskiej gospodarki na przykładzie przemysłu stalowego* [in:] Ekonomiczne skutki pandemii (eds) J. Błach. B. Barszczowska. Akademia WSB. Dabrowa Górnicza, pp. 271-284, 2021.
[57] GUS, Statistics Poland, Economy Report (Raport Gospodarczy), Warsaw, Poland 2020.
[58] B. Gajdzik, *Kryzys COVID-19 vs. kryzys finansowy z 2008-2009 w sektorze stalowym w Polsce*. [in:] Ekonomiczne skutki pandemii (eds) J. Błach. B. Barszczowska. Akademia WSB. Dabrowa Górnicza. 2021. pp. 285-300.
[59] Polish steel industry. Report 2019. Publisher: Polish Steel Association. Katowice. Poland.
[60] Polish steel industry. Report 2009. Publisher: Polish Steel Association. Katowice. Poland.
[61] Polish steel industry. Report 2020. Publisher: Polish Steel Association. Katowice. Poland.
[62] Report of European Commission about restructuring of Polish steel industry, 2007.
[63] R. Czyżycki, R. Klóska, *Econometrics and forecasting of economic phenomenon in examples and tasks* (Title in Polish: Ekonometria i prognozowanie zjawisk ekonomicznych w przykładach i zadaniach), Publisher: Economicus, Szczecin, 2011.
[64] A. Welfe, *Econometrics. Methods and Usingin Polish*: Ekonometria. Metody i ich zastosowanie), Polish Economic Publishing House, Warsaw, Poland, 2009.
[65] J. Nazarko (ed.), *Forecasting in enterprise management* (Title in Polish: Prognozowanie w zarządzaniu przedsiębiorstwem. cz. III. Prognozowanie na podstawie modeli adaptacyjnych), Publisher Technical University in Bialystok (Politechnika Białostocka), Białystok, Poland, 2005.
[66] R.G. Brown, Smoothing. Forecasting and Prediction of Diserte Time Series. Prentice Hali. Englewood Cliffs. New York, 1963.
[67] D. Błaszczuk, *Introduction to forecasting and simulation* (Wstęp do prognozowania i symulacji. Polish Scientific Pushing House (PWN), Warsaw, Poland, 2006.
[68] F.S. Hillier, G.J. Lieberman, Introduction to Operations Research. 8th Edition. McGraw-Hill. International Edition, 2005.
[69] G. Kiłdiszew, A. Frenkel, *Analysis of time series and forecasting* (in Polish: Analiza szeregów czasowych i prognozowanie), Polish Economic Publishing House (PWE), Warsaw, Poland, 1976.
[70] B. Gajdzik, R. Gawlik, "Choosing the production function model for an optimal measurement of the restructuring efficiency of the Polish metallurgical sector in years 2000-2015", *Metals*, 8, 23; ISSN 2075-4701, p. 2-11, 2018.
[71] H. Peters, Application of Industry 4.0 concepts at steel production from an applied research perspective. Presentation at 17th IFAC Symposium on Control, Optimization, and Automation in Mining, Mineral and Metal Processing, 2016 [online:] https://tc.ifac-control.org/6/2/files/symposia/vienna-2016/mmm2016_keynotes_peters.PowerPoint-Präsentation (ifac-control.org).
[72] H. Peters, How could Industry 4.0 transform the Steel Industry? Presentation at Future Steel Forum, Warsaw, 14.-15.6.2017, [online:] PowerPoint-Präsentation (futuresteelforum.com)https://futuresteelforum.com/content-images/speakers/Prof.-Dr-Harald-Peters-Industry-4.0-transform-the-steel-industry.pdf.
[73] B. Gajdzik, R. Wolniak, "Digitalisation and Innovation in the Steel Industry in Poland—Selected Tools of ICT in an Analysis of Statistical Data and a Case Study", *Energies*, 14, 3034, pp. 1-25, 2021, doi: 10.3390/en14113034https://doi.org/10.3390/en14113034.
[74] B. Gajdzik, R. Wolniak, "Transitioning of Steel Producers to the Steelworks 4.0 – Literature Review with Case Studies", *Energies*, 14, 4109; 2021, https://doi.org/10.3390/en14144109.
