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# Environmental Impacts of Sand Exploitation. Analysis of Sand Market

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**Abstract:** Sand is an indispensable natural resource for any society. Despite society's increasing dependence on sand, there are major challenges that this industry needs to deal with: limited sand resources, illegal mining, and environmental impact of sand mining. The purpose of this paper is twofold: to present an overview of the sand market, highlighting the main trends and actors for production, export and import, and to review the main environmental impacts associated with sand exploitation process. Based on these findings, we recommend different measures to be followed to reduce negative impacts. Sand mining should be done in a way that limits environmental damage during exploitation and restores the land after mining operations are completed.

**Keywords:** resilience; sand market; sand exploitation; environmental impacts

## 1. Introduction

Sand is a natural aggregate formed by rock erosion over thousands of years [1,2]. Evidence of sand use as an aggregate material for different civil constructions dates from ancient times [3]. The mortar used for bounding Egyptian pyramids blocks was a mixture of clay and sand or a mixture of mud, lime and sand [4]. Jackson et al. [5] consider that the mortar produced by romans 2000 years ago (as a combination of limestone and volcanic sand) had an essential role for preserving the buildings over centuries. The situation is not completely different today, as sand is still used intensively in the construction industry, but currently there are also many other industries that use this natural resource. Thus, sand is used as a main component in various construction materials such as cement, mortar, tile, brick, glass, adhesives, ceramics, etc.; and it has an important role in water filtration, in chemicals and metals processing and in plastic industry. These multiple utilizations led to an exponential consumption growth and this trend is expected to continue due to population growth and increasing standards of living.

The importance of this natural resource is given by the fact that, nowadays, after fresh water, sand is considered to be the second most consumed natural resource on Earth [6]. United Nations Environment Programme (UNEP) stipulates that "Sand and gravel represent the highest volume of raw material used on earth after water "but also sounded the alarm over the fact that "their use greatly exceeds their natural renewal rates" [7].

Considering that deserts cover almost 20% of Earth's land surface and 20–30% of the world's deserts are covered by sand [8], one can imagine that to cover sand demand is a problem that can easily be solved. The situation is quite different because not every type of sand is suitable for market demand. It may seem surprising but countries from Middle East, surrounded by desert, import large quantities of sand. The value of sand and gravel imported by Qatar in 2012 was around $6.5B [9], the country being considered the world's largest importer of sand and gravel for that year. In 2014, the value of United Arab Emirates imports of sand, stone and gravel was around $456M [10].

Desert sand, which consists of small and fine grains, does not meet certain multiple industry standards. The fact that a certain type of sand may or may not be used in different industries depends on several factors (size, density, composition, etc.). According to the Product Complexity Index (PCI), in 2015, sand occupied position 935 from a total of 1219 products [11], thus it is not considered a complex product and does not require complex knowledge, skills or technology to produce.

Based on certain characteristics, sand can be classified into different categories, as we can observe in Figure 1.

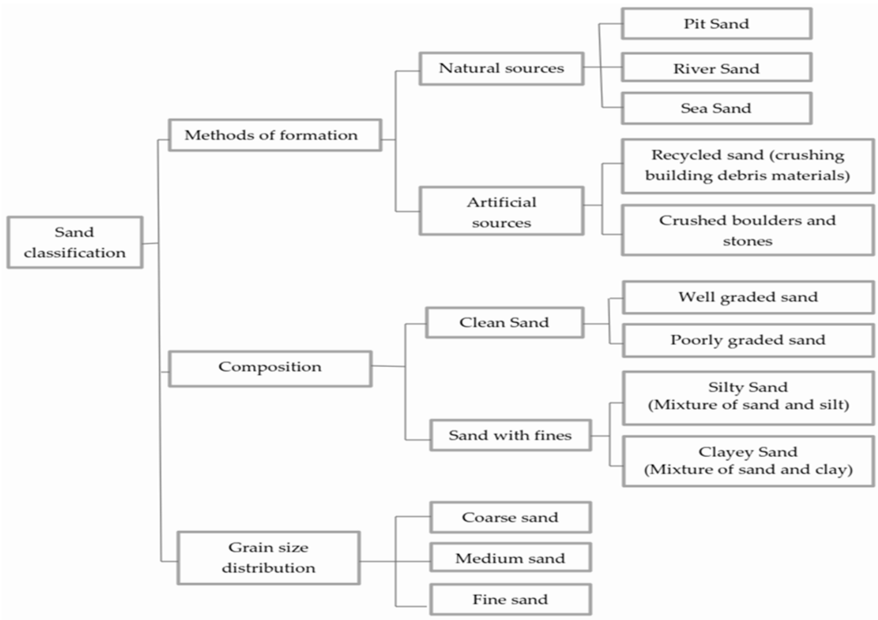


**Figure 1.** Sand classification. Source: Chart made by the author.

Different types of sand have specific properties and are used in different industries: construction, glass manufacturing, foundry industry, metal production, chemical production, ceramics and refractories, paint and coatings, filtration and water production, oil and gas recovery, recreational products, etc. [12,13]. According to International Monetary Fund, "the greatest consumer of sand and gravel is the cement industry" [14]. Based on economic growth, China, the ninth largest sand importer, used more cement between 2011 and 2013 than the U.S. used in the entire 20th century [15]. Beside this, sand is also used in land reclamation process; Singapore, the largest sand importer in the world is using this resource for territorial expansion [16,17]. Countries such as Netherlands and Belgium, Japan (second, third and fourth largest sand importer countries, respectively) also use large quantities of sand for land reclamation [18].

Sand deposits have two origins: terrestrial and marine (offshore) [19]. Terrestrial sources include residual soil deposits, river channel deposits and floodplain alluvial deposits, and the most common marine sources are shore and offshore deposits [19]. According to Kowalska and Sobczyk ([20], 2014), "sand deposits are located in the majority of cases on the mountain and river valleys, often in environmentally valuable areas". Being more expensive than terrestrial exploitation, offshore dredging is most common in developed economies due to the cost of specialized equipment and special environmental permits required [21].

Leaving aside the importance of this resource for many industries, sand industry has significant environmental consequences for the planet. Lawal [22] considered that sand demand is growing rapidly, while, at the same time, its exploitation is becoming an environmental issue.

The main objectives of this paper are: (1) to present an overview of the sand market, highlighting the main trends and actors for production, export and import; and (2) to review the main environmental impacts associated with sand exploitation process.

In the Section 3 we will analyze sand market worldwide to see the largest sand producers, importers and exporters [7].

Section "Sand Mining and the Environment" will present major environmental impacts and consequences of sand exploitation based on the analysis of existing literature associated with this issue. Underdeveloped and developing countries, where governments often lack the capacity to establish and enforce environmental regulations, are usually confronted with illegal sand mining operation, leading to a series of environmental issues and threats; therefore, special attention will be paid to these countries.

Once that negative environmental impacts related to sand exploitation are identified, in the next Section "Discussions", we will identify solutions for mitigating these impacts. This section also includes a discussion of future sand demand taking into consideration the main factors that influence demand: rapid population growth and urbanization, and increasing demand for products that use sand for their fabrication process.

Finally, the "Conclusion" indicates the major measures that can be adopted by governments and public authorities to limit the negative environmental impacts of sand exploitation.

## 2. Methodology

This study aims to obtain a better understanding of global sand market and to identify major environmental aspects of sand exploitation.

First, based on data collected from different database sources, we will analyze sand production, exports and imports to determine the main country countries that play a major role in this sector.

Second, we will identify main environmental consequences of sand exploitation based on a literature study conducted into the existing literature.

## 3. Analysis of Global Sand Market

In 2011, the human population reached seven billion, and since then the population continues to increase. Today, about 54% of the world's population is living in urban areas and it is assumed that by 2050 the percentage will reach 66% [23]. Both continuous global population growth and the increasing rate of urbanization will put pressure on governments, companies, etc., regarding the way they deal with urban development. For these reasons, aggregate demand is very high, as concrete is commonly used in the construction industry. Considering concrete is the most widely used construction material in the world [24,25], and, for concrete production, each ton of cement requires approximately six to seven tons of sand and gravel [7], sand demand is exploding.

