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Quarries Environmental Footprint in the Framework of Sustainable Development. The case study of Milos Island.

Grammati Goudouva[1], Pantelitsa Loizia,[2,3], Vasilis Inglezakis[4], Antonis A. Zorpas[2*]

[1]Forest Department Cyclades, Forester, Management and Protection of Environment, P.O.Box 84801, Milos, Cyclades, Greece
[2]Cyprus Open University, Faculty of Pure and Applied Sciences, Environmental Conservation and Management, Laboratory of Chemical Engineering and Engineering Sustainability antonis.zorpas@ouc.ac.cy, antoniszorpas@yahoo.com, Giannou Kranidioti 33, Latsia, 2220, Nicosia, Cyprus.
[3] ENVITECH (Environmental Technology) Ltd, Institute of Environmental Technology and Sustainable Development, Department of Research – Development, P.O.Box 34073, 5309, Paralimni, Cyprus
[4] Nazarbayev University, School of Engineering, Chemical Engineering Department, 53 Kabanbay batyr ave., Astana, Republic of Kazakhstan

*Corresponding author: E-mail: antonis.zorpas@ouc.ac.cy, antoniszorpas@yahoo.com

Abstract

The installation and operation of a quarry contains complex, difficult and sometimes unsafe processes (such as explosive) that may affect public health as well as the whole environment and the sustainable development in general in the area which guest the quary. This paper focus on the Environmental Footprint (EF) from quarries activities located in the island of Milos (Greece), where Bentonite, Perlite and pozzolan (type 1 and 2) are mined and extracted. Results indicated that energy consumption is consider to be higher for Bentonite than Perlite while Pozzolan presented with limited consumption per t of product. More specific for the production of Bentonite 1.81 l/t of oil is needed, 6.15 kWh electricity as well as 7.21 kg of production needs 1 m^2 area. Regarding the production of Perlite 2.86 l/t of oil is need, 16.38 kWh electricity while 7.43 kg required 1 m^2 production areas. Pozzolan type 1 consumed 0.71 l/t of oil, 0.87 kWh electricity and 0.01 kg explosives and 2 m^2 of production area is needed, while for the production of pozzolan type 2, 0.87 l/t of oil, 0.76 kWh electricity are needed as well as an area of 10m^2 is required. Concerning the waste generation (which mainly includes rock materials) is 0.83 m^3/t for Bentonite, 0.39 m^3/t for Perlite while in the cause of pozzolani 1 and 2 are zero due to the fact that both materials are homogenized. Gaseous emissions were calculated as equivalence of CO_2 and for the Bentonite was 1.52%, for Perlite was 2.18% per production t of final product.

Keywords: quarries, environmental footprint, greenhouses gas emissions, ecological footprint, carbon footprint, mining activities.

1. Introduction

Quarry processes contain complex procedures that may affect several environmental parameters such as energy, carbon dioxide emissions, waste production, lost of landscape etc. As a definition quarry reflect an area which excavations take place aiming to detect and mining natural resources [1]. The usual process may include mining, transportation of the raw materials from the mining area for further treatment, milling, crushing, washing, drying, sieving, temporary storage and then loading on a tracks or ships [2, 3]. Additionally, the lifetime of a quarry, mostly depends on the nature of the stocks, local situations, the market and the local conditions [4, 5]. The mining process demands significant amount of energy sources in several steps of the production, producing at the same time carbon dioxides, dust and waste.

