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EXTRACTION AND PRODUCTION OF NATURAL AGGREGATES IN POLAND AND THE EUROPEAN UNION – ANALYSIS OF CHANGES AND FORECASTS

Urbanisation, economic development and the growth of the world's population contribute to a continuous increase in demand for mineral aggregates. In many countries and regions (Arab countries, some Asian countries) there is a significant deficit of aggregates, contributing to unsustainable exploitation with a negative environmental impact. To regulate this unfavourable situation related to the management of aggregate resources, one of the main conclusions of the UNEP 2019 Report is the need for a universal introduction of planning and monitoring of the process of obtaining natural aggregates. The paper presents changes in the extraction and production of aggregates between 2005-2022 for Poland and the European Union (2008-2022). These changes confirm the dependence of aggregate production on cement consumption in both Poland and the EU. Econometric models estimated for these relationships were then used to forecast aggregate production. The relatively small errors shown in the ex-post forecasts (2020-2023) confirm the possibility of using the estimated dependencies for ex-ante forecasts (2024-2027), which is illustrated, for example, by the production of mineral aggregates in Poland and the EU.

Keywords: Aggregates production in Poland and the EU; econometric dependencies aggregates production on cement; forecasts of aggregates production

1. Introduction

The growth of the world's population, urbanisation and economic development contribute to a continuous increase in demand for mineral aggregates. Although sand, gravel, and crushed aggregate deposits are widespread and relatively shallow in many countries and regions (Arab countries, some Asian countries, e.g. Singapore [13]), there is a significant deficit of aggregates, which leads to unsustainable exploitation with a negative environmental impact. It is estimated that in countries with a shortage of aggregate resources, international trade in aggregates is growing

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at a rate of approx. 5.5% per year, with a large portion of these aggregates unfortunately coming from illegal mining. The magnitude of the phenomenon means that this problem has been noticed, among others, by the UN, and in 2019, a report by one of the agencies (UNEP) was published on the search for new solutions in the field of sustainable environmental management of global natural aggregates resources [3,11,13,20]. The key message of this document is that the challenges related to aggregate extraction and production (mainly sand and gravel) are among the key sustainability issues of the 21st century. The belief that aggregate resources are widely available is generally incorrect. To effectively regulate and improve the situation, it is recommended that planning and monitoring of the process for obtaining natural aggregates be widely implemented. In European countries, especially in the EU, the situation is generally much more favourable compared to many countries in Asia, Africa and South America. In European countries, information on the extraction and production of aggregates is often estimated and inaccurate [4,10,12].

2. Production of mineral aggregates in Poland and the European Union

In terms of total aggregate production (gravels, sands, marine aggregates, recycled) in the EU, Poland ranks 3rd with production in 2022 according to [12] 268 million Mg. The structure of aggregate extraction and production in Poland is as follows:

- sand and gravel – 63,5%,
- crushed aggregates (crushed rock) – 32,7%,
- recycled, marine, etc. – 3,8%.

In the European Union (EU27+UK) [12], crushed aggregates produced from solid rocks predominate in the structure of production and consumption and account for approximately 47% of the total aggregate production. The share of sand and gravel aggregates is 37.7%, and the share of other aggregates, including marine and recycled aggregates, is 15,3%. In some countries in the EU, the share of recycled aggregates is high, e.g. in Belgium – 31,7% (22,1 million Mg), in the Netherlands – 26% (26,4 million Mg), France – 18,2% (64,7 million Mg), in Germany – 14% (77.0 million Mg). In 2023, the total aggregate production in the EU amounted to 2788 million Mg and has remained at the level of 2800-2900 million Mg/y since 2017. The largest aggregate producers in the EU are Germany (545,7 million Mg) and France (354,6 million Mg [12]. The total production of aggregates in Europe (42 countries) is approx. 4350 million Mg and the largest producers from outside the EU are Russia (857 million Mg), Turkey (320 million Mg) and the United Kingdom (267 million Mg). Taking into account the average per capita consumption of aggregates – approximately 5.5 Mg – this indicates that a typical Earth resident consumes about 450 Mg of aggregates over their lifetime [12]. Aggregates are, therefore, the product used (after water) in the largest quantities. In Poland, over 30 years, aggregate extraction has increased more than 3 times, according to PIG-PIB [10], from approx. 85 million Mg in 1993 to 247 million Mg in 2023 r. (TABLE 1). The most significant increase was recorded in the first decade of the 21st century, especially after Poland acceded to the EU, and then in 2011, the extraction reached an unprecedented volume of over 333 million Mg. In the following years (2012-2014), however, there was a decrease in extraction to slightly more than 210 million Mg, and since 2017 it has been in the range of 250 to 280 million Mg. Over 30 years, the share of crushed aggregates in the total extraction of aggregates increased from approx. 17% to 32,7%.

