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# The environmental impact of extraction: A holistic review of the quarry lifecycle

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A R T I C L E   I N F O

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A B S T R A C T

As more companies start disclosing environmental, social, & governance (ESG) information, a holistic understanding of environmental impact is needed to provide transparency on the different concerns of stakeholders from different backgrounds. The extraction industries are poised to play a pivotal role in providing key environmental information to downstream organizations. However, these industries face unique environmental challenges, making it difficult to identify what is significant to disclose. This article explores significant environmental impacts within the quarrying sector, from a lifecycle perspective. Quarries, where mechanical extraction and processing for rock products (including aggregates and ornamental stone) occur, are integral for infrastructure projects worldwide. To identify significant environmental aspects that should be considered in comprehensive environmental assessment for quarry stakeholders, a systematic literature review is conducted with in-depth content analysis. This reveals potential significant environmental impacts, trends, and crucial knowledge gaps. Nine relevant environmental aspects are found across six lifecycle stages for quarries. Notably, differences in environmental concepts are observed. To help overcome some conceptual barriers and improve understanding at a holistic level, environmental aspects are mapped to endpoint impacts where notable damages can occur. The findings suggest more harmonization of significance assessment for environmental impacts is needed to facilitate cross-disciplinary discourse. Waste management and transport emerge as key areas that demand increased attention. Additionally, future research efforts should focus on exploring ways to reduce environmental impact in quarries.

## 1. Introduction

With rising concerns for sustainability, it is becoming increasingly important for companies to address environmental, social, & governance (ESG) risks to stay relevant and competitive in today's markets (Boulhaga et al., 2023). ESG is often considered a comprehensive way of reporting on a company's sustainability, yet it is still not commonplace for extraction companies. ESG disclosure requires several disciplines to collaborate in collecting and presenting information, involving environmental sciences, engineering, social sciences, business management, and economics. Disclosing quantitative data on the environmental element can be accomplished through different means, and there is a rise in companies utilising eco-labels and declarations at a product-level to achieve this (Testa et al., 2015). Disclosure of quantitative information benefits both customers and companies while indicating a higher level of commitment to environmental concerns (Marzocchini et al., 2023). However, caution should be taken not to fixate on the environmental performance at a product-level and overlook concerns that arise at the organizational level. Doing so risks falling into a greenwashing trap by only reporting relative impacts rather than absolute impacts (Azapagic, 2004; Yu et al., 2020).

Gaining information on the environmental sustainability of an organization has historically been done through voluntary environmental certifications, namely ISO 14001 for Environmental Management Systems (EMS). This is still seen to give both internal and external benefits, although the lack of support and guidance is considered a barrier to implementation (Bravi et al., 2020). More recently when discussing environmental sustainability in ESG, carbon footprints, eco-efficiency, and Life Cycle Assessment (LCA) are methods targeting environmental concerns that can be applied at either the company/facility level or product/process level (Götze et al., 2019). However, these usually only focus on resource efficiency or air emissions which can be poorly

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communicated as addressing ‘environmental impact’ giving an impression of a more encompassing environmental assessment. As attempts are made to aggregate quantitative data into one score for ‘total’ environmental impact in ESG disclosure (Götze et al., 2019), the lack of clarity for which environmental impacts are included becomes problematic for informed decision-making to achieve overall environmental improvement.

Rock products that are extracted from nature, in particular aggregates, are an often overlooked product by stakeholders (Miatto et al., 2017; Sandberg and Wallace, 2013), yet will still need to transition into more sustainable production practices to meet global sustainability goals.[1] As the largest component by mass for most infrastructure projects, aggregates underpin modern society and are the most extracted material on Earth (UNEP et al., 2016). Many aggregate producers count as small and medium-sized enterprises (SMEs) which are yet to see the benefits large corporations gain from ESG disclosure. Despite this, a drive to increase awareness on disclosing environmental elements through more regulation and guidelines is seen (Gholami et al., 2022). This is highlighted in the European aggregate sector by recent EU projects that aim to help the sector assess and minimize their environmental impacts (AGGREGACO2,[2] DIGIECOQUARRY,[3] and ROTATE[4]).

LCA, a methodology used to assess certain environmental impacts by applying lifecycle thinking, has now emerged as the predominant methodology for the evaluation of environmental impact at a product-level (Despeisse et al., 2022). This is likely because it is a quantitative methodology that can help gain a comprehensive understanding of environmental impact while avoiding problem-shifting between activities in the value chain. In Europe, aggregate producers have now begun sharing environmental information at a product-level based on LCA through Environmental Product Declarations (EPD). However, within the EPD framework, the LCA studies are often based on one year’s worth of production data (Papadopoulou et al., 2021) which can overlook impacts of the extraction facility (Azapagic, 2004), often referred to as the quarry.

Despite the many advantages of LCA, it is important to acknowledge its current limitations for aggregate producers. Notably, it does not encompass all environmental concerns and can fail to capture the long-term environmental implications of facilities within an organization. This is because many quarry activities fall outside the temporal boundaries of the LCA study. Further, it often reports results in relative terms which can hide increases in environmental impacts at an absolute level (Lee et al., 2022). Lastly, lifecycle impact assessment (LCIA) models which are employed to convert the lifecycle inventory (LCI) to impacts are generally less developed or entirely lacking for local impacts like land use and noise (Lewandowska, 2011). These aspects are typically more significant in quarries (Blengini, G.A. and Garbarino, E., 2011). Further, there is increased uncertainty surrounding the operational lifespans of extraction facilities compared to other manufacturing facilities, and they rely extensively on local natural resources which often occur within nature-sensitive areas (Capitano et al., 2017), making these shortcomings of high concern.

Therefore, to incorporate a broader spectrum of facility-specific environmental considerations, alternative methodologies are frequently employed at quarries that place less emphasis on quantification. Environmental Impact Assessments (EIA) prior to operations, and EMS during operations, are commonly adopted methodologies to gain a broad understanding of environmental impact (Matthews et al., 2014). However, there are still notable differences between approaches in each methodology (Lewandowska, 2011) and the inflexible nature of standardized LCAs for EPD production can make it harder to overcome these differences. To gain a holistic and comprehensive understanding of environmental impact at a company level, more effort is needed to harmonize methodologies.

With the current trends in increased ESG disclosure, many more quarries will likely need to start disclosing environmental information. As SMEs constitute a large proportion of the sector, both human and economic resources for this task will be limited. Therefore, the collection and collation of environmental information must be efficient, utilising information from multiple methodologies, while also being comprehensive and avoiding gaps in information around key environmental concerns that could harm companies’ reputations.

To aid both aggregate producers and stakeholders in utilising environmental information, this review compiles a comprehensive overview of known environmental impacts from quarries globally lifted in academic literature. The review addresses the environmental impacts of quarries throughout their lifecycle, from different disciplines, and using different methodologies and approaches, to provide insights on what environmental impacts can occur that producers and stakeholders may need to disclose, or be aware of. Considering the different backgrounds of stakeholders, what is deemed important can vary and this is also taken into consideration. The following research questions have been adopted to guide the review:

- What environmental aspects and their potential impacts are relevant to quarries in different lifecycle phases?
- Why are some impacts considered significant?
- Does the significance differ in different contexts?

The research objective is to contribute to academia by providing a common reference point for the conceptualization of environmental impact in quarries and identifying knowledge gaps in the current literature. Moreover, it is to provide the industry with a structured, scientifically sound knowledge tool for mapping results concerning environmental impact at a holistic level. The vision is to contribute to more comprehensive and valuable ESG disclosure for quarries, and more informed decision-making for improving the environmental performance of extraction in the future to meet sustainability goals.

## 2. Background

### 2.1. Environmental assessment methodologies

As LCA and EMS are seen to be significant for ESG, while EIA is an important methodology for extraction industries, these three methods are discussed further. Both EMS and EIA rely on the identification of significant ‘environmental aspects’, which encompass any element of an organization that interacts with the environment (Svensk Standard [SIS], 2015), rather than ‘environmental impacts’ which are the resulting change in the system from the interaction. This can be challenging for companies to identify (Babakri et al., 2003), and often relies on expert knowledge or stakeholder engagement.

EMS implementation often starts in the ecosphere, namely the natural systems that support life on the planet, to identify where an interaction can occur; thus identifying the potentially relevant environmental aspects for the company. LCA practitioners often start in the technosphere, namely the systems created or modified by humans, with an inventory of inputs and outputs (LCI) which should account for releases to different environmental aspects (soil, air, water etc.). Starting in the technosphere helps identify what input and output data is available. On the other hand, starting in the ecosphere can help inform on important data gaps. Both methodologies offer simplified models of complex systems, which is helpful given the numerous and intricate interactions that occur within these systems.

Lewandowska (2011) indicate that LCA can be used in environmental aspect identification, yet in the compilation of the LCI for LCA, environmental aspects are not always consciously identified as is done in

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[1] https://sdgs.un.org/goals.

[2] https://www.aggregaco2.com/en/.

[3] https://digiecoquarry.eu.

[4] https://rotateproject.eu.

EMS. This is due to the creation of the LCI now being heavily automatised by software, which converts processes, materials and waste into emissions based on emission factors as part of the background calculations or datasets. Lewandowska (2011) also raise the risk that even if an aspect is identified in LCA, it will not appear in the calculation results if there is no LCIA information available regarding that aspect. This is a relatively under-discussed challenge for LCA practitioners (Payen and Ledgard, 2017) and makes it difficult to see which environmental aspects are accounted for in results, with the term, ‘environmental aspect’ rare in LCA discourse.