The global community has implemented innovative techniques along with a wide range of environmental legislations, in order to reduce the pollution of air, water, soil and general environmental degradation [6]. However, many challenges remain and must be tackled together and in a controlled way [7] using a common methodological approach to introduced the effectiveness of natural resources and benchmark of the environmental performance of products, services and business, based on a systematic assessment of environmental impacts throughout the life cycle [8]. The term "Environmental Footprint" (EF) (Environmental or Ecological Footprint), was mentioned during 90s by Mathis Wackernagel and William Rees [9, 10]. EF stated in an indicator (qualitative), which measures the extent required for the disposal of waste generated during the production of the required resources [9]. Moreover, according to Ryan [11], EF is also used to estimate the impact at national and regional level as well as in any enterprises [8]. EF also is an innovative technique of calculating the ecological dimension of sustainability [12]. Also, EF is a method that can be used to evaluate the availability of natural resources and the degree to which production and consumption have an impact on them [13]. Wackernagel and Yount [12] declared as Ecological Footprint (Environmental Footprint) of an organization or an enterprise the entire greenhouse gas emissions (GHG) caused by the organization. EF is often calculated in terms of kilograms of carbon dioxide (kg CO_2), or its equivalent in other greenhouse gases emitted and is therefore referred to as a carbon footprint (CO_2 Footprint) [12, 13]. Carbon footprint is defined according to ISO/TS 14067:2013 Technical committee [14] *as a measure of the climate change impact of the product where all the greenhouse gas emissions emitted during the product life cycle are considered*. It is very important that, nowadays, several international standards exist for determining and certificating the carbon footprint in any organization as well as in any processes, such as ISO 14064-1 and GHG Protocol [6]. It is remarkable, that an Environmental Management System (EMS) can be applied in any kind of organization aiming to improve their environmental performances while at the same time set specific and measurables targets for continual improvement [15, 16, 17, 18, 19]. Solving environmental problems as a result of growth of business and the broader economic issues, is only possible by applying a systematic approach like EMS and the search for new methods of more efficient operational and state level in order to ensure economic and simultaneously eco stability [20]. The implementation of EMS from any organizations could be a sustainable tool in order to determine and control their environmental aspects and take measures to minimize their adverse impact on the environment. Hence, EMS, main objectives are the prevention of environmental problems, the development of environmental awareness and improving quality of life [18, 21].

Mining industry has declared its commitment for sustainable development and recognizes the need to control environmental performance, focus on cleaner technologies and efficient use of resources [22].. EF could serve as a tool to quantify and measure the environmental impact caused by the operation of an organization or business [23]. Knowing the EF, scientists or consultants can help the organization or the company to design a specific strategy to reduce the adverse impact of its operations on the environment [10]. This strategy can be integrated through innovative applications, technological development elements, improved procedures for production management and services, data collection, carbon emissions and creating indicators, new approaches to consumption, waste management, etc. [22].

To the best of our knowledge, there are limited available date regarding the EF from mining sectors and this paper focus on the determination of EF in quarries activities from Milos Island (Greece) using the EMS of ISO 14064.

2. Material and Methods

2.1 Description of the Area

The island of Milos (volcanic origin and hilly island) was chosen for the determination of EF (Figure 1). Milos belong to Cyclades, Greece, with subtropical climates [3] as the average precipitation does not exceed 500 mm.

[Figure 1]

Because of extensive volcanic activity and phenomena such as intense geothermal activity and tectonic modification, products of economic interest (in the eastern region of the island) have been created (Bentonite, Perlites, pozzolan etc.) and cover a total area of 20 km^2 (Figure 2). Morphologically, the island it is characterized as mountainous. In the natural environment according to Goudouva and Zorpas, [3], the island is dominated by bushy vegetation, with arboreal vegetation found only in suitable habitats, near small streams and slopes of more high mountains. The mining activity on the island is intense because of the large deposits that occur in the region and the mining of the minerals include the method of opencast with righteous consecutive open pit stages. When this method is implemented levels are opened, which start upstream and descend down to the bare deposit or learned to exploit the rock. Initially, there is removal of vegetation and then removing of the topsoil, which in many cases is stored to be reused in the process of restoration of the mining area. Then the overlying mineral materials are removed and follows extraction of the mineral. The extraction of the mineral is done mainly mechanically using promoters and occasionally with limited use of explosives. The mining area varies from 3-8 m height and 6 m width.

[Figure 2]

