



The progressive distancing of aggregate quarries from the demand areas: Magnitude, causes, and impact on CO₂ emissions in Madrid Region (1995–2018)

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ABSTRACT

Aggregates are natural materials of great demand. They are directly used for construction or as constituents of ready-mixed concrete or asphalt products, and they appear as an index of the economic activity of a country. Distance between quarries and demand points controls the price of high place-value products such as aggregates. Their potential exploitation depends on factors such as geology, environmental and heritage protection laws, or even on social rejection near populated areas. These factors are forcing quarries to move away from demand areas and make the aggregates to be transported for longer distances, with associated economic, environmental, and safety issues. Many authors have indicated the progressive distancing of the aggregates quarries from the demand areas based on perceptions but without estimations supporting this hypothesis.

This work has studied the location of the quarries supplying the demand of aggregates of Madrid region in the period 1995–2018. The study proves the progressive distancing of the quarries and even the relocation of part of the production to neighboring provinces. The kilometers travelled in excess due to the distancing and the associated CO₂ emissions, have been estimated. Despite the general opinion that the “Not in My Backyard” phenomenon (NIMBY) was the cause of the distancing of the quarries from the demand areas, it has been found that the main reason in the case of the Madrid region is not the opposition of the citizens but a combination of demographic factors and different land use restrictions.

1. Introduction

Aggregates (crushed stone, sand, and gravel) are, after water, the second most employed natural material by humanity. They are demanded for new construction projects or for the reparation of existing ones in the form of unbound materials or as constituents of ready-mixed concrete or asphalt products (UEPG, 2018). A continuous supply of great volumes of aggregates is required to sustain both developed and developing economies (Drew et al., 2002). Natural aggregates can be considered an infinite natural resource at a global level; however, some regions can face a supply restriction due to the overexploitation or sterilization of resources that could lead to serious economic, social, and environmental consequences (Ioannidou et al., 2017).

Due to their low unitary price, raw materials for building and construction (limestone for cement manufacture, brick clay, and aggregates), are considered high place-value products, deriving most of their

value from a low distance between the quarries and the demand areas (Bates, 1960; Escavy and Herrero, 2013; Herrero et al., 2013). The consequence of this is that most of the aggregates quarries tend to be located at distances less than 50 km from the demand areas, being the material mostly transported by truck (Careddu and Sancier, 2008; Escavy et al., 2020). Those demand areas with no exploitable aggregates deposits in the neighborhood must get the material from longer distances and the transportation by truck loses weight in favor of other lower cost means of transportation such as rail or ship (Jaeger, 2006).

Unfortunately, despite the abundance of different types of rocks suitable to be used as aggregates, the location of the deposits depends on the geology (Bleischwitz and Bahn-Walkowiak, 2007) and the exploitability is conditioned by several limiting factors. The presence of a geological material with enough quality is a necessary but not sufficient condition to have a viable quarry. Factors such as environmental or cultural protection, competition for land use, built areas, or social

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rejection near highly populated zones can sterilize the resources making them unavailable (Escavy et al., 2020). Despite the dependence of society on the built environment, and the use of aggregates for building roads, private and public buildings, etc., mining faces social rejection (Brown et al., 2011; Wernstedt, 2000). A land use conflict can be defined as the situation in which land use stakeholders have irreconcilable interest in a certain geographic location (Von der Dunk et al., 2011). The elements of disagreement are the opposed interests of stakeholders, the geographic location, and the usually negative consequences perceived for the different land uses (Brown et al., 2017). Mining activities are problematic because they are developed in both suburban and rural areas, their location is controlled by a favorable geology, and are mostly privately owned (Wernstedt, 2000). Natural aggregate producers face social and political worries associated with the mining activity (large holes generated, visual impact, dust, noise, vibrations from blasting, etc.), and with the large volume of truck traffic near aggregates operations. Some problems have been minimized thanks to the implementation of new technologies, especially for dust, noise, visual impact, and vibration, but the problems associated with the size of the quarry and the traffic of heavy trucks are still unsolved (Drew et al., 2002).

The rejection of mining activities is not something new, Roman naturalist Pliny the Elder wrote in the first century AD that mining activities were inappropriate in the homeland and should be developed only in conquered lands (Timmons, 1990). More recently, the opposition to mining near inhabited areas has impeded the opening of many natural aggregate quarries (Drew et al., 2002). The social rejection to mining activities near populated areas can be included in the NIMBY (Not in My Back Yard) phenomenon, but the extraction of mineral resources faces other limitations such as institutional NIMBY, land competition with other activities, or increasing surfaces with different degrees of environmental or heritage protection.

