GLOBAL SAND ANALYSIS SERIES

# An early exploration of data and knowledge availability for sand resources status

**Part 1: Identification of sand data and knowledge gaps: Setting priorities for further research**

## Technical report

## About UNEP/GRID-Geneva

GRID-Geneva is part of the UN Environment Programme (UNEP) Science Division and a member of the Global Resource Information Database (GRID) network. Established by UNEP, the Swiss Federal Office for the Environment and the University of Geneva in 1985, our mission is to transform data into information and knowledge in support decision making processes related to environmental issues.

## About this document

The Global Sand Observatory initiative is UNEP/GRID-Geneva's response to requests to identify knowledge gaps under the UNEA-4 Mineral Resource Resolution (UNEP.EA4.L.19). During 2020 and 2021, we reviewed and assessed current terminologies, data classifications structures and availabilities as a contribution to orienting future actions on sand, gravel and crushed rock extraction, transport and use. **This document is Part 1 of a 2-part technical report on these early explorations. The analysis will also support academic publications currently in production at UNEP/GRID-Geneva.**

UNEP/GRID-Geneva shares this working research product openly in the spirit of open science, giving free access for all and seeking feedback and corrections. Please contact us on sand@unepgrid.ch.

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**Layout & referencing style**
This document is designed as a digital resource not intended for print. APA style (7th edition) applies for references.

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## Abbreviations

| | |
|---|---|
| GDP | Gross domestic product |
| LCA | Life cycle assessment |
| LCIA | Life cycle impact assessment |
| MFA | Material Flow Accounting |
| Sand | The term 'sand' is used as an abbreviation to denote sand, gravel and crushed rock resources generally. |
| USD | US dollar |

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# OVERVIEW

**What?** This study explores gaps in data and knowledge on global sand resources. The intention is not to generate the final word on this topic. Rather, this report proposes a starting agenda on sand resources and alternatives monitoring, research and evaluation for consideration by regional and national government, private sector, research, civil society and the international communities.

**In Part 1 (current document)**, we synthetize knowledge and data, and identify priorities for further developments in this domain.

**In Part 2**, we present some quantitative estimates for sand supply, demand and trade based on the existing, publicly available data, and propose some approaches for supplementing existing data and knowledge in coming years.

**Why?** Quantification of resource stocks, pathways and flows along sand production-consumption chains at country, regional and global levels is needed for effective, equitable and coherent interventions on sand and sustainability challenges. Proactively developing capacities on this topic seems vital to the implementation of the 2030 Agenda for Sustainable Development, and green recovery post-COVID.
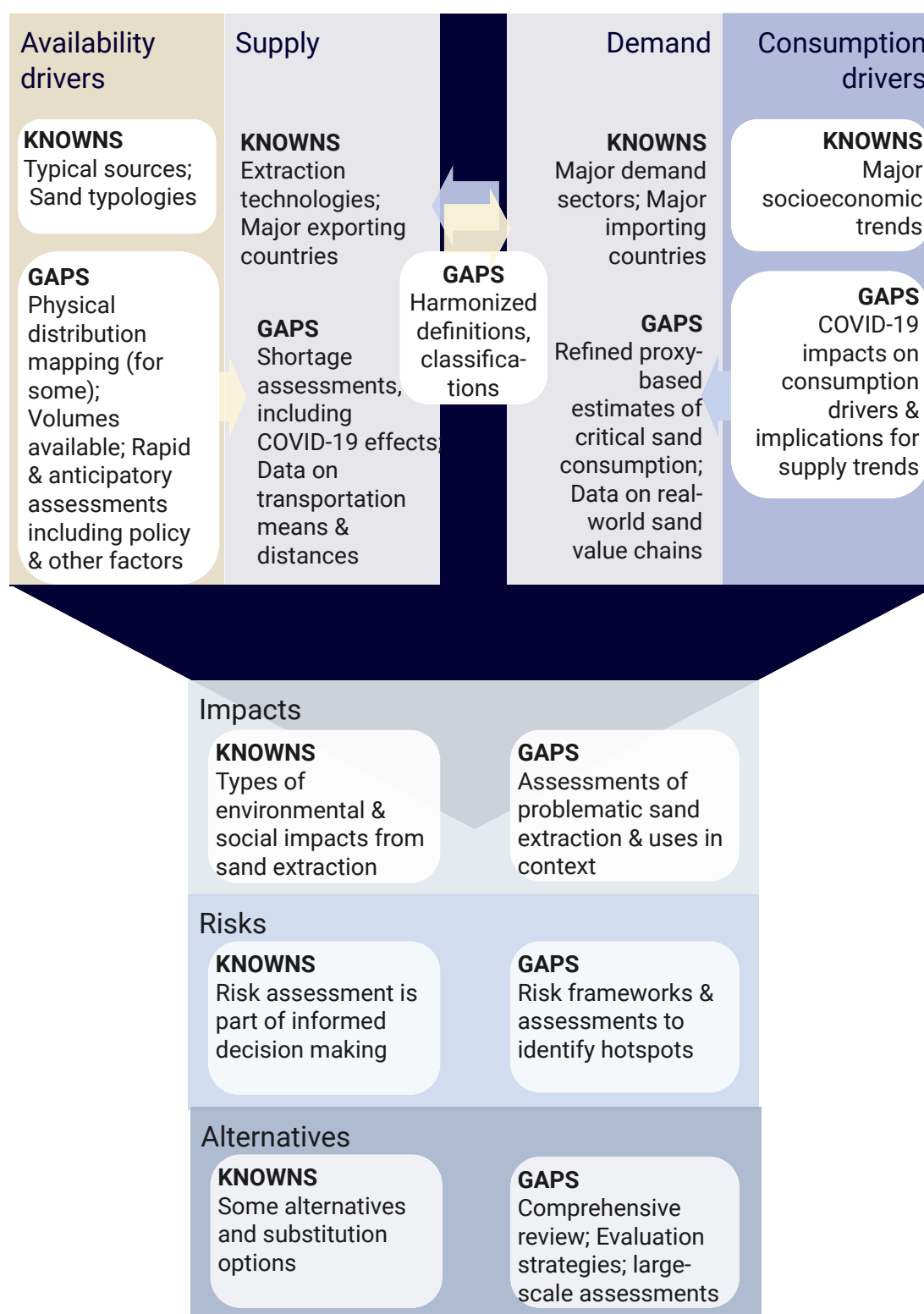
The current study contributes a rapid issue analysis, capturing key gaps in current knowledge and other capacities, and considering next steps for the nascent community of stakeholders to fill these.

