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### Cover Page Footnote

Conflicts of interest The authors declare no conflict of interest. Ethical statement The authors state that the research was conducted according to ethical standards. Funding body None.

# A systematic review of the use of environmental economics in the mining industry

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## Abstract

Environmental economics is increasingly being used in project appraisals, environmental liability estimates and design of market-based instruments. Mining, an actor capable of causing adverse effects on the environment, human health and well-being, has already been affected by these developments, at a great extent. Up to date, several research studies have been carried out to monetise the externalities of mining projects. Nevertheless, a systematic review of these publications has not been carried out, yet. This paper aims to fill this gap in the literature by investigating (i) the main non-market valuation techniques used; (ii) the main external costs or benefits of mining projects monetised; and (iii) the monetary estimates of mining-related externalities. The analysis shows that practically all economic valuation techniques have been implemented towards assessing, in monetary terms, the mining impacts on the environment. However, the findings from the statistical analysis reveal a wide range of monetary estimates, which are attributed not only to the valuation methods and assumptions used but also to the specific characteristics of the mining projects in question. Also, the research draws directions for future work, as the analysis of the published studies indicates areas of limited availability of estimates or high heterogeneity between the available estimates.

*Keywords:* mining, quarrying, externalities, environmental economics, nonmarket valuation, systematic review

## 1. Introduction

Over the last four decades, there is a growing interest in the monetary assessment of external costs (or benefits) of various economic operations on society using environmental economics valuation techniques. A significant boost in this direction was given by certain legislative acts relating to environmental protection and restoration. In particular, three issues played a major role in the development of environmental economics: the cost-benefit analysis of projects and policies, the natural resource damage assessment and the market-based instruments (e.g. pollution taxes and environmental subsidies) that are increasingly being used as a means of achieving specific environmental targets [1–4].

The theory of social cost-benefit analysis (CBA) was founded by the economists Nicholas Kaldor and

John Hicks in the 1930s [5] and has been developed independently of environmental valuation to appraise projects (or policies) from a societal perspective rather than a private one [6]. Yet, as Pearce argues: “... *Two of the triumphs of environmental economics have been to emphasize the incompleteness of appraisals that omit environmental change and to develop the means of incorporating environmental values into appraisal ...*” [1]. The first environmental valuation surveys for informing CBA studies were carried out in the U.S. in the 1950s and were expanded for evaluating new regulations in the late 1970s [3]. Nevertheless, the U.S. Flood Control Act of 1936 is often regarded as the first use of CBA [5]. In Europe, the interest in CBA arose in the 1980s as a result of growing awareness of the US applications [4]. Manuals for CBA can be found in a few European countries mainly for transportation projects but they do not always provide guidelines for economic valuation of environmental impacts [3]. CBA applications were first implemented in the UK,

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Germany, Scandinavian countries, and the Netherlands [7]. At the European Commission (EC) level, CBA was first introduced in 1994 by the Directorate-General for Regional Policy, with the release of the first CBA Guide [8]. Nowadays, CBA is mandatory to apply for co-funding to the European Regional Development Fund and the Cohesion Fund, following the latest version of the EC CBA Guide [9].

Natural resource damage assessment (NRDA) regulations, also known as environmental liability, were introduced in the US legislation in the 1970s with the Trans-Alaska Pipeline Authorization Act [2,10]. The environmental liability was extended beyond the oil industry with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 and the Superfund Amendments and Reauthorization Act (SARA) of 1986 [2]. In 1990, the Oil Pollution Act (OPA) passed, after a year of the Exxon Valdez oil spill, which establishes liability for damages resulting from oil pollution. CERCLA mandates that the damages from an injury cannot exceed the value of the lost resource, which includes use values and existence or non-use values. Under OPA, the environmental liability has three components: (i) the costs of restoring, replacing or providing the equivalent of the damaged resources, (ii) the compensation for interim losses and (iii) the reasonable cost of assessing the damages [11]. In Europe, a similar approach has been established on enforcement of claims to remedy environmental damages by the Environmental Liability Directive (ELD) 2004/35/EC. The ELD applies to damages to land, water and species and natural habitats and allows for three types of remediation, namely (i) restoration of the damaged resource to its baseline condition; (ii) complementary remediation when the affected site cannot be fully restored, and (iii) compensatory remediation of interim losses [12]. Also, the ELD notes that 'alternative valuation techniques shall be used, where restoration of services is not possible to inform the level of remediation [12].

Market-based instruments (MBIs) have emerged as an alternative to command-and-control measures. MBIs focus on market-level outcomes and, if properly designed and implemented, may protect and improve the environment at the lowest possible overall cost to society [13]. MBIs, include in general, tradable permits designed to reduce emissions or overexploitation of resources, environmental taxes that change prices, environmental charges that cover costs of environmental services and abatement measures, and environmental subsidies to foster new technologies and markets for

environmental goods and services [14]. Moreover, market friction, such as voluntary exchange of scarce resource rights, liability rules and information programs, such as energy-efficiency labels, are also considered as MBIs [13]. Nowadays, there are several hundreds of different MBIs, including among others effluent charges, deposit-refund schemes, tradable permits, sales and value-added taxes, etc., intending to change the behaviour of producers and consumers (for further details readers may refer to [13,14]).

Mining, being an activity capable of causing adverse effects on the environment, human health and well-being (e.g. [15–18]), could not stay unaffected from these developments. Environmental economics valuation techniques have been used in several real case applications. For instance, in 1983, the Colorado State filed a natural resource damage lawsuit against the owner and operator of the Eagle Mine site at that time for impacts to the Eagle River and surrounding areas. In 1985, economic analyses were conducted on behalf of the plaintiff and of the defendant to estimate the damages on the environment. There were significant discrepancies between the two studies due to different assumptions used [2]. In 1988, the Colorado State and the operator of the mine entered into a consent remedial action plan. In 1990, the Resource Assessment Commission conducted a study to assess the environmental value of the Kakadu Conservation Zone, intending to determine whether mining should be permitted in this area or whether the area should be added to Kakadu National Park instead [19]. Although the non-market valuation estimates were removed from the final report, it was argued that many Australians are highly concerned about the environmental consequences of mining and place relative high values on the wilderness [20]. In the UK, a flat rate environmental tax, i.e. the Aggregate Levy, was introduced on the exploitation of rock, sand and gravel to encourage the use of secondary and recycled aggregates [21]. The tax is equal to GBP 2 per ton of aggregates extracted, and proportionally for any amount under that weight.