[75] B. Gajdzik, "How Steel Mills Transform into Smart Mills: Digital Changes and Development Determinants in the Polish Steel Industry", *European Research Studies Journal* Volume XXV, Issue 1, pp. 27-42, doi: 10.35808/ersj/2827.
[76] B. Gajdzik, *Diagnosis of the steel industry transformation directions in Industry 4.0*. (Title in Polish: Diagnoza kierunków transformacji przemysłu stalowego w przemyśle 4.0). Monograph. Publisher: Silesian University of Technology, Gliwice, Poland, 2022, ISBN 978-83-7880-850-3 (www.wydawnictwo.politechniki.pl).
[77] Chao-Yung Hsu; Jhih-Wei Huang; Li-Wei Kang; Ming-Fang Weng,Fast image stitching for continuous casting steel billet images, *IEEE International Conference on Consumer Electronics-Asia* (ICCE-Asia), 2016, 26-28 October 2016, Seoul, Korea (South), Asia, doi: 10.1109/ICCE-Asia.2016.7804815.
[78] Chao-Yung Hsu; Bing-Shiou Ho; Li-Wei Kang; Ming-Fang Weng; Chih-Yang Lin. Fast Vision-based Surface Inspection of Defects for Steel Billets, *IEEE International Conference on Consumer Electronics-Asia* (ICCE-Asia), 2016, pp. 26-28 October 2016, Seoul, Korea (South), Asia, doi: 10.1109/ICCE-Asia.2016.7804804.
[79] J. Brandenburger, V. Collar, G. Nastasi, F. Ferro, Ch. Schrim, J. Melcher, Big Data Solution for Quality Monitoring and Improvement on Flat Steel Production, 17th IFAC Symposium on Control, Optimization and Automation in Mining, Mineral and Metal Processing (MMM)/2016/ Papersonline 49 (20), pp. 55-60, doi: 10.1016/j.ifacol.2016.10.096, (Download English Version: https://daneshyari.com/en/article/5002982).
[80] B. Gajdzik, J. Sitko, "An analysis of the causes of complaints about steel sheets in metallurgical products quality management systems", *Metalurgija*, Vol. 53, No. 1, pp.135 138, 2014.

[81] T. Małysa, B. Gajdzik,” Predictive Models of Accidents at Work in the Steel Sector as a Framework for Sustainable Safety”, *Energies*, 14 (1), (art. no 129), 1-20, 2021, doi: 10.3390/en14010129.
[82] T. Małysa, B. Gajdzik, “Research on Differentiation of Accidents at Work Considering Demographic Features of Workers in Steel Sector in Poland”, *Inzinerine Ekonomika-Engineering Economics*, 32 (2), pp. 165-176, 2021.
[83] R. Miskiewicz, R. Wolniak, “Practical Application of the Industry 4.0 Concept in a Steel Company”, *Sustainability* (MDPI), 12 (14), 2021.
[84] H. Kagermann, Change Through Digitalization – Value Creation in the Age of Industry 4.0, [in:]: H. Albach et al. (eds.), Management of Permanent Change, Springer Fachmedien Wiesbaden, pp. 23-45, 2015.
[85] T.A. Branca, B. Fornai, M.M.Murri, E. Streppa,A.J. Schröder, “The Challenge of Digitalization in the Steel Sector”, *Metals*, 10(2), 288; 2020, doi:10.3390/met10020288, [online:] https://www.mdpi.com/2075-4701/10/2/288/htm.
[86] B. Gajdzik, “Frameworks of the Maturity Model for Industry 4.0 with Assessment of Maturity Levels on the Example of the Segment of Steel Enterprises in Poland”, J. Open Innov. Technol. Mark. Complex., 8, 77, 2022, https://doi.org/10.3390/joitmc8020077.
[87] B. Gajdzik, W. Sroka, “Resource Intensity vs. Investment in Production Installations—The Case of the Steel Industry in Poland”, *Energies*, 14(2):443, 2021, https://doi.org/10.3390/en14020443.
[88] G. del Campo, S. Calatrava, G. Canada, J. Olloqui, R. Martinez, A. Santamaria, “IoT Solution for Energy Optimization in Industry 4.0”, Issues of a Real-life Implementation, Global Internet of Things Summit (GIoTS)/ 2018/ pp. 423-428.