**Who?** The intended audience for this work are analysts and researchers across government science institutions, academic institutions, civil society organizations aiming to support or develop research agendas on the topic of sand and sustainability.

**How?** Both reports have been produced through a secondary source review of available literature and available data on sand, gravel and crushed rock extraction, trade, transport and use. Data includes web articles, press, industrial associations, scientific articles, report and databases.

**Limitations.** While we were able to identify available data (both free and paid) and generate first results with publicly available data, there are many aspects for which quantified estimates were not found or could not be modeled in this first exploration.

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# Figure 1: Synthesis of data and knowledge gaps on global sand resources

## Availability drivers

**KNOWNS**
Typical sources; Sand typologies

**GAPS**
Physical distribution mapping (for some); Volumes available; Rapid & anticipatory assessments including policy & other factors

## Supply

**KNOWNS**
Extraction technologies; Major exporting countries

**GAPS**
Shortage assessments, including COVID-19 effects; Data on transportation means & distances

**GAPS**
Harmonized definitions, classifications

## Demand

**KNOWNS**
Major demand sectors; Major importing countries

**GAPS**
Refined proxy-based estimates of critical sand consumption; Data on real-world sand value chains

## Consumption drivers

**KNOWNS**
Major socioeconomic trends

**GAPS**
COVID-19 impacts on consumption drivers & implications for supply trends

## Impacts

**KNOWNS**
Types of environmental & social impacts from sand extraction

**GAPS**
Assessments of problematic sand extraction & uses in context

## Risks

**KNOWNS**
Risk assessment is part of informed decision making

**GAPS**
Risk frameworks & assessments to identify hotspots

## Alternatives

**KNOWNS**
Some alternatives and substitution options

**GAPS**
Comprehensive review; Evaluation strategies; large-scale assessments

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# PART 1: KNOWLEDGE AND DATA GAPS

## 1. Introduction

Sand, gravel and crushed rock use has tripled over the last two decades to reach an estimated 40-50 billion metric tons per year. And demand is still growing because of urbanization, population growth and infrastructure trends (UNEP, 2019).

From a global perspective, it is clear the magnitude of sand production and consumption is large and will keep growing – as will related local environmental and social issues. Yet, global press coverage is anecdotal and often focused on 'sand mafias' (National Geographic, 2019, June 26) or on whether we will 'run out of sand' (BBC Future, 2019, November 19). Contrary to the global explosion of concern on issues like plastic and climate change, sand has not been considered a global environmental issue or a critical resource except in some regional cases.

Our current global policy goal is to develop capacity to determine the saliency and urgency of sand at global scale and at regional scale around the world, amidst the myriad of other challenges and actions on the 2030 Agenda for Sustainable Development (UNEP/EA.4/L.19).

Recent research on sand, gravel and crushed rock extraction, trade and use have characterized the issue in general terms (e.g. Bendixen et al., 2019a) or in rich place-based case explorations (e.g. Dawson, 2021). Similarly, technical innovation of alternatives to sand from the natural environment is on a case-by-case basis, with a highly regionalized focus and often very specific to one material or use (e.g. Sivasakthi et al., 2020).

The holistic qualification and quantification of sand availability, consumption and impacts is generally not addressed in a structured way to support political agenda-setting, catalyze investment, design robust interventions and monitor circular economy progress.

In addition, sand extraction is affected by a combination of national legal frameworks (mining concessions, land use, biodiversity and environmental protection and management, river basin management and coastal zone management). In many cases, regulation and enforcement operate through different instruments and at different jurisdictional scales in an incomplete, uncoordinated and nontransparent way (UNEP 2019a; Pereira, 2020: 374). In many regions and countries, sand fits the definition of a development mineral- locally extracted, traded and used in ways that are not visible in formal economies and national statistics (Franks, 2020). Similarly, a high degree of variation in sand types, uses and products means tracing flows of this material throughout economies from source, to use and post-consumption fates is challenging. Global institutions in mineral resource governance do not focus on sand (UNEP, 2019a, 2020). These factors combined have created a situation whereby the best evidence on the current status for sand resource stocks and flows is poor for most of the world, and even missing completely at regional levels in many cases.

An attempt at empirical and quantitative analysis of supply-demand dynamics at different strategic scales of

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intervention (local, national, regional, sectoral and global) is now becoming urgent.