2.2 EF determination using ISO 14064

To identify and quantify EF of quarries operations the requirements of ISO 14064 were followed [13, 24]. ISO 14064 indicates the requirements and the instructions for inventory, quantification and reporting of GHG emissions including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2), hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulfur hexafluoride (SF6) [13]. These instructions provide a basic structure in which reliable and consistent controls are in force. Furthermore, the standard provides policy-makers with a set of well-organized practices to reduce GHG emissions [10]. The standard essentially defines three key aspects related to the development of the greenhouse effect. These aspects include establishing inventory levels, the quantification of GHGs and reporting [24]. A key objective of the process was to create a rigorous technical product that could be applied to a company regardless of the current policy of a country on tackling climate change [7]. The standard includes essential principles to ensure the validity of the results. These principles include relevance, completeness, coherence, accuracy and transparency. During the process of assessing the EF the following steps [13] were established: (i) identify specific sources of emissions, (ii) the selection of quantification methodology, (iii) data collection, (iv) quantifying emissions for each source, (v) determine total emissions. A guide to the organization of private and public sector, as well as a foundation for policy makers and development programs, aimed at tackling global environmental challenges of climate change [13. 25]. ISO 14064 [24] has four main steps in order to determined and evaluated EF and includes: (i) defining the objectives and context of the evaluation, (ii) census data analysis, (iii) impact assessment based in Life Cycle Analysis (LCA) or other methods (iv) interpretation of the results. To assess EF impact assessment according to LCA is needed to define the scope of the study, the boundaries of the system, the time and the geographical boundaries as well as the necessary data to be used. The Scope of the system includes five quarries (Figure 3), in which Bentonite, Perlite and pozzolan were mining (covering the geographical limits of the system). The functional unit is defined as a market producer production per t, were the survey data was examined for three years (covering the time limits of the system) of operation. Hence, all the data needed for this research had been collected from the quarrying companies through a questionnaire and survey audit. Those data include the amount of energy used for the operation of the quarry, the type of energy used, air emissions and amounts of waste produced. The statistical analysis was caring out using the Statistical Package for Social Sciences (SPSS V.22.0).

3. Results and Discussions

From the survey audit, Bentonite mining activities include the following steps: revelation - mining, transfer from the mining area to be treated, milling (during which breakage adding soda and drying), storage and finally loading in the ships to be transferred into the market. For the production of Perlite, the processing includes, the following steps were followed: revelation – mining, transfer from the mining area to be treated, milling, during which crushing, drying and sieving, storage, loading on ships. Finally, the production process of the pozzolan encompasses the following steps: mining, internal transfer, breakage when breaking and sifting is performed, storage, loading on ships.

Through the survey audit it was also find out that all the examined mining companies has certified (from several certification body) EMS in place in the framework of ISO 14001. Within the EMS, the mining industries has developed specific programs in order to maintain and control their activities which has diverse impact on the environment. Typically, all of the mining companies has written procedures in place which maintain and control the consumption of energy, their emissions (CO_2) on the environment, the water consumption, the waste production. For example, the water footprint (during those mining activities) as indicated by Goudouva and Zorpas [3] was 0.048 m^3/t for Bentonite, 0.07 m^3/t for perlit, 0.03 m^3/t and 0.18m^3/t for the pozzolan type 1 and type 2 respectively. Additionally, through the implementation of the EMS the industries developed their environmental policy and set specific objectives and targets to minimized their environmental impacts [16]. Through the commitment that indicated in their policy, organizations aim to improve their environmental performance [21].

The average production (mean values of the last three years) of the minerals Bentonite, Perlite and pozzolan extracted from quarries presented in Fig. 4. Bentonite production is up to 1.05±0.13 million of t/y followed by Perlite that the average production is 0.44±0.52 million of t/y and pozzolan (type 1 and 2) average production is 0.109±0.21 million of t/y.

[Figure 4]

Each mining process needs significant amount of energy (Table 1, 2, 3, 4). Regarding the mining process of Bentonite (Table 1) are needed 964823.30±95870.34 l/y of oil. Oil is needed also for the transportation step, which the average amount is 612427±441740.1 l/y. For the milling and distribution process, the industry used mazut (7539333±351420.5 kg/y) and electric powder (6113683±457439.5 kWh/y). Electricity also is needed when the mineral is loaded in the ships and the average consumption was 331141.7±29788.63 kWh/y. The energy consumption in the case of Perlite presents similarities with the energy consumption in the case of Bentonite. More specific, the liquid fuels (oil) that are needed (Table 2) for the mining and transportation process is 643216.3±63913.19 l/y and 613661.3±62353.93 respectively. For the milling and distribution process, the industry used also mazut and the consumption was 3273333±128484.8 kg/y while the electric powder was 7017333±531489.7 kWh/y. Electricity also is needed when the mineral is loaded in the ships and the average consumption was 220762±19858.58 kWh/y. In the case of Pozolan 1, beside liquid fuels and electricity, explosives are also needed. Explosive (3700 kg) are used in the mining process as its easier to breakdown the rocks (with this process mining industries saves time and fuels, but produced dust).

