

# The Dynamics of Industrial Activities in Galați, Romania

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## The Dynamics of Industrial Activities in Galați, Romania

Ștefania-Silvia AJDER

### **Dinamica activităților industriale în municipiul Galați, România.**

Dinamica dezvoltării industriale în România a fost puternic afectată de efectele negative ale procesului de dezindustrializare post-comunistă, remarcându-se dificultăți de redresare economică. Scopul acestui articol este de a analiza evoluția industriei municipiului Galați în perioada post-decembristă și impactul acesteia asupra dezvoltării economice și sociale a orașului. Metodologia de analiză a inclus prelucrarea datelor statistice și demografice privind evoluția populației și structura economică a municipiului Galați, precum și analiza informațiilor referitoare la dezvoltarea principalelor ramuri industriale reprezentative. Rezultatele au evidențiat o scădere semnificativă a activităților industriale după 1990, însoțită de pierderea locurilor de muncă și de transformări sociale importante în municipiul Galați. Concluziile analizei arată faptul că procesul de dezindustrializare a condus la șomaj de lungă durată și declin socio-economic, fiind necesare noi investiții și dezvoltare durabilă a economiei locale.

**Cuvinte cheie:** industria siderurgică, dezindustrializare, industria navală, dezvoltarea economică durabilă, Galați.

**The Dynamics of Industrial Activities in Galați, Romania.** The dynamics of industrial development in Romania have been strongly affected by the negative effects of the post-communist deindustrialization process, highlighting significant difficulties in economic recovery. The aim of this article is to analyze the evolution of industry in the municipality of Galați during the post-1989 period and its impact on the city's economic and social development. The methodology included the processing of statistical and demographic data regarding population trends and the economic structure of the municipality of Galați, as well as the analysis of information related to the development of the main industrial branches. These were completed by field observations of representative industrial sites. The results highlight a significant decline in industrial activities after 1990, accompanied by job losses and major social transformations in the municipality of Galați. The conclusions of the analysis indicate that the deindustrialization process has led to long-term unemployment and socio-economic decline, making new investments and the sustainable development of the local economy necessary.

**Keywords:** steel industry, deindustrialization, shipbuilding industry, sustainable economic development, Galați.

## 1. INTRODUCTION

A degraded environment is defined as a natural area composed of elements such as water, air, soil, and living organisms, whose characteristics have been altered due to anthropogenic interventions, thereby affecting the ecosystem's ability to function optimally (Iojă, 2013; Zia-ur-Rehman et al., 2016). The imbalances thus created within ecosystems are an imminent consequence of environmental degradation and represent a major issue faced by 21st-century society. On one hand, economically developed countries aim to improve this situation by embracing the concept of sustainable development, which involves meeting the current needs of society without compromising the ability of future generations to meet their own (Brundtland Commission, 1987). On the other hand, however, these same countries continue to base their national economies on consumerism and heavy or extractive industries (highly polluting sectors) by significantly increasing investments in primary sector activities that involve the exploitation of natural mineral resources (Wei et al., 2020).

As a result of global population growth and the continuous development of human civilization, particularly in technological and economic terms, environmental issues have become increasingly pronounced. These include climate change, the depletion of natural resources, pollution, and the disruption of geospheres balance (Sodiq et al., 2019; Manzoor et al., 2025). The scale of these challenges lies in the fact that they are not confined to specific regions of the world, but are instead the cumulative outcome of local anthropogenic actions. When such actions become more frequent and impactful, their consequences can escalate to national, regional, and even global levels (Tal, 2025). In response to these challenges, the United Nations (2025) has established the Sustainable Development Goals (SDGs), which serve as a global framework for addressing environmental, social, and economic issues. Notably, *SDG 12 – Responsible Consumption and Production* outlines key actions such as achieving the sustainable management and efficient use of natural resources, reducing the release of harmful chemicals into the environment, and promoting awareness of sustainable development and lifestyles in harmony with nature (United Nations, 2023). Furthermore, SDG 12 is closely interconnected with other goals that address environmental integrity and biodiversity, including *SDG 13 – Climate Action*, *SDG 14 – Life Below Water*, and *SDG 15 – Life on Land*. Together, these goals emphasize the need for integrated and coordinated efforts to ensure the long-term sustainability of natural systems and the well-being of future generations.

Limestone quarrying practices vary significantly across the globe, influenced by factors such as a country's economic development, mining legislation, and the geological characteristics of the deposits (Carrasqueira et al., 2024). As noted by Oates (1998), the majority of limestone extraction is conducted through open-pit operations. In

economically advanced nations like Poland, commonly employed methods include excavation, drilling, and blasting. These traditional techniques are increasingly integrated with modern technologies, such as digital mapping using Geographic Information Systems (GIS), and the implementation of comprehensive reclamation plans designed for post-extraction site restoration (Każmierczak, Strzalkowski, 2019). In the United Kingdom, collaborative initiatives between geoconservationists and the mineral extraction industry further enhance sustainable practices, ensuring that geoconservation is considered throughout the quarrying lifecycle, from initial development to final restoration (Prosser, 2018).