The global sand market is continuously affected by supply and demand imbalance. The leading producers of sand and gravel countries from 2010 to 2015 are presented below (Figure 2):

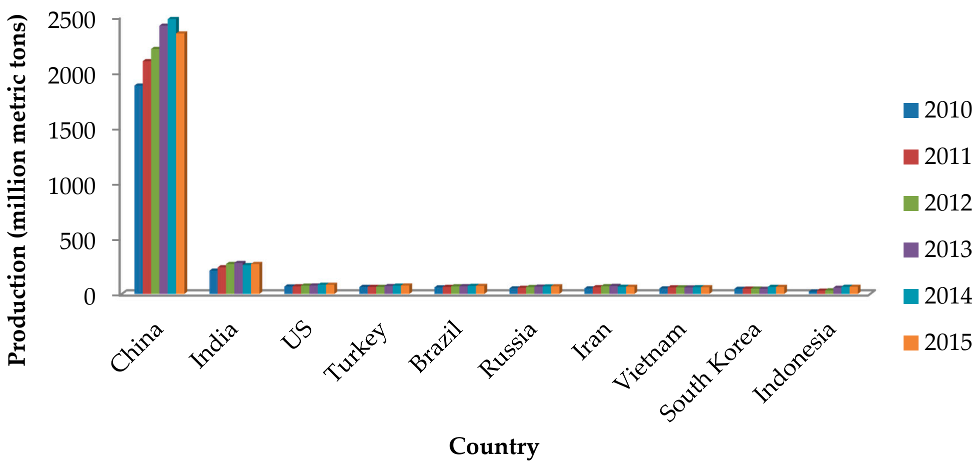


**Figure 2.** Leading Producers of Sand and Gravel countries from 2010 to 2015 (million metric tons). Source: Chart made by the author based on data from Statista database [26].

USA is the largest sand producer, followed by Italy, France and Germany. Figure 2 illustrates the fact that, with two exceptions (Italy and Spain), sand and gravel production has been growing since 2010. For Italy and Spain, the situation is determined by the fact that these countries recorded a long period of stagnation after the last economic crisis [27]. For example, in 2012, Italian cement production decreased by 20.9% as a result of declining construction industry due to the contraction of the economy [28].

USA is also the largest exporter (Figure 3) country followed by Germany, the fourth producer country in the world. From 2010 to 2014, USA exports followed a moderate upward trend, but this trend was not followed by all countries presented in Figure 3. The reasons for this situation can vary: decreased production of sand, internal use, etc.

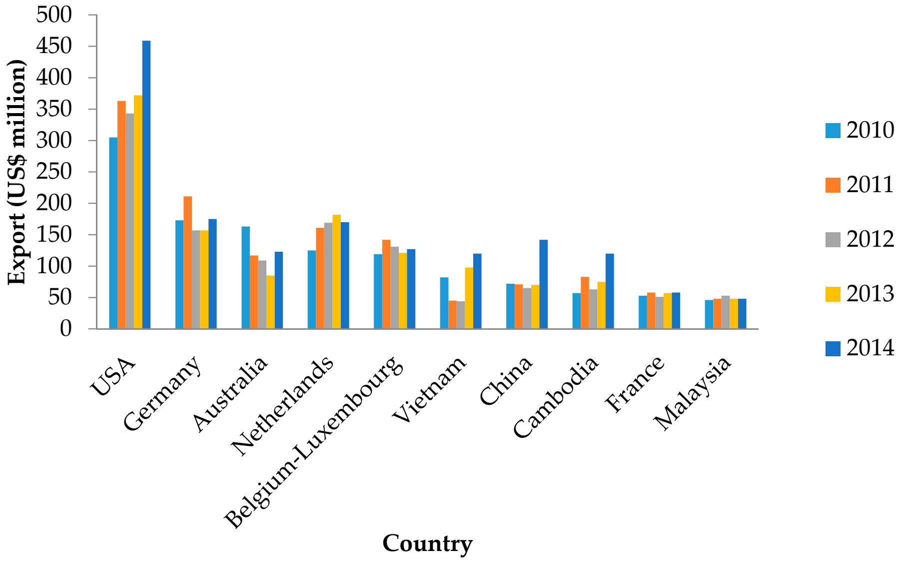


**Figure 3.** Top 10 sand export countries (2010–2014) (US$ million). Source: Chart made by the author based on data from OEC database [29].

Table 1 illustrates the fact that with few exceptions (Australia and China), countries kept almost the same position in Top 10 sand exported countries in the period 2010–2014. Figures 4 and 5 reflect USA's position as a major sand supplier. With a 22% share of sand export in 2014, USA continues to have the largest market share followed by Germany and Netherlands with 8.4% and 8.1%, respectively. Overall, five countries exported in 2014 more than 53% of total world sand exports that totaled $2.09 billion (US, $459M; Germany, $175M; Netherlands, $170M; China, $142M; and Belgium–Luxembourg, $127M).

**Table 1.** Top 10 sand exporting countries 2010–2014.

| Country Year | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| USA | 1 | 1 | 1 | 1 | 1 |
| Germany | 2 | 2 | 3 | 3 | 2 |
| Australia | 3 | 5 | 5 | 6 | 6 |
| Netherlands | 4 | 3 | 2 | 2 | 3 |
| Belgium–Luxembourg | 5 | 4 | 4 | 4 | 5 |
| Vietnam | 6 | 10 | 10 | 5 | 7 |
| China | 7 | 7 | 6 | 8 | 4 |
| Cambodia | 8 | 6 | 7 | 7 | 8 |
| France | 9 | 8 | 9 | 9 | 9 |
| Malaysia | 10 | 9 | 8 | 10 | 10 |

Source: Table made by the author based on data from OEC database [29].

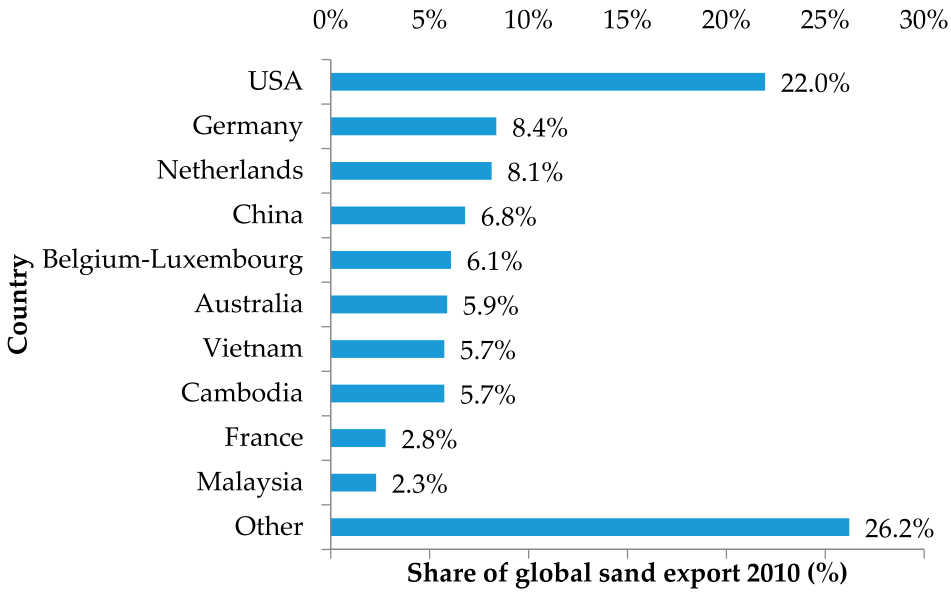


**Figure 4.** Share of global sand export 2010. Source: Chart made by the author based on data from OEC database [29].

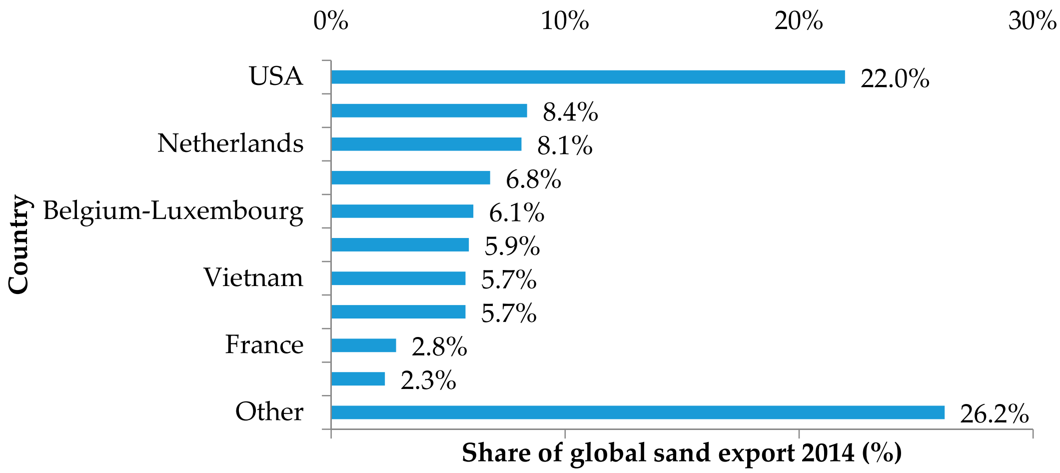


**Figure 5.** Share of global sand export 2014. Source: Chart made by the author based on data from OEC database [29].

There have been several changes of position during the years: China increased its market share (from 4.1% to 6.8%); Cambodia also increased it market share (from 3.3% to 5.7%); and Australia recorded a decrease in its market share (from 9.4% to 5.9%).

