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Not Mining Sterilization of Explored Mineral Resources. The Example of Native Sulfur Deposits in Poland Case History

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Abstract: The sterilization of mineral resources makes considerable amounts inaccessible for future use and may be a barrier to the free supply of commodities. During the exploitation of mineral deposits, some parts of their resources become sterilized as inaccessible because of natural hazards or unfavorable economic conditions. Not mining land use and the social opposition against mining is the purpose of sterilization of considerable demonstrated mineral resources of deposits not yet engaged in exploitation. The native sulfur deposits in Poland are a good example of such "not mining" sterilization, which makes a considerable part of known resources inaccessible. On the northern border of the Carpathian Foredeep within the Miocene gypsum formation, the systematic exploration had demonstrated about 1 billion tons of sulfur resources located in the deposits of varied dimensions. The sulfur opencast mining and underground melting (the modified Frasch method) flourished from 1958 up to 1993. The increasing sulfur supply, recoverable from hydrocarbons, caused the closing down of sulfur mines, leaving a place with considerable untouched resources. About 67% of sulfur resources left by closed mines and of other explored but not exploited deposits are sterilized by the advancement of settlements, industrial plants, road construction, and by social opposition against mining.

Keywords: resources; sterilization; self-guarding; sulfur deposits; Poland

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1. Introduction

The sterilization of resources is understood as a lack or loss of the possibility of their exploitation [1]. Most often, it occurs in areas where existing land use excludes any quarrying or underground mining [2–4]. The lack of mining possibilities may be demonstrated in a land-use plan [5–7]. However, geological data supported by exploration results often demonstrate mineral resources in advance to the planning of land utilization for such public purposes as residential buildings, road construction, and farming. Existing or planned land-use can make mining an unwanted activity and make considerable amounts of explored resources inaccessible for exploitation in the future. Serious sterilization of mineral resources also occurs when there is strong social opposition to mining, which makes it unacceptable. Such sterilization occurs in the case of explored deposits not involved in exploitation, which are the conflict area with planned or performed land use, or with the environment protection exigencies. This may be a barrier to the free supply of mineral commodities. It is a matter of concern and has provoked attempts for resource self-guarding against non-mining land utilization [3,8–10]. The resources not adequately protected may be stepwise sterilized and lost. The resources sterilization before the start of mining operations can make their considerable part inaccessible for future mining. It is a serious problem that should be considered in the evaluation of resource availability, and it makes self-guarding of their not sterilized an important task. The sterilization threat is commonly signalized, but their real results are not presented.

The native sulfur deposits in Poland are a good example of varied modes of "non-mining" resource sterilization, which dramatically decreased the quantity available. It is the perspicuous case history of consequences of the lack of sufficient resources self-guarding.

2. Sulfur Deposits in Poland, Geological Setting Exploration History and Mining

Native sulfur deposits in Poland occur in the northern border of Carpathian Foredeep within the Miocene gypsum formation. They are formed through gypsum reduction by hydrocarbons under the presence of sulfate-reducing bacteria. They occur on uplifted structural elevations, where gypsum is completely or partly replaced by sulfur-bearing limestone [11–13].

Sulfur mining in Poland has been documented since 1415. Until the beginning of the twentieth-century, small deposits, whose resources varied from some ten to a hundred thousand tons, were temporally exploited [14,15]. The possibility of the occurrence of greater resources in the Miocene deposits on the northern border of the Carpathian Foredeep was assumed by prof. Karol Bohdanowicz, the director of the Polish Geological Survey [16]. However, it was not until 1953, when in the borehole drilled for recognition of subsurface geology east of the Vistula River and the town of Tarnobrzeg, sulfur-bearing limestone of considerable thickness was found. Soon after the systematic exploration started, the methodology of which is based on the theory of epigenetic sulfur deposit formation [11]. During 40 years, from 1953 to 1993, about one billion tons of sulfur resources were demonstrated, located in the six separate areas of varied dimensions [17]. The two greatest are divided into seven segments called separate "deposits" (Figure 1). The new sulfur opencast mining started in 1958 and ten years later, e.g., in 1968, by underground melting, Frasch method, modified to the local geological conditions [18]. The sulfur production rapidly increased and gained a top value of over 5 million tons per year from 1978 to 1988. The increasing sulfur supply, recoverable from hydrocarbons, caused the sharp decrease in the demand for mined sulfur and closing down most mines. At the beginning of the twenty-first century, only one sulfur mine, the "Osiek" mine in Poland, has remained active to date. In the abandoned mines, about 222.4 million tons of explored resources were used, and 114.0 million tons of raw sulfur were produced with a 50% average recovery coefficient. The 42.3 million tons were lost, remained in place, as technically not accessible or/and economically not recoverable. 176.4 million tons of sulfur were left untouched in the deposits, the exploitation of which was terminated or interrupted.

