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Challenges to access and safeguard mineral resources for society: A case study of kaolin in Portugal

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ABSTRACT

Present and future demands of minerals require enlightened land use policies and practices that consider geological resources as a whole, anticipating potential conflicts and proposing/monitoring solutions to ensure the access to mineral resources and their responsible use. The use of a multi-criteria methodology able to balance the geological knowledge (grounding the identification of mineral resources) with the economic, environmental and social dimensions implicated in their current or foreseen exploitation may provide the way needed to conciliate the foremost goals of any mining planning and land-use planning exercises. The safeguarding of kaolin resources was the selected case study because: (i) the current and future access to these resources are confronted with different types of conflicts with other land uses; (ii) the exploitation and transformation of kaolin are increasingly important to the regional and national economy, generating as well numerous jobs all over the added value chain and attracting foreign investment; and (iii) the historical environmental liabilities related to old exploitations that still grounds strong apprehensions by the public in general. In this study, the Portuguese kaolin resources were represented by 136 specific tracts, 110 being classified as of "*public importance*" after considering criteria supporting the geological knowledge dimension. Preceded by a structured point densification scheme, an interpolation process was performed, within the kriging formalism. The resulting map delimited a total area of $\approx 342\,km^2$ (0.4% of Portugal mainland) whose intrinsic value should support a safeguarding decision on the current and future access to kaolin resources in Portugal mainland. The 29 active and productive mines were further classified based on the economic, environmental and social dimensions and distributed within the three levels of priority for safeguarding, as proposed by the methodology. The results achieved are underestimated mostly due to several limitations of the available databases. Nevertheless, this remains a powerful potential tool to be applied for kaolin mineral resources safeguarding in two distinct and coexisting ways: (1) for future access, ensuring the supply of forthcoming generations and avoiding the sterilisation of tracts of "*public importance*"; and (2) for the short-medium term access, assigning specific areas to exploitation activities, regularly supplying the industry and markets. This methodology has been successfully applied to other minerals (e.g. Mateus et al., 2017), but additional efforts must be made to extend the assessment to other raw materials.

1. Introduction

No modern economy can attain sustainable growth without adequate access to primary mineral resources, even in presence of very effective reuse and recycling practices (e.g. Ali et al., 2017; Mathieux et al., 2017). Therefore, a strong and competitive mining industry should stand as a backbone of any modern (socio-) economic cluster on raw materials, decisively contributing to the implementation of reliable models of Circular Economy. This means that mining industry has to ensure its active involvement in on-going decision processes and forward-looking discussions on future challenges, because only this role can constructively change biased judgments about exploration and exploitation activities, contributing in time with reconcilable solutions towards Sustainability. Additionally, this desirable interaction will create the adequate conditions to define and periodically assess the composition of the raw material mixings (involving primary and secondary mineral resources, urban mining, substitution and reused components) needed to support a responsible socio-economic

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prosperity of a given community, region, country or any political form of transnational union or alliance. However, the crossbar supporting the need of ensure the access to primary minerals and involve a social and environmental responsible mining industry could be severely weakened if contemporary public policies do not recognise the need of: (1) assign specific areas to exploration and exploitation works, assisting the outset of a correct (and stable) mineral development planning; and (2) safeguard the future access to mineral resources, ensuring the supply of forthcoming generations.

In Portugal, the active and committed interaction between the mining industry and other key players is still on its infancy, despite of various significant case studies and several milestones achieved in the last 15 years (e.g. Falé et al., 2006; Carvalho et al., 2016). According to the Portuguese legislation, mineral resources (as other geological natural capitals) can be safeguarded by administrative easements of public utility on the basis of their local, regional or national importance (Santos and Cortez, 2017). Even so, administrative procedures are unnecessarily long and their predictability low, particularly when dealing with sites not previously considered in current land use plans; significant delays or discontinuities in updating geological data or information may also cause various difficulties. In addition, the lack of public awareness about "responsible mining operations" represents one of the main threats to further developments, along with urban expansion and/or deficiently planned infrastructures. Consequently, the judicious use of a multi-criteria methodology able to balance the geological knowledge grounding the identification of mineral resources with the economic, environmental and social dimensions implicated in their current or foreseen exploitation, may provide the way needed to conciliate the foremost goals of any mining planning and land-use planning exercises (e.g. Owens, 1997; Cowell and Owens, 1998; Cowell and Murdoch, 1999; Evans et al., 2009; Tiess, 2010; Allington et al., 2016; Mateus et al., 2017).