[89] B. Gajdzik, W. Sroka, J. Vveinhardt, “Energy Intensity of Steel Manufactured Utilising EAF Technology as a Function of Investments Made: The Case of the Steel Industry in Poland”, *Energies*, 14, (art. no. 5152), 2021, doi: 10.3390/en14165152.
[90] Action Plan for a Competitive and Sustainable Steel Industry in Europe, European Commission, COM(2013) 407 final, European Commission, Brussels, (2013-06-11).
[91] F.J. Valente and A.C. Neto, Intelligent Steel Inventory Tracking with IoT / RFID, IEEE International Conference on RFID Technology and Application (RFID-TA)/2017/pp. 158-163.
[92] D.P. Penumuru, S. Muthuswamy and Karumbu, P. “Identification and classification of materials using machine vision and machine learning in the context of Industry 4.0”, *Journal of Intelligent Manufacturing*, 31 (5), pp. 1229-1241, 2020.
[93] L.S. Carlsson, P.B. Samuelsson, P.G. Jonsson, “Predicting the Electrical Energy Consumption of Electric Arc Furnaces Using Statistical Modeling”, *Metals*, 9 (9), 2019.
[94] Cheol Young Park; Kim, Jing Woom; Bosung Kim; Lee, Joongyoon, Prediction for Manufacturing Factors in a Steel Plate Rolling Smart Factory Using Data Clustering-Based Machine Learning, 2020 | IEEE ACCESS 8, pp.60890-60905, doi: 10.1109/ACCESS.2020.2983188 (https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9046761).
[95] S. Kesriklioglu, F.E. Pfefferkorn, Real time temperature measurement with embedded thin-film thermocouples in milling, 8th CIRP Conference on High Performance Cutting/2018/77 , pp.618-621
[96] L. Fumagalli, M. Macchi (...), A. Alfieri, A Smart Maintenance tool for a safe Electric Arc Furnace, 12th IFAC Workshop on Intelligent Manufacturing Systems (IMS) 2016 | IFAC Papersonline 49 (31) , pp. 19-24.
[97] B. Gajdzik, K. Grzybowska, “Example models of building trust in supply chains of metallurgical enterprises”, *Metalurgija*, Vol. 54, No. 4, pp.563-566, 2012.
[98] F. Frederico Guilherme, “From Supply Chain 4.0 to Supply Chain 5.0: Findings from a Systematic Literature Review and Research Directions”, *Logistics*, 5, 49, 2021, https://doi.org/ 10.3390/logistics5030049.
[99] W. Sroka, J. Cygler, B. Gajdzik, “The Transfer of Knowledge in Intra-Organizational Networks: A Case Study Analysis”, *Organizacija*, Vol. 47, No. 10, pp.23-34, 2014.
[100] Eurostat inflation 2022 Euro area inflation rate its main componnets. Eurostat (prc_hicp_inw)
[101] B. Gajdzik, R. Wolniak, W. Grebski, “An Econometric Model of the Operation of the Steel Industry in Poland in the Context of Process Heat and Energy Consumption”, *Energies*, 15, 7909, 2022, https://doi.org/10.3390/en15217909.
[102] B. Gajdzik, R. Wolniak, W. Grebski, “Electricity and Heat Demand in Steel Industry Technological Processes in Industry 4.0 Conditions”, *Energies*, 16, 787, 2023, https://doi.org/10.3390/en16020787, doi: 10.3390/en16020787.
[103] B. Gajdzik, J. Szymszal, “Generation gap management in restructured metallurgical enterprises in Poland”, *International Journal of Management and Economics*, no. 47, July-September pp. 107-120, 2015, online: http://www.sgh.waw.pl/ijme/.
[104] M. Kwiecińska, „Nowy wymiar konfliktów zbrojnych: konflikt hybrydowy a konflikt pełzający”, Doctrina *Studia Społeczno-Polityczne*, Tom 13, nr 13., 87-97, 2019, https://czasopisma.uph.edu.pl/doctrina/article/view/1291

Bożena Gajdzik
ORCID ID: 0000-0002-0408-1691
Silesian University of Technology, Poland
e-mail: bozena.gajdzik@polsl.pl