One way to aid companies in successfully identifying relevant environmental aspects can be through identifying industry specific environmental aspects, as done for ports by Puig et al. (2022). For aggregates, Aggregates Europe (UEPG) commissioned a report that includes relevant environmental aspects and is now available as part of their sustainability overview (Tost and Ammerer, 2022). The report is a valuable resource for producers, especially considering its connection to regulation in the industry. From the environmental perspective, it gives an overview of the product lifecycle and priority areas. Yet, the complete lifecycle for the facility is addressed alongside other non-energy extraction processes which do not all have the same concerns as quarries and could create confusion. Aggregate production is also a global industry and the European industry, which is heavily regulated, is not necessarily representative for all aggregate producers; for example, those in the Global South where different challenges may be prominent.

Producers need to be able to identify significant impacts in order to assess where mitigation, abatement, or avoidance actions should be deployed to minimize their overall environmental impact. This leads to the notable challenge for all methodologies in moving from an activity having an interaction with the environment (which can be an endless number of interactions in a single day for a company), to causing an impact that can be considered significant.

In EMS, significance assessments are used to determine when the aspect becomes a significant environmental impact (Milios, 2018). For an environmental aspect in EIA to move to becoming a significant impact, receptors are often considered (Dey and Ramcharan, 2008). In LCA, the LCI is converted to either midpoint or endpoint indicators using LCIA models for assessing significance. The midpoint indicators can be located anywhere on the impact pathway, or cause-effect chain, which starts at where the interaction with the environment takes place (emission) and moves towards an endpoint indicator representing the final damage to the environment. The closer to the endpoint indicator, the better understanding of significance that can be gained (Bare et al., 2000). However, uncertainty increases as you move along the impact pathway due to the complexities of interactions in the environment, as discussed by Payen and Ledgard (2017) for eutrophication impacts. Fate, exposure, accumulation, and receptor vulnerability are key mechanisms for what causes an emission to become a pollutant, thus making a significant environmental impact. Different LCIA models assess at different points on the impact pathway, therefore, some midpoint indicators account for fate and exposure models while others do not (Payen and Ledgard, 2017). The point on the impact pathway where assessment takes place should be considered by LCA practitioners when looking at the final list of impact categories and the associated LCIA models used to better understand the significance of the results.

The above points highlight some ways in which different assessment methodologies use different approaches, but they can be compatible by utilising the flexibility of these tools, as discussed by Lewandowska (2011).

### 2.2. *Quarrying & extraction industries*

Extraction industries have often been challenged on their sustainability where many researchers have contributed to identifying areas for improving the sustainability of mines (Azapagic, 2004; Laurence, 2011; Segura-Salazar et al., 2019). From a broader sustainability perspective, Azapagic (2004) developed general environmental indicators for the minerals sector based on stakeholder input. However, interest in environmental concerns was seen to be lower than economic or social aspects and may lead to some issues being overlooked.

Other previous studies have aided in gaining more comprehensive understandings of environmental aspects for quarries, yet are often limited to one methodology. Considering LCA, for example, Blengini, G. and Garbarino, E. (2011) (further discussed in Blengini et al., 2012) have developed guidelines for conducting LCA studies on quarries, and highlight the importance of taking the quarry lifecycle into account. More recently, de Bortoli (2023) has reviewed LCA studies for aggregates in the literature to aid future researchers in understanding current limitations. Other notable work from Peñaranda Barba et al. (2021) gives an overview of environmental impacts identified from EIA studies of arid to semi-arid quarries in Spain: though, the focus on a developed nation in the Global North with a relatively homogeneous landscape can overlook concerns relevant for developing nations from the Global South or other specific ecosystems.

As seen in the above literature, extraction operations can have many names, including gravel pit and dredging site. The terms quarry and mine are most common, yet they are often used interchangeably (Segura-Salazar and Tavares, 2021). This can cause issues for identification of significant environmental aspects, as most mining operations tend to be more chemical in nature compared to the more mechanical aspects of quarry sites. Therefore, the following definitions for a quarry and mine have been used to avoid capturing additional environmental aspects that are more characteristic of a mine and irrelevant for the current study on quarries:

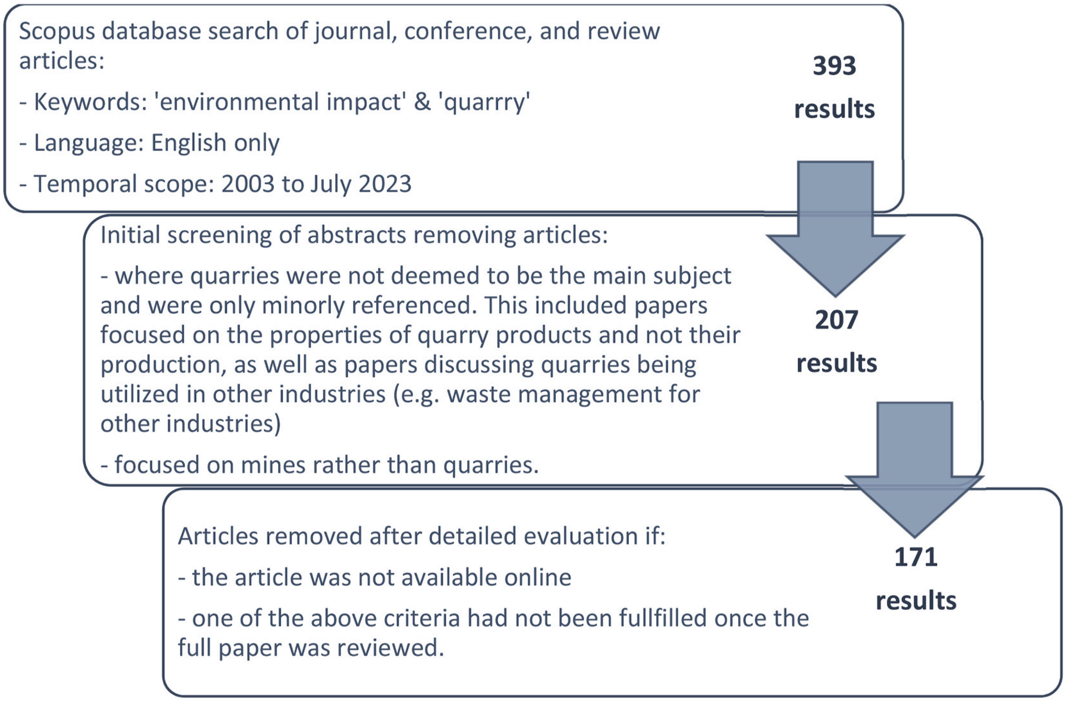
- *Quarry*: an extraction facility for naturally occurring rock or sediments where the value target is the rock itself i.e., no chemical alterations of the material are needed for it to fulfill its end purpose, only physical alterations if necessary. Processing of the material often takes place at the same site as extraction but is not necessary. End products can include aggregates, decorative stone, and talc.
- *Mine*: an extraction facility where an element or specific mineral is the value target and can require numerous processing steps to reach the required levels of purity. Processing can take place on-site but often takes place at facilities located away from extraction itself and in several stages. End-products can include base metals, industrial minerals, and precious metals.

## 3. Methodology

A qualitative systematic literature review (Snyder, 2019) conducted using the Scopus database was utilized to identify environmental impacts. The review protocol and results can be seen in Fig. 1. The field of research is relatively small, therefore, search terms were left broad to try to capture the cross-disciplinary nature of environmental sciences. Research quality was not assessed as the purpose was identification of environmental aspects and impacts rather than quantification of the impacts.

After the systematic literature review was conducted, content analysis (Bowen, 2009) was applied to the resulting 171 included papers to identify and synthesize: the environmental aspects covered, the environmental impacts that were discussed, the lifecycle phase that was addressed, the region, and objective of the research. Only the four most detailed environmental aspects addressed were designated to each study to avoid including brief statements with little empirical evidence/focus in the results.

Disciplines were allocated based on the Scopus analysis tool on subject area. Where multiple disciplines were listed for one paper, the first discipline given was chosen, unless the first discipline listed was Environmental Sciences, which can already be considered interdisciplinary. For those papers, the second listed discipline was used to give more distinct results.


Scopus database search of journal, conference, and review articles:
- Keywords: 'environmental impact' & 'quarrry'
- Language: English only
- Temporal scope: 2003 to July 2023

Initial screening of abstracts removing articles:
- where quarries were not deemed to be the main subject and were only minorly referenced. This included papers focused on the properties of quarry products and not their production, as well as papers discussing quarries being utilized in other industries (e.g. waste management for other industries)
- focused on mines rather than quarries.

Articles removed after detailed evaluation if:
- the article was not available online
- one of the above criteria had not been fullfilled once the full paper was reviewed.

**Fig. 1.** Criteria for assessment of relevant literature applied in the study and the respective results.

A one sample proportion test was applied to the results to compare the representation of different disciplines or regions to the average for the total sample, and identify if there were any statistically significant differences between results in the sub-samples compared to the total sample. The null hypothesis used was ‘there is no significant difference between the averages of the total sample and the sub-samples’.