US ranks first in both export value in 2014 ($459M) and growth value of exports for five years (2010–2014) ($282M) (Figures 6 and 7). Taking into consideration the growth value of exports for five years, China was the second largest exporter ($63.3M) (Figure 7).


**Figure 6.** Global sand exports 2014 (Value). Source: The Observatory of Economic Complexity [29].

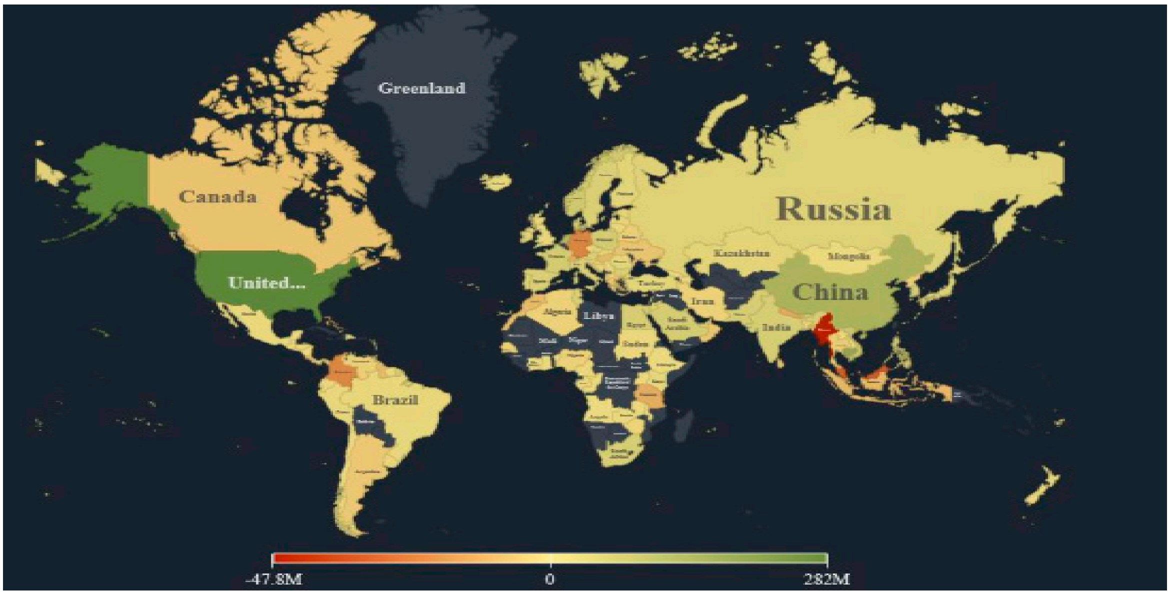


**Figure 7.** Growth value export 2010-2014. Source: The Observatory of Economic Complexity [29].

The statistics show that four of the world's leading sand and gravel producing countries are also the world's leading sand exporting countries: USA, Germany, Australia, and France (Figures 2 and 3).

The world's biggest sand importers are presented in Figure 8.

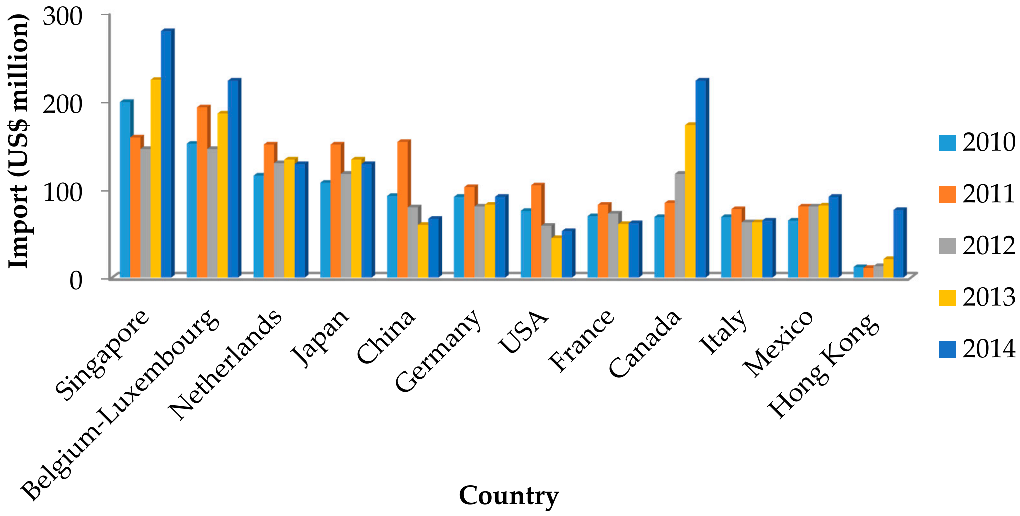


**Figure 8.** Top 12 sand importing countries (2010–2014) (US$ million). Source: Chart made by the author based on data from OEC database [29].

The position of the first 12 sand importing countries during 2010–2014 is presented in Table 2.

**Table 2.** Top 12 sand importing countries during 2010–2014.

| Country Year | 2010 | 2011 | 2012 | 2013 | 2014 |
| --- | --- | --- | --- | --- | --- |
| Singapore | 1 | 2 | 2 | 1 | 1 |
| Belgium–Luxembourg | 2 | 1 | 1 | 2 | 3 |
| Netherlands | 3 | 4 | 3 | 4 | 4 |
| Japan | 4 | 5 | 5 | 5 | 5 |
| China | 5 | 3 | 8 | 10 | 9 |
| Germany | 6 | 7 | 6 | 6 | 7 |
| USA | 7 | 6 | 11 | 11 | 12 |
| France | 8 | 9 | 9 | 9 | 11 |
| Canada | 9 | 8 | 4 | 3 | 2 |
| Italy | 10 | 11 | 10 | 8 | 10 |
| Mexico | 11 | 10 | 7 | 7 | 6 |
| Hong Kong | 12 | 12 | 12 | 12 | 8 |

Source: Table made by the author based on data from OEC database [29].

By analyzing Figures 3 and 8, we notice that countries such as Germany, Netherlands, and China are ranked among the largest sand importers and exporters. This situation is normal as different countries use different types of sand. China and developing countries require more sand for urbanization and economic growth [30], while other countries use other types of sand for glass industry, electronics industry, etc. [31].

By analyzing Top 10 countries according to their import share (Figures 9 and 10), we conclude that the situation has changed from 2010 to 2014. As Canada, Singapore, Mexico, and Hong Kong gained market share, Japan, Germany, China France, USA and Italy lost market share. Singapore was by far the largest sand importer, with a share market of 11% in 2010 and 13% in 2014.

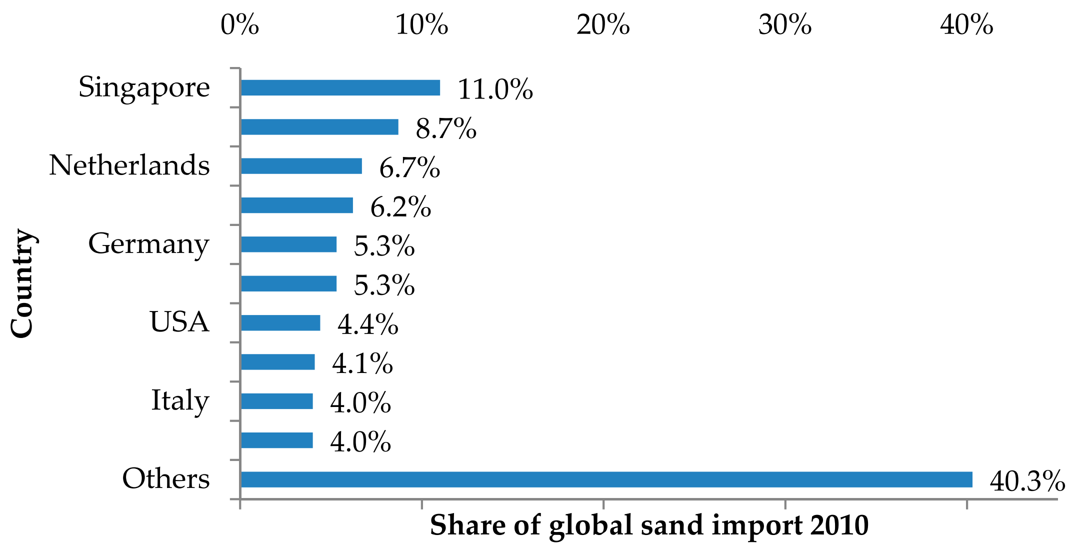


**Figure 9.** Share of global sand imports in 2010. Source: Chart made by the author based on data from OEC database [29].