Brazil, although classified as a middle-income country, serves as a notable example of integrating biodiversity offset strategies within limestone quarrying operations (Souza, Sánchez, 2018). The country combines conventional extraction methods with advanced technologies such as controlled blasting and diamond wire cutting. The latter is particularly valued for its precision and reduced environmental impact and is supported by favorable tax policies under Brazilian law (The Federal Government of Brazil, 1992). In contrast, developing countries like Algeria, where limestone quarrying plays a vital role in economic development, continue to rely heavily on traditional methods involving large-scale blasting and drilling machinery. As a result, Bendouma and Vapur (2020) advocate for the adoption of sustainable development principles to mitigate the environmental consequences associated with these practices.

Based on this premise, it becomes evident that, in Romania and beyond, a pressing environmental issue is the exploitation of natural resources without adequate consideration for their impact on the geospheres or the principles of sustainable development. Among the most frequently exploited and utilized solid mineral resources at the national level is limestone, which holds a long-standing history in Romania. The limestone extraction and processing industry reached its peak during the communist regime, largely due to the material's wide range of uses in everyday life and its economic value (Ministry of Geology and Geology and Geofizic Institute, 1983; Fodor, Georgescu, 2023; Carrasqueira et al., 2024). According to the most recent statistical data published by the European Union regarding the total number of limestone quarries across member states, there were 26,449 quarries recorded in 2012. Among EU countries, Romania ranked 10th, with a total of 1,225 limestone quarries (Eurostat, 2012).

The process of limestone extraction in Romania varies according to the physical and geological characteristics of the rock, as is showed in other studies regarding the rock characteristics (Carrasqueira et al., 2024). In the case of underground mining, limestone is obtained through conventional mining techniques, whereas surface quarrying typically involves the use of explosives to dislodge the material (Ministry of Environment Waters and Forests, 2020). As such, both the extraction and processing of

limestone entail not only economic considerations but also significant social and environmental ramifications. Behind the economic benefits associated with limestone extraction lies the environmental cost of polluting an entire geographical area, encompassing both the quarry perimeter and its surrounding landscape. Pollution may occur not only during the active phase of exploitation but also persist after operations have ceased (Manea et al., 2014; Fodor, Georgescu, 2023). In Romania, it is common for quarries to be abandoned once extraction is halted, whether due to economic non-viability, natural events that hinder operations, or the depletion of the resource (Buta al., 2019). Although national legislation provides for a formal decommissioning and land restoration process to be undertaken by the operator, the effective implementation of these measures requires systematic monitoring and the enforcement of penalties in cases of non-compliance (Romanian Parliament, 2003).

Accordingly, the present study was conducted with reference to the local context, focusing on the Bistrița limestone quarry located in Vâlcea County, Romania. This site was selected as the research area in order to identify the issues related to the exploitation of natural limestone resources, as well as the ecological imbalances and adverse effects on the local community. Within this framework we focused on two main objectives: (1) to assess the environmental impact of limestone quarrying, with a focus on both natural environmental components and the anthroposphere, and (2) to explore potential sustainable solutions for environmentally degraded areas resulting from extractive activities.

## **2. METHODOLOGY**

### **2.1. Study area**

For the present study, the selected research area is the Bistrița-Costești limestone quarry, located in the northern part of Costești commune, Vâlcea County, Romania. The quarry is situated on the southern slope of the Arnota Massif, which lies in the southeastern sector of the Căpățâanii Mountains, part of the Parâng Mountain Group within the Southern Carpathians. The Arnota Massif is primarily composed of Jurassic limestone, while its foothills feature Cretaceous and Paleogene sediments, indicating the presence of significant limestone resources (Ministry of Environment Waters and Forests, 2016). The quarry is located adjacent to the southern boundary of Buila-Vânturarița National Park, a nationally protected natural area classified as an IUCN Category II site, established in 2004. This park overlaps with Natura 2000 Network ROSCI0015 Buila-Vânturarița and ROSPA0025 Cozia-Buila-Vânturarița (Figure 1), as well as with several designated nature reserves (Romanian Government, 2004).