An attempt to overcome the differences between methodologies was made through providing a common framework for key concepts. To do this, the results of the content analysis were used to map flows starting from the technosphere with the system inputs & outputs moving to mid- and endpoint impacts, as used in LCA. However, environmental aspects were also included on the impact pathway while receptors and significance, which link midpoint impacts through to endpoint impacts, were described through relevant environmental mechanisms. The aim is to overcome some conceptual barriers that can arise in the discourse between methodological pockets and provide a common nomenclature for environmental concerns of quarries. Therefore, detailed descriptions of the environmental mechanisms (fate, exposure, accumulation, and vulnerability) are beyond the scope of the review. Further, various methodologies have been used in the literature for qualitatively and quantitatively assessing, modelling, or monitoring both midpoint and endpoint impacts, and should be investigated individually depending on the purpose, scope, and detail of the evaluation needed which is outside the scope of the review.

## 4. Results

### 4.1. *Environmental aspects in quarrying & their impacts*

The review identified nine areas where quarry activities in the technosphere interact with the environment to form an environmental aspect that can lead to impact: noise, vibration, aesthetics, geomorphology, toxic substances, air, water, land use, and natural resources which can be seen in Table 1 along with the number of references where they were described (see Appendix for individual references). The aspects are given at a high level to avoid being prescriptive, thereby helping quarries to build individual environmental aspects of concern through connecting the aspect to specific quarry activities in different lifecycle stages. The spatial extent of the aspect is also included in Table 1 where local aspects only apply to the immediate surrounding of the quarry; regional aspects can impact an area within the same system, for example water basin or meteorological system; and lastly global aspects can impact global systems.

**Table 1**
Nine identified environmental aspects with their spatial extent and frequency that they occurred in the reviewed references on studies on the environmental impact from quarries.

| Environmental Aspect | Spatial Extent | Number of References |
|---|---|---|
| Noise | Local | 20 |
| Vibration | Local | 34 |
| Aesthetics | Local | 21 |
| Geomorphology | Local | 34 |
| Toxic substances | Regional | 17 |
| Air | Local to Global | 57 |
| Water | Regional | 24 |
| Land use | Local | 63 |
| Natural resources | Local to Global | 35 |

These aspects can be intertwined and interact with other aspects, while they will not always lead to a significant impact on the environment. To help determine if an environmental aspect leads to a significant impact, the environmental impact pathway can be followed, as described in many LCIA methods. To move from an interaction in the environment to a damage or benefit, certain mechanisms must occur or be triggered. From the content analysis, different midpoint and endpoint impacts are discussed in different studies. These have been mapped to a midpoint, mechanism, and endpoint, and are summarized in Fig. 2. Environmental assessment methods (e.g. in different LCIA methods) should be investigated to determine where on the impact pathway the assessment occurs to gain a more holistic understanding of an assessment.

The environmental impact can be assessed qualitatively or quantitatively at any point from aspect to endpoint. Impact evaluation gets progressively harder the further one moves towards the endpoint impacts, while the significance assessment becomes more and more

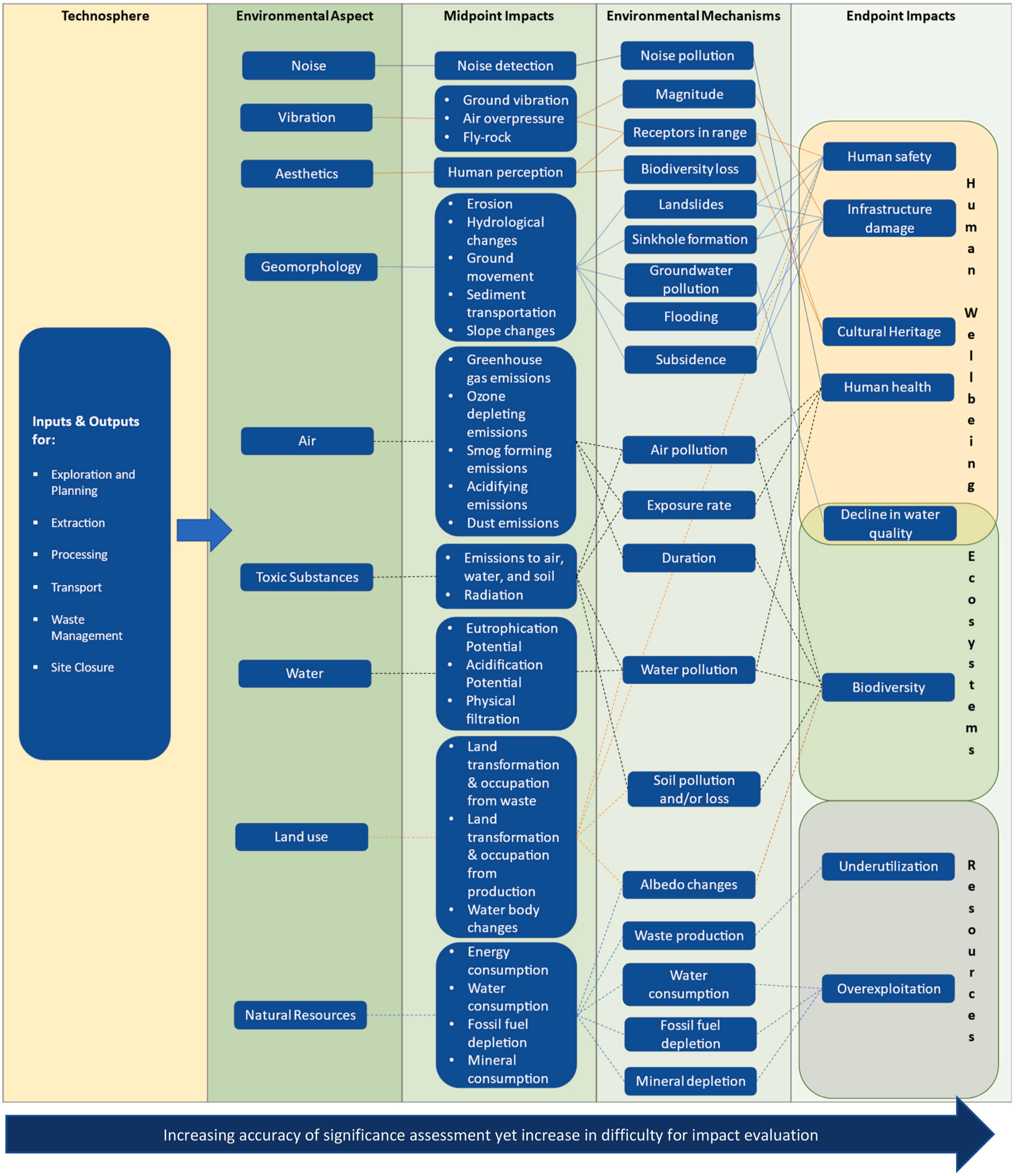


**Fig. 2.** Mapping from technosphere to endpoint impacts for the nine identified environmental aspects that can lead to impacts in quarries. Different line colours are only to ease readability. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

accurate. For example, a company may determine their site activities can have an aesthetic aspect. By assessing how many humans are within range to see this (exposure), a better understanding of the significance can be gained. Including an assessment of opinions and the local culture (vulnerability) can help assess the extent to which this would be damaging (endpoint impact) giving a more accurate assessment of the significance. Similarly, a site invoking blasting can determine that vibrations would be a relevant aspect. The vibration could be assessed by the fly-rock or ground vibrations produced (fate) as midpoint impacts, however, assessing the magnitude or if receptors are in range (exposure) will give a more accurate assessment of significance. Finally determining risk of infrastructure damage or risk to human safety (vulnerability) would encompass an assessment at the endpoint impact with a more complete understanding of significance.

### 4.2. *Impacts in different lifecycle stages*

The quarry lifecycle was divided into six main activities, or stages, based on the 171 reviewed papers: exploration & planning (33 studies), extraction (46 studies), processing (29 studies), transportation (7 studies), waste management (5 studies), and site closure (29 studies). The different activities in the quarry lifecycle are illustrated in Fig. 3 in relation to the aggregate product lifecycle. The remaining studies reviewed took a lifecycle approach (22 studies) with many of these using the LCA methodology. However, many LCA studies do not address the full lifecycle of the quarry but take the product-centric approach common for LCA studies (de Bortoli, 2023) and focus on production. This led to the identification a production phase involving extraction, processing, and transportation which is also highlighted in Fig. 3. The results showed that 86% of the studies taking a lifecycle approach address air emissions followed by natural resources covered in 73%. The number of studies taking a lifecycle approach show an increasing trend over the 20 year period covered by the review.

### 4.2.1. *Exploration & planning*

The stage of exploration and planning is often addressed using EIA before operations begin (Berry and Pistocchi, 2003; Chew and Vun, 2013; Dey and Ramcharan, 2008; Geneletti et al., 2017; Wahid, 2019), but can occur later when continuations of a quarry project are considered (Farkaš and Hrastov, 2021). The most common environmental aspect targeted in the exploration and planning stage is land use with 52% of the 33 studies addressing exploration and planning including it. This is followed by aesthetics and geomorphology at 27% and 24% respectively. The local or regional context is important during this stage, with many studies considering regional planning and policy (Blachowski and Buczyńska, 2020; Dellero and El Kharim, 2017; Dey and Ramcharan, 2008; Ioannidou et al., 2015; Kem and Pumjan, 2014; Lippiello et al., 2015; Worku, 2017). It is also the only stage where avoidance measures can be used to stop toxic substances being emitted into the environment, for example naturally occurring asbestos (Bruni et al., 2006; Burragato et al., 2005; Carvalho et al., 2014; Gianfagna et al., 2003; Punturo et al., 2015). Karstic environments are also noted as high risk ecosystems where extra care should be taken to avoid geomorphological impacts (Doctor et al., 2008; Pulido-Bosch et al., 2004).