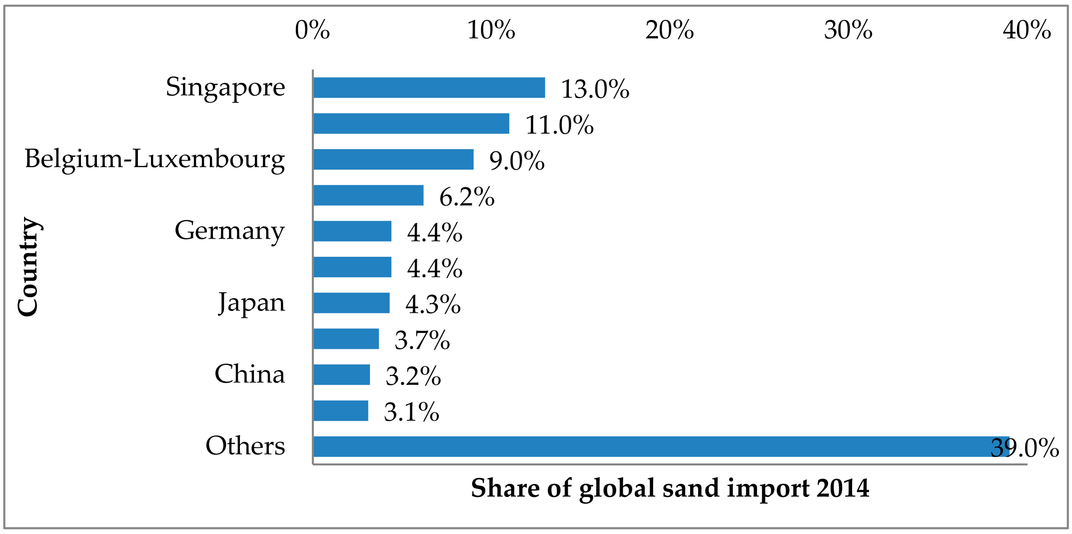


**Figure 10.** Share of global sand imports in 2014. Source: Chart made by the author based on data from OEC database [29].

In 2014, the Top 3 largest importers were: Singapore ($279M), Canada ($223M) and Belgium–Luxembourg ($188M) (Figures 11 and 12).

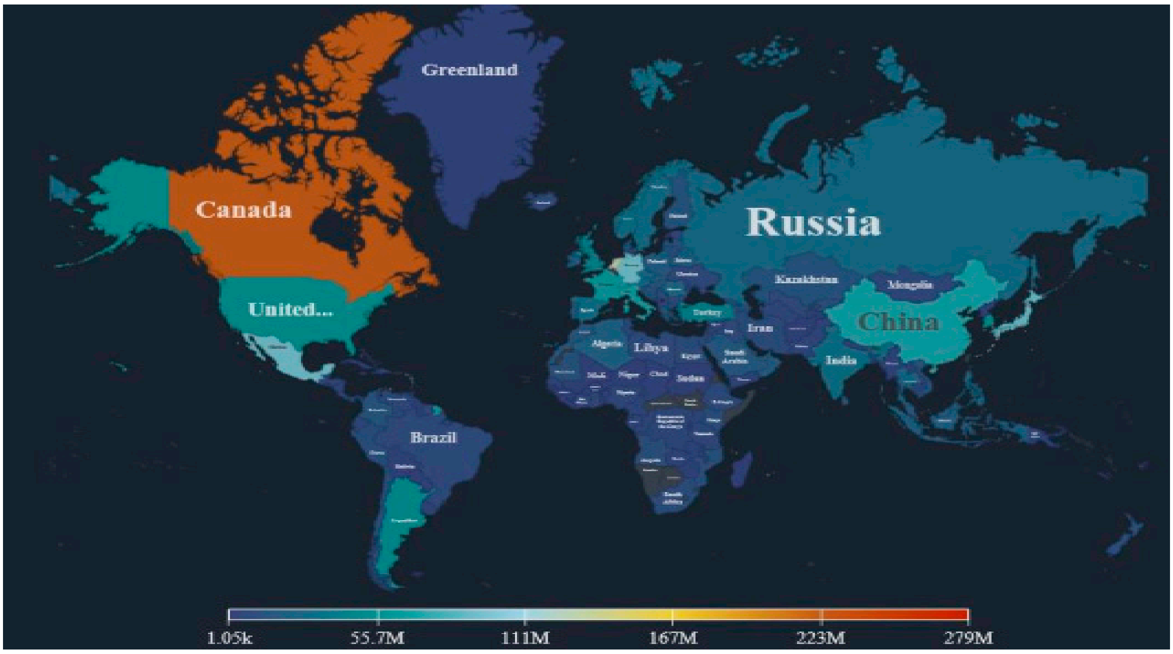


**Figure 11.** Global Sand imports in 2014 (Value). Source: The Observatory of Economic Complexity [29].

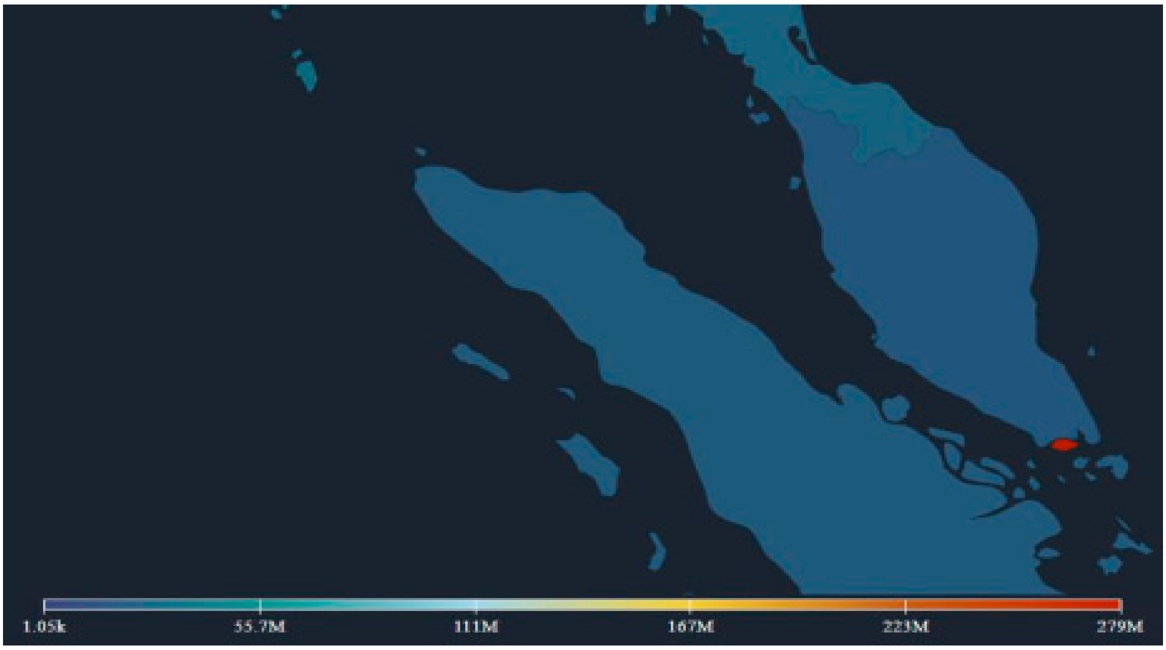


**Figure 12.** Global Sand imports in 2014 to the Singapore Region. Source: The Observatory of Economic Complexity [29].

Considering the growth value of imports for the period 2010–2014, Canada is situated in first place ($178M), followed by Singapore ($71.4M) and China ($ 23.6M) (Figures 13 and 14).