According to Făulete (1977), limestone extraction at the Bistrița-Costești quarry began in 1942, initiated by a private enterprise that installed a crusher for mosaic and filler production, sourcing raw material from the surrounding massif. The crusher was powered by a water turbine and operated by a team of 12 workers, producing approximately 8 tons of mosaic daily. In 1954, systematic extraction and processing of limestone commenced at the quarry, and by 1957, the operations were mechanized. Automation led to a reduction in the workforce by half, an increase in production capacity, and the expansion of mosaic distribution at the national level. The quarry was officially established in 1960 by order of the communist regime, which at the time prioritized the development of primary sector industries such as agriculture, heavy industry, and extractive activities. The primary objective of the quarrying operations was the extraction and processing of limestone for local use, particularly in the chemical industry, construction (e.g. limestone mosaic, filler), and asphalt mixtures. In 1965, the quarry was taken over by a state-majority-owned company, which succeeded in increasing production between 1970 and 1974. From 1976 to 1980, further investments were made in equipment and machinery to enhance production capacity (Figure 2).

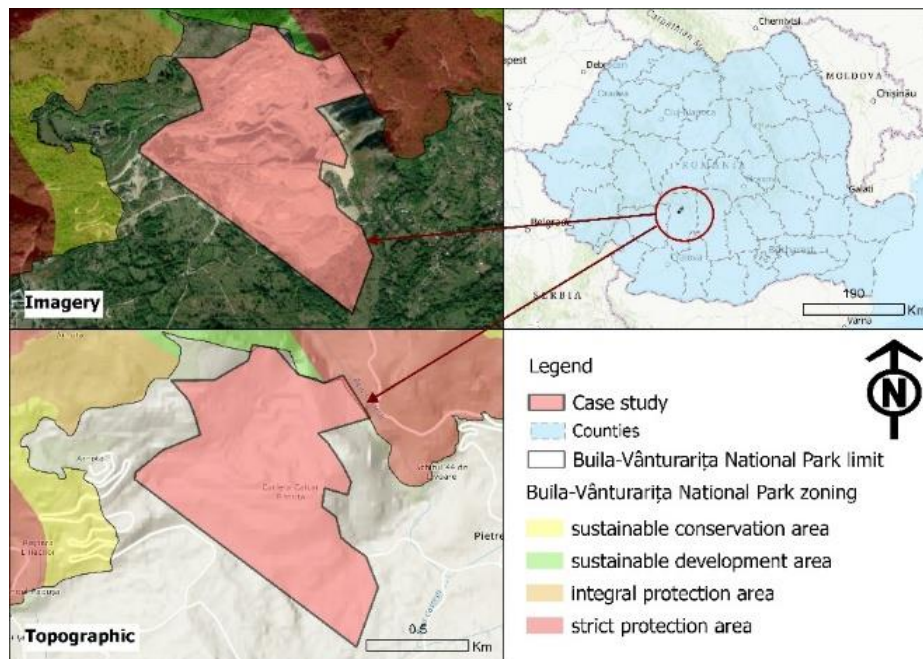


Figure 1. Location of Bistrița limestone quarry – study area

According to the former administrator of Buila-Vânturarița National Park, at the time of the park's establishment, the quarry was operational and partially overlapped with the park's territory. The extraction activities were conducted under an authorization issued in 2000 (Table 1).

However, following the designation of the new protected natural area, operations within the park boundaries were suspended. Subsequently, upon the expiration of the operating permit in 2020, the quarry ceased all activity entirely, as the exploitation costs were no longer economically viable (Kogayon Association, 2016).

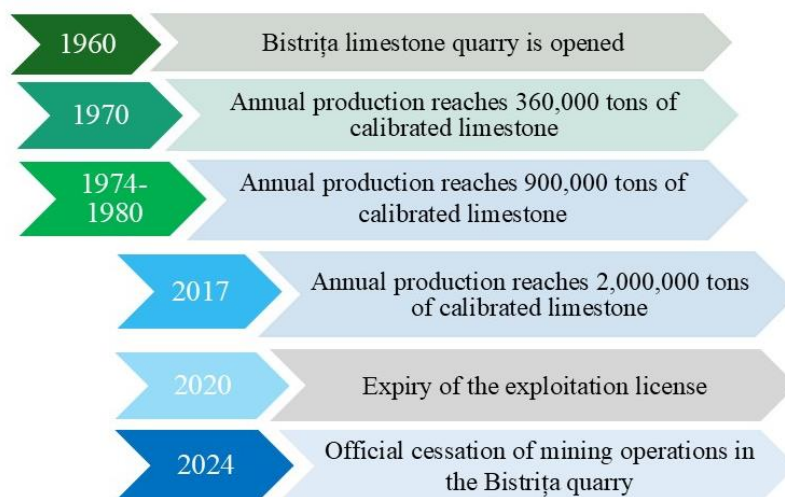


Figure 2. Exploitation evolution for Bistrița limestone quarry  
 Source: post-processing after Făulete (1977) and Costești Local Council (2024)