### 4.2.2. *Extraction*

The extraction stage is dominated by studies addressing vibrations, with 65% of the 46 studies referring to it. Impact prediction through computational modelling is a common methodology (Jahed Armaghani et al., 2015a; Moustafa et al., 2021; Ramesh Murlidhar et al., 2021). After this, geomorphology and air are the second most referenced aspects with both being accounted for in 22% of the studies. It is the only activity where the Global South has contributed more studies than the Global North. This could be linked to extensive regulation in the Global North for mitigating impacts from blasting in the extraction stage, with ground vibration monitoring at in-range receptors compulsory in several European countries as part of quarry permitting. This may have led to a notable drop in the significance of resulting impacts from vibrations as less environmental mechanisms are triggered. It is important to note the type of extraction is highly relevant to the related environmental impacts, with quarries using excavation extraction techniques rarely investigating vibrations due to the lack of blasting actions (Vandana et al., 2022).

### 4.2.3. *Processing*

Processing sees the largest focus placed on air emissions with 48% of the 29 studies discussing impacts related to air. From these, the largest focus is on dust emissions with some studies focusing almost exclusively on this midpoint impact (Appleton et al., 2006; Bluvshtein et al., 2011; Paramesha et al., 2007). Yet dust is often excluded from LCA studies

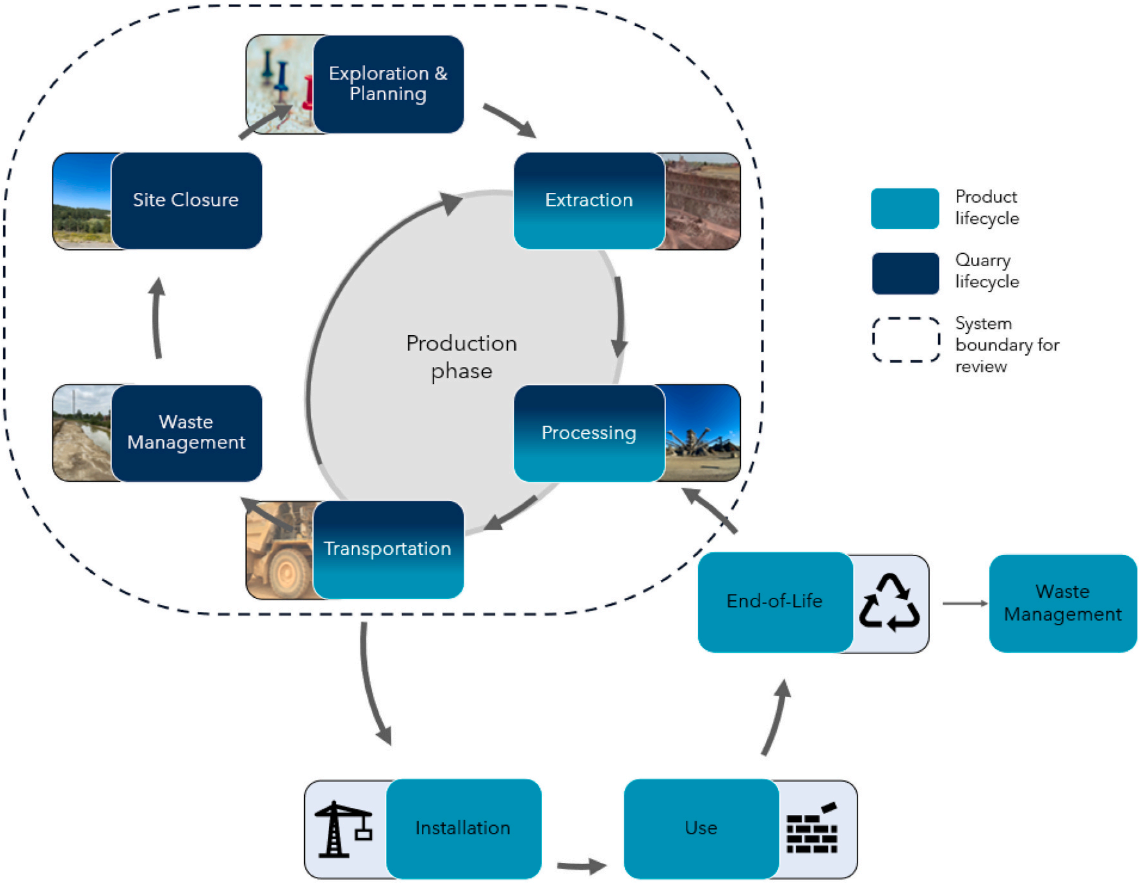


**Fig. 3.** The six main activities which constitute the lifecycle of a quarry (scope of the review) in relation to the product (aggregates) lifecycle. Within the lifecycle of a quarry, the production phase occurs which consists of the extraction, processing and transportation stages and highlights the overlap with the product lifecycle.

(Jullien et al., 2012). The exclusion could be linked to the short duration and locality of dust emissions (Bluvshtein et al., 2011) which are difficult to capture in LCA models, or from a lack of data in background datasets used for LCI modelling. Noise and water gain the most attention after air with the aspects included in 28% and 24% of the studies, respectively.

It could also be seen in several of the studies that the boundaries between extraction, processing and transportation are not always clearly defined giving rise to the production phase being the focus for many studies rather than a singular activity.

#### 4.2.4. *Transportation*

Transportation was under-represented in the studies assessed, with only seven studies dedicated solely to it. As previously discussed, many studies did not have a clear differentiation between activities in the production phase, particularly for dust emissions, and results were gathered on an aggregated level.

Air emissions were also the dominating aspect addressed in transportation studies with 71% of the studies including it. This was followed by 29% of studies referring to noise and/or natural resources, particularly resource management and access to resources, considering the difficulties in transporting such bulky and heavy products (Cardu et al., 2005; Kendall et al., 2010; Simić et al., 2016; Zuo et al., 2018). Vibration, geomorphology, water, and land use aspects were not addressed in any of the studies.

#### 4.2.5. *Waste management*

Waste management received the least amount of attention in the literature reviewed, with only five studies specifically targeting this stage of the quarry lifecycle. Toxic substances received the most attention (Stumbea, 2010; Yavuz Çelik and Sabah, 2008; Zichella et al., 2020) closely followed by water (Bourgeois et al., 2003; Yavuz Çelik and Sabah, 2008), land use (Rowe et al., 2005; Yavuz Çelik and Sabah, 2008), and natural resources (Bourgeois et al., 2003; Zichella et al., 2020). No studies addressed noise, aesthetics, vibrations, or geomorphology aspects.

#### 4.2.6. *Site closure*

The site closure and consequent remediation actions saw a strong coverage of the land use aspect, with it referenced in 79% of the 29 studies, particularly focusing on biodiversity as an endpoint impact (Bottero et al., 2020; Buondonno et al., 2013; Clemente et al., 2004; Duan et al., 2008; Fernández Montoni et al., 2014; Kun et al., 2012; Mota et al., 2004; Neri and Sánchez, 2010; Phillips, 2012; Semeraro et al., 2019; Tropek and Konvicka, 2008). After land use, geomorphological aspects were addressed in 31% of studies and aesthetics in 21%.

Remediation is now included in the permitting process for many quarries in Europe, however, it is important to note that remediation does not always include full restoration of the site. The studies identified included both remediation and restoration of sites, and was the only lifecycle stage where positive impacts were listed (Damigos and Kaliampakos, 2003). That said, many sites saw improvements compared to site closure (Buondonno et al., 2013; Duan et al., 2008), but studies using the surrounding nature as the baseline rather than the quarry at closure, often failed to reach the same levels of biodiversity and, therefore, indicated overall negative impacts (Fernández Montoni et al., 2014; Mota et al., 2004). Despite EMS being more set up for capturing local impacts like land use, restoration activities were seen to be poorly captured by implemented EMSs at quarry sites (Neri and Sánchez, 2010).

### 4.3. *Trends in the literature*

#### 4.3.1. *Different disciplines contributions to the discourse*

Most of the studies were classified within environmental sciences. However, as environmental science is already widely considered an interdisciplinary subject, secondary classifications were used for those studies, when available. After environmental sciences were removed as the primary classification, earth sciences were the most represented in the results, contributing largely to studies on extraction. This was followed by studies from environmental sciences which were more evenly spread between lifecycle stages. Engineering, social sciences, and biology all have similar contributions to the results, with most biological studies in the remediation phase, and most social studies in the exploration and planning phase. Engineering studies were most likely to take a lifecycle approach. The results are summarized for the different lifecycle stages in Fig. 4. After applying a one sample proportion test for each lifecycle stage, there was evidence of a significant difference from the average in seven of the disciplines, with a 95% confidence level. The discipline and lifecycle stage with the relative results can be seen in Table 2.

A network analysis was also conducted using VOSviewer to see if any themes related to discipline emerged from keywords used in the papers studied. The results are illustrated in Fig. 5 and highlight three distinct clusters forming around keywords used in the different papers. The blue cluster forms around production related topics and is where LCA can be seen, highlighting the production approach to LCA studies from engineering. The red cluster has a notable spatial element and includes EIA which can indicate the difference in approach when focusing on the spatial location of quarries and its associated impacts usually discussed in environmental sciences. Lastly, the green cluster emerges around blasting studies within the earth sciences which utilize modelling techniques with a strong mathematical focus, and highlights how these impacts are often viewed separately from other environmental impacts.