The need for a value measure on the otherwise intangible environment in the mining industry for project appraisals, damage assessments and implementation of MBIs, is undeniable. This fact is also reflected in the relevant literature, where there is a growing body of studies focusing on the monetisation of mining-related externalities. This paper aims to conduct a systematic review on this topic and, to the best of the authors' knowledge this is the first such study.

The rest of the paper is structured, as follows: Section 2 provides the methodological background of the systematic review, Section 3 presents and discusses the main findings of the review with regards to the basic research questions, and, finally, Section 4 draws the conclusions and raises suggestion for future work.

## 2. Materials and methods

There exist several publications providing guidelines on how to perform systematic reviews (e.g. [22–27]). This work follows the general steps of these guidelines, especially those focused on systematic reviews in environmental management (e.g. [26]). The systematic review presented in this paper aims to analyse the use of non-market valuation techniques in mining-related projects and activities. To this end, the main research questions addressed by the review are the following:

- (i) What are the main non-market valuation techniques used to monetising the environmental and social impacts of mining projects?
- (ii) What are the main external costs or benefits of mining projects monetised employing non-market valuation?
- (iii) What is the economic evidence (i.e. valuation estimates) on the external costs or benefits of mining projects?

For the review, the definitions of the environmental economic values and techniques are adopted from the related literature of environmental economics (e.g. [2]). Specifically, the Total Economic Value (TEV) of an environmental resource or service includes all use (i.e. direct, indirect and option values) and non-use values (existence, altruistic and bequest values). The direct use values refer to the actual use of a resource or service by the individuals, for either commercial purposes or recreation. The indirect use values derive from the ecosystem functions. The option value reflects an individual's willingness to pay (WTP) for the option of using the resource or service examined in the future. The non-use values typically consist of existence values, which are related to moral reasons and reflect WTP to preserve a resource in existence without actual or planned use for anyone; altruist values, which express WTP of an individual to make the resource or service available to others in the current generation; and the bequest values that derive from an individual's WTP to ensure the use of the natural resource or service for future generations.

The above-mentioned economic values of the environment can be estimated using non-demand (referred also as conventional market approaches) or demand curve methods. The non-demand curve techniques involve the use of market prices, replacement costs, damage avoided costs, mitigation costs, dose–response methods and opportunity costs. The demand curve techniques are categorised into two different types, i.e. revealed and stated preference methods. The revealed preference methods elicit preferences from the actual behaviour of individuals, based on market information. The two mainly used approaches are the Travel Cost method which is used in measuring the value of recreational sites and the Hedonic Pricing method which uses transactions in the housing market to estimate the value of environmental goods or services that are reflected on property values. Finally, the stated preference approaches are based on hypothetical markets and elicit people's WTP (or willingness to accept compensation – WTA) using carefully structured questionnaires. The most commonly acknowledged and widely used approaches are the Contingent Valuation (CV) method and the Choice Experiments (CE)/Conjoint Analysis. The CV has been the most commonly used non-market valuation method (for more details readers may refer to [28,29]). Finally, an alternative to revealed and stated preference methods, in cases of constrained budgets and timeframes, is the Benefit Transfer (or Value Transfer) method [2,30]. In reality, Benefit Transfer (BT) is not a valuation method. BT simply transfers “... existing data or information in settings other than for what it was originally collected ...” [31] by using value or function transfers or meta-data analysis. BT is increasingly being used in environmental valuation by scholars and organisations, although it cannot replace original research.

The review planning decided also on the data collection strategy (i.e. relevant databases, search strings and inclusion or exclusion criteria). As regards the data collection strategy, the Scopus database was preferred over Web of Science (WoS), because Scopus includes most of the journals indexed in WoS and has a larger number of exclusive journals than WoS in all fields [32]. Specifically, the Scopus database was selected because it includes over 75 million records and more than 24,600 titles in the areas of science, technology, medicine, social sciences, art and humanities.<sup>1</sup> The Google

<sup>1</sup> [https://www.elsevier.com/\\_data/assets/pdf\\_file/0017/114533/Scopus\\_GlobalResearch\\_Factsheet2019\\_FINAL\\_WEB.pdf](https://www.elsevier.com/_data/assets/pdf_file/0017/114533/Scopus_GlobalResearch_Factsheet2019_FINAL_WEB.pdf).

Table 1. The dataset publications.

ID	Title	Reference
1	Effect of Distance on the Preservation Value of Water Quality	[33]
2	An application of the Krutilla — Fisher model to appraising the benefits of green belt preservation versus site development	[34]
3	Air quality and view degradations due to copper mining and milling: Preliminary analysis and cost estimates for Green Valley, Arizona	[35]
4	Reconciling private profitability and social costs: The case of clay mining in Sri Lanka	[36]
5	Externalities from extraction of aggregates regulation by tax or land-use controls	[21]
6	A contingent valuation study of the environmental costs of mining in the Brazilian amazon	[20]
7	Economic approaches to valuing the environmental costs and benefits of mineral and aggregate extraction	[37]
8	Valuing watershed quality improvements using conjoint analysis	[38]
9	Contingent valuation of some externalities from mine dewatering	[39]
10	Assessing the benefits of reclaiming urban quarries: A CVM analysis	[40]
11	Environmental economics and the mining industry: Monetary benefits of an abandoned quarry rehabilitation in Greece	[41]
12	The “battle of gold” under the light of green economics: A case study from Greece	[42]
13	The hidden costs of relocating sand and gravel mines	[43]
14	Estimating the economic benefits of acidic rock drainage clean up using cost shares	[44]
15	Valuing acid mine drainage remediation in West Virginia: A hedonic modeling approach	[45]
16	Efficient management of marine resources in conflict: An empirical study of marine sand mining, Korea	[46]
17	The economic value of allocating water to post-mining lakes in East Germany	[47]
18	Private and social costs of surface mine reforestation performance criteria	[48]
19	Environmental accounting for pollution in the United States economy	[49]
20	Evaluating and modeling ecosystem service loss of coal mining: A case study of Mentougou district of Beijing, China	[50]
21	Water eco-service assessment and compensation in a coal mining region - A case study in the Mentougou District in Beijing	[51]
22	Costs of abandoned coal mine reclamation and associated recreation benefits in Ohio	[52]
23	External cost of coal based electricity generation: A tale of Ahmedabad city	[53]
24	Externalities, NIMBY syndrome and marble quarrying activity	[54]
25	Wind versus coal: Comparing the local economic impacts of energy resource development in Appalachia	[55]
26	Externalities from lignite mining-related dust emissions	[56]
27	Behind the life cycle of coal: Socio-environmental liabilities of coal mining in Cesar, Colombia	[57]
28	Economic valuation of coal mining activity in Samarinda city, east Kalimantan, Indonesia	[58]
29	A methodological framework to assess the socio-economic impact of underground quarries: A case study from Belgian Limburg	[59]
30	Economic valuation of mining heritage from a recreational approach: Application to the case of El Soplao Cave in Spain (Geosite UR004)	[60]
31	Estimation of external effects from the quarrying sector using the hedonic pricing method	[61]
32	Externality costs of the coal–fuel cycle: The case of Kusile Power Station	[62]
33	Life cycle cost estimation and environmental valuation of coal mine tailings management	[63]
34	Valuing environmental health for informed policy-making	[64]
35	Valuing environmental impacts of mercury emissions from gold mining: Dollar per troy ounce estimates for twelve open-pit, small-scale, and artisanal mining sites	[65]
36	An integrated framework to assess impacts on ecosystem services in LCA demonstrated by a case study of mining in Chile	[66]
37	Perceived health risk, environmental knowledge, and contingent valuation for improving air quality: New evidence from the Jinchuan mining area in China	[67]
38	Changes in ecosystem service benefit in Soma lignite region of Turkey	[68]
39	Habitat Equivalency Analysis, a framework for forensic cost evaluation of environmental damage	[69]
40	The value artificial lake ecosystems provide to recreational anglers: Implications for management of biodiversity and outdoor recreation	[70]
41	Understanding social demand for sustainable nature conservation. The case of a protected natural space in South-Eastern Spain	[71]
42	Assessment of the external costs of life cycle of coal: The case study of southwestern China	[72]
43	Is Mining an Environmental Disamenity? Evidence from Resource Extraction Site Openings	[73]
44	Model for assessing health damage from air pollution in quarrying area – Case study at Tan Uyen quarry, Ho Chi Minh megapolis, Vietnam	[74]

