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The Contribution of Industrial Minerals to Sustainable Recovery of Greek Economy

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Abstract

Industrial Minerals and Rocks are the raw materials of economic value that are not classified as metallic minerals, fossil fuels or precious stones. The production and export potential of domestic perlite reveal Greece as a leader both at European and at global level as well as other industrial minerals such as bentonite and magnesite, which also could contribute by a distinctive manner to the economic development of the country. The quality, however, and the processing expertise are important factors in producing special products to meet the needs and market requirements for specific end uses, specifically rare earth elements (REE) as critical strategic minerals in high-tech products. Occurrences and industrial mineral deposits, primarily in North Greece, are examined in relation to their uses, such as feldspars, pozzolan, pumice, kaolin, zeolites, quartz, gypsum, white carbonates.

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1. Introduction

It is no exaggeration to say that today there is no sector of human activity not to use in a greater or lesser extent raw materials, which are based on industrial minerals. In the global market, competition has increased significantly in recent years due to their low production costs in many third countries, a trend expected to continue. Industrial minerals are a significant part of Greek mineral wealth with a substantiall contribution to the export activity of the industry. The vast majority of the production value comes essentially from a few industrial minerals such as bentonite, perlite, huntite, pumice. (Christidis, 1992, Kosiaris & Michael, 1995). Large industrial mineral mining center in Greece is the island of Milos, Southern Aegean, in which bentonite,

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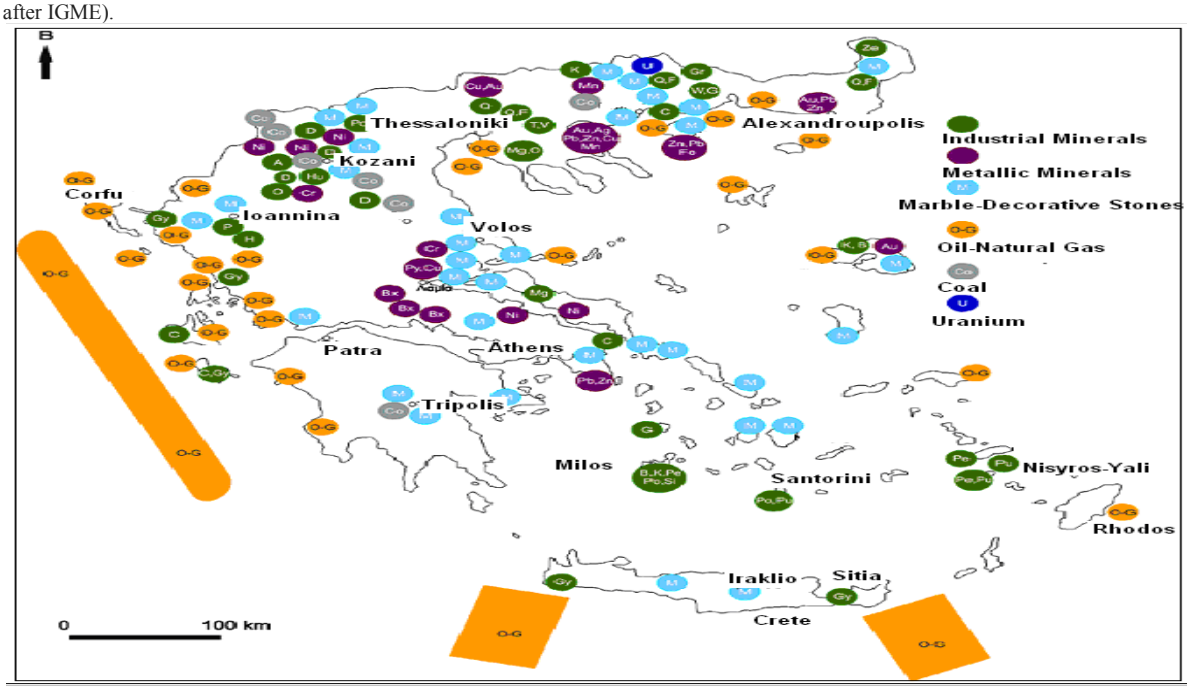
perlite, pozzolan and small quantities of kaolin and barite are mined. Other mineral raw materials which are mined in various regions of Northern Greece are: quartz, feldspar, kaolin, pozzolan, gypsum, silica, white carbon, magnesite (Kravvas, 1999, Vlahou et al., 2001). Platias et al. (2013) have discussed innovative processing techniques for the production of high purity quartz, based on domestic raw material.