[Table 1]

[Table 2]

[Table 3]

[Table 4]

Figure 5, presents the waste generation per mineral production while, Fig. 6 indicates the concentrations of dust for each mining stage. Bentonite disposed of in extracting greater amounts of sterile materials, compared with Perlite and pozzolan type 1 and 2. Concerning the waste generation (which is consist from rocks material) is 0.83±0.25 m^3/n for Bentonite, 0.39±0.19 m^3/t for Perlite (total needed area is equal with $1m^2$) while in the cause of pozzolan 1 and 2 are zero due to the fact that both materials are homogenized. From the Tables 1,2,3 and 4 it is observed that the production of oil, which is considered as hazardous waste [26] (according to the 2000/532/EC), is 0.0060±0.0026 kg/t for Bentonite, 0.009±0.004 kg/t for Perlite, 0.00064±0.0011 kg/t and 0.0063±0.0109 kg/t for the pozolani1 and the pozolani2. It's important to know that the sterile materials are used in the recovery process, while the remaining is collected for recycling. Tires from track lories (Table 1 and 2) are produced s and is 881.6±69.69 kg/y in the case of Bentonite, while for Perlites is up to 596.6±51.85 kg/y.

[Figure 5]

[Figure 6]

Significant amount of dust emissions appears in open-pit quarries as indicated by Sairanen, et. al., [27]. Comparing dust concentrations for each unit per production process, based in Figure 6, lower concentrations occur during the mining process, in which pozzolan 2 gives highest values and pozzolan 1 gives the lowest values. During the processing stage, Perlite presents high and significant concentration of dust than other minerals, due to the low material moisture. Pozzolan 1 shows the lowest concentrations of dust during processing. In the process of loading the materials on ships directed to the market, pozzolan 2 presents higher values (0.86±0.36 mg/m^3) than the other minerals. Moreover, the higher emission of dust in reverse series is 16.09±10.33 mg/m^3 for the production of Perlite, 6.59±5.14 mg/m^3 for the production of Bentonite, while Pozolan 2 is 1.23±1.21 mg/m^3 and for Pozolan 1 is 0.35±0.29 mg/m^3. Usually, the compositional analysis of dust around quarries presents similar characteristics with the mineralogical properties of the bedrock [28], but it is not identical since different minerals break down or are removed at different rates due to the quarrying processes [29]. Studies indicate that in open pit quarries the concentration of dust varies from 100-40000 μg/m^3 for crushing process while for drilling process the concentration may be up to 110000 μg/m^3 [28, 29]. Dust exposure can be related with serious health risks beside environmental effects [29] as some epidemiological studies have reported adverse health effects of exposure airborne particulate matter [30]. Also, other studies mentioned that exposure to quarry dust, harmful effect on lung function may exist [31, 32] as well as on pneumoconiosis, hard metal disease, allergies, cancer etc, [33].

As indicated in Tables 1,2,3, and 4 during the mining of all the materials significant concentrations of COx, NOx, SO_2 are realized into the air beside the dust. NOx is presented up to 99.48±17.86 mg/Nm^3 in the case of Bentonite and with the concentration of NO to be up 96.83±16.31 mg/Nm^3. In the case of Perlite, the concentration of NOx is 131.91±66.53 mg/Nm^3 while the concentration of NO is 126.81±63.28 mg/Nm^3. SO_2 emissions were 0.85±0.73 mg/Nm^3 for the production of Perlite and 5.31±6.72 mg/Nm^3 for the production of Bentonite. In the case of Bentonite CO_2 emissions was 1.52±0.31% and the CO was 31.38±28.66%, while in the case of Perlite the emissions of CO_2 and CO were 2.18±0.67% and 23.30±14.41% respectively.

During the evaluation of EF, special attention should be given to the changes that occur to land-use as those are metabolized. Quarries and mining activities worldwide has significant impact to the land use [34, 35]. The quarrying areas suffer and extensive land use change and the mining companies received pressure from the Authorities to restored the area [36]. In our case a large percentage of the mining area was originally grassland and forest type. It is estimated (from the survey audit) that the annual loss of forests land from anthropogenic effects (quarries, road construction, etc.) and land use conversion, contribute up to 20% of the total global greenhouse gas emissions. The IPCC (Intergovernmental Panel on Climate Change) has published a methodology to calculate the emissions from land use changes in circumstances (for example from forest areas in quarries or farms), but the guidance is designed for greenhouse gas inventories in national level and not at product level.