Our aim in this report is to clarify the current situation and future agenda for data and knowledge on sand, gravel and crushed rock resource stocks, extraction, transport, use and alternatives.

Current questions to be solved to develop sand and sustainability assessments include:

**What are the dimensions of the problem?** Is it an environmental, economic, social, technological and/or financial problem?

**Where is the problem located, what is the real scale?** Is it just in a few countries or is it spread around the globe?

**What are the critical problematic types of sand and sources: sand and/or gravel?** From rivers, beaches and/or nearshore environments?

**What are the related problematic human activities?** Is it a supply-side (extraction) and/or a demand-side (use) problem?

**How should the problem be evaluated?** In terms of resource use, damages and/or in terms of risks?

As a first step, in Part 1 of this analysis we review recent literature and identify key gaps on five dimensions of importance to future quantitative assessments for sand resources:

o   Sand availability

o   Sand consumption

o   Impacts

o   Risks

o   Alternatives

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## 2. Gap analysis

### 2.1 Evaluating sand availability

Mineral resource availability depends on the presence of the material; how much of the material there is in a region; its grades, qualities and characteristics relative to different uses; how much it costs to obtain or produce; and, where it is located relative to where it is to be used (Northey et al., 2018).

Sand and gravel availability assessment faces challenges in different forms, and to varied extents, from region to region. While we have some rich national data and case explorations, there is currently a lack of publicly available global mapping of sand distribution in the natural environment, nor a baseline assessment of sand and gravel availability and depletion around the world (Rhodes, 2019).

Current global estimations of sand production and consumption are solely based on a few proxies like cement and asphalt use (UNEP 2014, 2019a). Data on precise quality, quantity and source of sand, gravel and crushed rock is available for some major producers like the Netherlands and US – but not for all countries, even less so for informal and illegal activities. In addition, there is no precise assessment about how much sand and gravel is extracted from land compared to water sources, recycled from existing uses or produced as a secondary project from industrial and other processes at global level.

A final challenge to availability assessments is that availability is mostly conceptualized as physical distribution without considerations of institutional, legal, political, market or other factors.

There is thus a need for a publicly available estimation of the physical distribution showing where sand is located, per sand type and source type. Clarifying sources matters greatly for estimating environmental and socio-economic impacts in future. Projections of sand resource availability for the short term and longer term, are also needed to identify potential hotspots for extraction and supply constraints in future.

In addition, a refinement of the notion of scarcity and shortages of sand, gravel and crushed rock including institutional, legal, political, market and transport conditions is required since:

1) Institutional, legal, economic and political considerations govern resource access and use in practice. Sand resources might be physically available but cannot be accessed because of land use configurations and priorities, land tenure rights, protected area enforcement or lack of investment, for instance. In Europe, for example, some sourcing challenges result from land use and environmental management regulations, as well as decreasing public acceptability for mining activity, rather than physical scarcity.[1] The United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) proposes, for example, a classification of resources according to several

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[1] Baechtold, C. (2020, August 29). Les Vaudois et leur bac à sable magique. Heidi News. https://tinyurl.com/s4rbyhbj

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criteria focusing on the maturity of projects.

2) Transport modes and costs are a critical factor governing the availability of high-volume, low-value development minerals like sand and gravel (IRP, 2020:10). As such, fuel costs and transport ranges (50-70 km seems to be an upper limit in many region before sand transport by road becomes uneconomical) are part of availability assessments. Longer-range transport is a tiny proportion of sand trade but it is happening[2] and is considered a potential trend to watch given regional scarcities (Bendixen et al., 2019b), innovations in the shipping sector for large-scale transport (e.g. Eriksen, 2010) and future regional transport network developments.

The work underway by the United Nations Framework Classification for Resources (UNFC) and UN Economic Commission for Europe is a valuable contribution (UNECE, 2021), though standardized methods and data availability remains a hindrance to mapping and assessing offshore and riverine sand resources (e.g. Williams et al., 2012; Pereira, 2020:122).

## Evaluating sand availability: What is needed?

- A publicly available estimation of the physical distribution of sand, per sand type and source type. Clarifying sources matters greatly for estimating environmental and socio-economic impacts in future.

- Projections of sand resource availability for the short term and longer term, identifying potential hotspots for extraction and supply constraints in future.

- A refinement of the notion of scarcity and shortages of sand, gravel and crushed rock to include institutional, legal, political, market and transport conditions.

- Rapid availability assessments in known hotspots for extraction or areas expected to undergo large scale development of the built environment to ascertain potential extraction thresholds (or uncertainties for these) in local rivers, wetlands, coastal areas.

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2 For example: Mann, F. (2020, July 20). Construction sand mining a new WA export as first shipment heads to Singapore. ABC News. https://tinyurl.com/9u63tcd9

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## 2.2 Evaluating sand consumption

Sand, gravel and crushed rock use has tripled over the last two decades to reach 40-50 billion metric tons/year. Demand continues to grow due to urbanization, population growth and infrastructure trends (UNEP, 2014, 2019a).

Several accounting and/or analytical frameworks considering the relationship between resources (among which sand and gravel) and the economy have been published in the last decades, e.g. the System of Environmental-Economic Accounting (SEEA) (https://seea.un.org/) or very recently the 'system for the integrated and sustainable management of resources' (UNECE, 2021).

These accounting/analytical frameworks are implemented in a few countries only (mainly in developed economies).