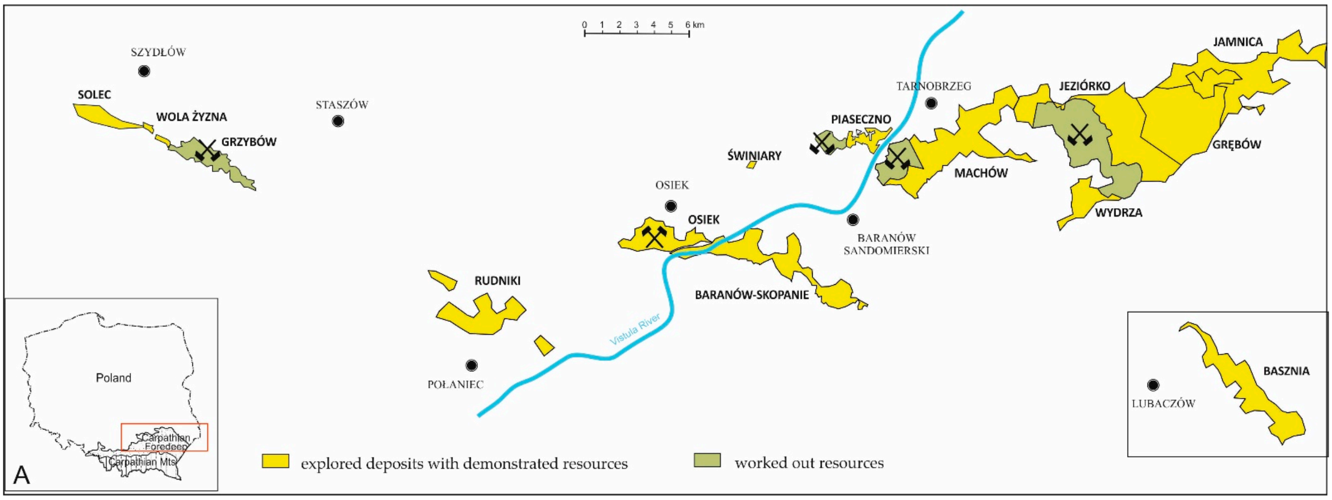

Figure 1. Location of native sulfur deposits ([19], by permission, modified); A—Location of the studied area.

The application of both methods of sulfur mining depends on the depth of deposit location:

- Opencast up to the depth of about 70 m;

- Borehole, by underground melting below 70 m and up to the depth of about 300 m (the maximum depth of known sulfur deposits).

Both methods of exploitation are not environmentally friendly but in varied modes [20,21]. The opencast mining transforms the landscape completely with a deep and widespread pit, and a change of underground water table. The accompanying noise and air pollution are limited to the mining area. After the termination of mining operations, the former pit is prepared for transformation into an artificial lake, which becomes a valuable component of a new landscape and environment, wild bird habitat, and recreational area [22].

Underground sulfur melting is accompanied by ground subsidence [23], but it does not transform the landscape substantially. The vegetation is partly removed on the mining field by mining equipment (boreholes, pipelines, and sulfur storage sites). The soil pollution by sulfur contamination occurs at the mining field. The environmentally unfriendly mining impact is mitigated after the termination of mining operations [24,25]. The soil-acidification, if it occurs, may be decreased by a lime-based recultivation, and agriculture or forestry may be restored. The uneven ground surface makes it difficult for construction, but it has a landscape favorable to wildlife habitats. The areas of deep subsided ground become local small lakes, i.e., favorable sites for birds and reptiles.

The mined sulfur is characterized by its high purity, hardly affected by sulfur recoverable from crude oil or natural gases. This makes it a valuable commodity for the chemical industry and fertilizer production. Recently, in 2019 the new "Basznia" mine was opened [26], and the other one is planned. The explored deposits, untouched by mining, are still interesting for future exploitation. However, the known sulfur deposits were explored, and their resources were reported several years before now. In the meantime, the advancement of settlements, industrial plants, and road construction made considerable areas of known deposits inaccessible for mining. The real resources that may be converted to recoverable reserves decreased considerably. They are additionally limited by social opposition against mining. The protection of non-sterilized resources untouched by previous mining becomes an important task for creating the possibility for their exploitation in the future.

3. The Source of Data on Sulfur Resources Sterilization, Study Methods, and the Aim

The basic problems of the protection of sulfur deposit resources have already been presented [20]. It was demonstrated that only their small part might be accessible for exploitation in the future. Considerable resources were sterilized. In a recent paper, we presented the detailed analysis of varied purposes and modes of such sterilization, supported by a cartographic presentation.

The data for sterilization sulfur resources analysis include:

- Reports of exploration results presented as "geological documentation of deposits" prepared in a uniform standardized manner defined by the Geological and Mining Law and stored in the National Geological Archive lead by Polish Geological Institute (Polish Geological Survey);
- The data on mineral resources of Poland published yearly since 1952 by the Polish Geological Institute [27];
- Feasibility studies and technical reports of mine closure prepared by mining enterprises;
- Land-use planning documents according to the Act on Spatial Planning and Land-use Management [28].

The basis for sulfur resources evaluation presented in the "geological documentation" of each deposit was the results of their exploration by 1076 cored boreholes drilled in a more or less rectangular grid, with an average 200 m distance (boreholes locations are presented in Figures 2–6). The polygonal method was used for resource calculation. The same data were used for the evaluation of the number of sterilized resources. The delineation of the areas of occurrence of sterilized resources is based on the feasibility studies, technical reports of mines closure, and documents for land use planning.