TABLE 1

Aggregate extraction in Poland in the years 1993-2023

Aggregates	Years							
	1993		2003		2013		2023	
	mln Mg	%	mln Mg	%	mln Mg	%	mln Mg	%
Crushed stone	14,3	16,9	25,7	25,3	58,4	25,2	79,6	32,3
Sand&gravel	70,5	83,1	78,6	74,7	173,3	74,8	167,1	67,7
Together (NA)	84,8	100	101,3	100,0	231,7	100	246,7	100,0

3. Dependence of mineral aggregate production on cement consumption in Poland and the EU

The absence of comprehensive records regarding aggregate resources and volumes – particularly for sand and gravel – along with the presence of numerous informal mining sites lacking appropriate permits and fluctuations in demand, complicate the development of national and global balances for aggregate production and consumption. In many countries, available data is approximate (estimated). For these reasons, indirect econometric methods are sought to determine forecasts of aggregate production and consumption in individual countries and regions of the world. The use of various forecasting methods to predict the volume of mineral aggregate production, including neural networks, is presented, among others, in the papers [1,2,5-7,9]. Examples of such studies are the analysed trends in production and econometric models of the dependence of aggregate production on GDP development indicators or other indicators of economic development. Fig. 1 presents the statistical dependence of the increase in the production of natural aggregates on the dynamics of GDP changes in Poland between 1991-2022. The model shows that on a national scale, the barrier to the growth of demand and production of mineral aggregates was at least a 2.8% increase in GDP. With lower growth dynamics, expenditure on infrastructure

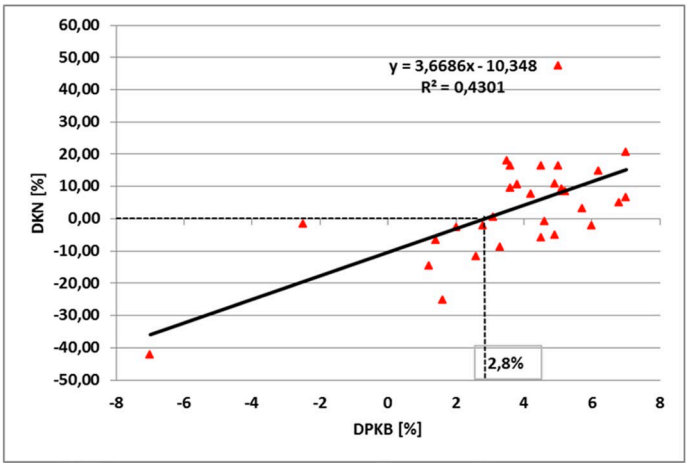
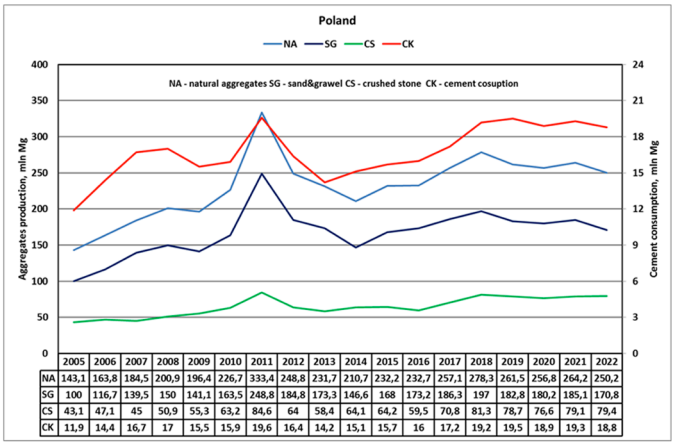


Fig. 1. Dependence of changes in the production of natural aggregates on GDP in Poland in the years 1991-2022

investments is generally reduced in the first place, which is why the demand for aggregates is lower. Econometric studies on the dependence of aggregate production on various indicators of economic development have confirmed that GDP is a relatively good indicator, but the developed models of dependence for both Polish and other countries are not accurate, hence the search for more precise relationships is still ongoing [1,2,5,8,19]. One of the indicators on which the extraction and consumption of construction aggregates depends is the consumption of cement, the production of which is generally quite accurately identified in the statistics of individual countries. It is estimated that about 2/3 of aggregate production is used for the production of concrete and various prefabricated products [1], i.e. at least 2/3 of aggregate production is used together with cement.