Several additional methodological guidelines and primary data quantitative estimates for current and future sand, gravel and crushed rock use have also been published for the global level and various countries: Fishman et al. (2014); Chilamkurthy et al. (2016); Schandl et al. (2017); UNEP (2014, 2019a); OECD (2019), Eurostat/OECD (2019, 2020); UNECE (2021)[3].

Various types of economic models covering all countries can and have been used in secondary data analysis to generate estimates: Exiobase (Merciai and Schmidt, 2018; Stadler et

al., 2018); a global inter-industry econometric model Input-Output model or GINFORS (Meyer and Lutz, 2007); World6 (Sverdrup et al., 2017).

As such, current estimates are however insufficient to deal with a potential sand issue at global or regional scale for three reasons:

First, in these global models, the classification of sand, gravel and crushed rock is not detailed enough to provide insights per type of sand. In addition, sand is not considered in similar ways between reporting frameworks and models. For example, sand is considered as a single category, i.e. either as "sand and gravel" (as reported by Eurostat in the material flow accounts statistics, though the latest subdivision is more detailed) or "Non-metallic minerals – primarily construction" (reporting on material flows by UN) or even mixed with clay (Exiobase database).

The lack of attention paid to low-value minerals in international development (Franks 2020) likely contributes to the lack of standardized classifications and systematic primary data collection in many cases also. Compatible classification systems allow for consistent recording and analysis of materials flows in supply chains. Without these good estimation of sand resource consumption rates is impossible.

Second, sand and gravel use is currently estimated in global models that rely on the same (or very similar) data sources originating from the work

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3 Part of the Economy Wide MFA (EW-MFA), for which indicators and approaches are standardized (European Commission, 2018)

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performed by the Wuppertal Institute (Moll et al. 2005). Values are computed as proxies by applying conversion factors to available flows.

Two approaches are implemented depending on available data in different countries:

- Using socio-economic data for sand, gravel and crushed rock used i.e. GDP per capita.

- Using physical data: cement use from the U.S. Geological Survey (USGS, 2018) for construction and infrastructure use, and bitumen/asphalt use from the International Energy Agency[4] for transportation consumption estimates.

Third, specific value chains are not documented or modeled explicitly for many sand types uses in many countries and regions. Additional data is needed to understand at a fine detail the origins, volumes, transformations steps, lifetime and end-of-life scenarios for distinct types of sand used in various uses, e.g. in construction, industrial (electronic, pharmaceutical and cosmetic, etc.), energy production or tourism.

In order to get a better understanding of the sand issue, more attention must thus be paid to the multitude of highly differentiated sand and aggregate material compositions and uses. This will enable understanding which types and uses of sand are critical as well as their potential alternatives at global, national and regional scales.

A refined classification of sand types, sources, products and uses as well as an updated definition of sand in the System of Environmental Accounting and all other international classifications among which the

**Evaluating sand consumption: What is needed?**

- A refined classification of sand types, sources, products and uses.

- An updated definition of sand in the System of Environmental Accounting[1] and all other international classifications among which the classification of goods and trade classifications.

- Refined proxy-based estimates considering additional socio-economic information and using additional engineering data, e.g. from Life Cycle Assessment (UNEP, 2018) as explored in Miatto et al. (2017).

- A clear mapping of the value chain including sand types, sources and the different production, use, and end-of-life stages.

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[4] For more information on the SEEA, please see
https://seea.un.org/

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classification of goods and trade classifications would enable a better data collection, monitoring and sustainability assessment. The UN Harmonized System for trade classifications is one interesting example since the 2017 update was made for environmental and social reasons, and so a precedent has been set for this kind of action.

Refined proxy-based estimates considering additional socio-economic information and using additional engineering data, e.g. from Life Cycle Assessment (UNEP, 2018) as explored in Miatto et al. (2017) would also enable improvement in the evaluation of the issue through a clear mapping and quantification along the value chain including sand types, sources and the different production, use and end-of-life stages.

Finally, creative approaches of mixing monitoring technology innovation, citizen science, artificial intelligence and geospatial analysis could provide other means for data collection based on earth observation and non-official reporting channels. While promising, such approaches will need to be prototyped and tested thoroughly before a global monitoring solution can be anticipated. An appropriate mix of public policy and scientific research funding will thus be needed.

## 2.3 Evaluating impacts

Monitoring and evaluating impact is an integral part of integrated policy, strategy and program planning, implementation and learning in public policy and civil society action; and increasingly so in finance and private sector decision making and project management (McKenzie, 2009; OECD-DAC, 2019a,b).[5]

The purpose is to inform decision making by: 1) identifying and quantifying deliberate and unintended positive and negative consequences, trade-offs and synergies before a new decision based on learning from past interventions and anticipating impacts from the proposed action; and 2) assessing what changed and worked in reality, what did not, and why during and after the action (OECD-DAC, 2019b).

In sustainability, such procedures are supposed to ensure a balancing of likely and actual outcomes at the nexus of plural societal goals, values, interests and capabilities, considering different scales of social groups, geography and time and issues of rights, justice and equity (Uitto, 2021).