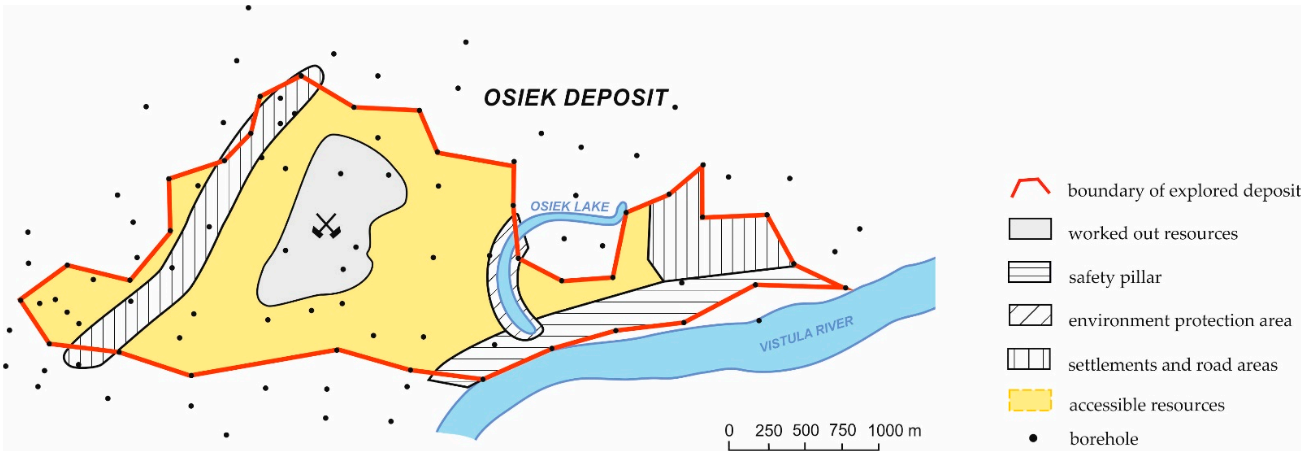

Figure 2. The "Osiek" sulfur deposit.

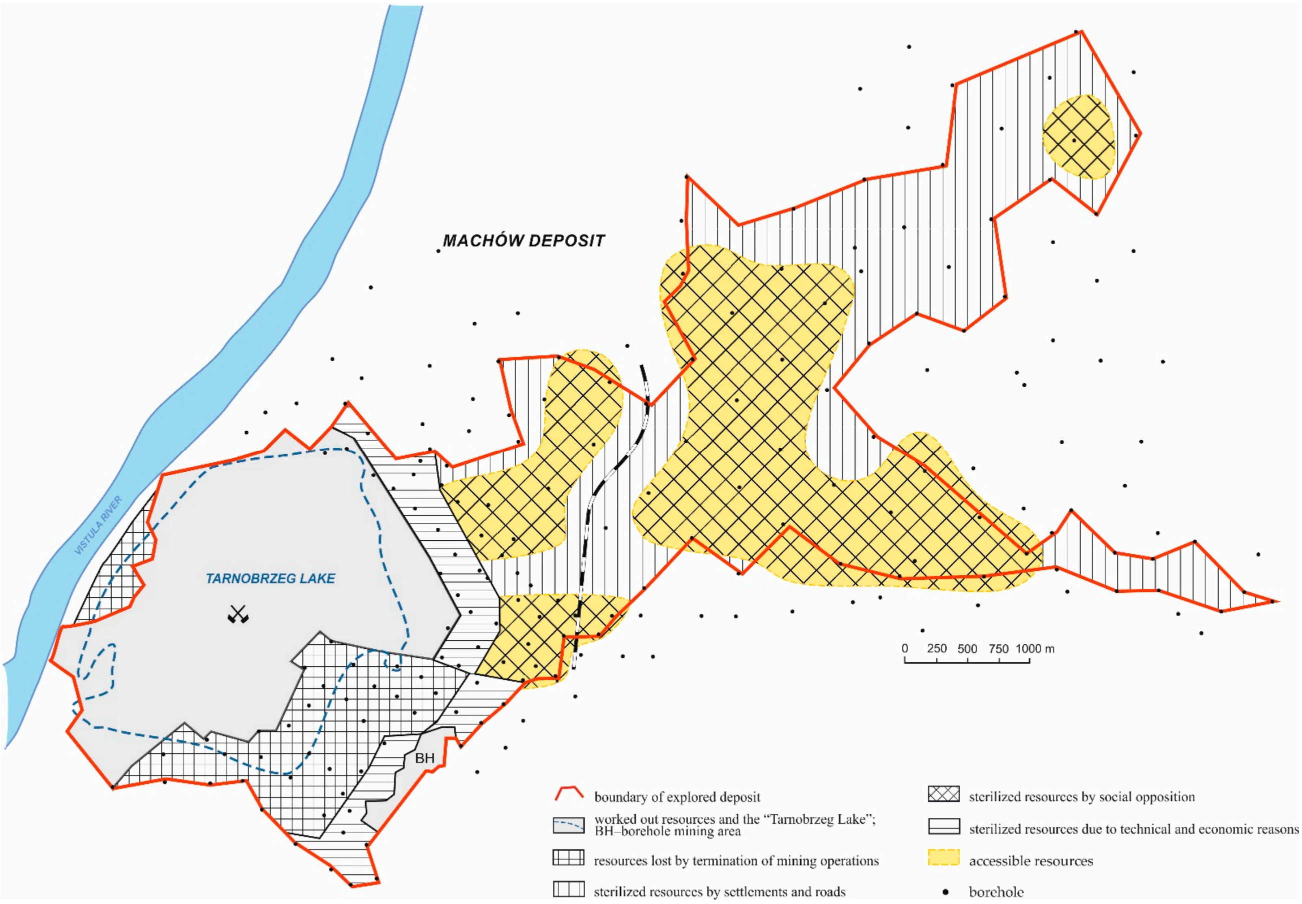

Figure 3. The "Machów" sulfur deposit.