The huntite/hydromagnesite is mined in Lefkara of Kozani and pumice at Yali islet near Nisyros island, South-Eastern Aegean sea (Calvo et al., 1995, Stamatakis, 1995, Hatjilazaridou, et al., 1998). Feldspar and quartz mined in Central Macedonia, gypsum mainly in Aetoloakarnania, Western Greece. Pozolans in Mylos island and Edessa, white carbonates in the Ionian islands and Kozani while magnesite in Chalkidiki. The last few years mining of other mineral deposits have also been started, such as attapulgite and olivine in Kozani, zeolites in Thrace, while there are prospects of exploring industrial minerals such as diatomite, clays, more zeolites, etc. (SME, 2011; Kandiranis et al., 2005; Kastritis et al.; 2003). Figure 1 lists the total mineral wealth of Greece, including metallic, industrial and energy raw materials as it is mapping today.

Given that a) the mining industry is an important parameter of modern society, b) industrial minerals are essential raw materials in most sectors of contemporary activities, c) technological progress leads to a constant evolution and expansion of both minerals we consume, as well as the fields of use, combined with the variety and size of industrial mineral deposits in Greece, further increase is expected in both the number of exploitable industrial minerals, as well as of application fields. The European strategy also imposes the need to adopt an integrated approach for sustainable development, aiming at a high level of economic and social development and environmental protection.

The European Union in 2010 adopted the initiative for sustainable production of domestic raw materials, sustainable consumption and recycling. The content of this initiative includes 14 minerals classified as critical and of strategic importance for the European industry. Many of them are located in Greece, but require additional research to determine certain reserves. In 2012, the Greek State passed a new mining law, in agreement with the European initiative on raw materials (initiative Verheugen), to reduce bureaucracy in the permitting process. The development of the mining and metallurgical industry in Greece has a strong comparative advantage in relation to other EU countries and this could be beneficial to national economy (Tsirambides & Filippidis, 2012a; Tsirambides & Filippidis, 2012b).

Figure 1: The total mineral wealth of Greece, including metallic, industrial and energy raw materials as it is mapping today (modified after IGME).



The vast majority of the production value in Greece comes essentially from a few industrial minerals such as bentonite, perlite, huntite, pumice (Christidis, 1992; Kosiaris & Michael, 1995). Other mined mineral raw materials are: quartz, feldspar, kaolin, pozzolan, gypsum, silica, white carbonates, magnesite (Kravvas, 1999; Vlahou et al., 2001).

Based on these data, an important area of research could be the development of technologies that lead to the exploitation of mineral raw materials, reduction of production costs, product quality improvement, new products, development of technologies to protect the environment and minimize the impact of mining processes on both health and environment. Charalampides et. al., (2013) discussed extensively the socio-economic impacts of development opportunities in mining and processing of mineral raw materials in Greece.

Pumice, volcanic ash, diatomite etc belong to the broader group of natural pozzolans commonly found in extensive layers with thicknesses of up to 40 m. In Greece pozzolan is known as «*Thyra gaia*» (contains about 65% amorphous SiO_2), due to the large and loose deposits on the homonymous island (Thyra = Santorin) and neighboring islets.

The pumice is one of the most important industrial raw material of Greece, mined in the only active pumice mine on Yali islet, South-Eastern Aegean sea. The production in 2011 was 469,000 tons.

Indicative reserves of pumice and other pozzolanic earths in Greece are estimated to 400 million tons and the gross value to 4 billion €.

2. Industrial Minerals and Geological Environment in Greece

The complexity and variety of geological formations and the geological evolution of Greece have led to the creation of significant occurrences/deposits of various industrial minerals (Fig. 1). The so called internal hellenic mountain ranges are hosted, due to their composition and development a variety of industrial minerals of endogenous origin. These were formed either by magmatic process comprising magmatic differentiation, contact metassomatos, hydrothermal activity or by metamorphism. In the internal hellenic mountain ranges significant occurrences/deposits of olivine, feldspar, quartz, wollastonite, garnet, kyanite, graphite, talc, vermiculite, magnesite, pozzolan, pumice, perlite, zeolite, bentonite, kaolin, etc have been identified. The external hellenic mountain ranges are characterized mainly by the presence of industrial minerals of sedimentary origin, including bauxites, phosphate rocks, gypsum, white carbonates, diatomite, attapulgite, etc. Both in internal as well as in external hellenic mountain ranges occur industrial minerals of exogenous origin (genesis) created by weathering processes, such as quartz sand, silica sand, kaolin etc.