Scholar was not originally searched since the search target comprises peer-reviewed articles only and not publications such as gray literature, presentations, keynotes, extended abstracts, etc. The initial Scopus search process started with a broad scoping of articles related to the environmental valuation of mining activities, using the following string: TITLE-ABS-KEY (((“environmental valu\*” OR “benefit valu\*” OR “environmental economics” OR externalities OR “natural resource damage assessment” OR “non-market valu\*” OR “environmental cost\*” OR “social cost\*”) AND (“mine” OR “mining” OR “quarry” OR “quarrying” OR “pit” OR “mining area” OR “quarry area” OR “quarry restoration” OR “mine restoration”))). A total of 968 records was originally returned. These records were limited to 200 using more specific keywords by adding the following expression to the previous string: AND (“contingent valuation” OR “hedonic pricing” OR “hedonic model\*” OR “travel cost” OR “benefit transfer” OR “value transfer” OR “market value” OR “choice experiment” OR “choice model\*” OR “external cost” OR “stated preference” OR “benefit-cost” OR “cost-benefit” OR conjoint OR “consumer surplus”).

These articles were further screened based on the following criteria: (i) Papers published over the past four decades, i.e. 1980–2020; (ii) Papers published in peer-reviewed scientific journals; (iii) Papers published in English; and (iv) Papers applying non-market valuation techniques on specific case studies.

The first three filtering criteria were applied through the Scopus search. After removing publications before 1980, conference papers, book chapters, etc., and articles not written in English, the number of articles fulfilling the criteria for abstract reading was 161. After reading the article abstract, 83 publications were excluded and 78 publications were selected and downloaded for full-text screening. Totally 41 publications fulfilled all the criteria. During the full-text screening, three additional publications were found by searching the reference lists of the identified articles and were added in the list. Hence, 44 articles were used in the analysis at the final stage, which are listed in Table 1. The search process is illustrated in Fig. 1.

In order to conduct the analysis, seventeen variables were defined during the reading of the publications included in the final set. These variables are described in Table 2.

The sampled studies follow different methodological approaches and do not share common monetary measures. Hence, to analyse the external costs or benefits of mining-related activities (i.e.

exploitation or restoration works) and provide basic statistics and information for the monetary estimates of the sample, the original values underwent two different transformations. First, all the original values were converted to 2019 international dollar equivalents (int\$) using the Purchasing Power Parity (PPP) conversion factor and the USA Consumer Price Index (both indices were retrieved by the World Bank [75,76]), to account for price level differences between countries and adjustments to inflation rates, accordingly. Then, the transferred values were transformed to appropriate unit values after certain manipulations. More explicitly, in cases where appropriate information was available, e.g. total population affected, total or annual production of energy and non-energy minerals and total area affected, the annual or total estimated economic values were converted to unit values, e.g. int\$ per household and year (HH), int\$ per hectare (ha), int\$

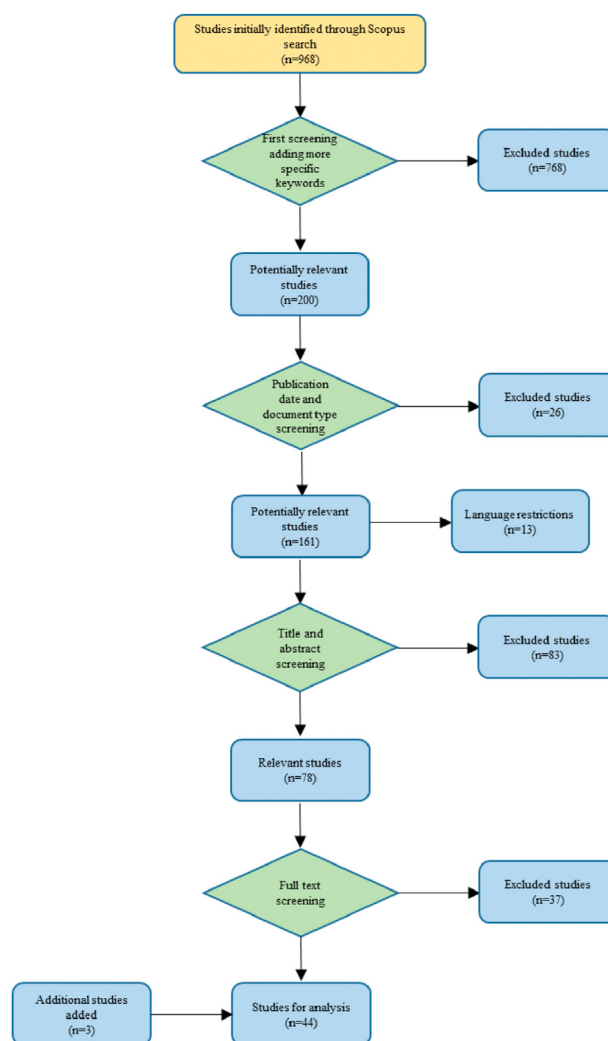


Fig. 1. Filtering of literature.