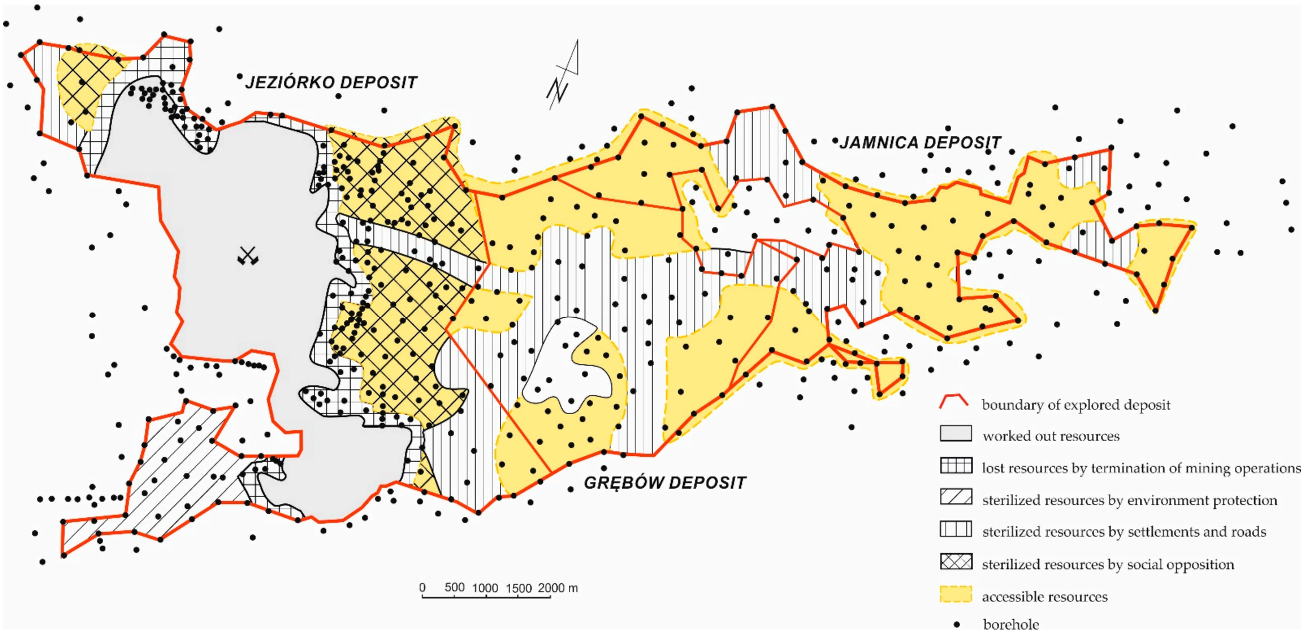

Figure 4. "Jeziórko", "Grębów", and "Jamnica" sulfur deposits.

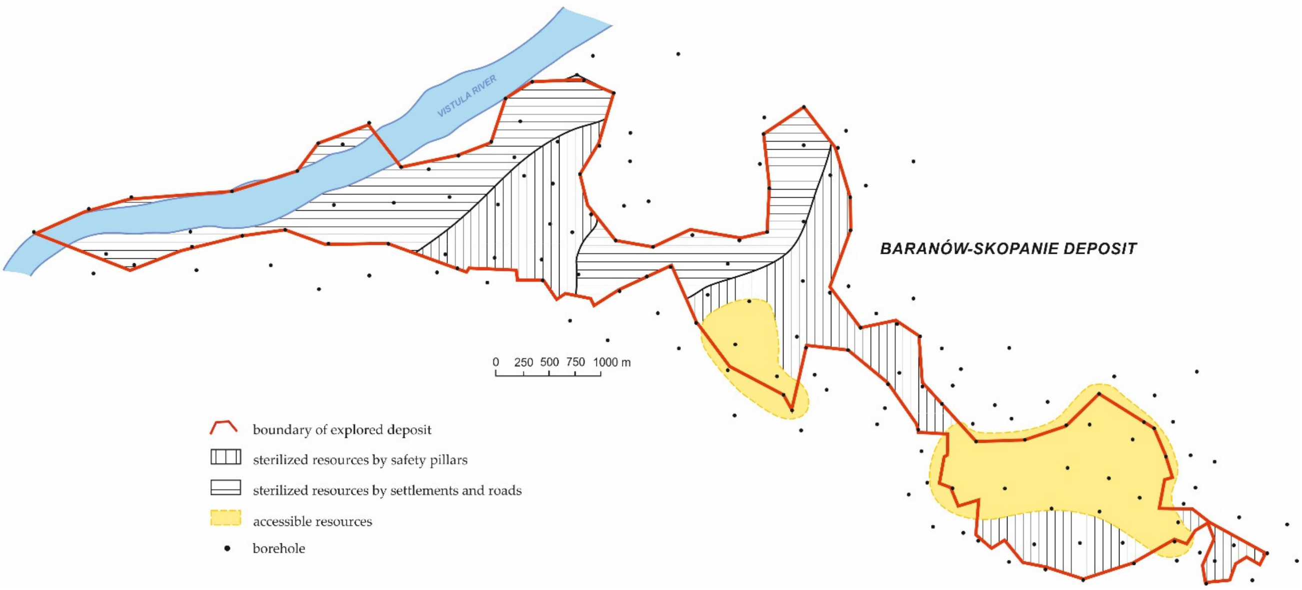

Figure 5. The "Baranów-Skopanie" sulfur deposit.