Table 1. The legal framework for the operation of mining exploitation of Bistrița limestone quarry

N°	Legal document issuer	Legal document	Document name
1.	Romanian Government (2000)	Government Decision no 652/2000	Regarding the approval of the Exploitation License no. 633/1999 issued by the National Agency for Mineral Resources
2.	Romanian Parliament (2003)	Law no 85/2003	Mining Law, as amended and supplemented
3.	Romanian Government (2003)	Government Decision 1208/2003	On the approval of the Norms for the application of the Mining Law No. 85/2003
4.	National Agency for Mineral Resources (2014)	Technical Norms	In the field of mineral resources exploitation

Source: post-processing after Kogayon Association (2016)

## 2.2. Study design

In order to achieve the proposed objectives, a methodology was applied that focused on three main types of activities: (1) content analysis of documents from the academic literature (scientific articles), public administration sources (official documents, legislation, reports, ordinances), and media outlets (online press articles);

(2) a comparative analysis of the environmental, economic, and social impacts before and after the quarry's exploitation activities; and (3) field observations aimed at data collection and validation of findings identified through document analysis, where relevant.

The documents were identified using keyword searches conducted via the Google search engine and the ScienceDirect database. The keywords used included: "Bistrița-Costești quarry", "limestone exploitation Bistrița-Costești," and "environmental impact limestone quarry", in both Romanian and English. Based on the search results, the materials were reviewed, and relevant information was extracted through content analysis. Documents whose subject matter did not align with the scope of the research were excluded from the analysis.

From the perspective of content analysis, several key aspects relevant to the study were identified, namely: *part 1 impact assessment*: (a) the domain affected (environmental, economic, or social); (b) the type of impact (positive, negative); (c) the duration of the impact (temporary, permanent); and (d) a description of the impact and *part 2 sustainable solutions*: (a) potential solutions, (b) description of the solutions, (c) advantages of the solutions and (d) disadvantages of the solutions. The analysis was conducted on 30 scientific articles, 14 public administration sources and 5 press articles. In addition, other data sources (both spatial and statistical) were used to support and complement the analysis (Table 2).

Table 2. Data sources used in the study

N°	Data	Year	Type of data	Source
1.	Protected areas limits	2024	Spatial	Ministry of Environment Waters and Forests (2024b)
2.	Species and habitat distribution	2024	Spatial	Ministry of Environment Waters and Forests (2024)
3.	Limestone quarry limits	2020	Spatial	National Agency for Cadastre and Real Estate Advertising (2020)
4.	Statistics about the industry of quarrying in the European Union	2012	Statistical	Eurostat (2012)

Also, the present study relied on direct field observations, photographic documentation, and field notes to identify and describe the visible environmental impacts caused by limestone extraction activities. These qualitative records provided valuable insights into the degradation of the natural landscape, the disruption of local ecosystems, and the presence of pollution indicators (the type, duration and description of the impact). Field visits for conducting direct observations were carried out during

the period of March-April 2025. The collected data were compiled and processed using Microsoft Excel, while graphical elements were created with Microsoft PowerPoint (Microsoft, 2019). For map production, ArcGIS Pro 3.2.1 software was employed (ESRI Inc., 2023).

### 3. RESULTS

The analysis of the impact generated by quarry exploitation focused on the three main pillars of sustainability (environment, economy and society) detailing the specific aspects that comprise each one of them (Table 3). Furthermore, in the context of sustainable development, the United Nations has established a framework for assessing sustainability through key issues, represented by the Sustainable Development Goals (SDGs). In our study, the analysis is centred on *SDG 12*, which is closely linked to natural and environmental implications and how these are affected. Additionally, three other SDGs are considered complementary within our analysis, based on the identified impacts: *SDG 13*, *SDG 14*, and *SDG 15*.