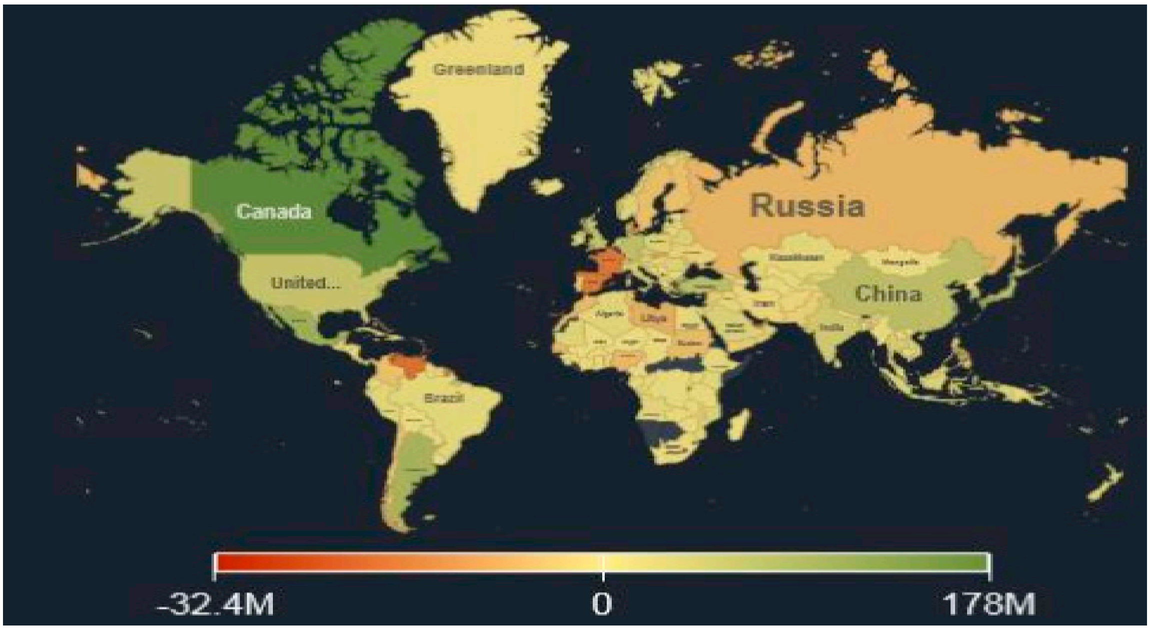


**Figure 13.** Growth value of imports during 2010-2014. Source: The Observatory of Economic Complexity [29].

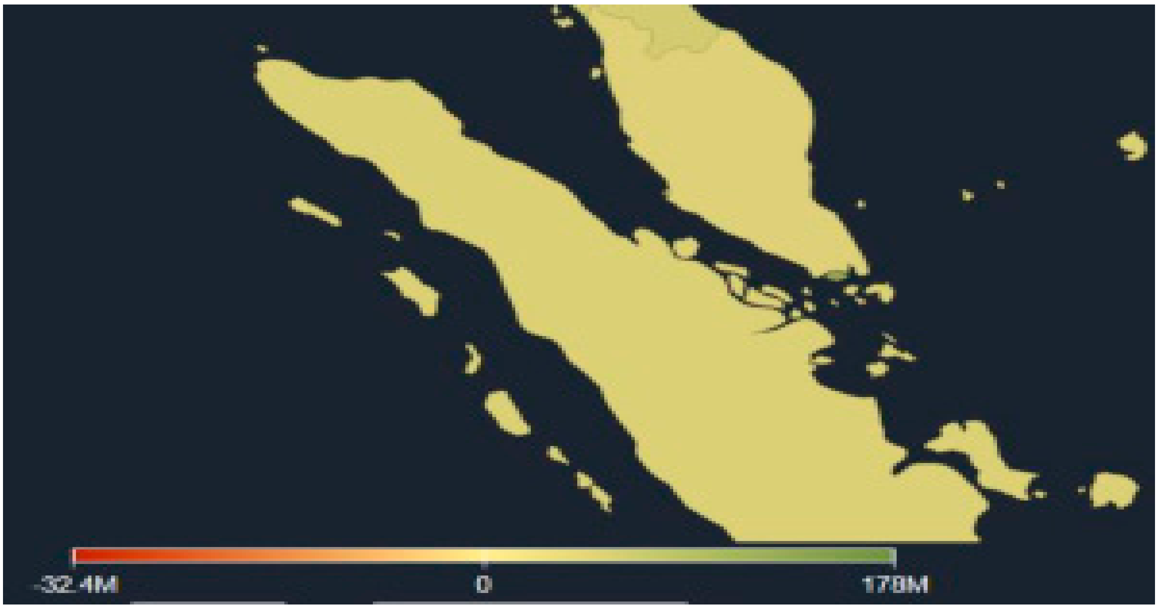


**Figure 14.** Growth value of imports during 2010–2014 in the Singapore region. Source: The Observatory of Economic Complexity [29].

Nowadays, China is the largest construction market in the world [32], which implies a high demand for construction sand. According to Swanson [15], China's cement consumption between 2011 and 2013 exceeds US consumption registered in the entire 20th century. Figure 15 illustrates that China is by far the world's leading cement producer. Below are the top cement production countries in the world from 2010 to 2015.

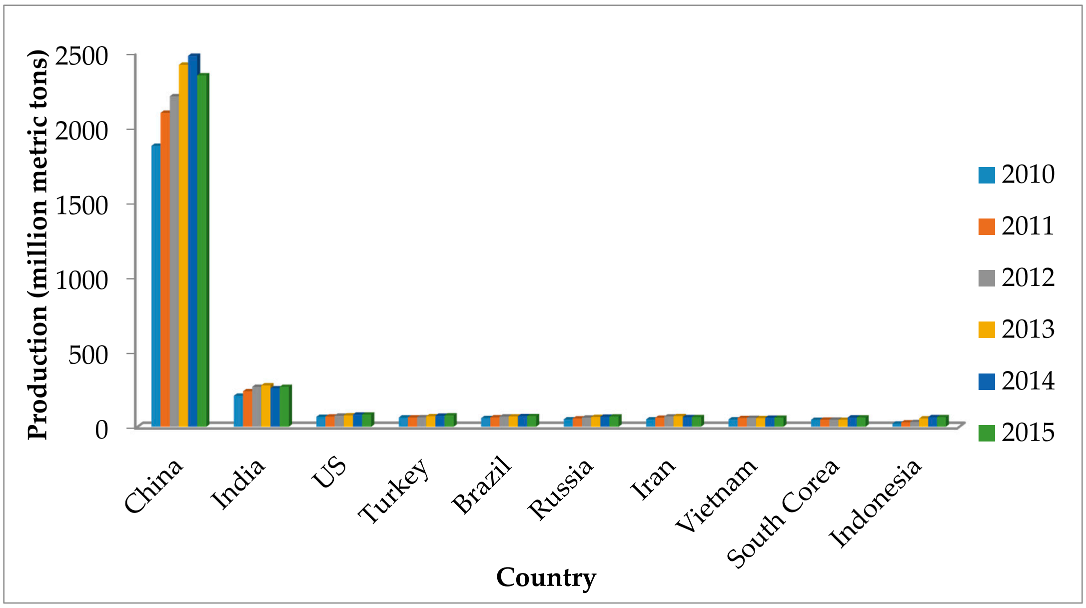


**Figure 15.** Leading cement production countries from 2010 to 2015 (million metric tons). Source: Chart made by the author based on data from Statista database [26].

China has the first position in the list of cement producing countries primarily because, even though the rate of China's economic growth is slowing, its construction sector continues to grow rapidly. Nowadays, China holds the first position in the world's construction market and it is expected to maintain this position into the future.

Figures 16 and 17 compare imports and exports in different regions.