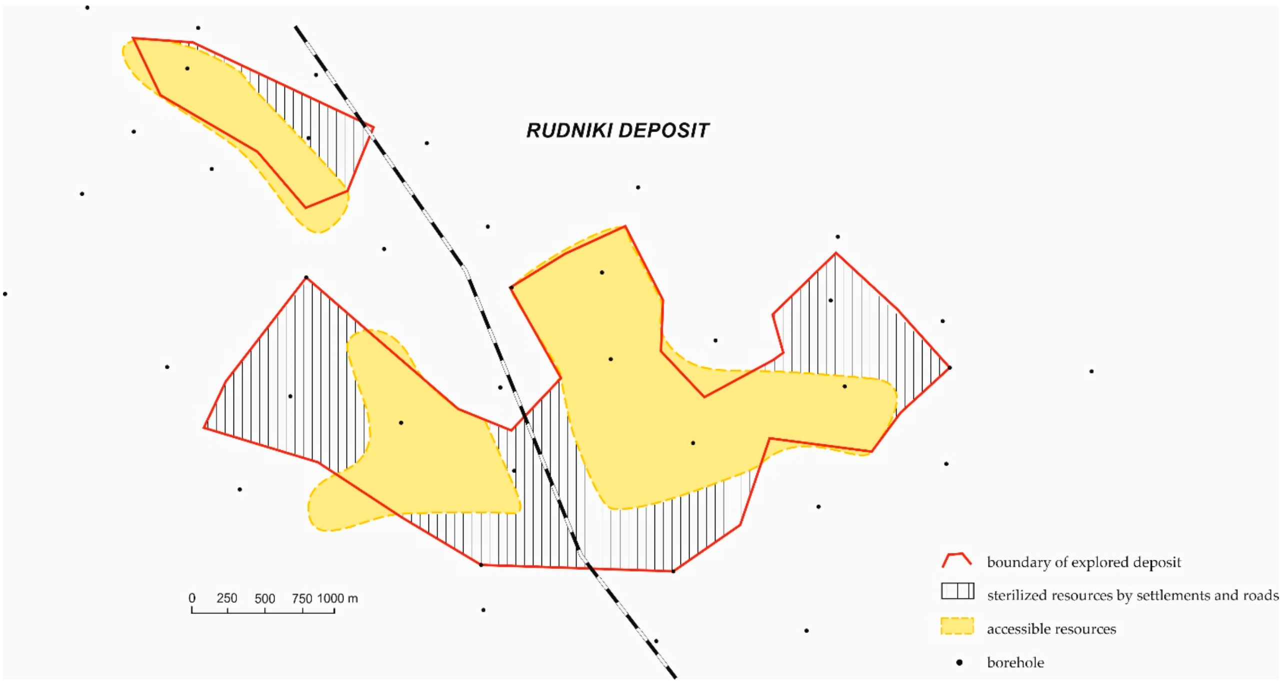

Figure 6. The "Rudniki" sulfur deposit.

4. Results of Sulfur Resources Sterilization Analysis

Sterilization of resources starts at the planning of mining operations stage. Sterilized parts consist of the safety pillars designed for defending the settlements, the sites of protected environments, and other sites for which protection is necessary. It is a well-known and inevitable reason for the loss of resources. It decreases the recoverable resources within the mining field but does not affect those located beyond it. In the still active "Osiek" mine, about 27% of resources are sterilized by a safety pillar bordering the Vistula River bed, by nature protection exigencies (natural swamp and bird habitat in the "Osiek Lake"), and by existing settlements (Figure 2).

The explored resources located beyond the mining fields are sterilized by varied modes of land use, whose purpose and share are varied across individual deposits. Sterilization may exclude any mining activity or make the area of deposit occurrence unfavorable for mining due to social opposition against it. During the process of closing down mines, some parts of their resources are sterilized and not exploitable because of technical and public safety exigencies or as permanently uneconomic. After closing down sulfur mines, about 176 million tons of demonstrated resources remained untouched. However, land use, environmental, and technical restraints make about 56 million tons of the resource sterilized, and social opposition makes an additional 120 million tons non-exploitable (Table 1).

The "Machów" and the "Jeziórko" deposits present the sterilization of resources after the termination of mining operations due to technical, economic, environmental, and social restraints.

The "Machów" deposit was opencast exploited until 1992, and mining stopped because it was demonstrated uneconomic. The remaining deeper part of the deposit may be designed for the borehole mining, which operated in the eastern part of it up to 1993.

Formation of the artificial lake on the area of the former pit, prepared with the surrounding territory for recreation purposes (the "Tarnobrzeg Lake"), made protecting it by surrounding safety pillars necessary, where occurs about 38 million tons of sulfur. Existing settlements and social opposition against mining in the outskirts of Tarnobrzeg completely sterilized the remaining 55 million tons of the resource (Figure 3).

Table 1. Sterilized sulfur resources. Data according to [20,27], modified and completed *.

Sulfur Deposit	Resources (mln ton)										
	Reported Resources	Mining Method and Period	Extracted Sulfur	Extracted and Lost in Mining Field	Technical-Economic Sterilization Forced by Terminated Exploitation	Resources Remaining after Termination of Mining	Sterilized Resources				Resources after Sterilization
							Technical-Economic	Settlements, Road Construction	Environmental	Social	
Piaseczno	9.9	Opencast 1958–1972	5.6	5.6	4.4						
Grzybów	51.5	Borehole 1968–1995	26.4	50.1		1.3	1.3				
Machów	109.2	Opencast 1967–1992	12.4	15.2	20.8	4.6	4.6			9.3	
		Borehole 1985–1993	0.8	1.1	17.1	16.7		16.9		24.2	
Jeziórko	270.3	Borehole 1968–2001	74.9	150.4		120.0	10.0		22.8	87.1	
Grębów	90.8					90.8		32.4 (64.0 **)			58.4 (26.8 **)
Jamnica	51.7					51.7		9.5 (29.5 **)			42.2 (22.6 **)
Wola Żyzna	1.3					1.3		1.3			
Solec	5.6					5.6	5.6				
Baranów-Skopanie	169.5					169.5	70.3	70.2			29.0
Rudniki	53.1					53.1		19.1			34.0
Basznia	109.5	Borehole 1978–1993	0.6	1.0	6.5	102.0					102.0
Total	922.3		120.6	223.4	48.7	616.8	91.9	149.0	23.0	121.0	266.0

* The reported resources of data may be biased by uncertainty error up to a few %, ** additionally expected.

The “Jeziórko” deposit is the eastward continuation of the Machów deposit. It was exploited by the borehole underground melting until 2001. About 75 million tons of sulfur were exhausted, and additional 79 million tons remained in place as unrecoverable. The southwestern part of the deposit with 22.8 million tons of sulfur must be sterilized because of the location on the territory of protected black stork habitat and the site of underground water supply for the town of Tarnobrzeg. The other 10 million tons of sulfur resources located at the deposit borders are technically inaccessible. After the mine closure in the eastern non-exploited part of the deposit, 87 million tons of sulfur remain (Figure 4). The attempts to restart the mining have failed due to the lack of acceptance by the local authorities. This part of the deposit must be considered sterilized.