3. Everyday life application examples of industrial minerals

Our houses are constructed by building materials of industrial minerals such as cement (limestone, slate, etc), the bricks (clays), sand, gravel, tiles, sanitary ware, plasterboard, windows (quartz sand), colors (calcium carbonate, dolomite, clays, talc, quartz, etc).

Utensils we use in our daily life, such as plates, cups, glasses, are made from raw materials of industrial minerals (quartz, feldspars, clays).

Plastics, depending on their type, contain various industrial minerals: kaolin, calcium carbonate, wollastonite, talc, etc.

Stationery also contains mineral raw materials such as calcium carbonate, kaolin, talc. In agriculture industrial minerals are used as soil conditioners. Industrial minerals are also used for the protection of the environment such as bentonite to seal landfills, zeolites, carbonates, etc. In pharmaceutical and cosmetic industry industrial minerals are main constituents, such as talc, antacid magnesium, calcite. These applications are just a few uses of industrial minerals, which are widespread and integrated into our everyday lives.

4. The production of Greek Industrial Minerals

During the years 2011-2012 the sector of mining and metallurgical activity continued the same downward trend that emerged in previous years due to the economic crisis, following the significant decline in demand

and prices of raw materials to the steel, construction, cement and concrete industry. The recession boosted by volatility in the international markets for raw materials, reduction in international metal prices and increasing energy prices across the EU.

The domestic market mainly in the predominantly construction products (aggregates, cement, ceramics, etc.) suffered a collapse and aggregate quarries enterprises as well as cement enterprises, face daily question of survival. Indicatively, the total production of primary aggregates crashed the years 2011-2012 to 25-35 million t, (from 90 million t in 2007) just because of the severe contraction of the internal market for construction products. In contrast, Greek export companies with products shipped to the European and international market in general (industrial minerals, aluminum, nickel, etc.) faced with relative success continued recession while maintaining satisfactory results.

The sector of industrial minerals maintained for 2012 much of the results of 2011, mainly thanks to the diversified export-oriented products to commodity markets that have almost not affected by the downturn in the construction sector (e.g. the North American markets). Specifically, production of bentonite and perlite remained at 2011 levels (Table 1), with a slight increase for both bentonite (1.24 million t) and perlite (1.33 million t). The exports of bentonite for foundry uses, iron metallurgy and oil drilling increased while sales in the infrastructure construction sector decreased. The «*S & B Industrial Minerals SA*» maintained its position as the largest export company of bentonite in the world (production in 2012 of 1.2 million t from the mines of the Milos island) with a total sales value of over 65 million € (100% exports). The corresponding figure for 2011 was a production of 1.19 million t with a total sales value of over 69 million €.

Similar picture presented also the branch of perlite, with export restrictions involved construction activities and expansion of other uses such as agricultural, foundry applications, filter media, special insulation etc. The «*S & B Industrial Minerals SA*» produced in 2012 (Tsigrado and Trachila mines, Milos island, Table 1) 1.33 million t perlite (compared to 1.35 million t in 2011) reaching a total sales value for the unprocessed and processed products of approximately 30.8 million € (compared to 33.4 million € in 2011).

Despite the slowdown in the global economy, very important was recently, for another year (2012) the international presence of the Greek raw magnesite, by «*the Greek Magnesite S.A.*» (over 351.000 t) and magnesite-integrated products (caustic-calcined magnesia and refractory masses, 27.000 and 45.000 tones respectively, Table 1). Also extremely encouraging for Greece was the fact that this purely export-oriented company (with a total sales value for 2012 of over 30 million €) achieved, despite the shrinking size compared with 2011, to maintain as the largest export company for magnesite products within the EU while focusing on quality and environmental restoration.

Table 1 is also illustrating that the production of huntite / hydromagnesite in Servia Kozani, amounted in 2012 to 24.200 t («*White Minerals SA*»), showing a steady upward trend in both production and sales of treated as well as crude material compared to previous years 2011 (production 23.800 t), 2010 (production 16.350 t) and 2009 (production 10.652 t). Also, the output from the feldspar company «*Mevior SA*» (Assyros Thessaloniki) was for 2012 13.000 t as compared to 10.600 t (2011) and 17.400 t (2010).