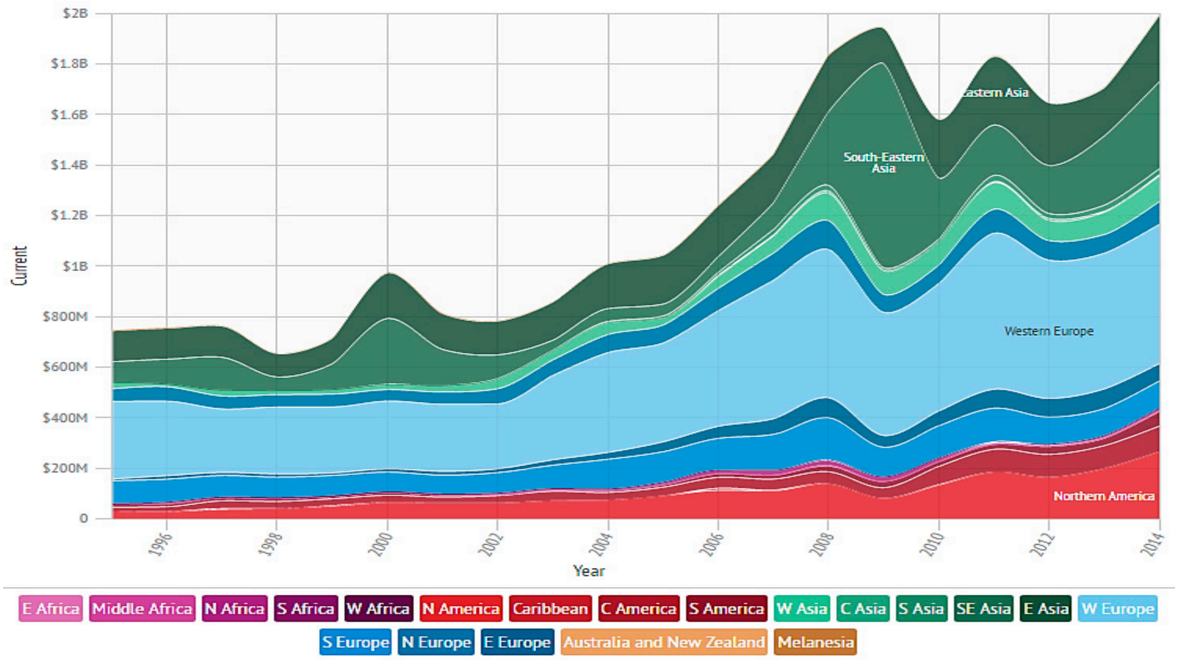


**Figure 16.** Global Sand imports during 1995–2014. Source: The Atlas of Economic Complexity [11].

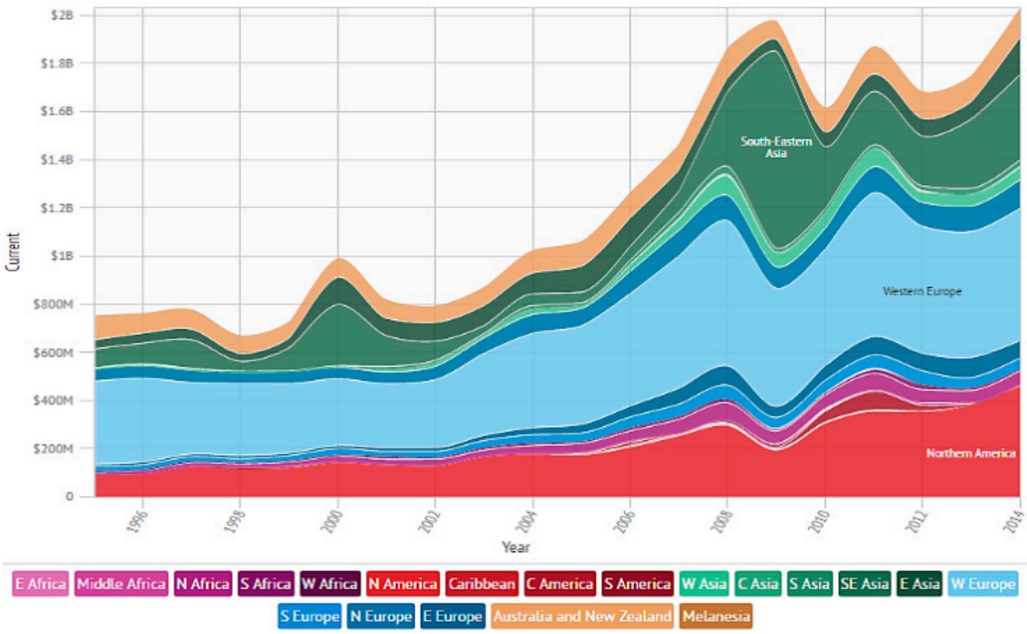


**Figure 17.** Global Sand exports during 1995–2014. Source: The Atlas of Economic Complexity [11].

Sand imports reached $2.09B in 2014 and four regions contributed more than 68% of total exports: Western Europe ($552M), North America ($268M), South Eastern Asia ($344M) and Eastern Asia ($263M).

As can be observed in Figure 17, the Top 3 export markets contribute more than 50% of all exports in the sector during the analyzed period. Sand exports reached $2.09B in 2014 and three regions contributed more than 65% of total exports: Western Europe ($550M), North America ($459M), and South Eastern Asia ($355M).

If we analyze the data provided by the Observatory of Economic Complexity, we can ascertain that exports usually go to nearby countries/continents. In 2014, USA's main sand exports went to North America ($313 million), South America ($54.7 million), Europe ($44.4 million), and Asia ($44.1 million). From Germany, the second biggest sand exporter, exports went to Europe ($165 million), Asia ($4.84 million), and North America ($2.39 million). This can be explained by the high cost of transport, which has a significant impact on the final price of this resource [33].

Analyzing sand exports and imports in EU, we notice a favorable balance of sand trade during the last years (Figure 18).

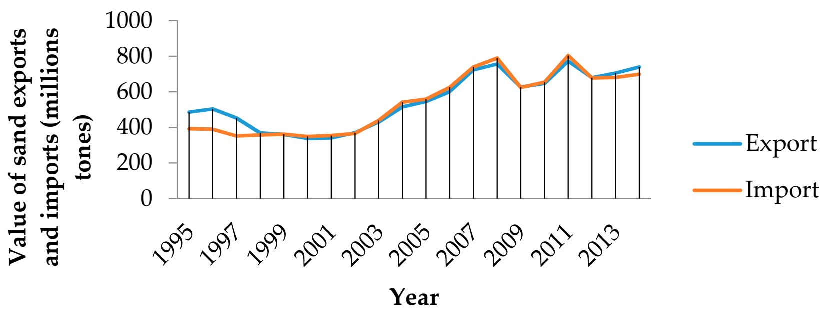


**Figure 18.** Value of sand exports and imports in EU-28 during 1995–2014 (millions tones). Source: Chart made by the author based on data from Eurostat database [34].

Figure 19 provides an overview of the EU countries that export the maximum quantity of sand. Germany ranks first in sand exports, followed closely by Netherlands and Belgium–Luxembourg.

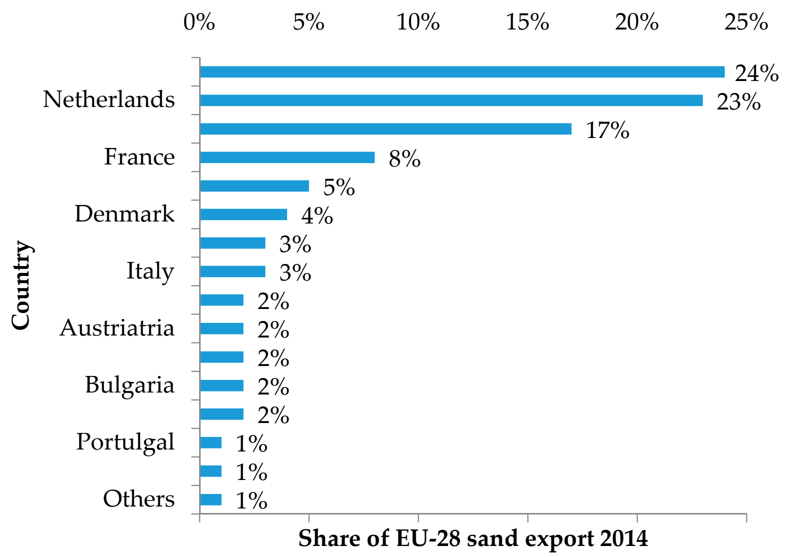


**Figure 19.** Share of EU-28 sand export in 2014. Source: Chart made by the author based on data from Eurostat database [34].

Germany, Netherlands and Belgium–Luxembourg are the EU's largest sand exporters and are also present in Top 10 sand exporters worldwide (second, third and fifth, respectively, in 2014 according to Table 1).

## 4. Sand Mining and the Environment

### *4.1. Environmental Impacts and Consequences of the Increasing Demand for Sand*

#### 4.1.1. Negative Environmental Impacts of Sand Exploitation

Worldwide resources' exploitation has a considerable impact on environment. Figure 3 presents main environmental impacts associated with different types of mining and different types of primary resources extracted.

Comparing with the exploitation of other resources (coal, gold, etc.), we conclude that sand mining has fewer negative impacts (Table 3).

**Table 3.** Types of mining and their environmental impacts.

| Type of Mining | Method | Primary Resource Extracted | Environmental Impacts |
|---|---|---|---|
| Surface mining | Removes the soil and rock that cover mineral deposits | Gravel, sand, coal, oil sand | Deforestation, loss of biodiversity, soil erosion and acid drainage |
| Mountaintop removal | Uses explosives to blast off entire tops of mountains to access veins of coal | Coal | Deforestation, soil erosion, leveling of mountains, loss of biodiversity, disruptions to ecosystems, exposure to toxic metals and radioactive elements to weathering, filling in and destroying thousands of streams, and poisoning water for local communities |
| Placer mining | Uses water to separate the heavier minerals from lighter silt and clay | Gems, gold | Pollution of streams, production of toxic wastewater, erosion of seam banks, and loss of habitats |
| Open pit mining | Involves digging to reach the desire resource | Copper, iron, diamonds, gold, coal | Complete ecosystem destruction, acid mine drainage, and toxic wastewater production |
| Surface mining | Create shafts deep underground to extract resources from pockets or seams of minerals | Gold, copper, uranium, zinc, lead, nickel, coal, salt and other metals | Health hazards to miners and local communities, air pollution, acid mine drainage, and produces toxic wastewater |

Source: Healing Earth [35].