In some countries, sand exploitation permitting requires strategic environmental and social impact assessments – however these are rarely system-scale and are largely failing to prevent damaging practices (Caratti et al., 2004; Fischer & González, 2021). Environmental Impact Assessments (EIA) are legally established in most countries (UNEP, 2019b), and required as part of formal mining and environmental regulatory procedures. These assessments are poorly implemented and rarely followed up on however (Bond et al., 2021); and rarely applicable to

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5 BetterEvaluation.org provides detailed description and further links on impact evaluation. https://tinyurl.com/23mj772c

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informal sand extraction, which represents a significant part of this sector in emerging and developing economies (Lamb et al., 2019) in any case.

In addition to Environmental Impact Assessment (EIA), which aims to quantify the environmental impacts of a real new construction in a specific place, standardized, sustainability-oriented impact assessment frameworks and procedures for sand extraction and use could advance the data and knowledge needed to support global deliberations, national policy, sectoral initiatives, financial investment and implementation programs.

Such sustainability frameworks will need to:
- Link changes in sand extraction, trade and use activities, or the use of substitutes, to changes in environmental and social conditions, for better or worse, based on evidenced causal relationships.

- Link changes in environmental and social conditions to economic effects, impacts on vulnerable groups, and systemic-wide effects including on long term resilience.

- Anticipate environmental and social impacts and make adaptive decisions about extraction, trade, transport and uses.

River and marine dredging should probably be a first focus for sand monitoring efforts at any scale

because these are the dynamic environments for which impacts seem to be manifold and hidden while having large cascading impacts on ecosystem functioning and services like climate resilience, agricultural productivity, siltation and deposition patterns in river deltas and coastal zones (UNEP, 2019a).

Case-level assessments of sand mining impacts exist (*See* Leal Filho et al. 2021 for a recent overview) but additional understanding is needed to consider local specificities given that sand governance and management is mainly a local issue.

One opportunity is to build on the frameworks and indicators classically used in Life Cycle Assessment[6] (LCA) to evaluate the impacts of critical sand extraction.

Climate change, biodiversity loss, water use, acidification, human health, equity, poverty – some core pillars of social and environmental Life Cycle Assessment – have each been linked to sand extraction activities in a variety of situations (Leal Filho et al., 2021; Schwartz et al., 2021).

This perspective has been applied for years and provide a different perspective than current resource modeling and monitoring as applied in the economy-wide material flow accounts that typically focus on resource use and material flows, not on their impacts (Eurostat, 2018).

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[6] Life Cycle Impact Assessment is a core method widely applied in sustainability assessments for other mineral resources and materials sciences innovation and circular economy strategies (Balanay & Halog, 2019; European Commission, 2010)

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A need for caution however is illustrated by the case of the Swiss ecoinvent database (Wernet et al., 2016). While sand extraction from rivers is included in the database, the available LCIA indicators are, as it is usual in LCA, generic and do not reflect specific conditions: the consequence of river sand extraction on downstream biodiversity do not therefore reflect the full range impacts and current estimates in extraction hotspots are probably underestimated. To our knowledge, Life Cycle Impact Assessment (LCIA) frameworks for comprehensive sustainability assessments of sand extraction that enable regional/site-specific views have yet to be created.

On the consumption/use end of the sand value chain, existing environmental Life Cycle Impact Assessment frameworks and data can already be used to assess sustainability impacts of sand-related products and uses, to a degree. It is already possible to compare sand products with alternatives. For example: concrete versus wood structures in buildings (Chen et al., 2020) or replacement of sand in concrete production by waste materials (Gursel & Ostertag, 2019; Jain et al., 2020), using standard Life-Cycle Analysis databases and methods. As usual in environmental LCA, results however concern mainly environmental impacts with less emphasis on social aspects.

In conclusion, while it is clearly possible and desirable to build on what has come before, evaluating environmental and social impacts of problematic sand extraction and use will require new analytical frameworks, data and indicators –including but not limited to the indicators from Material Flow Accounting (MFA) and from LCIA.

**Evaluating impacts: What is needed?**

- An understanding of the environmental issues of sand extraction in dynamic environments like rivers, coastlines and nearshore marine areas, defining clearly what constitutes problematic sand extraction and uses in context.

- Evaluate if, and how, the consequences of problematic sand extraction could be included in existing LCIA methods and what investment in monitoring and other data collection procedures would be required to implement them.

- Include problematic sand extraction impacts in rivers, coastlines and nearshore marine areas in existing Life-Cycle Analysis databases, such as ecoinvent (Wernet et al., 2016).

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## 2.4 Evaluating risks

Risk assessment is a key element of evidence-based decision making. Applying this approach is however known to be challenging in complex social-ecological system interactions like sand production and consumption.

Risk-informed decision making[7] – under large degrees of scientific uncertainty – requires considering multiple social groups, dynamics over time and the potential for 'unknown, unknowns'.[8] Essentially, five key questions are asked during a risk assessment:

1) What is the likelihood and magnitude of a hazard and associated uncertainties?

2) What are the future consequences of action or inaction to avoid or mitigate risks as characterized by stakeholders, as well as by expert quantification?

3) How are those risks and consequences distributed or shared by different groups? What is the risk tolerance and capacity or resilience of the natural system and of different social groups to absorb or avoid the potential consequences?

4) What are the options, costs and benefits of risk mitigation and management strategy alternatives? How does early action compare to later intervention?

5) How will risks be evaluated over time to support learning and adaptive risk governance as well as management that is more likely to increase resilience?

These questions are difficult to answer – and would likely not be asked – for most sand extraction and use today. This is partly because risks induced by sand, gravel and crushed rock consumption and production are poorly defined.