The demand of aggregates is stronger in or near populated areas. Nevertheless, the combination of the competition for land use and the social rejection of mining near urban areas is forcing the extraction points to be located away from the demand areas, increasing the transport distances with subsequent economic, social and environmental costs (Coelho, 2001; Poulin and Sinding, 1996). Most natural aggregates are transported by truck and the average distances travelled from the quarries to construction sites are around 56 km (Drew et al., 2002), but the distances are progressively increasing due to the depletion of their natural aggregate deposits (Danielsen and Kuznetsova, 2015). The trucks transporting aggregates and other construction materials, due to their size, weight, noise, and emissions from the exhaust are seen as pollutants, unpleasant, and menace to safety and peace in the neighborhood (Drew et al., 2002). In addition to the environmental and safety issues, the progressive increase of the distance from the production site to the construction areas impacts on the transportation cost, becoming the cost of aggregates more than double at distances above 50 km between the quarry and the construction site (Kaliampakos and Bernardos, 1999).

One of the challenges for sustainability in the near future is to ameliorate the management of natural resources to decrease the anthropogenic impact on the environment. Manufacturers of construction materials are modifying their techniques and procedures toward more environmentally friendly products to meet the society demand for greener products. Some improvements regarding aggregates will be related to the use of local raw materials promoting "Made in my area" products, the incorporation of greater quantities of renewable or second-life raw materials, and the design of concrete being easier to be recycled and reused at the end of their service life (Levy, 2021). The use of recycled construction and demolition waste, that is mostly generated in urban areas, would reduce the need for extraction of natural aggregates (Drew et al., 2002). Unfortunately, the use of recycled and artificial aggregates is marginal in Spain, where natural aggregates were 97.5% of the total aggregates consumed in the country in 2019. The average use of natural aggregates in Europe is lower than in Spain (87.8% in 2018) but

is still very high, showing the difficulty of replacing natural aggregates with recycled or artificial aggregates for most uses (ANEFA, 2020). The main barriers for the use of recycled aggregates are related to legislation, quality, and cost. The use of recycled aggregates is expected to rise in the future in Spain, but the increase will be slow. This is because its growth will require the change of the norms that limit their use, the establishment of measures to promote their use, and the implementation of new technologies to reduce the cost and produce materials of enough quality from construction and demolition waste.

The local sourcing of products is a movement that is influencing the purchase of different products, giving preference to those produced close to the consumption points. The most developed sector for local sourcing is food. The benefits of buying local food can be grouped into economic (i.e., money remains in the local community and reduction in supply risk, etc.), social (i.e., easier communication with the producer and stronger sense of place), physical (improved nutrition and reduction of food safety risks through production decentralization), and environmental, including the preservation of genetic diversity and the reduction of fossil fuel consumption, air pollution, and greenhouse gas emissions due to lower transport distances (Brain, 2012). Some of the benefits from local sourcing of food can be made extensible for other highly consumed products by society such as construction materials, but these benefits have not been estimated yet.

1.1. Environmental impact of aggregates transportation

Transport of aggregates has an environmental impact that should be taken into account by policy-makers and regulatory departments. This can be made by integrating information on the spatial distribution of the deposits (controlled by geology), demand areas (related to human settlements and infrastructure projects), past and present production areas, and transport networks (Blachowski, 2014). Depending on the relative location of demand and supply areas, aggregates have to be transported, sometimes reaching hundreds of kilometers. The distances between the aggregates consumption areas and the quarries are increasing progressively due to, among other reasons, land use conflicts or pressure by local communities. This has a significant impact on the ecological footprint of the use of aggregates (Athousaki et al., 2008).

Aggregates mostly travel by road for distances up to tens of km, and by railway for longer distances (hundreds of km). In addition to the distance, the way of transport of aggregates is also dependent on the availability of a transport infrastructure network near the geological deposit (Blachowski, 2014). The transport of aggregates by road has an impact on the environment, health, and safety. Safety issues are mostly related to the risks of accidents on the road and in the loading and unloading operations. Environmental and health impacts are related to the emissions of greenhouse gasses and other pollutants from fuel consumption, the manufacturing of vehicles including the need for extraction and processing of raw materials (metals and industrial minerals), the deterioration of infrastructures that reduce their useful life, etc.

In terms of CO₂ emissions, the road transport sector is one of the main emitters and one of the hardest sectors to decarbonize. There are several lines of action focused on the cut of CO₂ emissions from road traffic, such as the promotion of public transport, electrification of vehicles, changes from road transport to railroad transport, or the use of low-carbon fuels in vehicles such as natural gas, hydrogen, etc. (Gianakis et al., 2020). Most of these solutions are not applicable in the short term to the transport of goods and only the switch to low CO₂ emission fuels seems realistic for the mid-term. Anyhow, the effect on the CO₂ emissions produced by goods transport will take a long time to be perceivable due to the low rate of changing to low emission ways of transport, and the time required to renew the truck fleet.