Table 3. Key aspects for assessing impact of limestone quarry exploitation

N°	Impact	Domain	Type	Duration	Description
1.	Changes in the relief	Environment	Positive	Temporary	Calcareous substrate, raw material
2.	Exokarst	Environment	Positive	Permanent	Karst valley with gorges, limiting the area of exploitation
3.	Landslides	Environment	Negative	Permanent	Stripping, blasting and excavation, land instability, tailings dumps
4.	Soil pollution/ degradation	Environment	Negative	Permanent	Silica (SiO <sub>2</sub> ), alkaline dust, sulfur oxides (SO <sub>x</sub> ), nitrogen oxides (NO <sub>x</sub> ), tailings dumps, infertility
5.	Water pollution	Environment	Negative	Permanent	Turbidity, pH, methane (CH <sub>4</sub> ), sulphur oxides (SO <sub>x</sub> ), phenols, zinc (Zn), copper (Cu), lead (Pb)
6.	Air pollution	Environment	Negative	Permanent	Particulate matter (PM <sub>2.5</sub> , PM <sub>10</sub> ), carbon monoxide (CO), carbon dioxide (CO <sub>2</sub> ), sulphur dioxide (SO <sub>2</sub> ), hydrogen sulphide (H <sub>2</sub> S), silica (SiO <sub>2</sub> ), nitric oxide (NO), nitrogen dioxide (NO <sub>2</sub> ), nitrous oxide (N <sub>2</sub> O), ammonia (NH <sub>3</sub> )
7.	Noise pollution	Environment	Negative	Temporary	Explosions, heavy machinery
8.	Vibration pollution	Environment	Negative	Temporary	Explosions, heavy machinery
9.	Proximity	Environment	Negative	Permanent	Exploited area (1,161 km <sup>2</sup> and 200 m

N°	Impact	Domain	Type	Duration	Description
					depth)
10.	Conflicts	Environment	Negative	Temporary	Functional incompatibility with the national park and Arnota monastery
11.	Biodiversity	Environment	Negative	Permanent/ Temporary	Loss of species and habitats, reduction in the range of species and habitats, damage to the conservation status of species and habitats
12.	Production capacity	Economic	Positive/ Negative	Temporary	From 360,000 tons per year in 1970 to 900,000 tons per year in 1989 and to 2 million tons in 2017, permanently closed in 2024
13.	Local investments	Economic	Positive	Permanent	Developed infrastructure through railways, road network for transporting products
14.	Funds to the local budget	Economic	Positive	Temporary	Payment of local taxes and fees
15.	Job reduction	Economic	Negative	Temporary	Approximately 400 people were laid off
16.	Affected communities	Social	Negative	Temporary	Approximately 30,000 people were affected
17.	Illnesses	Social	Negative	Permanent	Silicosis, respiratory diseases

From the environmental point of view, the results of the study indicate that limestone exploitation at the Bistrița quarry has significantly degraded environmental components, including biodiversity, water, air, soil. The Vâlcea County Local Action Plan (Vâlcea Environmental Protection Agency, 2021) reports major ecological alterations in the Arnota Massif, with the quarry spanning 161 hectares and reaching depths of 200 meters. Tailings make up approximately 40% of extracted material, leading to landscape transformation and visual pollution.

Anthropogenic disturbances, such as blasting and excavation, have triggered erosional and gravitational processes, increasing land instability and the risk of landslides (Adevărul, 2010; Stringfield, Rapp, 1976; Ekmekci, 1993; LaMoreaux, Powell, LeGrand, 1997), notably in 1970 and 1972. These events altered the course of Costești Creek, necessitating hydraulic regulation. In 2024, stabilization of hazardous tailings dumps was undertaken (Făulete, 1977). Unstable tailings dumps have been identified as potential contributors to such hazards. In response, stabilization works were undertaken in 2024 to mitigate these risks (Costești Local Council, 2024).

Pollutants from quarrying operations, including silica, SO<sub>x</sub>, NO<sub>x</sub> and alkaline dust, contribute to soil degradation (altering pH and reducing fertility) and water contamination (pH, turbidity, chemical composition) (Chenot et al., 2018). Disruption of hydrological and physicochemical conditions affects biodiversity and human health

(Fugiel et al., 2017). Water and soil quality are further compromised by chemical emissions such as CH<sub>4</sub>, phenols, Zn, Cu, and Pb. The impact is not only at local level, but regional because of the potential of the contamination of soil and then the infiltration to the groundwater which has effects to a higher zone than the exploited one (Mouloudi et al., 2025).

Quarrying processes, including blasting, crushing, excavation, and transportation, also contribute to air pollution that is exacerbated by emissions of CH<sub>4</sub>, CO<sub>2</sub>, CO, particulate matter (PM<sub>2.5</sub>, PM<sub>10</sub>), and various nitrogen compounds (European Environment Agency, 2024). Noise from drilling and transport, as well as vibrations from blasting, disrupts local fauna (Oggeri et al., 2019; Nesticò et al., 2024). Blasting operations in quarries affect the environment in five distinct ways: through the propagation of seismic waves, air shock waves, the ejection of fragmented rock, the release of dust, and the emission of gases (Fodor, 2006).

Ecologically, quarrying reduces photosynthetic activity and biomass production, degrades habitat quality, and threatens protected species such as plants, herpetofauna (*Bombina variegata*), chiropters and large mammals (*Ursus arctos*, *Lynx lynx*, *Canis lupus* - Figure 3; Kogayon Association, 2016; Ministry of Environment Waters and Forests, 2016). Studies showed that this kind of activities have a medium impact on plants and faunal population (Pop et al., 2025). Sustainable management practices are imperative to mitigate these impacts and uphold biodiversity conservation within national and international frameworks.