The development of sustainable land use management policies and practices rely on a knowledge-based procedure that seeks for an integrated (multifaceted and interdisciplinary) approach to meet present and future needs of people and the natural systems on which they depend. Therefore, the resulting land use planning must anticipate potential conflicts and propose and/or monitor solutions that should: (1) reflect a comprehensive understanding of the potential impacts on natural resources that sustain all kinds of living communities; (2) include measures to prevent over-allocation, chronic depletion, and/or degradation of natural resources and/or eco-services; and (3) foresee future needs and ensure equivalent opportunities to the access of natural resources and fruition of eco-services, thus minimising disturbances in natural flows that may be difficult, expensive, or even impossible to reconcile with common biogeophysical and biogeochemical processes (e.g. Meadows et al., 1972; WCED, 1987; Munasinghe, 1993). Geological resources are intrinsically natural capitals, so their inclusion is unavoidable in any effective management and planning of land and associated resources for sustained uses. Mineral resources do not configure an exception to this framework and represent a *natural geological capital* whose use must be responsible and optimised while minimize and mitigate as far as possible environmental impacts.

One of the crucial and higher impact strategic reforms accomplished recently in Portugal is the National Program for the Land Use Planning Policy (Law no. 58/2007). It considers the inevitability of include geological resources in land use management and planning strategies, from local to national scales. The main motivations for the development of a unified methodology to assist this issue were (and still are) as follows: (1) *ensure the future access to mineral resources*; this is one of the keys to the future success of the mining industry worldwide and should be considered or weighed equally with other land uses; (2) *include all the activities related to the mining sector* (from exploration to rehabilitation after exploitation) *in policies/practices of land use management and planning*, recognising their inherent inter-relationship and relative importance to the best use of mineral resources in the present and future; and (3) *consider the fundamental critical factors determining the non-linear dynamic behaviour of mining industry*, as well as specific scale-dependent features, making available the information needed to speed up investment decisions without jeopardising local priorities regarding concurrent land uses and/or outcomes from other economic players.

The current and future access to mineral resources and their relevance in conciliating approaches to mineral planning and land-use planning will be addressed in the present work by means of the multi-criteria methodology reported in Mateus et al. (2017). The Portuguese resources of kaolin will assist as a case study, selected from among others because of: (i) different types of conflicts with other land uses that the current and future access to these resources are confronted; (ii) the growing importance of kaolin to the regional and national economy, generating as well numerous jobs all over the added value chain and attracting foreign investment; and (iii) the historical environmental liabilities related to old exploitations that still grounds strong apprehensions by the public in general.

2. The main clusters of kaolin production in Portugal

2.1. Kaolin outlook and spatial distribution

Kaolin is an industrial clay of white or almost white colour that remains or becomes whiter after drying and firing (Gomes, 2002). This industrial clay comprises mainly mineral phases of the kaolin sub-group (Guggenheim et al., 1997), most commonly kaolinite, but there are deposits of economic interest where the relative abundance of these mineral phases are of the order of 10 wt% or slightly lower. Mineral phases of the illite group are frequently present as well as non-clay minerals such as quartz, feldspar and mica and goethite. In raw kaolin clay, the content of these accessory mineral phases can be significantly reduced by means of refining or concentration processes, depending on the foreseen use.

Kaolin can be classified genetically as primary or secondary. Primary (or residual) kaolin is formed in situ by advanced chemical alteration of feldspar- and mica-rich rocks, their origin being thus related to weathering processes, hydrothermal activity (under a wide range of temperature conditions) or mixed. Genetic conditions are determinant for the crystallinity and size of kaolinite particles. However, when kaolin clays are derived from granitoids, the most common situation in Portugal, the distinction between those generated by means of hydrothermal processes and chemical weathering is not usually evident. Secondary (or sedimentary) kaolin clays result from the deposition of clay-sized products in various types of basins as a consequence of intensive erosion of potential (weathered or hydrothermally modified) feldspar-rich sources such as granitoid, gneissic or migmatitic rocks; the most common depositional environments are deltaic and lagoonal. Secondary kaolin clays can also be formed by the chemical weathering of feldspar-bearing sandstones (arkoses), mainly resulting from the interaction of these immature sediments with chemically reactive groundwater flows.

The residual or sedimentary origin is determinant for the properties of kaolin clay, as well as the presence of "industrial contaminants" – quartz, mica, montmorillonite and iron and titanium oxides – which require the implementation of treatment/benefiting procedures that might compromise the economic feasibility of exploitation. Porcelain ceramic and paper industries are the most important (high-valued) and traditional applications for kaolin clay and also the most demanding in quality (increasing the requests in purity and fineness), therefore putting additional pressure on exploitation and treatment/benefiting procedures of raw kaolin.

In Portugal mainland, residual and sedimentary kaolin deposits are distributed mainly over two distinct areas: the Lusitanian Meso-Cenozoic basin, placed at the occidental mainland boundary, and along a narrow strip at NW, between Aveiro and Viana do Castelo (Gomes,