The life of a quarry depends basically on the nature of the stocks and the local conditions [4]. The operation of a mining entails the creation of steps, excavations, deposits, roads and other interventions [37] which needs energy, producing at the same time several kinds of waste and emission to the air. In general, the adverse consequences arising during the stages of extracting the mineral, the transportation, the processing and disposal and dispersion in the environment of each waste type. Within the framework of sustainable development, the adoption of EMS is considered essential for the control of environmental parameters of a business [15, 18, 38] and furthermore for quarry activities [22]. Additionally, it is an essential prerequisite for any business to include the environment in the long-term development planning [39].

Conclusions

Generally, the operation of a quarry is a long-term process that requires time and adequate planning. Installing a quarry is not subject to rational choice or planning processes and the locations of mineral deposits are specific and determine the final design, location and size of the business. Therefore, mining activities above the surface of the quarry brought several radical changes in the environment than any other human activity which has adverse effects on the environment. EMS can be a sustainable tool for any type of organization in order to maintain and control their adverse impact on the environment in comparison with the EF. Knowing the EF scientists and consultants can help any type of organization to design and implement a specific strategy in order to reduce the adverse impact of its operations on the environment. To ensure the sustainability of the mining sector must be a systematic and continual approach to improve their environmental performance in order to maintain economic growth simultaneously with ecological stability. The findings from this research could be very useful for policy makers, local and regional authorities in order to push the owners of the quarries for continual improvement recording their impacts on the environment. It is clear from our research that the main issues from the mining activities is the metabolism of the areas as well the production of dust while the energy consumption is also a crucial point. Moreover, all those mining companies must implement more sustainable production practices in order to be able to reduced their adverse impact on the environment, through a holistic life cycle analysis.

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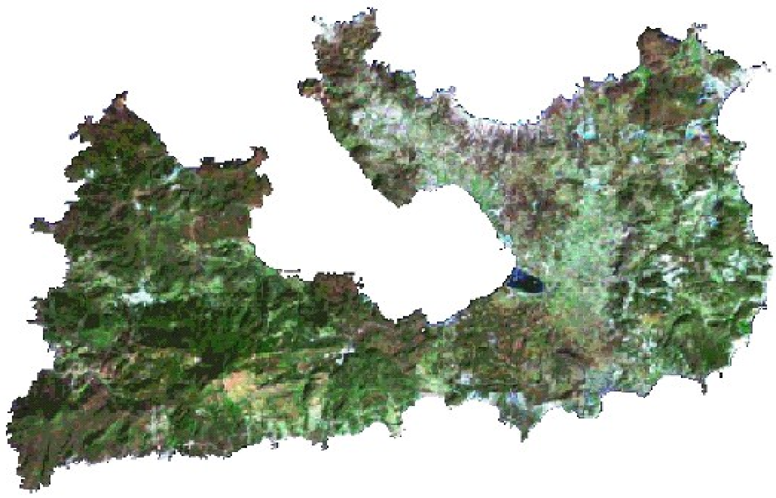

Figure 1: Satellite image of Milos. (Source: QGIS, unit 1 cm: 1 km).