Table 2. Variables used for the analysis.

Variable	Description	Type
Year of publication	Publication year of the article	Discrete
Country of origin	Country of the valuation case studied	Nominal
Journal	Title of the journal	Nominal
Valuation method	Stated preference; Revealed preference; Non-demand method; Benefit transfer	Nominal
Valuation approach	Contingent valuation; Choice experiment; Hedonic pricing; Travel cost; Cost of illness; Market price; Replacement cost; Dose–response; Damage cost avoided; Mitigation cost; Opportunity cost	Nominal
Type of value	Total value; use value; non-use value	Nominal
Elicitation approach	Willingness to pay (WTP); Willingness to accept (WTA); Other	Nominal
Data collection method	Face-to-face interviews; Telephone interviews; Mail survey; Web survey; n/a	Nominal
Year of survey	Year of the data collection campaign	Discrete
Original value	Original monetary estimate	Continuous
Valuation units	E.g. per household, per person, per ton, etc.	Nominal
Transformed value	Transformed monetary estimate	Continuous
Transformed valuation units	Transformed valuation units	Nominal
Mining project	E.g. quarry, metal mine, coal mine, etc.	Nominal
Externalities	External costs; External benefits	Nominal
Valuation item	E.g. air quality, landscape quality, water quality, human health, soil quality, recreation, housing market, etc.	Nominal
Spatial scale	Local; Regional; National; Global	Nominal

per ton or m<sup>3</sup>, etc. Using this process, 156 unique monetary values derived from the review of the sampled studies.

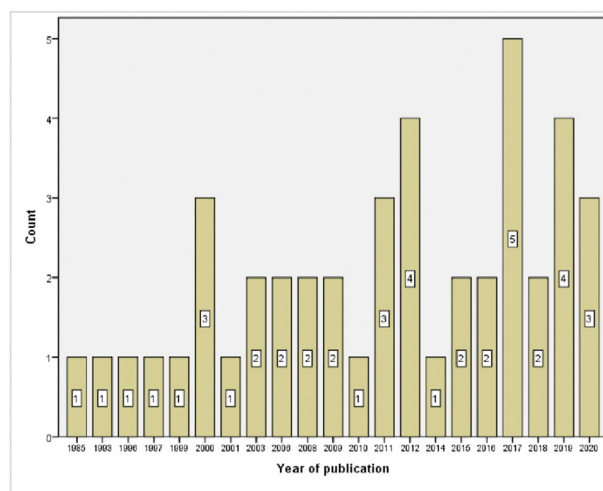
### 3. Results and discussion

#### 3.1. Year of publication, country of origin and scientific journal

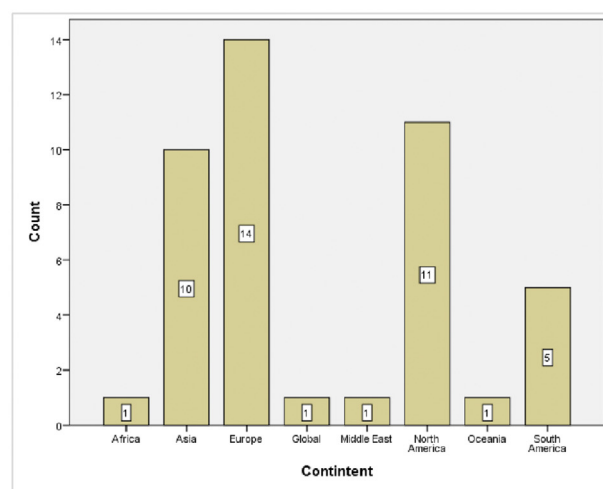
As shown in Fig. 2 (a), five publications (11.4%) were published before 2000 (and only one before 1990), twelve studies (27.2%) were published between 2000 and 2009, and the rest twenty-seven studies (61.4%) after 2010.

Further, the majority of publications have studied mining projects located at Europe (14 cases or 31.8%), North America (11 cases or 25%), Asia (10 cases or 22.7%) and South America (5 cases or 11.4%). More specifically, externalities of mining projects have been studied in the USA (11 cases), Greece (5 cases), China (4 cases), UK (3 cases), Brazil (2 cases), Chile (2 cases), Germany (2 cases), Spain (2 cases), Australia (1 case), Belgium (1 case), Colombia (1 case), Czech Republic (1 case), India (1 case), Indonesia (1 case), Israel (1 case), Korea (1 case), South Africa (1 case), Sri Lanka (1 case), Turkey (1 case), and Vietnam (1 case). Further, one study examines externalities at the global scale.

The papers are published in journals of various disciplines (Table 3). As regards mining journals (i.e. journals that refer to mining activity in their statement mission), four papers have been published in “Resources Policy”, two in “Environmental Geology” and one paper in each of the following



(a)



(b)

Fig. 2. Publication year (a) and continent of case studies (b).



Table 3. Ranking of journals per papers published.

Journal	Frequency	Percent
Resources Policy	4	9.1
Ecological Economics	3	6.8
Energy Policy	3	6.8
Journal of Environmental Management	3	6.8
Ecological Complexity	2	4.5
Ecosystem Services	2	4.5
Environmental Geology	2	4.5
Journal of Environmental Planning and Management	2	4.5
American Economic Review	1	2.3
Annals of Regional Science	1	2.3
Economics and Human Biology	1	2.3
Energies	1	2.3
Environmental and Resource Economics	1	2.3
Environmental Management	1	2.3
Heliyon	1	2.3
International Journal of Applied Engineering Research	1	2.3
Journal for Nature Conservation	1	2.3
Journal of Sustainable Mining	1	2.3
Journal of Water Resources Planning and Management	1	2.3
Land Economics	1	2.3
Land Use Policy	1	2.3
Landscape and Urban Planning	1	2.3
Minerals and Energy	1	2.3
Minerals and Energy - Raw Materials Report	1	2.3
Natural Resources Research	1	2.3
Project Appraisal	1	2.3
Reviews on Environmental Health	1	2.3
Science of the Total Environment	1	2.3
South African Journal of Science	1	2.3
Sustainability	1	2.3
Water Resources Management	1	2.3

journals: “Journal of Sustainable Mining”, “Minerals and Energy” and “Minerals and Energy - Raw Materials Report”. This finding is related mainly to the affiliation of the authors. Specifically, only the authors of nine papers are affiliated with mining departments. The majority of the authors (i.e. 15 publications) are affiliated with environmental, agricultural and resource economics or business departments, followed by authors affiliated with environmental and civil engineering departments

(11 publications). The rest of the papers are authored by scholars affiliated with departments in agriculture, forestry, town planning, infrastructure and building management and policy.