In the years 2018-2023, cement production in the European Union remains at the level of 170-180 million Mg [14-17]. The main recipients are residential construction (45.5% market share), infrastructure construction (roads) and non-residential construction (industrial, service). Non-residential construction is expected to be the fastest-growing segment of the cement market in the future. In the past, the EU was a large exporter of cement (in 2014 – about 28 million Mg). Now, this export has decreased significantly to about 10 million Mg/y, and at the same time, imports have increased to a volume close to 10 million Mg [17]. This is a result of the increase in the cost of cement production in the EU due to the transition towards carbon neutrality. In Poland, cement sales in 2018-2022 were at the level of approx. 19 million Mg/y, but in 2023 cement production decreased by about 12% (16.6 million Mg). Sales were slightly higher (16.9 million Mg) as a result of growing imports of cement from Ukraine. Preliminary data [18] show that in 2024 cement production increased by about 5%, and cement sales could exceed 18 million Mg, with the prospect of further growth to over 21 million Mg in 2027. The increase in demand for cement in Poland is influenced by the planned development of infrastructure and industrial construction, as well as the demand for residential construction. However, the rapidly growing imports of cement from non-EU countries (Ukraine, Turkey and Algeria) are a firm competition for domestic producers, burdened by increasing climate and emission fees [15,18]. Changes in aggregate extraction and cement consumption in Poland and the EU are presented in Figs. 2 and 3. In Poland, the production of aggregates takes into account the division into sand and gravel aggregates (SG) and crushed aggregates (CS) and the total production of natural



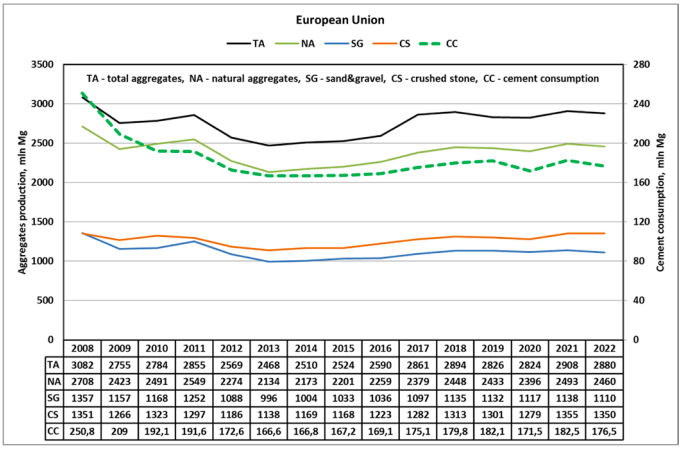
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
NA	143,1	163,8	184,5	200,9	196,4	226,7	333,4	248,8	231,7	210,7	232,2	232,7	257,1	278,3	261,5	256,8	264,2	250,2
SG	100	116,7	139,5	150	141,1	163,5	248,8	184,8	173,3	146,6	168	173,2	186,3	197	182,8	180,2	185,1	170,8
CS	43,1	47,1	45	50,9	55,3	63,2	84,6	64	58,4	64,1	64,2	59,5	70,8	81,3	78,7	76,6	79,1	79,4
CK	11,9	14,4	16,7	17	15,5	15,9	19,6	16,4	14,2	15,1	15,7	16	17,2	19,2	19,5	18,9	19,3	18,8

Fig. 2. Changes in the production of natural aggregates and cement consumption in Poland in 2005-2022

aggregates (NA). In the EU, due to the significant share of recycled, marine and artificial aggregates in production, the total production of aggregates is also taken into account. The nature and trends of the individual graphs for aggregates and cement consumption (CK) are similar for both Poland and EU data, which suggests correlational relationships. Linear regression parameters and correlation coefficients were calculated for these relationships (Figs. 4-5).

For the date for Poland (Fig. 4), the following econometric models and coefficients of determination and linear correlation were obtained:

- NA = 13,612 × CC + 11,041 ; R^2 = 0,5406, r = 0,735,
- SG = 8,6535 × CC + 27,753 ; R^2 = 0,3897 , r = 0,624,
- CS = 4,9585 × CC - 16,712 ; R^2 = 0,7346 , r = 0,857.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
TA	3082	2755	2784	2855	2569	2468	2510	2524	2590	2861	2894	2826	2824	2908	2880
NA	2708	2423	2491	2549	2274	2134	2173	2201	2259	2379	2448	2433	2396	2493	2460
SG	1357	1157	1168	1252	1088	996	1004	1033	1036	1097	1135	1132	1117	1138	1110
CS	1351	1266	1323	1297	1186	1138	1169	1168	1223	1282	1313	1301	1279	1355	1350
CC	250,8	209	192,1	191,6	172,6	166,6	166,8	167,2	169,1	175,1	179,8	182,1	171,5	182,5	176,5