#### 4.3.2. *Location*

From the results, research covering environmental aspects of quarries has been conducted in 48 countries spread over six continents, as can be seen in Fig. 6. Mediterranean countries have made the largest contribution to the literature, likely related to their large marble deposits used for ornamental stone, and their significant history in quarrying. Africa at large has had a small contribution to the literature with most African countries not represented in the results.

Overall, the Global North has made a larger contribution to the literature, representing 60% of all studies examined compared to 40% from the Global South. The focus is also different between the Global North and South with the Global South making larger contributions to research within extraction and processing, and the Global North contributing more to site closure, and significantly more to waste management and transportation research, highlighted in Fig. 7. Studies in the Global North are also more likely to take a lifecycle perspective. However, when a one sample proportion test was conducted, only the results for processing were statistically different from the average with a 95% confidence level. This is in part due to the small sample sizes, particularly for transportation and waste management.

#### 4.3.3. *Study objectives*

The final part of the content analysis referred to the interpreted objective of the study. Three overarching objectives were identified in reviewed studies which were described as: impact evaluation, method development, and impact reduction. As can be seen in Fig. 8, almost half of the studies aimed to evaluate one or more environmental impact. Just over a quarter of the papers were developing and testing new methodologies for impact evaluation, and 23% were investigating methods for reducing the environmental impact of quarries in one or more aspect.

## 5. Discussion

A concern with environmental assessment methods is the lack of harmonization between them, along with the limitations in coverage of environmental aspects (Angelakoglou and Gaidajis, 2015). The result of this review addresses these concerns by providing a novel mapping of

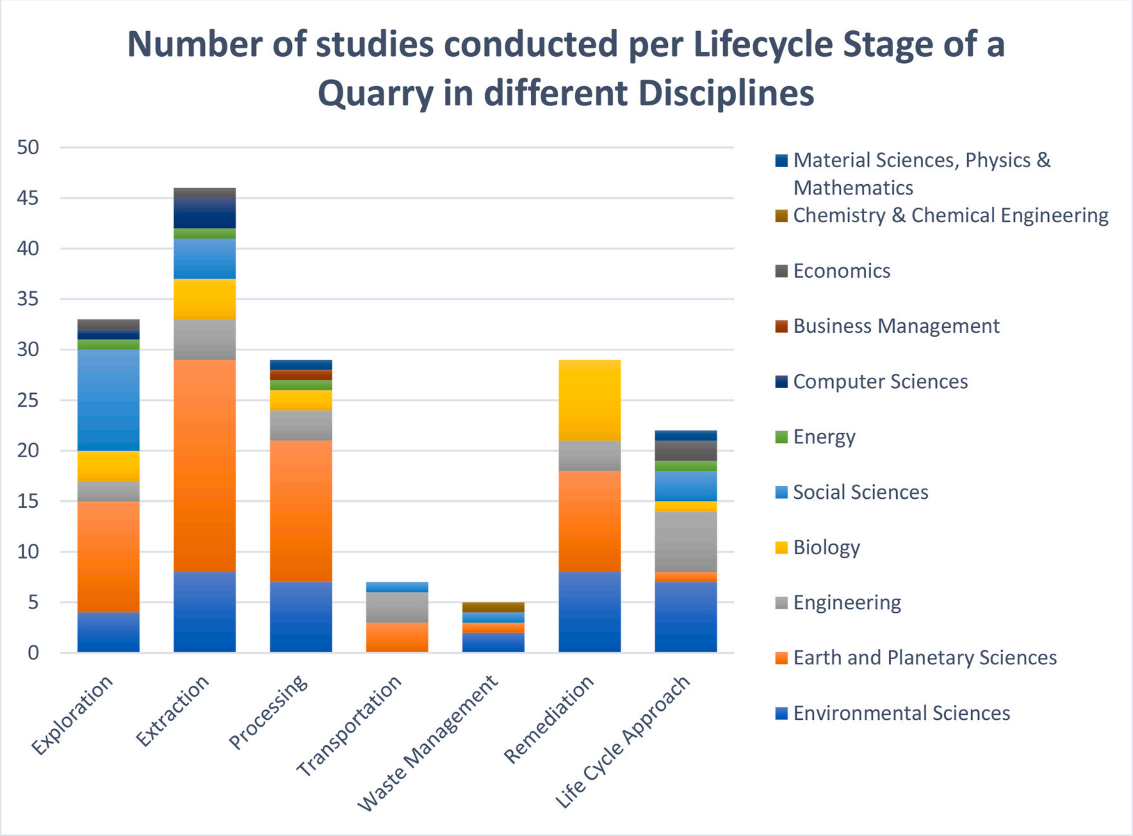


**Fig. 4.** The distribution of different disciplines in which studies on environmental impact on quarries were conducted across each lifecycle stage of a quarry.

**Table 2**
Summary of one sample proportion test results for representation of disciplines of research papers investigating environmental impact of quarries in each lifecycle stage of a quaary compared to the average representation of all studies in the sample. The following abbreviations have been used: ES = Environmental Sciences, EPS = Earth & planetary sciences, E = Engineering, B = Biology, SS = Social Sciences, En = Energy, CS = Computer Sciences, BM = Business Management, Ec = Economics, C = Chemistry & Chemical engineering and MS = Material Sciences, Physics & Mathematics.

| | Under-represented in sample | Over-represented in sample | Null hypothesis could not be rejected |
|---|---|---|---|
| *Exploration* | | SS | ES, EPS, E, B, En, CS, BM, Ec, C, MS |
| *Extraction* | | | ES, EPS, E, B, SS, En, CS, BM, Ec, C, MS |
| *Processing* | | BM | ES, EPS, E, B, SS, En, CS, Ec, C, MS |
| *Transportation* | | E | ES, EPS, B, SS, En, CS, BM, Ec, C, MS |
| *Waste Management* | | C | ES, EPS, E, B, SS, En, CS, BM, Ec, MS |
| *Remediation* | | B | ES, EPS, E, SS, En, CS, BM, Ec, C, MS |
| *Lifecycle Approach* | EPS | E, Ec | ES, B, SS, En, CS, BM, C, MS |

relevant environmental concerns from the technosphere to endpoint damages for the aggregate sector. By not being methodology specific, the review aids environmental assessment practitioners in the sector in providing holistic context to environmental studies, regardless of the methodologies being applied, going beyond recent reviews of environmental impact for the sector (de Bortoli, 2023). The work is consistent with that of Azapagic (2004) where environmental indicator categories were established for the mining industry through expert knowledge and collaboration with a mining company. However, it expands and adds to this knowledge by putting these indicators into impact pathways from the technosphere (company activities) to the endpoint damages. Further, where Azapagic (2004) noted interest varied between stakeholders in environmental issues across lifecycle stages, this review indicates that within environmental issues, significance denoted to different impacts varies across disciplines as well as between lifecycle stages, warranting more work in harmonizing significance assessments in the future.

### 5.1. *Relevant environmental aspects and their impacts*

The review identified nine environmental aspects across six lifecycle stages that were relevant for quarries. To aid producers and stakeholders in identifying relevant environmental aspects, environmental mechanisms, and their associated impacts; Fig. 2 presents a mapping of the nine aspects from system input and outputs through midpoint impact, environmental mechanisms, and endpoint impacts that can help in assessing which impacts are relevant to a quarry in different lifecycle stages. The mapping can also provide a holistic overview to locate sole impact studies in the broader picture of environmental impact from quarries.

With the goal of the mapping exercise to harmonize the diverse concepts from the different methodologies used in different fields of study, it is important to highlight differences seen for the starting point of their analysis. LCA, with its stronger association with engineering, for example, often starts in the technosphere while EMS and EIA start in the ecosphere. Each of these approaches has its own strengths and limitations. By combining both technosphere and ecosphere perspectives, a more comprehensive understanding can be gained, identifying the essential aspects and the key inputs and outputs that warrant the