From the economic point of view, limestone extraction at the Bistrița quarry has fostered notable development in the Costești commune, particularly through improved transportation infrastructure (roadway and railway). Production increased from 360,000 tons in 1970 to 2 million tons by 2017 (Costești Local Council, 2024), that created several key benefits include revenue generation, budgetary contributions, and affordable construction materials. However, these gains entail considerable environmental costs. Pollution has extended beyond the quarry, and conflict has arisen due to its proximity to Buila-Vânturarița National Park and Arnota Monastery. A proposed 2008 expansion, requiring reclassification of 29 hectares, highlighted this tension (environmental conflicts), leading to partial rezoning as a sustainable development area (Kogayon Association, 2016; Mitrache, 2018). The ongoing unsustainable use of non-renewable resources underscores the need for responsible practices. Operationalizing SDG 12 through localized initiatives is crucial to ensure long-term environmental equity and resilience for future generations.

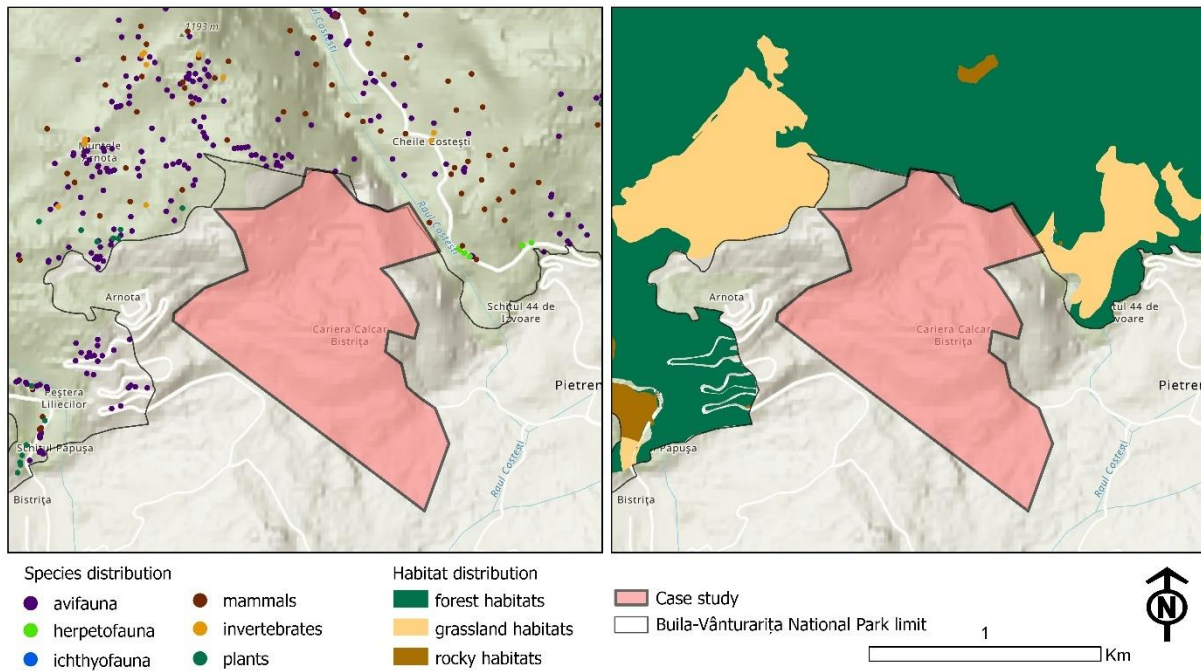


Figure 3. Species and habitat distribution in Buila-Vânturarița National Park near the case study

From the social point of view the results show that limestone exploitation at the Bistrița quarry has had more adverse than beneficial effects on the local population of Costești (Poiană, 2024). Sociological surveys confirm the significant socio-economic impact of the quarry's closure, both at the local and county levels. The cessation of operations resulted in widespread job losses among direct employees and subcontractors, affecting approximately 30,000 individuals when including their families (Befu, 2017).

Beyond economic repercussions, the quarrying activities have also had serious public health implications. Airborne particulate matter (dispersed by wind or released during the transportation of limestone) has posed long-term health risks to the local population (Costești Local Council, 2024; Poiană, 2024). Prolonged exposure to fine dust particles containing silica has been linked to severe respiratory illnesses (Fugiel et al., 2017; Nesticò et al., 2024). According to a former quarry worker numerous of his colleagues have reported suffering from pulmonary conditions, with silicosis being the most prevalent disease attributed to the inhalation of silica-laden dust.