Fig. 3. Changes in construction aggregates production and cement consumption in the EU in 2008-2022

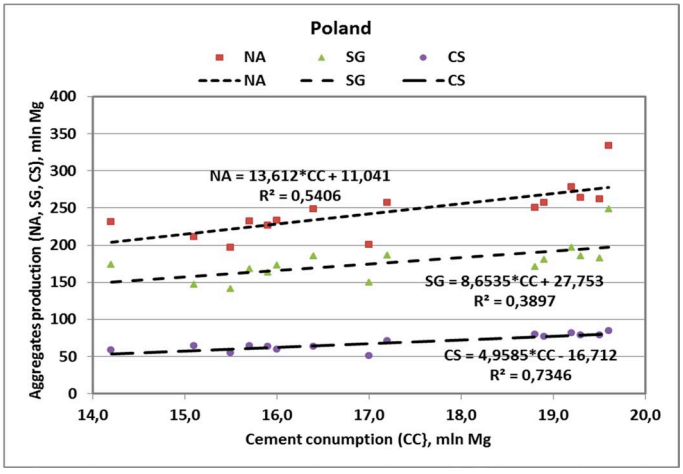


Fig. 4. The dependence of the sand and gravel and crushed aggregate production on the cement consumption in Poland in the years 1992-2022

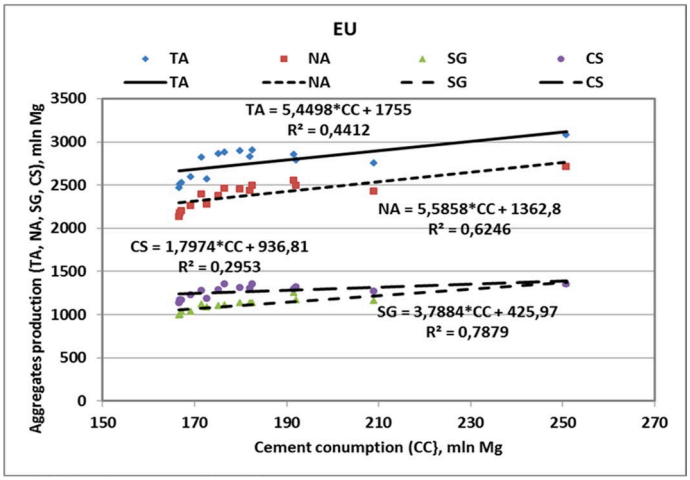


Fig. 5. The dependence of the construction aggregates production on the cement Consumption in the EU in the years 2008-2022

For the EU, these dependencies are as follows (Fig. 5):

- TA = 5,4498 × CC + 1755 ; R^2 = 0,4412, r = 0,664,
- NA = 5,5858 × CC + 1362,8 ; R^2 = 0, 6246, r = 0,790,
- CS = 1,7974 × CC + 036,81 ; R^2 = 0,2953, r = 0,543,
- SG = 3,7884 × CC + 425,97 ; R^2 = 0,7879, r = 0,888.

The individual symbols in regression models stand for:

NA – production of natural aggregates (sand, gravel and crushed stones), million Mg,
SG – production of sand and gravel, million Mg,
CS – production of crushed aggregates, million Mg,
TA – total production of aggregates (natural, recycled, artificial), million Mg,
CC – cement consumption, million Mg.

The presented relationships show that all dependencies are significant at a significance level of at least $\alpha = 0.05$. For Poland, the most favourable correlation coefficient was obtained for the dependence on the extraction (production) of crushed aggregates of cement consumption and the EU for the dependence on the production of sand and gravel aggregates. The estimated econometric models can be used, among other things, to develop current and medium-term forecasts of aggregate extraction.