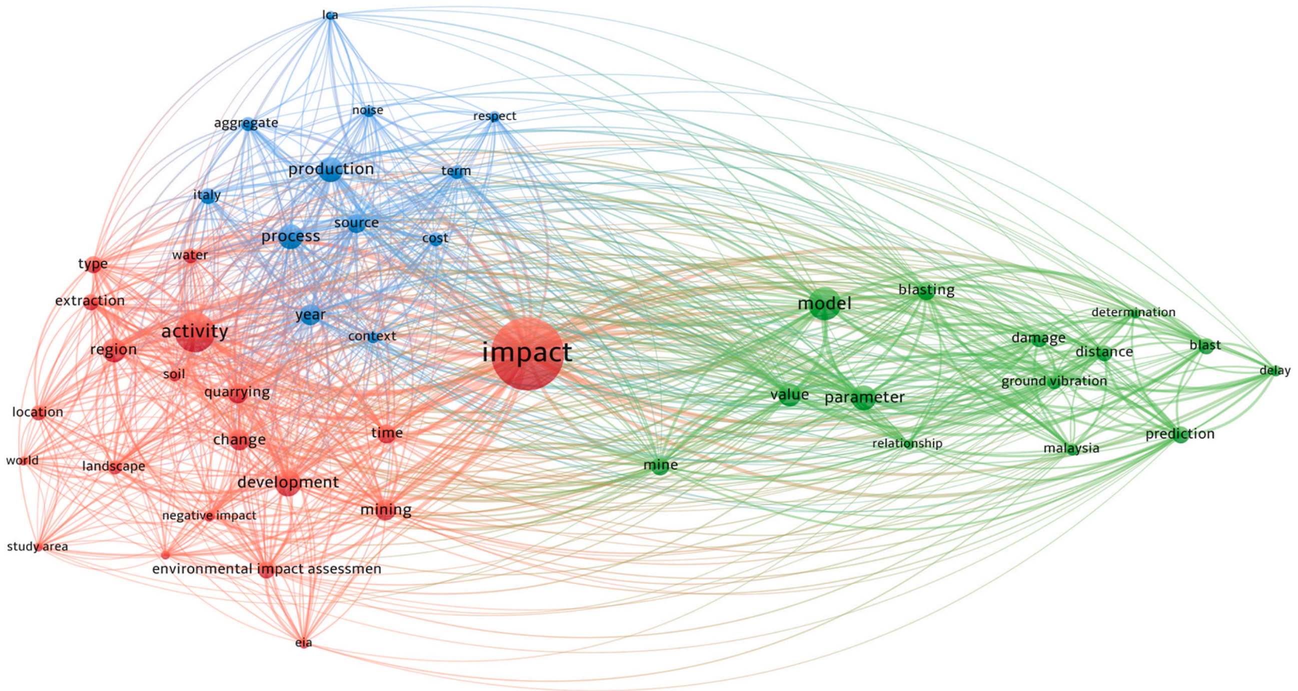


**Fig. 5.** Network analysis of keywords in a sample of research papers investigating environmental impact in quarries.

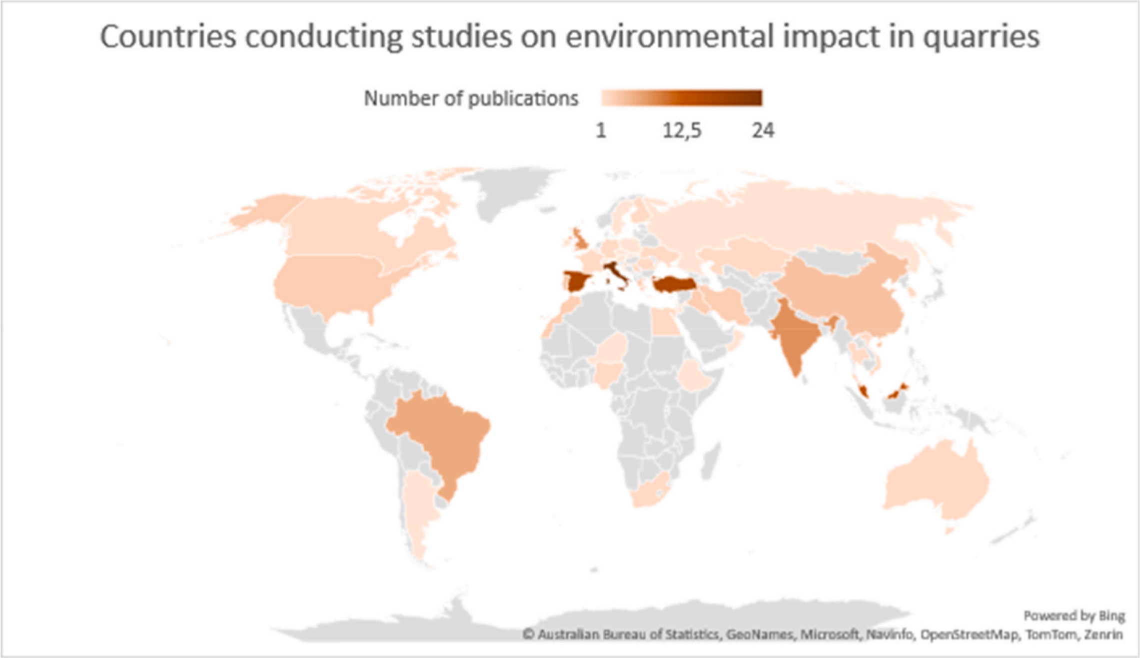


**Fig. 6.** Locations and number of studies from different countries conducting research into environmental impact of quarries.

attention of the producer for monitoring or mitigation actions.

The results show that some environmental aspects are more evident in certain lifecycle stages, and this should be considered to ensure no impact shifting occurs. Further, there are some aspects that can only be avoided when addressed in a particular stage, despite impacts only occurring in later stages (for example toxic substance release from naturally occurring asbestos can be avoided only in the exploration phase despite being released in the production phase). For this reason, not only should the environmental aspect be considered, but the environmental mechanisms that cause impacts. The findings are particularly relevant for LCA studies that only include the production phase rather than the complete lifecycle of the quarry, especially as LCA is seen to be a prominent tool for ESG where results can be used in decision-making by businesses.

### 5.2. *Determining significance*

For determining which impacts are considered significant, diverse approaches were seen across the studies. What is considered significant appears to vary between disciplines, based on the results of the content

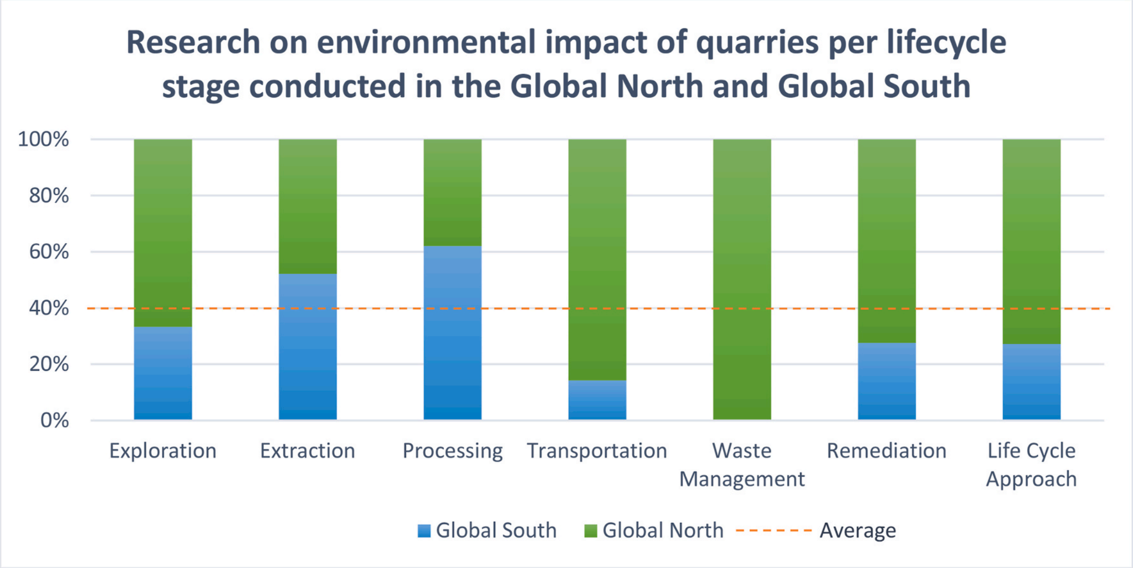


**Fig. 7.** The spread of identified literature on the environmental impact of quarries being conducted in the global north and south per lifecycle phase in comparison to the average for all studies of 60%–40% respectively.

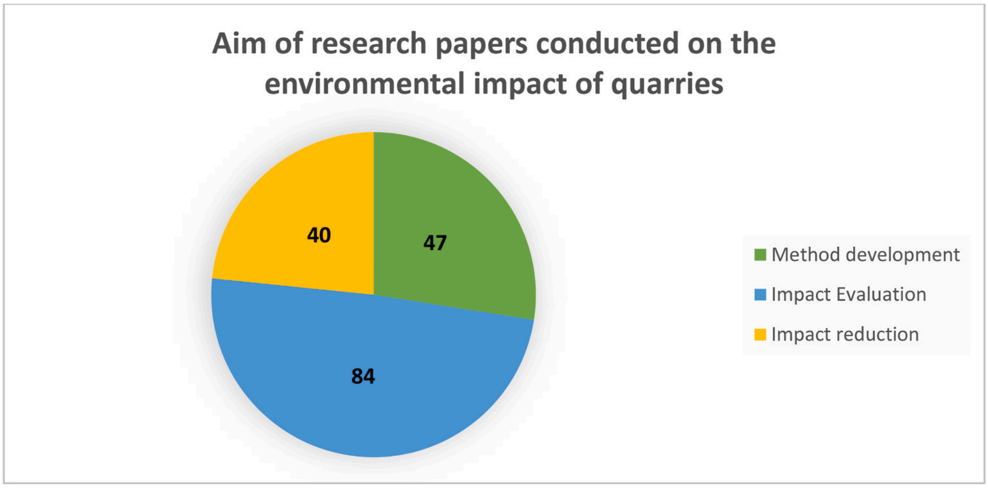


**Fig. 8.** Results showing the distribution of studies on environmental impact in quarries for the different identified aims of the studies analysed.

analysis, where a significant difference was seen between discipline and the lifecycle stage addressed. For environmental impacts, some methodologies have a more structured approach to assigning significance whereas other methodologies, for example those related to vibrations, do not formally address it. For evaluating the significance of environmental impacts, it is important to understand where on the impact pathway evaluation takes place. This can help understand how well the results represent the significance of an impact. The mapping in Fig. 2 can help practitioners start to provide some context for how significant different impacts are, especially if used with normalization of quantitative results to local, regional, or global perspectives, dependent on the aspect in question.