The studies dealing with the impact of aggregates transport on the environment are scarce in the scientific literature, and those specifically dealing with the impact of increasing transport distances from the quarries to the demand areas are almost inexistent. Agioutantis et al.

(2013) proposed a methodology for estimating the Ecological Footprint (EF) of aggregates transported from quarries to urban areas considering the tonnage, distance, and truck capacity. These authors estimated the CO₂ emissions for different truckloads and distances. Being aware of the progressive increase of the distance between supply and demand areas, these authors proposed the establishment of intermediate transport stations close to the demand areas for the use of bigger trucks for the aggregates transportation from quarries to intermediate stations and smaller ones from intermediate stations to demand points. Blachowski (2014) studied the aggregates in Lower Silesia (Poland) from a regional spatial planning perspective. This author located in the region the available resources in the active mines, the magnitude of road transport, the railroad network for its potential use for aggregates transport, and the undeveloped aggregates deposits located out of environmentally protected areas. The author has generated the information required to manage regional aggregates resources based on the environmental, economic, and social impacts of their exploitation. Danielsen and Kuznetsova (2015) identified the transport of aggregates as one of the sources of pollution and emissions related to the aggregates industry and claimed for the transport of aggregates to be included in the LCA (Life Cycle Assessment) and LCC (Life Cycle Cost) studies in this sector. These authors also highlighted the progressive need to substitute natural sand and gravel with alternatives (such as crushed, manufactured, or recycled aggregates), and the increased transport activities due to the rapid depletion of natural aggregate sources in areas of high consumption.

1.2. GIS based modelling of aggregates supply

This research uses the capabilities of the Geographical Information System (GIS) to estimate the distance between the quarries and demand points (usually urban areas). Very few studies are available on modelling aggregates with GIS and most of them are related to the finding of the optimal location of the quarries by combining geological information, land use, and restrictions on mining. This is the case of Premasiri and Dahanayake (2018) who developed a model to rank aggregate deposits and find the most suitable locations for sustainable aggregate exploitation in two districts of Sri Lanka. The study was based on the different land uses present in the area of the study, weighted by the distance of the potential locations to the more sensible land uses. The impact of the transport of the aggregates was not considered. In the same line, Gudissa et al. (2020) combined GIS and Analytic Hierarchy Process (AHP) to find the most suitable areas to exploit crushed rock aggregates in the Harer and Dire-Dawa area, Ethiopia. These authors combined factors from various fields such as geology (lithology), physical geography (distance to water bodies, relative relief, and slope angle), and human geography (land use, distance to constructed areas, and distance to roads). The impact of the transport of the aggregates was also out of the scope of this research. Other works modelling aggregates with GIS, trying to find suitable areas for aggregates production are those of Robinson et al. (2004) and Barakat et al. (2016). Other authors such as Kelly and Bobrowsky (2002) employed the capabilities of GIS to build geographical inventories of aggregates. The location and characteristics (quality, quantity, and limitations for exploitation) of the deposits were combined with social, economic, and environmental parameters for land planning. For “near-urban mining” products whose deposits cannot be relocated, such as aggregates, this geographically represented information becomes crucial (Kelly and Bobrowsky, 2002).

Taking transport into account, Göswein et al. (2018) made a geo-spatial analysis of the transportation of raw materials for ready mix manufacture combined with the Life Cycle Assessment. These authors found that the impact of the production of ready-mix concrete is much higher than that of its transportation. Anyway, the impact of transportation is variable, depending on the location of the quarries in relation to the concrete plant. These authors also included the use of recycled aggregates (RA), reaching to the conclusion that the use of RAs is not always better than the use of natural aggregates when undertaking Life

Cycle Assessments, requiring a case-by-case analysis.

In this work, the area modelled to quantify the increase of the average distance from the quarries of aggregates to the demand areas (and the impact on CO₂ emissions) is Madrid region and the five surrounding provinces (Fig. 1). Madrid region is the third most populated region of Spain with more than 6.7 million inhabitants in the year 2019 (14% of Spain’s population), and is one of the smallest, accounting for only 1.6% of Spain’s area. The combination of these two factors results in Madrid being the region with the highest population density in Spain with 844 persons per km² (INE, 2020). The economy of Madrid is mostly based on the services sector (86.6%), industry (8.6%), building and construction (4.7%), and agriculture (0.2%). Madrid is surrounded by five provinces much less populated (average population density of 24 persons per km²), a more diversified economy, and a territory much less anthropized.