### 3.2. Valuation method, approaches and type of value

This section presents the main findings in regards to the first research question (i.e. what are the main

Table 4. Valuation methods used in monetising mining-related externalities.

Valuation method	Frequency	Percent
Stated preference methods	16	34.1
Non-demand curve methods	11	25.0
Benefit transfer method	8	18.2
Non-demand curve methods and Benefit transfer method	4	9.1
Revealed preference methods	4	9.1
Stated preference methods; Revealed preference methods	1	2.3
Demand and non-demand curve methods	1	2.3

Table 5. Valuation approaches used in monetising mining-related externalities.

Valuation approach	Frequency	Percent
Contingent valuation	10	22.7
Benefit transfer	8	18.2
Choice experiment	4	9.1
Dose–response	4	9.1
Hedonic pricing	3	6.8
Avoided costs	2	4.5
Market price	2	4.5
Market price; Mitigation cost; Replacement cost; Benefit transfer	2	4.5
Conjoint analysis	1	2.3
Contingent valuation; Travel cost; Hedonic pricing	1	2.3
Cost of illness; Productivity loss	1	2.3
Market price; Benefit transfer	1	2.3
Market price; Opportunity cost; Replacement cost	1	2.3
Market price; Opportunity cost; Replacement cost; Cost of illness	1	2.3
Market price; Replacement cost; Damage cost avoided; Contingent valuation; Hedonic pricing	1	2.3
Replacement cost; Benefit transfer	1	2.3
Travel cost	1	2.3

non-market valuation techniques used to monetising the environmental and social impacts of mining projects). More than 70% of the cases have employed primary methods (Table 4). Specifically, the authors have used stated preference approaches in fifteen cases (34.1%) [20,21,33–35,37–40,44,47,54,67,70,71], non-demand curve approaches in eleven cases (25%) [36,43,48–51,53,56,58,64,74], revealed preference approaches in four cases (9.1%) [45,60,61,73] and

combination of stated and revealed preference methods and demand and non-demand curve approaches in two cases [41,59]. Further, eight studies (18.2%) were based on the benefit transfer method [42,52,55,57,62,63,65,72] and four studies (9.1%) combined the benefit transfer method with non-demand curve approaches [58,66,68,69].

The following Table 5 presents the valuation approaches that have been employed in estimating external costs or benefits of mining projects.

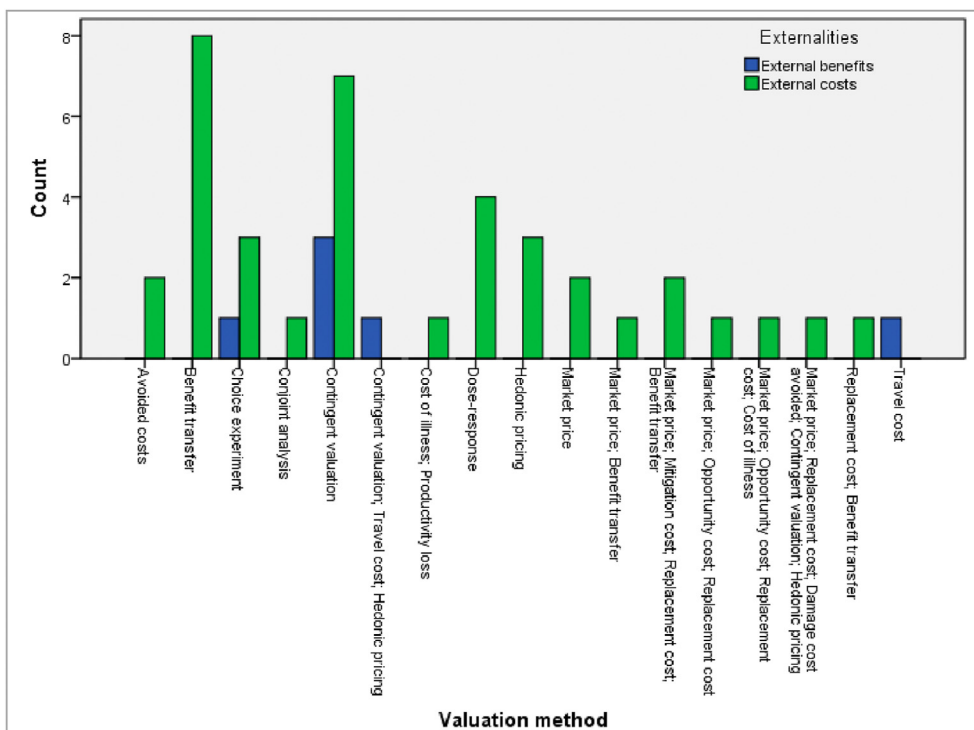


Fig. 3. Estimation of external costs or benefits per valuation approach.

Table 6. Number of valuation studies per environmental medium, type of externality and valuation item.

Environmental medium and valuation item	External benefits	External costs	Total	Reference
Air	–	7	7	
Health impacts	–	5	5	[56,64,65,67,74]
Health impacts; Agricultural production; Infrastructure; Global warming	–	1	1	[53]
Health impacts; Agricultural production; Timber production; Infrastructure; Recreational services	–	1	1	[49]
Air; Land	–	2	2	
Air quality; Landscape quality	–	1	1	[35]
Health impacts; Agricultural production; Infrastructure	–	1	1	[36]
Air; Land; Water	–	1	1	
Land quality; Air quality, Global warming	–	1	1	[63]
Biota	–	5	5	
Deforestation	–	1	1	[20]
Forest ecosystem services	–	2	2	[68,69]
Fisheries	–	2	2	[38,46]
General	–	10	10	
Environmental quality; Health impacts	–	4	4	[55,57,62,72]
Environmental quality; Quality of life	–	4	4	[21,37,42,54]
Property values	–	2	2	[61,73]
Land	3	5	8	
Agricultural production	–	1	1	[43]
Property values; Infrastructure; Agricultural production; Recreational services	–	1	1	[59]
Protected areas	–	1	1	[71]
Recreational services	1	–	1	[60]
Recreational services; Environmental quality	2	–	2	[40,41]
Restoration	–	1	1	[48]
Timber production; Forest ecosystem services	–	1	1	[58]
Land; Water	–	1	1	
Water and land ecosystem services	–	1	1	[50]
Water	3	7	10	
Ecosystem services	–	2	2	[51,66]
Recreational services	3	3	6	[33,34,39,47,52,70]
Water quality	–	2	2	[44,45]
Total	6	38	44	