### *5.3. Variations from context: multidisciplinary research*

Considering whether the significance differs in different contexts, the results indicate a challenge for all methodologies in that the identification of significant environmental impacts is a subjective process (Berry and Pistocchi, 2003) and can be influenced by the discipline or background of the actors involved. This is not a new challenge, and as the study of the quarry system can fall under the realm of industrial ecology, Erkman (1997)'s statement from 1997 surrounding the need for the field of industrial ecology is still relevant:

> "… ecologists (not only political ecologists, but scientific ecologists as well) usually do not know about the industrial system. However, engineers, and people from industry in general, have a very naive view of nature and are very defiant against ecologists and ignorant about scientific ecology."

As more and more actors become involved in ESG work, the discussion on environmental impact is not just limited to engineers and ecologists but will expand to business management, social sciences, and economics. Understanding different priorities or approaches in different disciplines can be helpful in enabling more constructive cross-disciplinary discourse and overcome preconceptions.

An example of possible conflicts between different clusters that could arise are significance assertions: many studies on vibrations list this as one of the most significant aspects for quarries yet studies from a lifecycle perspective barely mention it. This poses some challenges for cross-disciplinary discussions to gain a holistic perspective of significant environmental impacts. Part of the confusion can be associated with lack of consideration of the longevity of impacts in studies. The temporal extent of impacts are beginning to be discussed more in LCA (Shimako et al., 2018), while emergency or short-lived events are highlighted in EMS (Lewandowska, 2011), and the incremental or additive characteristic of impacts are considered in EIA. However, it was not seen where all temporal approaches were considered, and reflection on how the temporal extent could influence the results when deeming significance was missing. Another possibility for confusion can be linked to a lack of discussion on the human value placed by different groups on aspects of the environment discussed, described by Hofstetter (1998) as the 'valuesphere'.

Another possible conflict can arise as some environmental impacts start to cross over into social impacts and difficulties arise in drawing a line between. One way to address this is including a distinction between the human environment and biophysical environment. However, this distinction is rarely made and may be why some aspects, like aesthetics where the human environment is in focus, are excluded from discussions. As almost all the studies analysed reported overall negative environmental impacts, it will be important to define social and economic benefits (but also losses from endpoint impacts) in a way that informed decision-making can be conducted concerning quarry operations. Another key governance concern that was often brought up in the literature was that of illegal practices and their effect on environmental impact (Darwish et al., 2011; Koca and Kincal, 2004; Ozcelik, 2022; Stalin and Kumar, 2021; Tsolaki-Fiaka et al., 2018; Vandana et al., 2020b; Worku, 2017) which is a key cross over that should be considered in ESG disclosure for quarries.

### 5.4. Future research and limitations

Overall, research into the subjectivity of significance assessment in different lenses of the discourse is encouraged from the findings of this review to help overcome any barriers it may course. Further, more research is encouraged into deeper understanding of the environmental mechanisms involved on impact pathways to help reach more objective significance assessments that can contribute to the cross-disciplinary discourse. As part of this, discussions on the longevity of impacts and the consideration of the valuesphere are encouraged in future studies on environmental impacts.

The results confirm previous discussions on the lack of relevant LCIA models for regional and local impacts from Ioannidou et al. (2015) and sees a strong need for not only more regional impact models in resource use, but also for dust emissions and land use, which are some of the most referred to impacts from the quarry perspective yet often overlooked in LCA. Jullien et al. (2012) discuss the limitations of LCI datasets available from literature, particularly considering the significant differences between quarries, and quarry types (e.g. hard rock or dredging operations). This also emphasizes the lack of inclusion of local aspects in LCI data and why the reliance on datasets without consideration of what environmental aspects are included is a concern for the industry. To address this, either more LCIA models need to be developed with the associated updates to LCI datasets for local impacts, or other assessment methods must be deployed to ensure that they are addressed, and a holistic perspective is achieved.

The results show that waste management and transportation are significantly under-represented in the literature and highlights a need for more research into these lifecycle phases to gain a comprehensive understanding of possible impacts for quarry operators. Generally, many countries in the Global South are not represented, and more research is encouraged for these locations to identify any regionally specific concerns.

Another research area where more attention could provide benefit is the trade-offs or synergies between different environmental aspects and lifecycle phases. It is seen in LCA studies, particularly between energy consumption and air emissions, and in EIA, where the planning and exploration phase considers impacts on most consequent lifecycle phases. Yet, more in-depth assessments of trade-offs and synergies encompassing several aspects and lifecycle stages is lacking and could provide valuable insights for holistic approaches and decision-making.

This study was limited to investigating environmental elements for quarries, however, economic, governance and social aspects are all important in sustainability discourse, and should be considered when using the results in ESG implications. The applicability of the discussions to other extraction sectors should also be considered. Further, despite the large overall sample size of 171 studies, when the studies were separated into various categories, the sub-sample size dropped as low as five, making it difficult to draw any conclusions concerning trends within these areas and emphasizing the need for further study. The authors of the study come from environmental sciences and engineering backgrounds which can have influenced the content analysis and researchers from other disciplines are encouraged to conduct similar studies to test the robustness of the results.

### 5.5. Implications for the industry

The results provide further guidance for quarry operators in assessing the comprehensiveness of environmental information that can be shared in ESG disclosure. It also provides stakeholders a reference for more informed decision making on environmental performance of quarries. Further, it highlights potential problems for the industry in ESG disclosure, for example, the importance of presenting both relative and absolute impacts, as well as local and global perspectives along with issues surrounding perspective from different disciplines and backgrounds for comprehensive ESG disclosure, not only environmental disclosure.

A majority of the studies aimed towards impact evaluation, with much less of the literature focused on impact reduction. For quarry operators wanting to avoid, mitigate, or abate various impacts deemed significant, more academic literature to support scientifically sound actions can be helpful (Peñaranda Barba et al., 2021), especially where appropriate trade-offs are addressed to aid decision making. Another prominent point seen in the literature is that only one paper actively discussed a positive environmental impact from quarries (Damigos and Kaliampakos, 2003) with most indicating an undetermined or negative impact. This is partly linked to the subjectivity of assessing what is positive or negative, particularly considering different ecosystems providing different biodiversity (Tropek and Konvicka, 2008). Where baselines are set for assessing if a quarry has a net positive or negative environmental impact can be a prominent contributor, with a majority of academics setting the baseline to pre-quarry conditions or that of the surrounding ecosystems (Duan et al., 2008; Mota et al., 2004). Industry is much more likely to state a positive impact being achieved, particularly for biodiversity (Tost and Ammerer, 2022) by setting baselines to the end of quarry production. This contrast indicates more consensus is needed over how to assess when an environmental impact is positive or negative and could aid in making better judgement in ESG disclosure. It implies more collaboration between the industry and academia is needed in the future.

Capitano et al. (2017) discussed a need for more holistic and simpler tools linked to concerns with the ability of LCA to capture significant local impacts. Although, the authors agree that simpler tools are needed for quarry operators from a use perspective, care should be taken to not oversimplify the mechanisms or complexity of the environmental impacts themselves. This is important as we see more engineers deploying holistic lifecycle tools, as demonstrated by the notable contribution from engineering to lifecycle studies in the literature, who may lack in depth knowledge on the intricate environmental systems in study, and risks key interactions being overlooked.

## 6. Conclusions

The review analysed a sample of 171 academic studies addressing environmental impacts in quarries where nine key environmental aspects have been identified throughout six lifecycle stages. These have been mapped at a high level to allow industry experts and academics to place detailed studies that consider only a limited number of environmental aspects in a holistic context. Several knowledge gaps in the literature have been identified, particularly on deeming significance of environmental impacts. Further, the location and disciplines of the studies have been analysed along with the objectives of the papers to gain insights into differences between contexts of studies. The results show that different stages of the lifecycle of a quarry are not addressed equally in the different disciplines, illustrating that some disciplines are more active than others in certain lifecycle stages. This shows the need for a holistic approach to environmental assessment, especially for decision-making; one of the applications of environmental assessment for ESG.

Waste management and transportation are two lifecycle stages that should be investigated further in the literature. For LCA studies, efforts should be put into developing new LCIA models for land-use and dust emissions suitable for quarries, as these were the most frequently referred to impacts throughout the quarry lifecycle and are not sufficiently included in LCA studies yet. In the absence of these models, incorporation of other methods to ensure a holistic picture of the environmental element is included in ESG disclosure is encouraged. In general, more effort is encouraged by researchers in the future to provide a holistic context when discussing environmental impact for improved understanding of the significance of results for the quarry or company.

## CRediT authorship contribution statement

**Christina Lee:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Gauti Asbjörnsson:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Erik Hulthén:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization. **Magnus Evertsson:** Writing – review & editing, Supervision, Funding acquisition.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The research data is shared in the attached document.

## 7. Acknowledgements

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## Appendix A Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cesys.2024.100201.