The resources explored but not engaged in mining are sterilized mostly due to the land use by the settlements and construction of a road network. It is the case with the “Baranów-Skopanie” deposit. It was explored, and its resources reported as indicated. A part of the resources close to the Vistula River right bank is inaccessible because of their location within the zone of necessary anti-flooding safety pillar. Safety pillars were also designed parallel to the border of the town of Baranów and a historical monument, a castle. The advancement of housing of Baranów and surrounding settlements, as well as the construction of roads network, made most of the western part of deposit resources and the eastern part of it inaccessible. As a result, from 169.5 million tons of explored sulfur resources, only 29 million tons remain accessible for mining, located in two separate areas with 6.7 and 22.3 million tons, respectively (Figure 5).

The resources of two deposits located eastward from the “Jeziórko” deposit, i.e., “Grębów” and “Jamnica”, are partly inaccessible due to the settlements and roads network on the territory of their occurrence. The sterilization of about 63.97 and 29.04 million tons of sulfur is expected; their demonstrated total quantity is 70.5% and 56.2%, respectively.

Resources of small deposits “Solec” and “Wola Żyzna” (Figure 1) are completely sterilized due to the settlement land use and the remaining part being uneconomic.

The “Rudniki” deposit is a special case of consecutive resource sterilization. It is located close to the still-active “Osiek” mine, and it is interesting as a reserve base for the future continuation of mining operations. There were documented resources of 53.1 million tons, classified as inferred (C_2 category). The railroad construction and development of local settlements had sterilized 3.15 million tons of sulfur resources in the area, which divide the main part of the deposit into two separate parts. The consecutive spreading of surrounding villages and electric plants caused additional sterilization of about 15.95 million tons. After such sterilization, 34 million tons of sulfur resources remain, and they are located in three fields, with 6.4, 7.0, and 20.6 million tons, respectively (Figure 6).

The example of the great “Basznia” sulfur deposit located close to the state border with Ukraine is different, as there is the total acceptance of mining by the local authorities and the society. The sterilization of resources by local settlements is small, and 5.84 million tons of the total demonstrated resources were recently assigned to the newly opened “Basznia” mine. The remaining ones, located on farm or forest lands, may be self-guarded for future use.

5. Discussion

The presented sulfur deposits case history demonstrates varied modes of resource sterilization (Table 2). They are of three types:

- Permanent as a result of not removable infrastructure (settlements, industrial plants, and road networks);
- Conditional due to social or administrative restraints that may change in time;
- Semi conditional due to environmental restraints, which may be overturned if protected components of the environment disappear.

Table 2. The share of sterilized resources in respect to explored (demonstrated) ones.

Sterilization Mode	Percent of Explored Resources	Percent of Resources Remained after Termination of Mining	Remarks
Lost in mining fields	24.2	36.2	
Technical-economic forced by mining termination	5.3	7.9	
General technical-economic	10.0	14.9	Lack of technical or economic possibility of mining
Settlements, road construction	16.2	24.2	
Environmental	2.5	3.7	
Social opposition	13.1	19.6	

Conditional sterilization may be temporary if the social opinion changes. The environmental restraints may also sometimes be removed, e.g., due to changing wildlife habitats. The social opposition against mining is a common sterilization method [29–32] and makes considerable parts of resources inaccessible for utilization. It may be mitigated by social dialogue, which should be supported by education at each teaching level on the importance of mineral resources for the production of goods necessary for everyday life.

The presented example of sulfur deposits demonstrates that sterilization may substantially decrease the resources accessible for mining, which should be self-guarded for future use. However, there arises a problem of the length of the self-guarding period if the time of possible use of the explored resources is unknown. It is a problem not discussed and resolved yet. The most valuable resources should be self-guarded as long as they may be used for the production of a demanded mineral commodity. The coal deposits are a good example. Their self-guarding was postulated as long as they are the main source of mineral fuel. The general attempts to remove the use of mineral fuels due to air pollution leads to questions about the necessity of their self-guarding continuation. In the case of other mineral resources, the expected time of their utility is hard to predict. In the case of the industrial rocks, whose utility may be expected constant and the resources are much greater than expected demand, their valorization may be the way for defining the time-dependent self-guarding limits [33]. For more valuable resources, e.g., rare metallic ores, especially considered as critical, the self-guarding may be declared as permanent.

The discussed sulfur case is a special one. Recently the great supply of sulfur recovered from hydrocarbons make the demand for mining sulfur limited. The expected future decrease in crude oil and natural gas resources and their decreasing use in favor of green energy will limit the recovered sulfur supply. In not so distant future, the increasing importance of native sulfur deposits may be expected. A great amount of explored sulfur resources have been sterilized to date. The social opposition against sulfur mining is very strong, and the change of such opinion is not expected. The conditional sterilization should be considered permanent in the predictable future. This makes the resources located outside the sterilized parts of deposits valuable for future sulfur supply. Their limited amount proves the need for their actual protection.

6. Conclusions

Mineral resources formed by natural processes are not a renewable part of the environment and occur in the Earth's crust in limited quantity. The possibility of their utilization as a source of mineral raw materials for the production of varied goods, necessary for everyday life and sustainable development, is a matter of concern of mineral policy at the national and local community levels [1,3,4,34].

The sulfur deposits' case history in Poland demonstrates how a lack of sufficient protection of the areas of their occurrence against land utilization excluding their exploitation, and social opposition against any mining activity, dramatically decreases future mining availability of explored resources. The non-mining land use, environmental protection exigencies, and the social opposition against mining caused the sterilization of 24%, 4%, and 20% of native sulfur resources, untouched by mining operations, respectively. The expected constant demand for high purity native sulfur from natural deposits for the chemical and fertilizer industry makes self-guarding of remaining resources an important task.