Sand mining is a global activity in both developed and developing countries [36]. Exploiting sand from different sources has both multiple benefits (poverty reduction [37,38], economic growth [39], new habitats for plants and animals [20], new water reservoirs are created [20,40], etc.) and a series of negative impacts on the environment [41,42].

Based on the research fo Kowalska and Sobczyk [20], several factors must be taken into account when the environmental impact of sand mining is analyzed:

- location of sand mine;
- size of mining area;
- time of exploitation;
- secondary mineralogy;
- habitats and vegetation diversity across the mining area; and
- technical conditions for exploitation.

Until recently, sand has been mined predominantly from land quarries and riverbeds, but, due to intensive exploitation and because this practice has been banned in many regions and environmental regulations have become much more strict or no longer allow this, nowadays mining of marine sand is increasing significantly. Thus, due to the negative environmental impact, marine sand mining activities are nowadays regulated more strictly by global, regional and national legislation [43]. United Nations Convention on the Law of the Sea (UNCLOS) [44], Environmental Impact Assessment Directive (85/337/EEC) [45], and Deep Sea Mining Act 2014 [46] are only a few examples of regulations with impact on marine sand mining activity.

Even though we are talking about surface or underground sand mining, the activities related to this industry cause severe negative environmental impacts: they lead to major changes in the local flora and fauna, contaminate the groundwater and air, disrupt the landscape, etc. However, many of the environment impacts are not quantifiable [47,48]. Special attention should be given to all environmental aspects related to the sand mining process. The process is complex and involves five stages (Table 4). Every stage affects the environment and causes serious damages. Restoring an ecosystem is often very expensive, and often the ecosystem cannot be restored to its original state.

**Table 4.** Stages in the life of sand mine.

| Mining Stages | Process Description |
|---|---|
| Precursors to mining | |
| Prospecting<br>Exploration | Searching for sand resources using multiple exploration techniques [49]<br>Determining the possible size and value of the sand deposit using different evaluation techniques [49,50] |
| Mining proper | |
| Developing<br>Exploitation | Setting-up and commissioning facilities to extract, treat and transport sand [49–51]<br>Large scale sand production [49] |
| Post mining | |
| Closure and reclamation | Returning the land to its original state [49,52,53] |

Source: Author's compilation.

Every stage of the process has negative environmental impacts [53–58] and schematically the negative environmental impacts and consequences of sand mining are presented in Table 5.

**Table 5.** Environmental impacts.

| | Main Impact | Reference | Consequences | Reference |
|---|---|---|---|---|
| Air | Increase level of air pollutants concentration | [59–64] | Human health risks | [63] |
| Flora and fauna | Habitat loss | [63–68] | Alteration on fish population<br>Increasing level of weed infestation | [69,70]<br>[67,71] |
| | Physical disturbance of the habitat | [68] | Degradation of aquatic biota<br>Alter number of animal species | [72]<br>[66,73] |
| | Vegetation is destroyed | [63] | Reduction of farmlands and grazing lands | [63] |
| Water | Increase water turbidity | [22,74] | Decrease plants photosynthetic activity<br>Changes in nutrient parameters<br>Disturbing feeding activity for different aquatic animal species<br>Reduce light penetration and oxygen levels that can affect aquatic animals activities and composition of phytoplankton<br>Affect spawning and hatching<br>Affect aquatic animals respiration (Cause respiratory distress)<br>Negative changes in fish population diversity and trends (major decline in population)<br>Increase infections and death risk for aquatic animals<br>Redistribution of fine particles in the water | [67,75]<br>[75]<br>[67,75]<br>[59,67,76,77]<br>[78,79]<br>[77,78]<br>[75]<br>[75]<br>[74] |
| | Increase soil and coastal erosion | [74,80,81] | Seawater intrusion<br>Affect infrastructure projects | [82–84]<br>[81,85] |
| | Water quality deterioration | [22,59,62,68,86] | Increase water salinity<br>Alteration of water sources<br>Increase water treatment cost | [87,88]<br>[22,63,87]<br>[89] |
| | Water pollution | [64,67,75,77,90] | Affects the biodiversity | [91] |
| | Sinking and deformation of riverbeds and banks | [22,62,63,68,87,92,93] | Drying up wells around the river<br>Lateral channels erosion and instability<br>Negative effect on groundwater<br>Waterways siltation<br>Influence the uncertainty of the slope and levee | [22,87]<br>[7,59,68]<br>[68]<br>[94]<br>[93] |
| | Affects hydrological function | [7] | Change in water flows, flood regulation and marine currents | [7,83] |
| Soil | Decrease soil quality | [62,95] | Increase dark areas (fertile land became unfertile due to lowering groundwater levels)<br>Changes in soil geochemistry (increase concentration of lead, arsenic, mercury, etc.) | [87]<br>[63] |
| | Soil erosion | [64] | Watercourses, wetlands and lakes pollution | [87,91] |
| Land | Landscape disturbance | [61–63] | Dramatically change of the landscape<br>Deforestation<br>Loss of bathing beaches<br>Decrease sand reserve for natural beach storm response | [61,67,81]<br>[63]<br>[65]<br>[81] |
| | Mine-Induced Seismicity | [64] | | |
| | Structures stability | [22,68] | Damage of the public and private property. | [65,68,96] |

Source: Author's compilation.

Even if in the past there were scientists that were concerned about environmental issues and brought them to the attention of public and authorities, only in the last years special attention was granted to all these negative environmental impacts. Nowadays, solving environmental problems is an essential objective, and experts are more aware that economic and social development needs to be correlated with environment protection.

Talking about negative effects, we need to mention the fact that sand exploitation also has a negative effect on climate change phenomenon. Direct impact is related to extraction process and transport, and indirect impact to the cement production [97]. It is estimated that carbon dioxide emissions from cement production accounted for around 5% of global $CO_2$ emissions from all industrial process and fossil fuel combustion in 2013 [98].

Related to direct impact, we need to outline that even construction minerals are used at a large scale, exploitation emissions are in generally limited [99] compared with other emission sources. Given the magnitude of environmental problems associated with this activity, it is necessary for authorities to impose regulatory strategies related to environmental protection. Frequent monitoring is required to ensure that sand mining operations meet regulatory standards.

#### 4.1.2. Positive Environmental Impacts of Sand Exploitation

Negative impacts of sand mining on environment are multiple, but we also need to put emphasis on the fact that this industry has also positive benefits. Many researches outline that mining processes have positive impacts on society, referring here on social and economic benefits [39,91,100,101]. Taking into consideration that this study is referring to environmental aspects of sand mining, we will not discuss these issues in detail and we will focus on the positive impacts of mining activities on environment. According to Mobtaker and Osanloo [39], positive effects of mining operations on environment refer to land, water and air. These benefits occur in both phases: during regular mining activity and after mining operations have ceased (see Table 6).

**Table 6.** Positive environmental effects of mining activities.

| | Main Impact | Consequences |
|---|---|---|
| Land | Increase slope stability (changes in ground water flow patterns that decrease the possibility of land erosion) [39] | Interconnection between vegetation and slope stability [102] |
| | Landscape improvement [39,100,101,103,104] (artificial vegetation restoration techniques use different types of vegetation, land is converted into forests, farmland or parks ) | Improve soil moisture, slope stability [105] |
| | | New wildlife [39] |
| | Waste disposal [39] | |
| Water | New water reservoirs and new water supply systems are created [39,100,101] | Support aquatic life and terrestrial wildlife [39,91] |
| | Create more stable channels by the reduction of bedload (decrease in channel width-depth ratio and increase sinuosity) [106] | Conditions of habitat for flora and fauna [107] |
| Air | Dust control [39,108] | Less air pollution [39] |

Source: Author's compilation.

Taking into account that sand exploitation causes severe negative environmental effects (see Table 5), researchers emphasize on these issues, so positive environmental aspects of this activity are rarely approached. Leaving aside the positive environmental aspects of these activities, we must focus with priority on the negative ones and how they can be eliminated or at least mitigated. Because the environmental risks associated with sand exploitation are outweighed by economic and social benefits, is very difficult to find right solutions to maintain a balance between all these aspects.