Products of olivinite, amphibolite and attapulgite maintained their upward trend and the export orientation utilizing both the productive potential and existing reserve from previous years to supply the processing plants. In addition to the numerous uses, it should be noted that these minerals which cover the needs of the chemical industry, manufacturing industry, steel industry, refractory etc. are also widely used in predominantly environmental uses, as bleaching substances, in refining and waste management, as molecular filters, filtering, insulation media, etc.

Relative uses are shown by zeolite, with a very low production of only 2.850 t in 2012 and diatomite for which there is not yet any legal exploitation. Especially for zeolite of Thrace North-eastern Greece, no investment has up to now taken place.

Emery production from Naxos Island fell (2012) to 4.250 t (from 5.900 and 7.000 t in 2011 and 2010 respectively) in an effort to control the unsold inventory of 160.000 t in Moutsoúna mine, Naxos island. Significant efforts were made to channel into the market in 2011 and 2012 these amounts and therefore over 45.000 t emery have been marked for 2012.

The production of liquid carbon dioxide (CO_2) from Messochori Florina, border area Northern Greece, was for the years 2011-2012 about 10.000 t annually (Table 1). Carbon dioxide is used in food industry as an

additive (as carbonate, acidifier), for inactivation packaging, in industry (cutting - weld metals, steel, chemical industry), in research centers for operating analytical instruments, in health sector, in wastewater treatment to adjust pH, for refilling of fire extinguishers etc.

In 2012, the production of pozzolan reached to the very low historic level of decade 280.000 t (350.000 t in 2011) just because the main use of this material as an additive in cement has undergone a tremendous bending in the internal market. It is indicative that the production of pozzolan in Milos island by Lava SA in 2012 was limited to 139.000 (as compared to 178.000 t in 2011, 258.000 t in 2010 and 440.000 t in 2009) while the corresponding output by Interbeton SA from the same mine in Milos was zero for 2012 . Zero was also the production of silica and kaolin at country level, production of pozzolan for special uses (eg for special mortars, fillers, etc.) and the production of quartz and quartzite (2012, Table 1).

The same downward path have also undergone the products of ceramic industry, products of calcium carbonate (marble powder, mortars etc.) and pumice that the period from 2011 to 2012 remained at low output levels below 500.000 t. Specifically, about 385.000 t of primary pumice were produced from Yali, island of Nysiros, South-Eastern Greece, in 2012 (compared to 470.000 t in 211) with a total sales value of 4.3 million € (compared to 3.86 million € for 2011). Indicatively in periods before the economic crisis, the production and distribution of pumice from the Yali consistently exceeded 800.000 t and value sales over 6.7 million €. Table 2 refers to indicative reserves and the corresponding value of the industrial minerals and rocks in Greece.

Table1: Mining Industry in Greece. *Production of Industrial and Quarry Minerals* (after Tzeferis P., 2013)

Mining Industry in Greece
Production of Industrial and Quarry Minerals

Production	**Quantity in metric tons**				
	2008	**2009**	**2010**	**2011**	**2012**
Magnesite	455.069	250.234	513.487	541.813	351.266
Caustic Magnesia	70.545	55.545	31.594	38.343	26.832
Refractory Masses	35.617	31.634		45.202	44.821
Bentonite (primary material)	1.500.000	844.804	1.384.118	1.188.442	1.235.105
Attapulgitic clay	28.584	81.382	39.012	17.7488	19.8728
Huntite / Hydromagnesite	19.600	10.652	16.350	23.800	24.200
Pozzolan	1.059.000	830.000	550.000	350.000	270.000
Pozzolan for special uses (not for cement industry)	NA	21.532	79.600	49.7339	0
Kaoline	4.360	0	1.045	NA	0
Perlite (primary material)	1.000.000	862.935	790.100	842.870	876.396
Perlite (after treatment)	600.000	398.451	440.000	507.235	450.000
Pumice	828.000	381.000	412.700	468.960	385.917
Silicon Dioxide	64.521	37.905	5.742	1.671	0
Gypsum and anhydrite	1.000.000	730.000	574.768	590.000	621.329
Olivinite (primary)	37.150	48.050	35.300	55.325	20.285
Amphibolite	57.500	25.902	23.453	23.263	10.398
Calcium Carbonate (amorphous and Crystalline)	126.357	580.000	450.000	400.000	380.000
Feldspars	62.000	28.617	17.380	10.563	13.000
Quartz and quartzite	16.201	10.909	30.794	11.241	0
Carbon Dioxide (liquid)	12.200	8.000	9.980	10.200	10.760
Zeolites	NA	NA	200	NA	2.850
Salt (not mineral, evaporation product)	220.000	189.000	164.765	174.500	191.970
Mineral aggregates (sand, gravel, crushed stones etc.)	85.000.000	65.000.000	50.000.000	38.000.000	29.000.000
Marbles (rough blocks in m^3)	347.526	155.516	268.033	285.000	320.000
Marble by-products (gravel, slate, tiles etc.)	1.218.056	761.933	598.111	650.000	500.000
Emery	NA	NA	7000	5.900	4.250