The knowledge of possible modes of resource sterilization should allow for predicting and counteracting it. The parts of explored deposits designed for protection should be surrounded by a "security belt" within which any land use, opposite to mining, should not be allowed. Such a mode of protection strategy was proposed in Poland [29], the United Kingdom [6], and it is recommended as a standard procedure in the EU countries [35]. The explored, demonstrated, and expected mineral deposits should be protected against sterilization, permanently excluding their exploitation, even if there is recent social opposition against mining. The future demand for mineral commodities may mitigate or remove such resistance.

Considering the possible social opposition against mining expressed by the NIMBY theory (Not In My Back Yard), mineral resources self-guarding may be implemented if:

1. The areas of their occurrence are properly delineated by geological mapping, confirmed by preliminary exploration, and presented in land-use plans;
2. The criteria of valorization of mineral deposits of local, regional, and national importance are defined;
3. The clear criteria and modes of allowable resources sterilization are presented, and social consultation areas are defined.

The implementation of effective self-guarding of mineral resources for future exploitation may be gained if there are appropriate legal measures. The Act on mineral self-guarding or incorporating the self-guarding rules to the Act on Mining Law (Geological and Mining Law in Poland) has been proposed [20].

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References

1. Pendock, M.J. Sterilization and safeguarding of mineral deposits in Britain. *Miner. Environ.* **1984**, *6*, 23–41. [CrossRef]
2. Nieć, M.; Radwanek-Bąk, B. Recent and future use of mineral deposits in Poland and threats to security of mineral raw material supply. In *Mineral Resources and Mine Development, Proceedings of the AIMS, RWTH, SIDMI, Aachen, Germany, 26–27 May 2010*; Volume 9, pp. 137–147. Available online: https://www.miningmagazine.com/equipment/news/1260209/aachen-mining-symposia (accessed on 20 November 2020).
3. Weber, L. Minimum requirements for national mineral policies. In Proceedings of the 22nd World Mining Congress&Expo, Istanbul, Turkey, 11–16 September 2011; Volume 2, pp. 51–57. Available online: http://www.ptumk.umcs.lublin.pl/files/articles/promotion/22%20Word%20Mining%202011.pdf (accessed on 22 November 2020).
4. Shields, D.J.; Šolar, S.V. *Sustainable Mineral Resources Management and Indicators: Case Study Slovenia*; Geological Survey of Slovenia: Ljubljana, Slovenia, 2004. Available online: https://www.geo-zs.si/PDF/Monografije/SUSTAINABLE_MINERAL_RESOURCE.pdf (accessed on 20 November 2020).