#### 4. DISCUSSION

Considering the European and the national legislation, we need to have an Environmental Impact Assessment (EIA) for any kind of resource exploitation. As Lee et al. (2024) show in their study, the quarry lifecycle creates a cause-effect chain, that is

not limited only on the environmental aspects such as noise, pollution, aesthetics, geomorphology, air, water, soil etc. but also have implication on the human wellbeing ecosystem (healthy, safety, infrastructure).

All of the sustainability domains are impacted mostly negative and for a long term by the quarry exploitation practices, but we need to take in consideration to improve this kind of activity if we want a more positive impact rather than a negative one (Nesticò et al., 2024). When we cannot improve the exploitation and we are in the last cycle of the exploitation we should use different kind of solution to make it sustainable and with less impact on the environment.

The current state of the quarry indicates an abrupt closing of operations, with the potential for resumption pending license renewal. The site presents an evident contrast to the natural wooded landscape of the southern Arnota Massif, now severely altered by extensive excavation from base to peak. The barren, industrial terrain is visually unappealing, with only sparse pioneer vegetation. The southern slope appears as a scar on the Căpățâni Mountains, reflecting the profound environmental impact of human activity. The Bistrița quarry is characterized by unstable tailings dumps that pose a risk of collapse onto adjacent roads. A conveyor belt runs alongside the road, emphasizing ongoing limestone processing. Although access to the exploitation zone is restricted, heavy machinery is visible at multiple levels (

Figure 4).

Rainfall leads to water accumulation in excavated areas due to the permeability of limestone. Active geomorphological processes include runoff, gravel collapse, and occasional landslides or seismic activity. According to the Administration of Buila-Vânturarița National Park (Kogayon Association, 2016; Ministry of Environment Waters and Forests, 2016), the quarry lies in a tectonically active zone with steep fault planes and mylonite zones, increasing the risk of slope failure and landslides involving both carbonate and sedimentary rocks beneath the waste dump.



Figure 4. Field photos of the Bistrița limestone quarry

The abandoned Bistrița limestone quarry forms a unique landscape where technological and environmental heritage intersect, creating a form of patrimonial pluralism that calls for innovative protection and valorisation strategies. According to Talento et al. (2020) quarry recovery approaches can be categorized by intended use: naturalistic, recreational, cultural, educational, or productive. The proposed solutions (Table 4), adapted from the literature to this case study, require long-term investment and comprehensive analysis and monitoring. Implementation must align with the 'polluter pays' principle and comply with the EU Regulation on Nature Restoration (European Parliament and Costești Local Council, 2024), part of the European Action Plan for Nature, aiming to balance economic development and environmental protection by 2050.

The scientific literature shows that there are different approaches for sustainable practices on quarry exploitation that involve ecological restoration, rehabilitation, reforestation and even reconversion of the land. *Ecological restoration* refers to the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed, aiming to return it to its original structure, function, and biodiversity (Fan et al., 2025). *Ecological rehabilitation* involves improving the ecological integrity of a degraded ecosystem without necessarily restoring it to its original state. It focuses on re-establishing key functions and processes to support biodiversity and ecosystem services (Osterkamp, Hupp, 2010). *Reforestation* is the process of replanting trees in a deforested or degraded area, typically using native or ecologically appropriate species, to restore forest cover and associated ecological functions (Pragya et al., 2017). *Reconversion* refers to the transformation of land from one use to another, a former extractive site to ecological, agricultural, or recreational purposes, through planned interventions that support sustainable land use, social and environmental recovery (Talento et al., 2020).

In this particular context, the integration of the proposed solutions may serve as a medium to long-term strategy for reshaping both economic and environmental frameworks. However, the active engagement and consensus of local stakeholders remain essential in determining the priorities and requirements for future generations. These solutions collectively support the achievement of *SDG 12*, while also contributing to *SDG 13*, *SDG 14*, and *SDG 15*. Quarry exploitation practices can be environmentally, economically, and socially sustainable both during their operational phase and, more importantly, following closure provided that comprehensive and forward-thinking approaches are implemented.