NA: Not Available

The gypsum production in 2012 increased mainly due to the relative increase of exports, which exceeded 50% of the total production volume. Indicative characteristic example is the gypsum production from Altsi, Sitia, Eastern Crete, where from the total production of 224.000 t in 2012, exports referred to 158.500 t (rate 70.5 %). The corresponding figures for 2011 production were 260.000 t (exports 168.000 t, rate 65%). Also, the production of salt (from 7 sites of saltpans across the country) increased in 2012 to 192.000 t (against 174.000 in 2011), mainly due to improved weather conditions during the period of evaporation and harvesting (Table 1).

5. The Economic Impact of selective Greek industrial minerals to international markets

The production figures for most of the mineral commodities that enter international trade by country, over the five-year period from 2007 to 2011 have been comprised to a comprehensive and continuous dataset by British Geological Survey (BGS, 2013). Table 3 refers to fluctuations in the production of bentonite for the period 2007-2011 in selected countries with production over 300.000 metric tons globally. This represent the period of current economic crisis where Greece despite the recession holds globally steady in third place after the U.S.A. and China, throughout the period 2007-2011. The percentage contribution of Greek bentonite production in the world market varies between 8.4% (2007) and 7.7% (2011), while the corresponding contribution of U.S.A. ranges between 25.7% (2009) and 32% (2011). However, at European level, Greece maintained its first position with a contribution varying between 33.6% (2008) and 23.9% (2009), while Turkey follows with a share ranging from 21.3% (2009) to 9.5% (2011).

Table 2: Indicative reserves and economic value of Industrial Minerals & Rocks in Greece (www.indmin.com, In Tsirampidis A. & Filippides A., 2013, 1€ = 1,45$ Sept. 2011).

Mineral resource	Reserves (in 10^3 t)	Value (€/t)	Value (10^6 €)
Feldspars	80.000	15	1.200
Attapulgite	13.000	20	260
Bauxite	250.000	20	5.000
Gypsum and anhydrite	350.000	6	2.100
Kaoline/Clays	50.000	15	750
Pumice/ Pozzolan	400.000	10	4.000
Magnesite	280.000	35	9.800
Bentonite	100.000	35	3.500
Olivinite /Dunite	50.000	10	500
Perlite	1.200.000	10	12.000
Quartz	5.000	20	100
Huntite / Hydromagnesite	4.000	40	160
Halite	20.000	4	80
Vermiculite	500	40	20
Wollastonite	500	40	20
Granate	1.300	30	40
Graphite	650	30	20
Diatomite	100.000	25	2.500
Zeolites	600.000	30	18.000
Micas	800	25	20
Talc	1.000	20	20
Phosphorites	500	20	10
Total			60.100

Table 3: World production of bentonite for selected countries with production over 300.000 metric tons per year for the period 2007 to 2011 (simplified after BGS, 2013).