The nature of risks and drivers vary for diverse types of sand, sources, extraction methods, and uses, as well as ecological and social contexts. As such, they will need to be identified per region considering variability in availability of sand resources and alternatives, development needs, ecosystem and environmental conditions and institutional factors. For example, is it a problem of environmental pollution or biodiversity loss in rivers? Or potential scarcity limiting construction? Or illegal/uncontrolled extraction threatening public funding flows?

Sand-related risk assessments will also need to go beyond a purely local perspective and consider river basin and coastal, as well as supply-chain, scales, to account for aspects like

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7 Synthesized from Amendola (2001); Haimes (2009); IDF (2020); Komljenovic et al. (2019); REAP Secretariat (2021); UNDP (2019).

8 Donald Rumsfeld's full typology: known knowns (what we know we know), known unknowns (what we know we don't know), and unknown unknowns (what we don't even know we don't know) (Yung et al., 2019).

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exported, downstream and cascading risks. For example, in China, the shortage of sand and sediment within major river systems (due to a complex mix of factors like hydropower development, river channel modifications and sand mining) indicates risks of a reduced coastal resilience to sea-level rises (Wu et al., 2021).

Finally, as risks from sand extraction and use manifest differently across actors, scales and timeframes, governance will need to contend with situations of high scientific uncertainty and low consensus on problems and priorities (Hurlbert & Gupta, 2015). As such, future risk assessments will need to grapple with uncertain and unknown stakeholder values and capacities and varying risk perceptions, as well as anticipating changing dynamics in the systems being studied (Guston, 2014; Scheffer et al., 2012). This will require mixed approaches and methods, as well as a willingness to engage with different knowledges, values and rules across

sub-national, national and regional scales.

In order to advance towards risk-informed decision making, two first steps seem relevant.

First, the development of a risk assessment framework that acknowledges and map different actors, drivers and potential risk mitigation and adaptation strategies. This framework should include a definition of the problematic situations and risks in context, considering different stakeholder values, adaptive capacities and uncertainties.

Second, the development of two levels of tools: High level hot spots analysis to target areas and supply chains with the highest potential risks worldwide, and detailed tools to be implemented by regions or within supply chains to get more specific assessments.

## Evaluating risk: What is needed?

- A risk assessment framework that acknowledges and map different actors, drivers and potential risk mitigation and adaptation strategies.

- A definition of the problematic situations and risks in context, considering different stakeholder values, adaptive capacities and uncertainties.

- High level hot spots analysis tools for large scale data-driven assessments to identify areas and supply chains to be prioritized for interventions.

- Mandatory evaluation strategies, documents and tools for both rapid and detailed local assessments that could be used for more local or case-specific evaluations and policy changes.

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## 2.5 Evaluating alternatives

Reduction of natural sand use can be achieved through some tried and tested technologies and materials (e.g. wood for construction), as well as rapidly emerging new materials (e.g. bottom ash from incinerated waste, or by-products from mining, also referred as ore-sand). The issue is however much larger than purely technical due to the large number of people and key products (e.g. cement) involved in sand-related activities. Any changes in current practices will probably have large consequences.

Assessing alternatives and substitutes thus requires first understanding the suitability of these materials to the intended use and their relative advantages and disadvantages compared to conventional materials across many dimensions (Kapoor et al., 2014). Such evaluations for sand and gravel require (at least) six perspectives often not integrated in individual studies currently.[9]

A *technological perspective*, exploring possibilities for technical (eco-)design and process improvement facilitating the substitution or reduction of sand and gravel in key demand sector uses while also maintaining intended performance. Everything else being equal, sand from the natural environment is preferred for many uses in construction, industrial and other demand sectors. In the push for 'green' concrete, as just one example, any alternative evaluation must contend with key national or international technical standards[10], as well as performance factors which have become expected within construction usage (50-year longevity guarantee, flow dynamics, etc.).

A *cost perspective*, considering relative financial costs of alternatives to sand and gravel. This includes tracking cost factors and market prices of sand and its alternatives, and outlooks for short term and long-term scarcity of both types of materials. For example, in India, concerns about river sand supply shortages for construction uses is spurring an explosion of investments in alternatives research and development in public research and in the private sector (for example, Aggarwal & Siddique, 2020; Jain et al., 2020; Khan et al. 2021).

A *policy perspective*, considering the political feasibility, policies, existing or possible legal standards and targets, or regulatory procedures for alternatives innovation and their adoption. One example is circular economy and waste management policies. These create opportunities and incentives for reuse and recycling targets and material circularity (i.e., Material Circularity Indicator (MCI)[11],

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[9] Please find a living database for alternatives solutions relevant for sand substitution and reduction efforts at this link: https://tinyurl.com/umyj37ej. As of 26 April 2021, the database includes 85 individual studies.

[10] Mades, N. (2018, March 26). 7 International Standards for Concrete That You Should Read and Use. Quality Assurance and Quality Control in Construction. https://tinyurl.com/ym3856c8.

[11] Includes: share of the material from sustained sources; share of the material from reused/recycled sources; duration of product use (reuse, increased durability, increased lifetime); intensity of use of products; and share of uncontaminated/reusable products. (Ellen MacArthur Foundation, 2019).

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as landfill taxes and recycling targets have done for the demolition waste in Europe (Di Maria et al., 2018).

An **equity and justice perspective**, including reflections on who wins and who loses in transitions to alternatives. This is particularly critical given informal artisanal and small-scale sand mining and its importance for poverty alleviation in many countries (Lamb et al., 2019).