5. Weber, L. (Ed.) *Der Österreichische Rohstoff Plan. Archiv Fur Lagerstätten-Forschung. 26, Geologische Bundesanstalt*; Wien: Vienna, Austria, 2012. Available online: https://www.bmlrt.gv.at/dam/jcr:c8e8c460-df7b-43df-80e5-5ed064885f4d/Rohstoffplan.pdf (accessed on 20 November 2020).
6. Wrighton, C.E.; Bee, E.J.; Mankelow, J.M. The development and implementation of mineral safeguarding policies at national and local levels in the United Kingdom. *Resour. Policy* **2014**, *41*, 160–170. [CrossRef]
7. Hernandez-Duran, G.; Arranz-Gonzales, J.C.; Vega-Panizo, R. El analisis del potencial geologico de rocas industrials en proyectos de planification territorial: Una revision. *Bol. Geol. Min.* **2014**, *125*, 474–492. Available online: https://www.researchgate.net/publication/275342785 (accessed on 24 November 2020).
8. Radwanek-Bąk, B.; Kivinen, M. Legal and formal factors related to mineral raw material deposits accessibility in Europe. *Miner. Resour. Manag.* **2016**, *32*, 59. [CrossRef]
9. Tiess, G. Mineral Policy in Europe: Some recent Developments. *Resour. Policy* **2010**, *35*, 190–198. [CrossRef]
10. Mateus, A.; Lopes, C.; Martins, L.; Carvalho, J. Towards multi-dimensional methodology supporting a safeguarding decisions on the future access to mineral resources. *Miner. Econ.* **2017**, *30*, 229–255. [CrossRef]
11. Pawlowski, S.; Pawlowska, K.; Kubica, B. Geology and Genesis of the Polish sulfur deposits. *Econ. Geol.* **1979**, *74*, 475–483. Available online: https://pubs.geoscienceworld.org/segweb/economicgeology/article-abstract/74/2/475/19217/Geology-and-genesis-of-the-Polish-sulfur-deposits?redirectedFrom=fulltext (accessed on 27 November 2020). [CrossRef]
12. Kubica, B. Lithofacial development of the Badenian chemical sediments in the northern part of the Carpathian Foredeep. *Pr. Państwowego Inst. Geol.* **1992**, *133*, 1–64.
13. Nieć, M. Native sulfur deposits in Poland. In *Native Sulfur. Developments in Geology and Exploration*; Wessel, G.R., Wimberly, B.H., Eds.; Society of Mining and Metallurgical Exploration: Littleton, CO, USA, 1992; pp. 23–50.
14. Osmólski, T. Geologische Untersuchungen der Schwefellagerstätten in der schwefelführenden Provinz der Vorkarpaten und die Entwicklung ihres Abbaus. *Z. Angew. Geol.* **1974**, *20*, 321–327.
15. Sermet, E.; Górecki, J.; Musiał, A. Six centuries of the Polish sulphur mining: Past, today and future. In Proceedings of the Science and Technologies in Geology, Exploration and Mining. SGEM 18th International Multidisciplinary Scientific Geoconference, Albena, Bulgaria, 2–8 July 2018; Volume 18, pp. 473–479. [CrossRef]
16. Krupiński, B. Karol Bohdanowicz—Pedagog i człowiek, Report of the celebration to mark the centenary of the birth of Karol Bohdanowicz. *Biul. Inst. Geol.* **1969**, *232*, 15–19.
17. Gutman, E.; Kwiecień, K. *Polska Siarka (Polish Sulphur, in Polish)*; Zakład Wyd—Usługowy Adam Konieczny: Warszawa, Poland, 1992.
18. Żakiewicz, B. Exploitation of bedded Sulphur deposits by hydrodynamic method. *Sulphur* **1975**, *120*, 35–43.
19. Nieć, M.; Ślizowski, K.; Kawulak, M.; Lankof, L.; Salamon, E. *The Criteria of Protection of Resources Left by Closed Mines in the Framework of Sustainable Development; the Model Example of Native Sulfur Deposits; Kryteria Ochrony Złóż Pozostawianych Przez Likwidowane Kopalnie w Warunkach Zrównoważonego Rozwoju na Przykładzie Modelowym Złóż Siarki Rodzimej*; IGSMiE PAN: Kraków, Poland, 2007. Available online: https://www.researchgate.net/publication/303233697 (accessed on 25 November 2020)(In Polish with English Summary).
20. Małecki, Z.; Stypuła, A. Sozological problems of sulfur indrustry (in polish). Problemy sozologiczne zagłębia siarkowego. *Biul. Kom. Inżynierii Sr. PAN* **1992**, *1*, 1–72.
21. Ślizowski, K.; Nieć, M.; Lankof, L. Sulphur. In *Mineral. Raw Materials of Poland. Chemical Commodities. Surowce Chemiczne*; IGSMiE PAN: Kraków, Poland, 2000; pp. 1–421. (In Polish)
22. Sermet, E.; Górecki, J. From the "Machów hole" to the "Tarnobrzeg Lake". The development of the post mining area of open sulfur mine in Machów. *Hered. Minariorum* **2020**, *VI*, 51–55.
23. Maciaszek, J.; Szewczyk, J.; Nieć, M. Evaluation of sulphur recovery mined by the borehole method based on ground subsidence measurement. Ocena stanu wykorzystania złoża siarki eksploatowanego metodą otworową na podstawie poeksploatacyjnych deformacji powierzchni. *Miner. Resour. Manag.* **1990**, *6*, 687–707.
24. Małecki, Z. Impact of sulphur industry on the natural environment and the mode of its mitigation. *Oddziaływanie przemysłu siarkowego na środowisko przyrodnicze i kierunki ograniczenia jego zagrożenia. Przegl. Geol.* **1993**, *41*, 89–95.
25. Hajdo, S.; Klich, J.; Galiniak, G. Ecological and technical achivements in 40 year of boreholes sulfur mining in Poland. Ekologiczne i techniczne osiągnięcia w 40-letniej historii górnictwa otworowego siarki w Polsce. *Górn. Geoinż.* **2007**, *31*, 199–215.
26. Bokwa, P.; Kasztelewicz, Z. Technologia wydobycia siarki metodą otworową na złożu "Basznia 1". *Gorn. Odkryw.* **2019**, *59*, 51–59. Available online: https://www.igo.wroc.pl/wp-content/uploads/2019/04/GO_6_2018_5_51_60.pdf (accessed on 27 November 2020).
27. *Bilans Zasobów Złóż kopalin w Polsce (Register of Mineral Resources in Poland)*; Polish Geological Survey (PGS), PIG-PIB: Warszawa, Poland, 2019. Available online: https://www.pgi.gov.pl/en/ (accessed on 12 January 2021).
28. Act of 6 February 2020 on Amendment of Act on Spatial Planning and Land-Use Management. DZIENNIK USTAW RZECZYPOSPOLITEJ POLSKIEJ 2020, Item 293. Available online: https://isap.sejm.gov.pl/isap.nsf/download.xsp/wdu20200000293/O/D2020 (accessed on 12 January 2021).
29. Badera, J. Problems of the social non-acceptance of mining projects with particular emphasis on the European Union—A literature review. *Environ. Socio-Econ. Stud.* **2015**, *2*, 27–34. [CrossRef]

30. Nikitina, N.K. Geoethical principles for balancing the interests of government, local communities and abiotic nature in legislative decisions (case study). In Proceedings of the International Conference on Geoethics, Přibram, Prague, 13–18 October 2013; Němec, V., Ed.; Hořnicka: Přibram, Česká Republika, 2013; pp. 1–11.
31. Conde, M. Resistance to mining: A review. *Ecol. Econ.* **2017**, *132*, 80–90. [CrossRef]
32. Conde, M.; Billon, P.L. Why do some communities resist mining projects while others do not? *Extr. Ind. Soc.* **2017**, *4*, 681–697. [CrossRef]
33. Nieć, M.; Radwanek-Bąk, B. *Protection and Reasonable Use of Mineral Deposits (in Polish: Ochrona i Racjonalne Wykorzystywane Złóż kopalin)*; IGSMiE PAN: Kraków, Poland, 2014.
34. Lusty, P.A.; Gunn, A.G. Challenges to global mineral resources security and options for future supply. *Geol. Soc. Lond. Spec. Publ.* **2015**, *393*, 265–276. [CrossRef]
35. Horvath, Z.; Sari, K.; Szabo, K.; Csaba, V.; Hegymegi, E. Multi-Sectoral Analysis of Mineral Policies and Land Use Policies in EU Countries. 2016 MINATURA Deliverable D 3.1. Available online: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5abcf9218&appId=PPGMS (accessed on 27 November 2020).