Concerning the valuation approaches used, almost one-fourth of the studies have been conducted using the contingent valuation [20,33–35,39,40,44,47,54,67], eight studies (18.2%) have used the benefit transfer method [42,52,55,57,62,63,65,72], four studies (9.1%) have applied choice experiments [21,37,70,71] and dose–response approaches [53,56,64,74] respectively, three studies (6.8%) have implemented the hedonic pricing approach [45,61,73] and two studies (4.5%) have used the market price [46,49] and the avoided cost approaches [43,48], accordingly. The rest of the cases have employed different approaches, i.e. conjoint analysis [38] and travel cost [60], or a combination of approaches [36,41,50,51,58,59,66,68,69].

In accordance with the valuation approaches, half of the studies have estimated use values [36,43,45,46,48–53,55–57,60,61,64–66,70,72–74] and nineteen studies (43.2%) have estimated the total economic value of the environmental

good or service examined [20,21,33–35,37,38,40–42,44,47,54,58,62,63,67,68,71]. Finally, three cases (6.9%) have combined different approaches and have estimated use and total economic values, separately [39,59,69].

### 3.3. Externalities monetised

As far as the second research question is concerned, that is the main external costs or benefits of mining projects monetised employing non-market valuation, the vast majority of the studies (i.e. 38 or 86.4%) have monetised externalities relating to negative impacts of mining on the ecosystem, the human health and the quality of life. Only six studies have monetised external benefits associated mainly with mining rehabilitation works. As illustrated in Fig. 3, external benefits have been measured using only the contingent valuation,

Table 7. Number of valuation studies per mining type, type of externality and valuation approach.

Mining type/Valuation method	External benefits	External costs	Total	References
Aggregate quarrying	2	7	9	
Avoided costs		1	1	[43]
Choice experiment		3	3	[21,37,71]
Contingent valuation	1		1	[40]
Contingent valuation; Travel cost; Hedonic pricing	1		1	[41]
Dose–response		1	1	[74]
Hedonic pricing		1	1	[61]
Market price; Replacement cost; Damage cost avoided; Contingent valuation; Hedonic pricing		1	1	[59]
Clay, sand, gravel mining	1	3	4	
Choice experiment	1		1	[70]
Cost of illness; Productivity loss		1	1	[36]
Market price		1	1	[46]
Replacement cost; Benefit transfer		1	1	[69]
Coal mining	1	16	17	
Avoided costs		1	1	[48]
Benefit transfer		6	6	[52,55,57,62,63,72]
Contingent valuation	1	2	3	[33,34,47]
Dose–response		3	3	[53,56,64]
Market price; Benefit transfer		1	1	[58]
Market price; Mitigation cost; Replacement cost; Benefit transfer		1	1	[68]
Market price; Opportunity cost; Replacement cost		1	1	[50]
Market price; Opportunity cost; Replacement cost; Cost of illness		1	1	[51]
Marble quarrying		1	1	
Contingent valuation		1	1	[54]
Metal mining	2	8	10	
Benefit transfer		2	2	[42,65]
Conjoint analysis		1	1	[38]
Contingent valuation	1	4	5	[20,35,39,44,67]
Hedonic pricing		1	1	[45]
Travel cost	1		1	[60]
Mining total		3	3	
Hedonic pricing		1	1	[73]
Market price		1	1	[49]
Market price; Mitigation cost; Replacement cost; Benefit transfer		1	1	[66]
<b>Total</b>	<b>6</b>	<b>38</b>	<b>44</b>	

Table 8. Number of valuation studies per mining type, type of externality and valuation item.

Mining type/Valuation item	External benefits	External costs	Total	References
Aggregate quarrying	2	7	9	
Agricultural production		1	1	[43]
Environmental quality;		2	2	[21,37]
Quality of life				
Health impacts		1	1	[74]
Property values		1	1	[61]
Property values;		1	1	[59]
Infrastructure;				
Agricultural production;				
Recreational services				
Protected areas		1	1	[71]
Recreational services;	2		2	[40,41]
Environmental quality				
Clay, sand, gravel mining	1	3	4	
Fisheries		1	1	[46]
Forest ecosystem		1	1	[69]
services				
Health impacts;		1	1	[36]
Agricultural production;				
Infrastructure				
Recreational services	1		1	[70]
Coal mining	1	16	17	
Ecosystem services		1	1	[51]
Environmental quality;		4	4	[55,57,62,72]
Health impacts				
Forest ecosystem		1	1	[68]
services				
Health impacts		2	2	[56,64]
Health impacts;		1	1	[53]
Agricultural production;				
Infrastructure; Global				
warming				
Land quality; Air		1	1	[63]
quality; Global warming				
Recreational services	1	3	4	[33,34,47,52]
Restoration		1	1	[48]
Timber production;		1	1	[58]
Forest ecosystem				
services				
Water and land		1	1	[50]
ecosystem services				
Marble quarrying		1	1	
Environmental quality;		1	1	[54]
Quality of life				
Metal mining	2	8	10	
Air quality; Landscape		1	1	[35]
quality				
Deforestation		1	1	[20]
Environmental quality;		1	1	[42]
Quality of life				
Fisheries		1	1	[38]
Health impacts		2	2	[65,67]
Recreational services	2		2	[39,60]
Water quality		2	2	[44,45]
Mining total		3	3	
Ecosystem services		1	1	[66]
Health impacts;		1	1	[49]
Agricultural production;				
Timber production;				
Infrastructure;				
Recreational services				
Property values		1	1	[73]
Total	6	38	44	

choice experiment and travel cost approaches, i.e. demand curve methods.

As presented in Table 6, ten studies have estimated external costs (seven studies) or benefits (three studies) on water systems, eight studies have monetised impacts on land resources (three studies have estimated external benefits and five studies external costs, respectively), seven studies have assessed the external costs of mining activities on air quality, five studies have estimated external costs on biota, four studies external costs on more than one environmental media and ten studies have estimated external costs of environmental problems caused by mining activities in general.