Table 4. Identified solutions for the degraded environment as a result of limestone quarrying

N°	Solutions	Description	Advantages	Disadvantages	Reference
1.	Ecological restoration of the relief	Restoration of the natural topography in the southern Arnota Massif quarry area, integrating it with the surrounding landscape through terrain reshaping. This process involves slope stabilization and may require topsoil replacement.	Promotes naturalistic restoration of the quarry site; Mitigates morphological impacts of excavation; Reduces vulnerability to natural hazards; Enhances potential as a habitat for avifauna; Improves visual and ecological landscape quality.	Demands a cost-intensive ecological assessment to guide appropriate technical interventions; Requires sustained, long-term financial investment; May involve heavy machinery, contributing to environmental degradation through vibrations and NOx emissions from diesel combustion.	Rosiere et al. (1989) Mouflis et al. (2008) Talento et al. (2020) Legwaila et al. (2020)
2.	Reforestation	Artificial reforestation of the degraded site using native species, alongside <i>Populus alba</i> , <i>Quercus rubra</i> , and <i>Rosa canina</i> , which act synergistically to support partial restoration of key ecosystem functions.	Supports naturalistic quarry restoration; Mitigates natural disaster risks; Contributes to microclimate regulation; Reduces soil erosion; Enhances watershed stability; Restores habitats for native species; Promotes biodiversity recovery and enhancement; Improves landscape aesthetics.	Requires a cost-intensive and complex ecological assessment to inform appropriate vegetation strategies.	Talento et al. (2020) Semeraro et al. (2021)
3.	Ecological rehabilitation	Partial restoration of key ecosystem functions involves soil decontamination, land reshaping and stabilization, soil rehabilitation, revegetation with native species, and, if necessary, reintroduction of native fauna	Facilitates naturalistic quarry restoration; Promotes biodiversity recovery and enhancement; Reduces susceptibility to natural disasters.	Requires a cost-intensive, in-depth ecological assessment of the site; Long-term monitoring may also entail significant financial investment.	Burger (2008) Zhang et al. (2024)
4.	Reconversion	Enhancing the rehabilitated area's appeal to promote ecotourism, including its	Creates opportunities in both ecological and economic sectors; Supports the	Tourism-related activities may lead to environmental pollution, potentially	Gandah and Atiyat (2016) Talento et

N°	Solutions	Description	Advantages	Disadvantages	Reference
		integration into a sustainable tourist trail. This approach leverages the site's overlap with Buila-Vânturarița National Park and its proximity to cultural landmarks such as the Arnota and Bistrița Monasteries and the Cave of Grigore Decapolitul.	development of ecological tourism.	impacting all ecosystem components.	al. (2020) Ivasyshyna (2024)

Regarding the limitations of the present study, it is important to note that the authors did not have access to confidential data provided by the mining company. Quantitative information on the annual limestone extraction from the Bistrița quarry was obtained from historical sources, some of which date back to the communist period (1947–1989). Due to the lack of publicly available official extraction reports, the authors were unable to verify these figures through direct consultation of primary sources and the information was used with caution, acknowledging that this limitation could affect the accuracy and depth of the study's findings.

In addition, a significant limitation of the present study lies in the absence of direct environmental measurements and laboratory analyses concerning the quality of air, water, and soil within the limestone quarry area, which restricts the ability to comprehensively assess the ecological impact of extractive activities.

## 5. CONCLUSIONS

In conclusion, the exploitation activities at the Bistrița limestone quarry have exerted a considerable impact on various environmental components, leading to imbalances within the microecosystem of the Arnota Massif, as well as socio-economic repercussions for the local community. Despite the existence of numerous European directives and national legislation aligned with sustainable development goals, the area remains in a state of degradation due to insufficient implementation of environmental measures. The solutions proposed in this study may serve as a foundation for future research aimed at identifying favourable conditions and assessing the feasibility of ecological rehabilitation, not only for this specific case study but also for similar quarry sites.

The present study underscores the dual nature of limestone exploitation, which entails both advantages and disadvantages, depending on the perspective from which it is evaluated. Over the course of approximately 78 years, human activity within the

Arnota Massif has resulted in the extraction of millions of tons of limestone, employing methods that have significantly impacted the environment. These practices have led to the transformation of the natural landscape, the disruption of local ecosystems, and the pollution of the environmental components. The consequences have also extended to the social and economic domains, particularly affecting nearby communities that have experienced sustained economic growth, at the expense of environmental integrity.

Achieving sustainable exploitation of limestone resources requires the prior completion of comprehensive studies and the development of appropriate documentation to assess the impact on all environmental components. This process must be followed by responsible spatial planning of extraction sites and the continuous monitoring of both extractive activities and their associated pollution effects. The measures proposed in this study aim to protect, conserve, and sustainably valorize the natural heritage of the Arnota Massif, especially in areas affected by previous quarrying operations.

Ultimately, the study highlights the necessity of integrating sustainable development objectives into the field of mineral resource exploitation. It also advocates for the active involvement of local communities, not only in resource extraction and processing, but also in monitoring environmental impacts and contributing to the restoration of degraded areas. Promoting community engagement and raising public awareness regarding the environmental consequences of industrial activities are essential steps toward ensuring a just transition to sustainable mineral resource management.

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