## Appendix B

The Table below lists the associated references from the literature for the nine identified environmental aspects identified in the review.

| Environmental Aspect | Spatial Extent | References |
|---|---|---|
| Noise | Local | (Agharroud et al., 2023; Al-Kharraz et al., 2020; Asdrubali and Baldinelli, 2003; Boutsougame et al., 2022; Călămar et al., 2015; Cardu et al., 2005; Careddu and Siotto, 2011; Hoang et al., 2022; Ilseven and Kasot, 2020; Kem and Pumjan, 2014; Kumar and Yarrakula, 2022; Lippiello et al., 2016; Onder et al., 2012; Ozcelik, 2023; Peñaranda Barba et al., 2021; Raisian et al., 2016; Vandana et al., 2020b; Végsöová et al., 2019; Wichers et al., 2018; Zawawi and Ibrahim, 2021) |
| Vibration | Local | (Agharroud et al., 2023; Al-Kharraz et al., 2020; Alvarez-Fernandez et al., 2012; Armaghani et al., 2015, 2016; Berry and Pistocchi, 2003; Boutsougame et al., 2022; Călămar et al., 2015; Careddu and Siotto, 2011; Coltrinari, 2016; Faradonbeh et al., 2018; Fernández et al., 2022; Fişne et al., 2011; Hajihassani et al., 2015; Hasanipanah and Bakhshandeh Amnieh, 2020; Ilseven and Kasot, 2020; Jahed Armaghani et al., 2015a, 2015b, 2016; Kalayci and Ozer, 2016; Kuzu and Ergin, 2005; Lawal et al., 2021; Li et al., 2020; Mesec et al., 2018; Mohamad et al., 2013a, 2013b; Mohamed and Mohamed, 2013; Moustafa et al., 2021; Ozer et al., 2008; Phillips, 2012; Raisian et al., 2016; Ramesh Murlidhar et al., 2021; Tonnizam Mohamad et al., 2016; Toraño et al., 2006; Vasović et al., 2014; Yang et al., 2020) |
| Aesthetics | Local | (Alfaro Degan et al., 2014; Berry and Pistocchi, 2003; Capitano et al., 2017; Cardu et al., 2005; Careddu and Siotto, 2011; Coratza et al., 2018; Damigos and Kaliampakos, 2003; Dentoni et al., 2020, 2023; Dentoni and Massacci, 2013; Dey and Ramcharan, 2008; Gül et al., 2019; Lippiello et al., 2015; Lopes et al., 2013; Panagopoulos et al., 2007; Prendergast and Rybaczuk, 2004; Pulido-Bosch et al., 2004; Qanazi and Zawawi, 2022; Tsolaki-Fiaka et al., 2018; Vandana et al., 2020a; Worku, 2017) |
| Geomorphology | Local | (Adabanija and Oladunjoye, 2014; Agharroud et al., 2023; Anh et al., 2020; Baikalov et al., 2022; Bona et al., 2016; Brunetti et al., 2013; Carabassa et al., 2021; Carabassa et al., 2020; Coratza et al., 2018; D'Agostino et al., 2023; Darling et al., 2010; Dey and Ramcharan, 2008; Doctor et al., 2008; Fabri et al., 2012; Ilseven and Kasot, 2020; Karahanoglu and Doyuran, 2003; Kesimal et al., 2008; Koca and Kincal, 2004; Kumar and Yarrakula, 2022; Kun et al., 2012; Ozcelik, 2022; Phillips, 2012; Pulido-Bosch et al., 2004; Ramcharan and Dey, 2005; Sahar et al., 2020; Salim et al., 2017; Stalin and Kumar, 2021; Ubeid and Albatta, 2014; Vandana et al., 2020a; Vandana et al., 2020b; Vandana et al., 2022; Worku, 2017; Zarubin, M. et al., 2021) |
| Toxic substances | Regional | (Aboelkhair et al., 2012; Bruni et al., 2006; Burragato et al., 2005; Carvalho et al., 2014; de Bortoli, 2023; Gianfagna et al., 2003; Hoang et al., 2022; Hossain et al., 2016; Ilseven and Kasot, 2020; Organiscak and Reed, 2004; Punturo et al., 2015; Stumbea, 2010; Teixeira et al., 2010; Turtiainen and Weltner, 2007; Yavuz Çelik and Sabah, 2008) |
| Air | Local to Global | (Abu-Allaban and Abu-Qdais, 2011; Agharroud et al., 2023; Al-Awadhi et al., 2013; Al-Kharraz et al., 2020; Alqadi et al., 2023; Alvarez et al., 2008; Appleton et al., 2006; Argimbaev, 2016; Babitha Rani and Shadakshara Swamy, 2007; Bendouma et al., 2020; Berry and Pistocchi, |

(*continued on next page*)

(*continued*)

| Environmental Aspect | Spatial Extent | References |
|---|---|---|
| | | 2003; Bianco and Blengini, 2020; Bluvshtein et al., 2011; Boonpeng et al., 2023; Boutsougame et al., 2022; Călămar et al., 2015; Capitano et al., 2017; Carabassa et al., 2020; Cardu et al., 2005; Careddu and Siotto, 2011; de Bortoli, 2023; Dey and Ramcharan, 2008; El-Fadel et al., 2009; Fernández et al., 2022; Flower and Sanjayan, 2007; Gazi et al., 2012; Ghanbari et al., 2018; Hoang et al., 2022; Hossain et al., 2016; Ilseven and Kasot, 2020; Jullien et al., 2012; Kem and Pumjan, 2014; Kim et al., 2021; Liguori et al., 2008; Meng et al., 2014; Organiscak and Reed, 2004; Ozcelik, 2022, 2023; Paramesha et al., 2007; Petit et al., 2021; Phillips, 2012; Qanazi and Zawawi, 2022; Raisian et al., 2016; Ramcharan and Dey, 2005; Sandberg and Wallace, 2013; Torno et al., 2011; Traverso et al., 2010; Vandana et al., 2020a; Vandana et al., 2020b; Vandana et al., 2022; Végsöová et al., 2019; Winiwarter et al., 2009; Yavuz Çelik and Sabah, 2008; Yuval et al., 2019; Zarubin, Mikhail et al., 2021; Zarubin, M. et al., 2021; Zawawi and Ibrahim, 2021; Zuo et al., 2018) |
| Water | Regional | (Adabanija and Oladunjoye, 2014; Agharroud et al., 2023; Al-Kharraz et al., 2020; Argimbaev, 2016; Bilgin, 2015; Bourgeois et al., 2003; Carvalho et al., 2014; Darwish et al., 2011; de Bortoli, 2023; Dellero and El Kharim, 2017; Fabri et al., 2012; Kosharna et al., 2021; Kumar and Yarrakula, 2022; Ozcelik, 2022; Peña González et al., 2006; Peñaranda Barba et al., 2021; Qanazi and Zawawi, 2022; Sahar et al., 2020; Sikakwe et al., 2021; Traverso et al., 2010; Yavuz Çelik and Sabah, 2008; Zarubin, Mikhail et al., 2021; Zarubin, M. et al., 2021) |
| Land use | Local | (Agharroud et al., 2023; Al-Awadhi et al., 2013; Baikalov et al., 2022; Bendouma et al., 2020; Berry and Pistocchi, 2003; Bilgin, 2015; Bottero et al., 2020; Boutsougame et al., 2022; Buondonno et al., 2013; Carabassa et al., 2020; Chew and Vun, 2013; Clemente et al., 2004; Coratza et al., 2018; Damigos and Kaliampakos, 2003; Darwish et al., 2011; Darwish et al., 2008; Dellero and El Kharim, 2017; Duan et al., 2008; Dursun et al., 2022; Fabri et al., 2012; Fernández-de Arriba et al., 2013; Fernández Montoni et al., 2014; Geneletti et al., 2017; Gül et al., 2019; Hossain et al., 2016; Kem and Pumjan, 2014; Kosharna et al., 2021; Kumar and Yarrakula, 2022; Kun et al., 2012; Lopes et al., 2013; Milgrom, 2008; Moeletsi and Tesfamichael, 2018; Mota et al., 2004; Neri and Sánchez, 2010; Ozcelik, 2022, 2023; Peñaranda Barba et al., 2021; Perotti et al., 2016; Phillips, 2012; Pitz et al., 2016; Pulido-Bosch et al., 2004; Qanazi and Zawawi, 2022; Ramcharan and Dey, 2005; Rowe et al., 2005; Sahar et al., 2020; Salim et al., 2017; Sandberg and Wallace, 2013; Semeraro et al., 2019; Souza and Sánchez, 2018; Stalin and Kumar, 2021; Tropek and Konvicka, 2008; Tsolaki-Fiaka et al., 2018; Ubeid and Albatta, 2014; Vandana et al., 2020a; Vandana et al., 2020b; Vandana et al., 2022; Végsöová et al., 2019; Wahid, 2019; Worku, 2017; Yavuz Çelik and Sabah, 2008) |
| Natural resources | Local to Global | (Agharroud et al., 2023; Al-Awadhi et al., 2013; Alqadi et al., 2023; Bendouma et al., 2020; Bianco and Blengini, 2020; Bilgin, 2015; Bourgeois et al., 2003; Capitano et al., 2017; de Bortoli, 2023; Esmailzadeh et al., 2018; Farkaš and Hrastov, 2021; Fernández-de Arriba et al., 2013; Fernández et al., 2022; Flower and Sanjayan, 2007; Gazi et al., 2012; Ghanbari et al., 2018; Gül et al., 2019; Hossain et al., 2016; Ioannidou et al., 2015; Jullien et al., 2012; Kendall et al., 2010; Liguori et al., 2008; Meng et al., 2014; Ozcelik, 2023; Ramcharan and Dey, 2005; Rodrigues and Lima, 2012; Räisänen and Torppa, 2005; Simić et al., 2016; Stalin and Kumar, 2021; Traverso et al., 2010; Worku, 2017; Yavuz Çelik and Sabah, 2008; Zarubin, M. et al., 2021; Zichella et al., 2020) |

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