A **sustainability perspective**, integrating many of the other lenses mentioned above, aims to evaluate overall highest contributions to accelerating progress on the Sustainable Development Goals. It requires a systems view, recognizing that alternatives can also have unintended negative consequences too, social and environmental. Standard LCA procedures, for example, explore issues like energy use and carbon emissions from recycling and potential biodiversity issues due to deforestation in the case of emphasizing wood in construction.

Ideally, an **impact investment perspective**, estimating maximum positive social and environmental impacts in choosing between alternatives investment options should also be considered in order to foster private investment. This is an important assessment measure in development and philanthropy sector interventions to identify which investments will yield best desired outcomes. It is also becoming increasingly important in finance and industry sectors as social impact investing and private contributions to the Sustainable Development Goals come into focus for some institutional and individual investors (Mudaliar et al., 2016).

The drive for Circular Economy solutions to resource scarcities, impacts and costs is already catalyzing avoidance, reduction and total substitution options in certain value chains.[12] Learnings from other recent developments from potentially problematic materials (e.g. plastics) could provide guidance in how to deal with sand and aggregates materials reduction. Efficiency and displacement strategies will need to be evaluated so that they do not create unexpected economic,

## Evaluating alternatives: What is needed?

- A comprehensive review of all alternatives, categorized per type of sand reduced or replaced and per type of use.

- A systematic review of LCA/circular economy studies in order to generate a state-of-the-art approach applicable to sand alternatives assessments.

- An evaluation of the potential and consequences of large-scale applications of alternatives.

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12 For some recent studies please see: Akhtar et al. (2021); Bui et al. (2021); Huang et al. (2020); Kazmi et al. (2020); Sabour et al. (2021); Sivasakthi et al. (2020).

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environmental or social side-effects. In addition, due to the local nature of the sand issue, one size will not fit all.

Concretely, three next steps look both possible and worth taking: First, make a comprehensive review of all alternatives, categorized per type of sand reduced or replaced and per type of use. Second, to perform a systematic review of LCA/circular economy studies in order to generate a state-of-the-art approach applicable to sand alternatives assessments. And eventually to generate an evaluation of the potential and consequences of large-scale applications of alternatives.

## 3. Priorities

In order to clarify the current situation and future agenda for data and knowledge on sand, gravel and crushed rock resource stocks, extraction, transport, use and alternatives, we suggest to start by answering the key questions mentioned in the introduction:

- What are the dimensions of the problem?

- Where is the problem located, what is the real scale?

- What are the critical problematic types of sand and sources?

- What are the related problematic human activities?

- How should the problem be evaluated?

We need to 1) start generating analyses that integrate and then transcend sectoral, national, local experiences, and 2) advance qualification and quantification of the issues at stake in order to assess, weigh, and compare appropriate courses of action in different contexts.
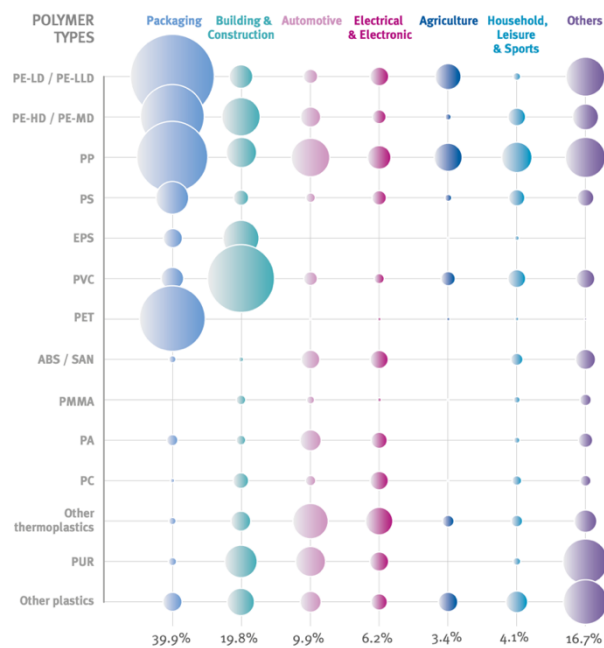
Priorities are established here in the order in which we think the major gaps would have to be filled sequentially:

1. Set definitions and classifications of demand-driven sand types and products to support improved data collection systems.

2. Establish a temporary (assuming this will be updated later and regularly) quantitative baseline against which later assessments could be compared.

3. Develop and publish a quantitative methodologies for assessing sand resource extraction and use that accounts for data poverty, based on structural modeling (to provide insights) at global and country scale.

4. Suggest a framework for thinking about critical sand production and consumption in terms of risks and hotspots.

5. Explore if, and how, hotspot assessment method and decision support systems could be developed at regional scale.

6. Develop a robust risk assessment framework that can be adapted and customized to local contexts, while still maintaining integrity and allowing comparability between regions.