Seventeen studies (38.6%) refer to coal mining projects, ten studies (22.7%) to metal mines, nine studies (20.5%) to aggregate quarrying, four studies (9.1%) to sand, gravel and clay mining and one study to marble quarrying. Further, ten studies (22.7%) have monetised externalities of mining activities, in general. In more detail, the number of valuation studies per mining type, type of externality and valuation approach is presented in Table 7.

Also, Table 8 provides the analysis with regards to the number of valuation studies per mining type, type of externality and valuation item.

Concerning coal mining, sixteen studies deal with external costs and only one with external benefits. Particularly, two studies focus exclusively on health impacts; four studies examine impacts on health and the environment and one study monetises health impacts, losses in agricultural production, damages to infrastructure and contribution to global warming. Four studies are related to recreational services, two studies to forest ecosystem services, one study to water and land ecosystem services and one study to ecosystem services, more generally. Finally, one study contributed to the monetisation of restoration works and another one to the deterioration of land and air quality, as well as to the contribution to global warming. Six of the studies have been conducted using the benefit transfer method and two using a stated preference method, namely contingent valuation. The rest of the studies have employed non-demand curve methods, such as dose–response, market price, avoided cost, etc.

Eight out of the ten valuation studies in metal mining have estimated external costs related to health impacts (two cases), loss of recreational services (two cases), water pollution (two cases), air and landscape quality deterioration (one case), impacts on the environment and the quality of life (one case), deforestation (one case) and impacts on fisheries (one case). Finally, two studies have monetised benefits

Table 9. Number of value estimates per unit value, mining type and valuation method.

Unit value/Mining type	Benefit transfer	Demand/ Non-demand	Non-demand	Non-demand/ Benefit transfer	Revealed preference	Stated preference
% loss in property value						3
Coal mining						3
% of added value			2			
Mining total			1			
Total dimension stone mining and quarrying			1			
% reduction in tax						6
Aggregate quarrying						6
% premium in dwellings owing to restoration works					1	
Aggregate quarrying					1	
% increase in property value for 10% increase in distance from quarries					1	
Aggregate quarrying					1	
% reduction in rent					2	
Mining total					2	
loss in CS by single HH unit						1
Metal mining						1
loss in property value by single HH unit					3	
Metal mining					3	
per ha	1		5	4		
Aggregate quarrying			1			
Coal mining	1		4	2		
Sand, clay, gravel mining				2		
per ha.year				1		
Coal mining				1		
per HH loss in CS						1
Metal mining						1
per HH.one-time-payment						13
Aggregate quarrying						6
Metal mining						7
per HH.year					2	15
Aggregate quarrying						3
Coal mining						1
Marble quarry						1
Metal mining						10
Mining total					2	
per kWh	2		2			
Coal mining	2		2			
per m <sup>3</sup>			6			
Aggregate quarrying			1			
Sand, clay, gravel mining			5			
per m <sup>3</sup> groundwater supply				1		
Mining total				1		
per m <sup>3</sup> seawater supply				1		
Mining total				1		
per oz Au	5					
Metal mining	5					
per person.year						11
Coal mining						6
Metal mining						3

(continued on next page)

Table 9. (continued)

Unit value/Mining type	Benefit transfer	Demand/ Non-demand	Non-demand	Non-demand/ Benefit transfer	Revealed preference	Stated preference
Sand, clay, gravel mining						2
per ton	25		26			2
Aggregate quarrying						2
Coal mining	17		26			
Metal mining	8					
per ton CO <sub>2</sub>	1					
Coal mining	1					
per trip						1
Metal mining						1
per unit of water	1					
Coal mining	1					
per visitor	3					
Coal mining	3					
per visitor CS benefit					1	
Aggregate quarrying					1	
per year compensation to a community fund						1
Marble quarry						1
per year damages to cultural values due to collapse		1				
Aggregate quarrying		1				
per year damages to ecological values to collapse		1				
Aggregate quarrying		1				
per year direct damage cost to collapse		1				
Aggregate quarrying		1				
per year indirect damage cost to collapse		1				
Aggregate quarrying		1				
total recreational CS per year					2	
Aggregate quarrying					1	
Metal mining					1	

associated with recreational activities. As regards the valuation method, eight studies employed demand curve approaches. More precisely, the sample includes six stated preference studies (five contingent valuation surveys and a conjoint analysis) and two revealed preference studies (namely hedonic pricing and travel cost). The rest two studies measured external benefits using the benefit transfer method.

Fourteen studies measure external costs (eleven cases) or benefits (three cases) from ornamental stone (one case) and aggregate quarries (nine cases) and sand, gravel and clay pits (four cases). Only two studies are concerned with impacts on human health (explicitly or among other externalities). Moreover, four studies examine adverse effects on the environment and the quality of life, three studies estimate the value of recreational services, two studies investigate the impact of the above-

mentioned pits and quarries on property values and infrastructure and one study focuses on protected areas. Five studies examine, among other impacts, losses in agricultural production, fisheries and forest ecosystem services. In eight studies, the external costs of benefits have been valued using stated preference methods, i.e. contingent valuation (four cases) and choice experiment (also four cases). Further, four studies have employed revealed preference methods, such as the hedonic pricing (three cases) and the travel cost (one case). The rest of the studies have implemented non-demand curve approaches or the benefit transfer method.

Finally, three studies estimate the external costs of the mining sector, generally, employing non-demand curve methods (namely market price, mitigation cost and replacement cost), the benefit transfer method and the hedonic pricing method.

Table 10. Average value estimates (in Int\$2019 or per cent) per unit value, mining type and valuation method.