### *4.2. Sand Exploitation in Underdeveloped and Developing Countries*

A special attention needs to be paid to sand exploitation in underdeveloped and developing countries. Many problems must to be solved related to sand exploitation in these countries.

First many underdeveloped and developing countries are confronted today with the phenomenon of illegally sand mining: India [3,109,110], Malaysia [68,111], Sri Lanka [3,112–114], Nepal [115], Bangladesh [116], South Africa [117,118], Tanzania [119], Botswana [89], Puerto Rico [120], Philippines [121]. Padmalal and Maya [3] consider that "almost one third of the total sand demand in Sri Lanka is met from illegal sources". This process affects not only its surroundings but also cause environmental damage worldwide [68].

Second, implementation of clean mining technology in these countries may be a difficult process: these technologies can be very expensive, so they cannot afford it.

Borregaard and Dufey [122] pointed out that another major problem is the transfer by investment companies of inadequate technology or prohibited technology due to its negative environmental effects from their countries of residence to their subsidiaries.

Another issue for these countries is their capacity of environmental restoration. The cost can be unaffordable for them and requires qualified employees: biologists, engineers, geologists, scientist, etc. Finding qualified specialists in developing countries may also be challenging.

Finally, these countries are confronted with the lack of monitoring systems, environmental legislation and regulations related to sand mining process. "The lack of adequate information" represents one of the causes that are limiting the regulation of extraction in these countries [97]. Other countries do not understand the importance of environmental protection so they are not taking immediate action to formulate a legal and regulatory framework related to sand exploitation issue [123]. Another issue for these countries is the lack of tools and manpower to properly enforce the environmental regulations.

Monitoring sand exploitation requests adequate technology and social costs that sometimes cannot be implemented due to existing corruption [121].

## 5. Discussion

An overview of the actual sand market triggers some questions that require the right answers.

We raise some questions and based on the existing information we tried to give the right answer. Based on these answers, experts may elaborate efficient measures that will help sand industry to adapt to nowadays need.

### *5.1. Will Total Sand Demand Continue to Increase Over the Next Decades?*

Nowadays, the population exceeds 7.5 billion [124], and is expected to reach 8.5 billion by 2030 and 11.2 billion in 2100 [125]. We assume the continuing of population growth will generate an increase in demand for different goods. Taking into consideration the fact that sand is an important resource for many industries [126] and demand for different products will increase in the future, sand demand will also increase.

According to UN DESA report, "World Urbanization Prospects: The 2014 Revision, Highlights" continuing population growth and urbanization are projected to add 2.5 billion people to the world's urban population by 2050 [23], that obviously will increase demand for infrastructure and new constructions. Because sand is the principal component of concrete [127], which is used intensively in constructions sector, we assume that this will have a direct impact on sand demand (it will increase demand).

### *5.2. Can the Negative Environmental Impacts of Sand Exploitation Be Decreased?*

As observed in Section 4, sand mining is causing multiple negative effects to the environment. We identify the following four major measures that can be adopted to reduce the negative environmental effects of sand exploitation.

#### 5.2.1. Reducing Sand Consumption

Substitutes for sand or optimizing the use of existing buildings and infrastructure represent only a few steps that can be made to reduce sand consumption [97]. Different substitutes are available, depending of the type of sand that is required. For example, waste products [128], crushed granite [129], barite powder [130], quarry dust [131,132], etc. are sand substitutes in concrete, while waste glass is used as sand replacement in cement mortar [133]. Replacing sand partially by quarry dust determines a better performance of blocks [131,132,134] and also the costs for these replacements are not very high [131]. In addition, partial replacements of sand with crushed rock in concrete production preserve its properties and determine a decrease of the concrete price [135].

#### 5.2.2. Reducing the Negative Consequences of Sand Exploitation

Technological innovation solves environmental problems and plays an important role in environmental sustainability [136,137]. Fortunately, modern methods and clean technologies for mining operations have been developed to minimize damages to the environment [138–140]. Clean technologies are described by Hilson as "highly efficient environmental equipment, and state-of-the-art environmental management" [141]. However, transition to clean technologies is not very simple, even if we are talking about developed countries such as USA [141].

Governments need to develop programs especially designed to provide incentives for using new and clean sand mining technologies to encourage companies from this industry to use them [142]. Supporting companies to research and develop emerging technologies for mining sector can also be a strategy to reduce the environmental impact.

Bedload removal in in-stream mining can be calculated so the exploitation is realized in a way that does not affect the environment [68,111]. A prediction of the replenishment rate of rivers helps specialists to determine the sand quantity that will be exploited with minimal environmental impacts [68].

#### 5.2.3. Set Taxation and Royalty Policies for Sand Exploitation

Sand is considered a cheap resource [7,97], thus, to profit, companies need to cover only the exploitation cost (costs of equipment, labor, fuel, and transport) [97]. Introducing specific taxes/royalties for sand exploitation [143] increases the total production cost of sand so different industries that use this resource will find other substitutes and companies that operate in this field will find other investment opportunities in other areas.

#### 5.2.4. Set Up Environmental Laws, Regulations and Standards Related to Mining Process

Governments try to ban or to restrict sand mining in specific areas to limit the environmental impacts. Mining operations in countries such as Canada, Australia, Finland, Sweden, or Russia require obtaining environmental permits designed to achieve positive environmental outcomes [144].

A reduction of in-stream mining for example can be achieved by state regulation. In-stream mineral mining is strongly regulated in countries such as Portugal, Italy, and New Zealand and is prohibited in countries such as France, the Netherlands England, Germany, and Switzerland [87].

The exploitation of beach sand deposits is another issue that must to be solved by imposing strict rules and regulations. Pilkey asserts that: "the natural sources of beach sand are decreasing, and the natural causes of sand removal are increasing" [145]. Countries such as Malaysia, Indonesia, and Vietnam try to limit beach sand exploitation by restricting or banning the export of sand to Singapore [146], and Grenada limited beach sand exploitation to a small number of beaches [147].

To solve environmental problems related to sand exploitation, it is necessary to establish a complex regulatory system that comprises: environmental regulation, sand exploitation regulation, and land use planning regulation [120].

An important aspect of sand mining process is that it may cause long term environmental implications difficult to be quantified [148–150]. Mitigation of negative environment effects requires a detailed understanding of the environmental impacts and the consequences of this process.

### *5.3. Can We Prevent Illegal Sand Mining?*

Theoretically, illegal sand mining can be reduced by governments by setting regulation and penalties, by increasing patrols in areas favorable for exploration, and by monitoring areas using performant systems. In practice, it is very difficult to accomplish these because, usually, illegal operations take place in underdeveloped or developing countries [3,68,109,110,112–117,119–121] where governments do not have necessary resources (financial, human, etc.), or corruption is very high. There are countries that registered a success in their battle with illegal groups but the efforts need to continue: India has reduced its illegal sand exploitation from about 70% to about 30% [151]. We can find solutions for problems related to sand exploitation but every solution require time and financial, human efforts and demand doesn't take account of any of this.

## 6. Conclusions

Sand is indispensable for many economic activities, and construction industry plays a major role in sand demand. Rapid population growth and urbanization increased demand for construction minerals. Being in direct connection with the construction sector, demand for construction sand is growing exponentially in countries where this sector is very active.

Even if it can be found everywhere, sand that is used for different industries is becoming scarce so the pressure on existing sources is very high.

In the last years, countries have been maintaining their relative global positions in production, exports, and imports, and USA remains the biggest sand producer and exporter. Sand industry brings many benefits to countries involved in this sector, but, besides economic and social benefits, sand exploitation also has negative effects on the environment. Sand mining involves a high degree of environmental degradation in every stage of mine's life; therefore, specific measures must be adopted to mitigate environmental impacts. Special attention must be paid to undeveloped and developing countries, where lack of regulation, illegal mining, etc. seriously affect the environment.

Companies must to be conscious about the environmental impacts, to start thinking about the environmental costs and to include it as a part of production cost. A company that operates in this sector, must focused both on determining, monitoring and reducing negative environmental impacts of this activity and also on finding and applying solutions for various risks, such as those associated with climate change.

To minimize the environmental impacts, all parties involved in sand mining process are responsible for taking the right measures. Governments and public authorities with responsibilities in mining sector and environment must: (1) set up and enforce environmental laws, regulations and standards related to the mining process; (2) permit sand mining operations based on a license; (3) monitor and inspect operation places to ensure that companies fulfill all obligations arising from mining standards, regulations, laws; and (4) support mining companies to have access to clean technologies. Companies need to know and respect environmental regulations, invest in clean technologies, and preserve the environment from the potential impacts of its exploitation processes.

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