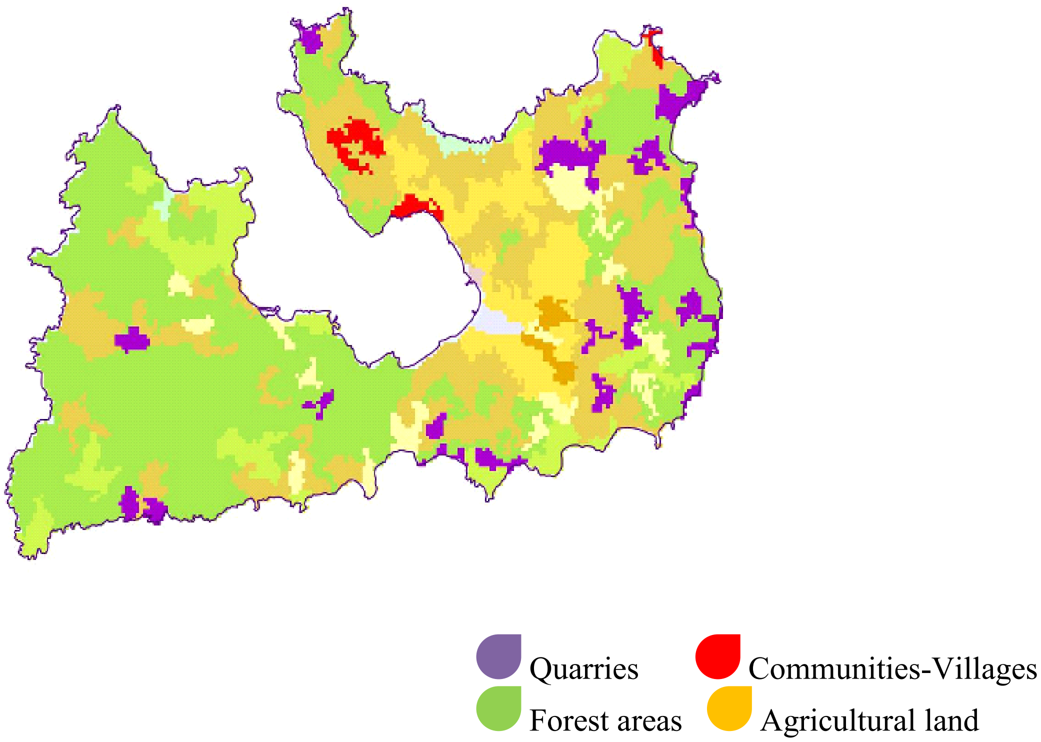

Figure 2: Map covers land use base of Corine classification system.
(Source: QGIS unit 1 cm: 1 km)

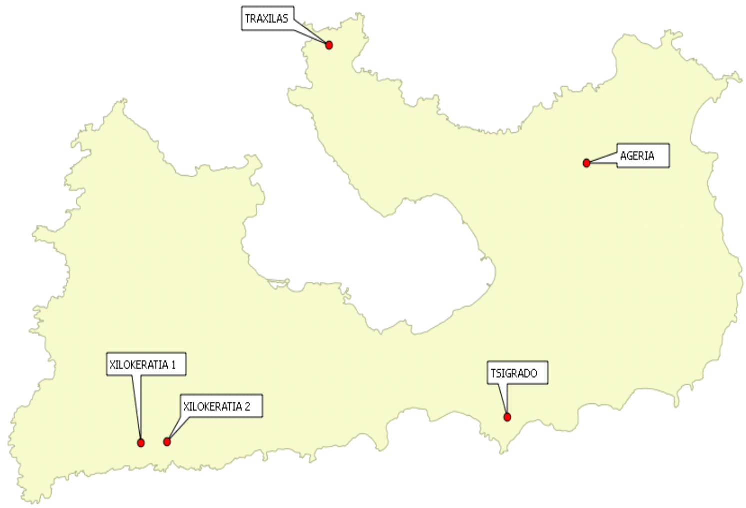

Figure 3: Quarries under consideration (unit 1 cm: 1 km).

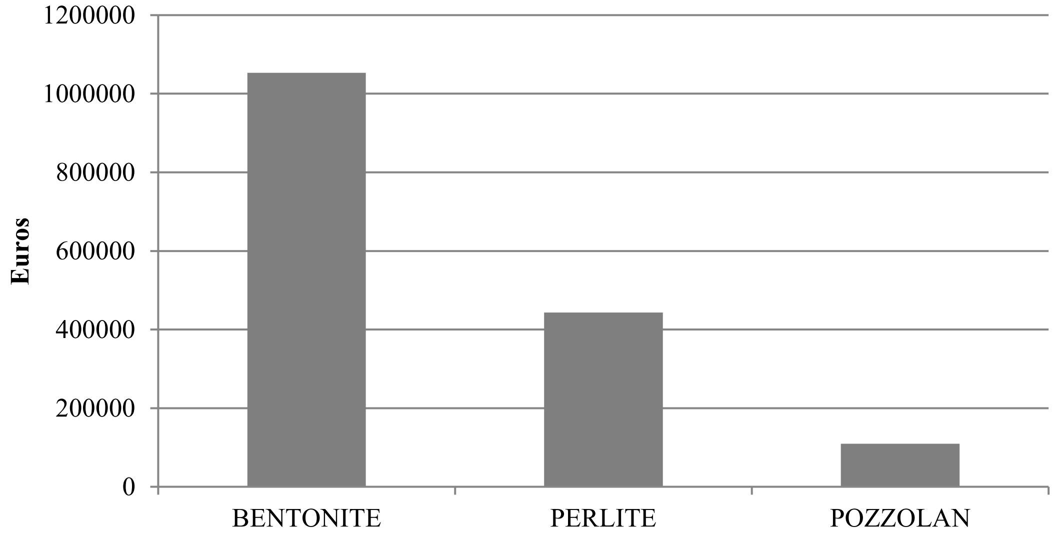

Figure 4. Market value of mineral per t.