Unit value/Mining type	Benefit transfer	Demand/ Non-demand	Non-demand	Non-demand/ Benefit transfer	Revealed preference	Stated preference
% loss in property value						13.6%
Coal mining						13.6%
% of added value			95.5%			
Mining total			2.0%			
Total dimension stone mining and quarrying			189.0%			
% reduction in tax						0.3%
Aggregate quarrying						0.3%
% premium in dwellings owing to restoration works					26%	
Aggregate quarrying					26%	
% increase in property value for 10% increase in distance from quarries					1%	
Aggregate quarrying					1%	
% reduction in rent					14%	
Mining total					14%	
loss in CS by single HH unit						13,798
Metal mining						13,798
loss in property value single HH unit					9688	
Metal mining					9688	
per ha	4078		4586	49,885		
Aggregate quarrying			21,191			
Coal mining	4078		435	12,465		
Sand, clay, gravel mining				87,305		
per ha.year				528		
Coal mining				528		
per HH loss in CS						3795
Metal mining						3795
per HH.one-time-payment						89
Aggregate quarrying						109
Metal mining						72
per HH.year					588	303
Aggregate quarrying						1132
Coal mining						180
Marble quarry						34
Metal mining						93
Mining total					588	
per kWh	0.11		0.01			
Coal mining	0.11		0.01			
per m <sup>3</sup>			1.53			
Aggregate quarrying			3.40			
Sand, clay, gravel mining			1.15			
per m <sup>3</sup> groundwater supply				0.15		
Mining total				0.15		
per m <sup>3</sup> seawater supply				0.55		
Mining total				0.55		
per oz Au	987.92					
Metal mining	987.92					
per person.year						54.62
Coal mining						24.95
Metal mining						135.50

(continued on next page)



Table 10. (continued)

Unit value/Mining type	Benefit transfer	Demand/ Non-demand	Non-demand	Non-demand/ Benefit transfer	Revealed preference	Stated preference
Sand, clay, gravel mining						22.33
per ton	16.70		0.94			1.59
Aggregate quarrying			0.94			1.59
Coal mining	23.40					
Metal mining	2.46					
per ton CO <sub>2</sub>	7.93					
Coal mining	7.93					
per trip						23.73
Metal mining						23.73
per unit of water	2.18					
Coal mining	2.18					
per visitor	17.55					
Coal mining	17.55					
per visitor CS benefit					1.94	
Aggregate quarrying					1.94	
per year compensation to a community fund						48,751
Marble quarry						48,751
per year damages to cultural values due to collapse		171				
Aggregate quarrying		171				
per year damages to ecological values to collapse		306				
Aggregate quarrying		306				
per year direct damage cost to collapse		116,209				
Aggregate quarrying		116,209				
per year indirect damage cost to collapse		446,182				
Aggregate quarrying		446,182				
total recreational CS per year					1,628,291	
Aggregate quarrying					1,299,859	
Metal mining					1,956,722	

### 3.4. Monetary estimates

In order to answer the third research question concerning the economic evidence (i.e. valuation estimates) on the external costs or benefits of mining projects, the original values were transformed to appropriate unit values, in cases where necessary information was available. This process resulted in 156 unique monetary values. The following Table 9 presents the number of value estimates per valuation method, transformed unit value and mining type.

In total, 15 values are expressed in percent form (e.g. percentage loss in property value, percentage reduction in taxes paid by the affected population, etc.), 11 values in Int\$ per ha or per ha and year, 35 values in Int\$ per HH either per year or as one-time-payment, 4 values in Int\$ per kWh, 15 values in Int\$

per person or visitor, 64 values in Int\$ per ton or m<sup>3</sup> of mineral production, 7 values in total losses or CS per year, 3 values in units of water consumed by mining activities, 1 value in Int\$ per trip and 1 value in Int\$ per ton CO<sub>2</sub> emitted by mining activities.

Further, Table 10 provides average value estimates (in Int\$2019 or percent) per transformed unit value, mining type and valuation method.

According to Table 10, there is a wide range in the estimates. For instance, the monetary values per HH and year range from Int\$2.3 (non-use value WTP for improvements in watershed quality in the USA) to Int\$2418.6 (WTA per year for 314 days with noise, dust and mud disturbance from quarrying activities in the UK), while the per HH one-time-payment monetary values range between Int\$17.6 (one-time payment for the removal of a drainage culvert from a stream in the USA) and Int\$140.9 (one-time tax

payment for the rehabilitation of an urban abandoned quarry of 20 ha in Greece). The external costs per ton of mineral production span from Int\$0.001 (externalities of coal mining on several ecosystem services in China) to Int\$228.8 (socio-environmental liabilities of coal mining in a region of Colombia). Also, the external costs of gold mining due to mercury emissions range from Int\$1.1 per troy ounce (for open-pit gold mines in Nevada, USA, where imposed controls on smelting operations have drastically reduced mercury emissions) to Int\$3510 per troy ounce (for artisanal and small-scale mining where mercury is applied to the whole ore). The last estimates come from the same study and derived following an identical methodology.

Considering the above-mentioned examples, it is evident that the divergence in the estimates is attributed to several factors, with the most important being the valuation approach used in each case study, the economic value estimated (i.e. total, use or non-use value), the assumptions adopted by the authors (e.g. the adverse impacts considered by the study, the influence range of these impacts and, consequently, the size of the population affected) and, most importantly, the particular characteristics of each mining project and of the surrounding natural and man-made environment. Therefore, in benefit transfer applications, the selection of previous valuation studies for calculating monetary costs or benefits for a new site should be done with extreme caution.

#### 4. Conclusions

Environmental economics is increasingly being used to meet the demand for information on nonmarket values of environmental resources and services for socio-economic project appraisals, environmental liability estimates and design of MBIs. These developments have already affected the mining industry at a great extent. As a result, tenths of research papers have been published in refereed journals. Nevertheless, a systematic review of these publications has not been carried out, so far.

This paper aims to fill this gap in the literature by investigating: (i) the main non-market valuation techniques used to monetising the environmental and social impacts of mining projects; (ii) the main external costs or benefits of mining projects monetised; and (iii) the monetary estimates of mining-related externalities. The analysis shows that practically all economic valuation techniques (demand and non-demand curve approaches and the benefit transfer method) have been used to assess in monetary terms the potential economic, environmental,

health and quality of life impacts from coal and metal mines, aggregate and ornamental stone quarries and sand, gravel and clay pits. Moreover, the findings from the statistical analysis of the (transferred and transformed) monetary values reveal a wide range of estimates. The scale of the monetary values varies not only by valuation method (or the specific methodological assumptions adopted by the researchers) but also by the type of the mining activity (e.g. metal mine, aggregate quarry, etc.), and the specific characteristics of the mining projects (e.g. size of the activity, location of the project – national park, urban area, urban area, etc.). Finally, the systematic review draws directions for future research. The analysis of the published studies indicates areas of limited availability of estimates or high heterogeneity between the available estimates. In this direction, future valuation efforts should aim at filling these gaps by conducting valuation surveys for a wide variety of mining projects and with different valuation methods.

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The authors state that the research was conducted according to ethical standards.

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#### Conflicts of interest

None declared.

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