Country	2007	2008	2009	2010	2011
Czech Rep.	335.000	235.000	177.000	183.000	160.000
Germany	384.709	414.336	326.461	362.623	375.332
Greece	1.342.000	1.500.000	844.804	1.384.118	1.188.442
Italy	305.905	161.313	114.682	110.982	102.756
Russia	460.000	460.000	460.000	460.000	460.000
Turkey	748.170	683.253	753.155	718.260	379.918
Ukraine	314.000	200.000	195.000	185.000	211.000
Mexico	613.895	374.933	511.430	590.998	563.795
U.S.A.	4.820.000	4.900.000	3.650.000	4.630.000	4.950.000
Brazil	329.647	340.141	217.926	326.428	330.000
China	3.300.000	3.300.000	3.400.000	3.400.000	3.400.000
India	563.000	671.000	561.000	739.000	996.000
World Total	16.000.000	15.700.000	14.200.000	14.900.000	15.500.000

Dealing with world production of perlite Greece holds the position of world leader in spite of crisis while China occupies the second position for the same period 2007-2011 (Table 4). Perlite production in Greece varies globally from 64.2% (2008) to 55.0% (2010), with China showing a global participation rate 17.5% (2007-2011). In other words more than half of European perlite production is based on the Greek contribution with rates ranging between 59.3% (2007) to 65.9% (2011).

Table 4: World production of perlite for selected countries with production over 50.000 metric tons per year for the period 2007 to 2011 (simplified after BGS, 2013).

Country	2007	2008	2009	2010	2011
Greece	1.100.000	1.600.000	1.261.386	1.230.100	1.350.105
Hungary	67.542	132.000	82.058	70.990	70.108
Italy	60.000	60.000	60.000	60.000	60.000
Turkey	478.579	551.266	522.832	737.077	429.776
USA	409.000	434.000	348.000	414.000	400.000
China	700.000	700.000	700.000	700.000	700.000
Japan	230.000	230.000	220.000	210.000	300.000

Moreover, world leader in the production of magnesite remains China with 14.5 million tones (2011) corresponding to 62.0% of world production, while Greece produced 541.813 tons (2011), rate 2.33% (Table 5). The corresponding percentage participation of Greece involving the European production of perlite is 8.1% while in the mean time the top place in Europe is occupied by Russia with 2.6 million tones, corresponding to 38.9% of European production (2011).

Table 5: World production of magnesite for selected countries with production over 100.000 metric tons per year for the period 2007 to 2011 (simplified after BGS, 2013).

Country	2007	2008	2009	2010	2011
Austria	811.556	837476	544.716	757.063	867.912
Greece	351.414	455.069	250.234	513.487	541.813
Netherlands	245.000	316.264	183.256	236.053	274.877
Russia	2.600.000	2.600.000	2.600.000	2.600.000	2.600.000
Slovakia	957.000	806.500	477.600	650.100	751.700
Spain	464.498	442.339	390.311	462.959	577.725
Turkey	1.984.908	2.143.047	861.180	1.541.860	1.000.000
Canada	140.000	140.000	140.000	150.000	150.000
Brazil	399.314	421.300	410.000	439.500	500.000
China	14.000.000	15.600.000	13.000.000	14.000.000	14.500.000
India	252.849	252.880	301.070	229.734	215.455
Iran	112.229	115.987	130.575	126.702	130.000
Israel	103.023	108.852	132.636	135.930	126.988
Australia	343.424	147.698	366.188	295.000	663.000

6. Conclusions

The declaration of the «*National Committee for the Utilization of Mineral Resources of Greece*» (2012) which introduced the main policy for the exploitation of the mineral wealth of Greece in terms of «sustainability» is necessary and very important. Key elements of this declaration is to integrate principles of sustainable development and planning in the mining activity, promoting «*education-research-innovation*» and the creation of an institutional framework as simple, stable and predictable as possible, which will inspire confidence in investors and ensuring access to deposits, taking into account the particularities of mining activity, and other related and parallel activities. In this context the Greek state must provide all the detailed information available in databases for mineral deposits and operating mines across the country, in order to be dealt with in regional planning.

The statistics on worldwide industrial mineral production for 2011, included in this work, reveal global outputs of the elective industrial minerals, bentonite, perlite and magnesite, showing that the production of these minerals have remained relatively flat compared to 2010 with single digit percentage increases or decreases, except for Greek bentonite, the annual production of which reflect an enormous increase rate 48% for 2011 compared to 2010. However, it is important for the recovery of Greek economy, to underline that the potential total value of these industrial minerals could exceed 60 billion €.

The critical strategic minerals are to be studied by an ongoing European project conducted by a consortium of Research Institutes, Enterprises and Geological Surveys. At a European level the Geological Surveys of member states are involved with the newly developed *European Innovation Partnership on Raw Materials*. This partnership has been developing its Strategic Implementation Plan during 2013 and is looking to support innovative research relating to the entire raw materials supply chain through the ongoing Horizon 2020 EU funding programme.

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