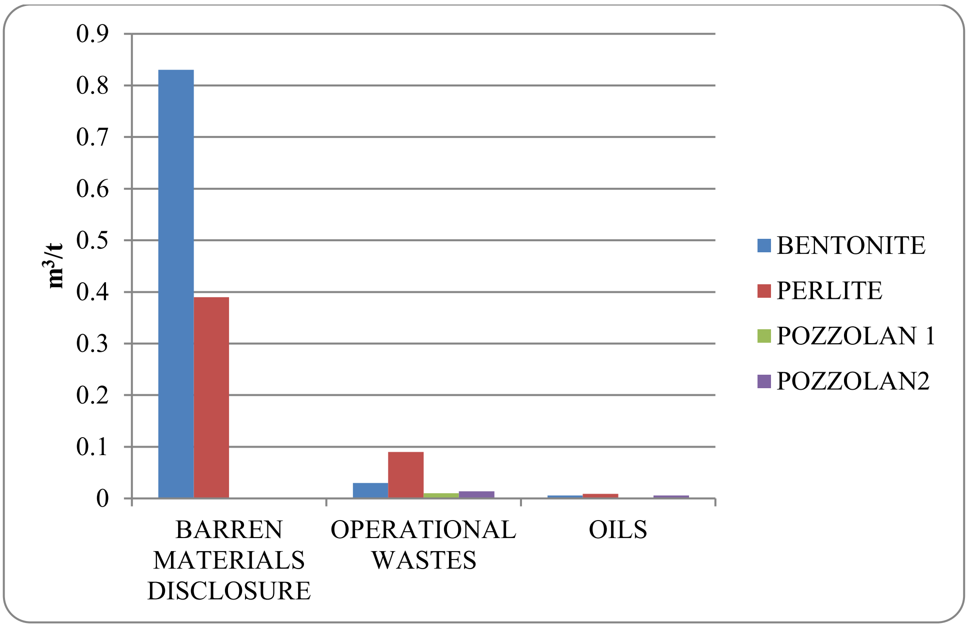

Figure 5. Waste production per category of industrial mineral.

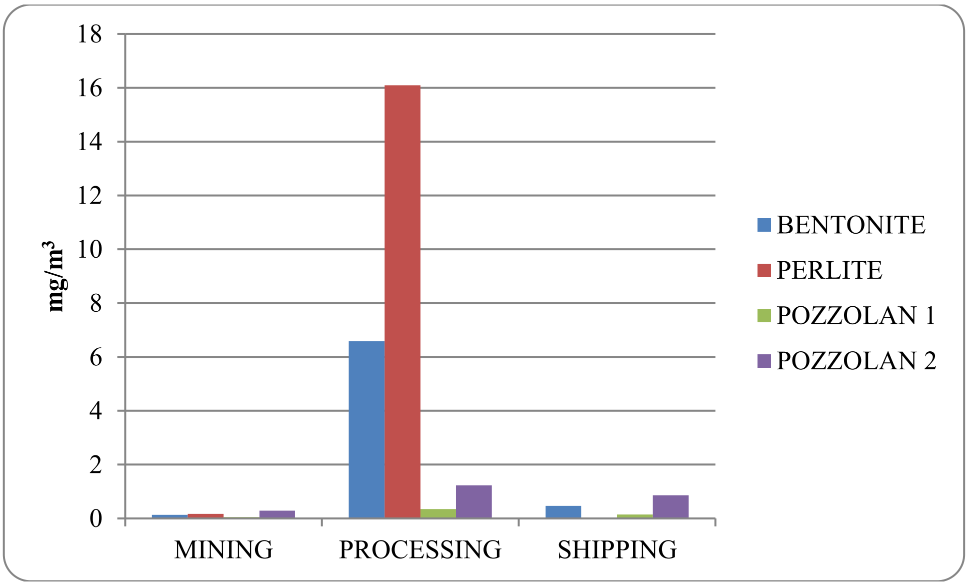

Figure 6. Dust concentrations per production process.