4. Aggregates production forecasts

The advantage of the estimated econometric models is that they can be used to forecast aggregate production. Both the production and consumption of cement in Poland, as well as in most other countries, are monitored and reported in industrial data statistics (in Poland by the Central Statistical Office, in the EU by Eurostat), while the extraction and production of aggregates are

generally not reported or are given with a long delay and are not always accurate. The reason for this is, among other factors, the high number of mines, most of which are small operations employing fewer than 10 workers. There are over 2800 aggregate mines in Poland and about 28000 in the EU [10,12]. Table 2 presents ex-post forecasts for Poland and the EU for the years 2020-2023 and compares them with the actual production volumes. On this basis, forecast errors were determined for individual types of aggregates and years. For Poland, the smallest errors in ex-post forecasts were obtained for the total extraction of natural aggregates, and these errors range from 0.3 to 4.3% (2.2% on average). Significantly higher errors were obtained for the production forecasts of individual types of aggregates. For crushed aggregates, forecast errors range from 0.1 to 14.5% (average 4.9%), and for sand and gravel aggregates from 5.1 to 11.5% (average 7%). In the case of the EU, forecast errors of several percent were also obtained. The lowest was obtained for the forecast of sand and gravel aggregates production from –1.4 to –3.7% (–2.4% on average), and the highest for the forecast of crushed aggregate production from –2.7 to –7.1% (–5.4% on average). In both cases, these forecasts were underestimated. These errors and discrepancies in the forecasts are mainly caused by inaccuracies in the fit of econometric models. For the dependence of sand and gravel aggregates production on cement consumption, the coefficient of determination R2 (Figs. 4-5) is the highest among the examined relationships and amounts to 0.7879, and for the dependence of the production of crushed aggregates on cement consumption, this coefficient is the lowest (0.2953). TABLE 2 also includes forecast aggregate production volumes for 2024 (PIG-PIB and UEPG provide total production volumes only in the second half of 2025) and 2025-2027. These forecasts show that in Poland, aggregate production should grow to the level of approx. 300 million Mg in 2027 and the EU stabilisation of production with the possibility of a slight increase is expected.

TABLE 2

Forecasts of aggregate production in Poland and the EU in 2020-2023 (ex-post) and 2024-27 (ex-ante Poland)

Years	Poland, Aggregates, Forecast, mln Mg/y / Error forecast, %			European Union (EU27+UK), Aggregates, Forecast, mln Mg/y / Error forecast, %			
	NA	CS	SG	TA	NA	CS	SG
2020	259,8/+1,2	77,0/+0,5	191,3/+6,2	2689,6/–4,8	2320,0/–3,3	1245,1/–2,7	1075,7/3,7
2021	265,0/+0,3	79,0/–0,1	194,8/+5,2	2749,6/–5,4	2382,2/–4,6	1264,8/–6,7	1117,4/–1,8
2022	258,5/+3,1	76,5/–4,3	190,4/+11,5	2716,9/–5,7	2348,7/–4,5	1254,1/–7,1	1094,6/–1,4
2023	236,1/–4,3	68,1/–14,5	175,7/+5,1	2689,1/–3,5	2320,2/–1,7	1244,9/–5,0	1075,3/–2,4
2024	257,4	73,0	184,4	2683,6	2314,6	1243,1	1071,5
2025	272,4	78,5	193,8	2691,8	2323,0	1245,8	1077,2
2026	284,6	83,0	201,7	2702,7	2334,2	1249,4	1084,8
2027	299,6	88,4	211,2	2710,9	2342,5	1252,1	1090,5

Symbol designation:

SG – production of sand&gravel, million Mg,

CS – production of crushed stone(rock), million Mg,

NA – production of natural aggregates (sand&gravel and crushed stones), million Mg,

TA – total production of aggregates (natural, recycled, artificial), million Mg.

5. Final conclusions

1. Economic and industrial development, urbanisation and population growth, especially in most countries in Asia and Africa, contribute to a continuous increase in the demand for mineral aggregates, which are essential for construction and many other applications.
2. Despite the very large scale of production and consumption (approx. 45 billion Mg/year), aggregates remain one of the least regulated sectors of economic activity. To improve this situation, introducing planning and monitoring for the process of obtaining natural aggregates is necessary.
3. Econometric analyses of the dependence on natural aggregate production and various indicators of economic development have confirmed that cement consumption is a relatively good indicator.
4. The paper presents an analysis of changes in aggregate extraction (production) and cement consumption for Poland and the EU, followed by the calculation of correlational relationships. The coefficient determination (R^2) obtained for the studied relationships, though varied, confirms the possibility of such relationships existing at least at the confidence level $\alpha = 0.05$.
5. The econometric models estimated for these relationships were used to forecast aggregate production. The relatively small errors in the ex-post forecasts for Poland and EU data confirm the potential of using the estimated dependencies for ex-ante forecasts. Relatively low values of R^2 correlation indices were obtained for some relationships, and slightly larger prediction errors for these relationships, however, indicate the need for further research to determine more accurate relationships.

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