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# Appendix 1. Examples of a demand-driven classification

*Extract from the annual publication of Plastics Europe "Plastics – the Facts 2019.*

An analysis of European plastics production, demand and waste data is provided to showcase an example of a demand-driven classification (namely location of production, demand per segment, demand per type of resin and main segments), and how it could possibly be presented.
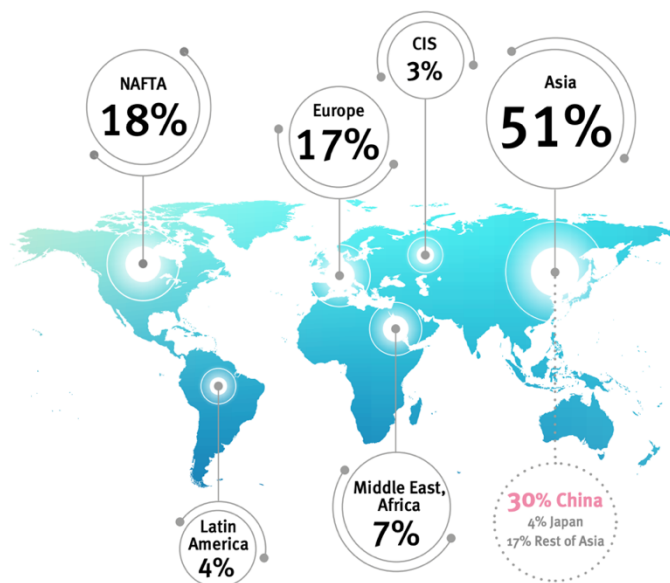
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## Plastics demand distribution by resin types 2018

Data for EU28+NO/CH.

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**19.3%**

**PP**
Food packaging, sweet and snack wrappers, hinged caps, microwave containers, pipes, automotive parts, bank notes, etc.

**17.5%**

**PE-LD / PE-LLD**
Reusable bags, trays and containers, agricultural film, food packaging film, etc.

**12.2%**

**PE-HD / PE-MD**
Toys, milk bottles, shampoo bottles, pipes, houseware, etc.

**10%**

**PVC**
Window frames, profiles, floor and wall covering, pipes, cable insulation, garden hoses, inflatable pools, etc.

**7.9%**

**PUR**
Building insulation, pillows and mattresses, insulating foams for fridges, etc.

**7.7%**

**PET**
Bottles for water, soft drinks, juices, cleaners, etc.

**6.4%**

**PS / EPS**
Food packaging (dairy, fishery), building insulation, electrical & electronic equipment, inner liner for fridges, eyeglasses frames, etc.

**19%**

**OTHERS**
Hub caps (ABS); optical fibres (PBT); eyeglasses lenses, roofing sheets (PC); touch screens (PMMA); cable coating in telecommunications (PTFE); and many others in aerospace, medical implants, surgical devices, membranes, valves & seals, protective coatings, etc.

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## Plastics demand by segment 2018

Distribution of European (EU28+NO/CH) plastics converters demand by segment in 2018. **Packaging** and **Building & Construction** by far represent the largest end-use markets. The third biggest end-use market is the **Automotive** Industry.

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**3.4 %** AGRICULTURE

**4.1 %** HOUSEHOLD, LEISURE & SPORTS

**6.2 %** ELECTRICAL & ELECTRONIC

**9.9 %** AUTOMOTIVE

**19.8 %** BUILDING & CONSTRUCTION

**16.7 %** OTHERS
Others includes appliances, mechanical engineering, furniture, medical etc.

**39.9 %** PACKAGING

**51.2 M t**
**Total European plastics converters demand**

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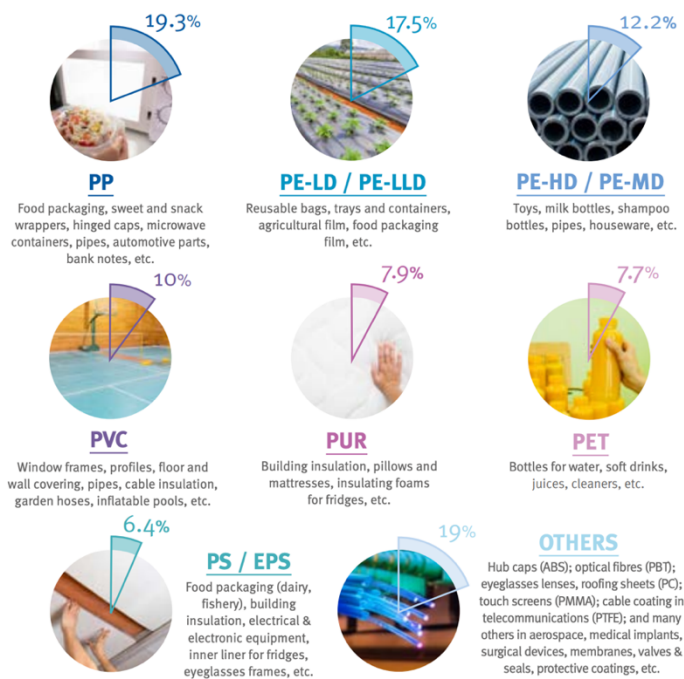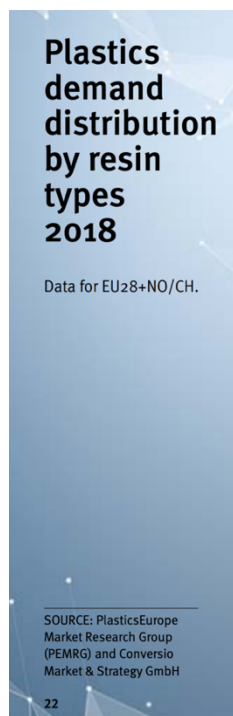
Source:
https://www.plasticseurope.org/application/files/9715/7129/9584/FINAL_web_version_Plastics_the_facts2019_14102019.pdf

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