Table 1. Bentonite production data for the years 2012-2014

			Unit	2012	2013	2014
Production			t	1206219	978738	974510
Energy consumption per mining steps	Mining	Oil	l	1039128	998736	856606
	Transportation	Oil	l	851206	883387	1026880
	Milling (distribution) and Storage	Mazut	kg	7945000	7328000	7345000
		Electrical powder	kWh	6625600	5970450	5745000
	Loading to the ships	Electrical powder	kWh	362260	328275	302890
Water Consumption	From municipality		m^3	1711	1943	2811
	From natural mining bounds		m^3	38665	50524	54096
	Sea water		m^3	0	0	0
Waste production	Sterile materials		m^3	873005	1100414	629828
	Batteries		kg	0	0	1117
	SCRAP		kg	94500	29400	55200
	Tires (track lories)		kg	77	1296	1272
	Papers / paper cardboard		kg	1405	1278	0
	Oils from cars/engine maintains		kg	3756	8220	6480
Air emmissions	O2		%	19.4	18.75	19.1
	CO2		%	1.2	1.8	1.55
	CO		mg/Nm^3	9.2	21.2	63.75
	SO2		mg/Nm^3	1.45	13.08	1.4
	NO		mg/Nm^3	78.25	108.8	103.45
	NO2		mg/Nm^3	0.97	4.1	2.95
	NOX		mg/Nm^3	79.2	112.9	106.35
Dust concentration	Mining		mg/m^3	0.14		
	Milling (distribution)		mg/m^3	1.45	9.11	9.2
	Loading to the ships		mg/m^3	0.22	0.3	0.91
Total covered area	800 hectares					

Table 2. Perlite production data for the years 2012-2014

			Unit	**2012**	**2013**	**2014**
Production			t	468740	383301	479136
Energy consumption per mining steps	Mining	Oil	l	692753	665824	571072
	Transportation	Oil	l	567471	588925	684588
	Milling (distribution) and Storage	Mazut	kg	3345000	3125000	3350000
		Electrical powder	kWh	7490000	6442000	7120000
	Loading to the ships	Electrical powder	kWh	241507	218851	201928
Water Consumption	From municipality		m^3	1141	1296	1874
	From natural mining bounds		m^3	25777	33683	36064
	Sea water		m^3	0	678163	799228
Waste production	Sterile materials		m^3	88387	219440	199551
	Batteries		kg	0	0	745
	SCRAP		kg	63000	19600	36800
	Tires (track lories)		kg	51	864	848
	Papers / paper cardboard		kg	938	852	0
	Oils from cars/engine maintains		kg	2504	5480	4320
Air emmissions	O2		%	17.5	17.65	19
	CO2		%	2.6	2.55	1.4
	CO		mg/Nm^3	7.05	34.55	28,3
	SO2		mg/Nm^3	0	1.3	1.25
	NO		mg/Nm^3	190.6	125.8	64.05
	NO2		mg/Nm^3	8.45	4.85	1.9
	NOX		mg/Nm^3	199.05	130.7	66
Dust concentration	Mining		mg/m^3	27.64	7.69	12.94
	Milling (distribution)		mg/m^3	0.17		
Total covered area	470 hectares					

Table 3. Pozzolan type 1

			Unit	2012	2013	2014
Production			t	139000	189000	136000
Energy consumption per mining steps	Mining	Explosive	kg	0	0	3700
	Mining and internal Transportation	Oil	l	106283	114283	101424
	Milling (distribution), Storage, loading	Electrical powder	kWh	130706	145317	120718
Waste production	Batteries		kg	680		
	Papers / paper cardboard		kg		100	200
	Oils from cars/engine maintains		kg	270		
	Municipal waste		kg		3000	2000
Air emissions (total emissions)	Mining		mg/m^3	0.05	0.05	0.05
	Mining and internal Transportation		mg/m^3	0.35	0.35	0.35
	Milling (distribution), Storage, loading		mg/m^3	0.15	0.15	0.15
Total covered area	440 hectares					

Table 4. Pozzolan type 2

			Unit	2012	2013	2014
Production			t	40378	32120	42870
Energy consumption per mining steps	Mining and internal Transportation	Oil	l/t	0.9	0.87	0.83
	Milling (distribution), Storage, loading	Electrical powder	kWh/t	0.76	0.82	0.71
Waste production	Oils from cars/engine maintains		kg	0	609	0
	Other waste		kg	571	513	509
Air emissions (total emissions)	Mining (mainly dust)		mg/m^3	0.29	0.29	0.29
	Milling process		mg/m^3	1.23	1.23	1.23
	Loading		mg/m^3	0.86	0.86	0.86
Total covered area	350 hectares					