This work tries to test the hypotheses that a) the distances from quarries to demand areas are increasing, and b) that the NIMBY effect is the main cause of the increase of the average distance. For this, the paper analyses the changes in the location of active quarries supplying aggregates to Madrid region from 1996 to 2018 and quantifies the increase of kilometers travelled and CO₂ emitted in excess due to the gradual distancing of the quarries from the demand areas. This environmental impact should be taken into account, with the rest of the potential impacts of aggregates exploitation, for resources delimitation in land planning. Moreover, the potential reasons behind the increase of the distance have been evaluated. By knowing the real reasons, actions could be taken by the authorities to prevent or solve this problem. This same methodology could be used to determine environmental issues related to other high-place value raw materials such as brick clay, gypsum, limestone for cement manufacture, etc.

2. Sources of information and methodology

All information employed for this study has been collected from public databases available in different governmental and private entities, covering annualized data for the period 1995–2018. The information required for the study is, on a yearly basis, the demand points and their tonnages demanded, the active aggregates quarries and their average production, and the road network. The function OD Matrix of the Network Analyst Module of ArcGIS© 10.5.1 has been used to assign the available trucks from each quarry to the closest villages until their demands are satisfied while minimizing travel distances. The projection coordinate system employed is ETRS 1989 UTM Zone 30N. For simplicity, the term “aggregates” in this paper covers all types of rocks employed directly or forming part of precast concrete or mortar in construction.

2.1. Location and assignment of the demand of aggregates to urban areas

The demand of aggregates has been obtained from the annual reports of ANEFA (Spanish National Association of Aggregates Manufacturers) at a regional level. The global demand of each year in the Madrid region has been distributed among the cities and villages based on two variables: the change in population for each year, being this the most relevant variable for estimating the demand of aggregates (Escavy et al., 2020), and the total population. Half of the demand was assigned based on the village population, whereas the other half depends on the population increase.

The data of the population and population change of Madrid villages have been obtained from the Comunidad de Madrid Statistics Agency. The locations of the villages and cities have been downloaded from the Geographical National Institute of Spain (IGN). The number of trucks demanded by each village has been calculated following the methodology of Blachowski (2014), dividing the tons required by each city by the average load of haulage trucks used to transport aggregates in Spain (25.5 tons/truck). Tables with the location coordinates of the demand

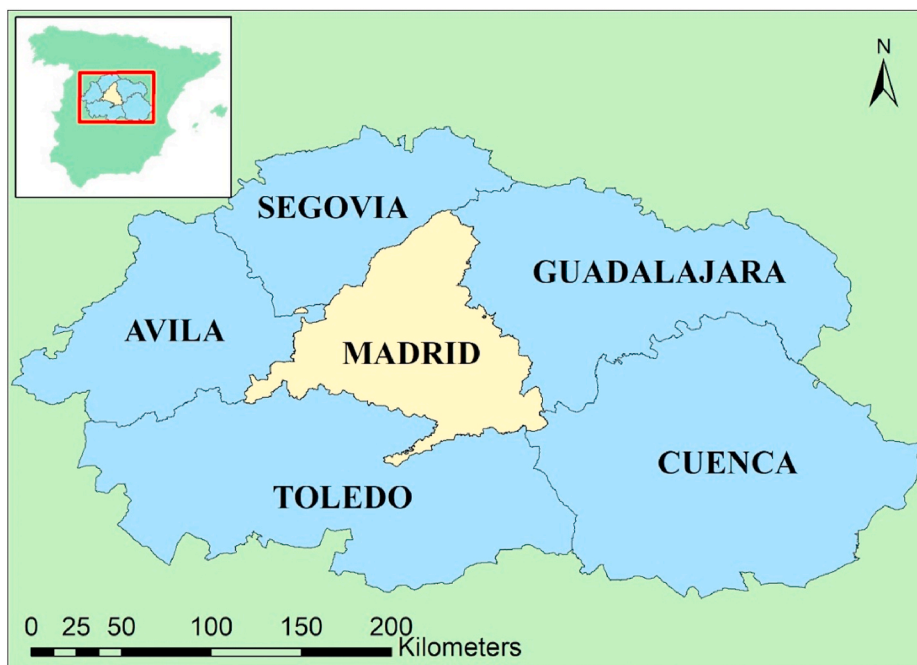


Fig. 1. Area of study.

points (villages) and the number of trucks of aggregates demanded in each location have been generated for each year and imported into ArcGIS©. The resulting demand shape file has fields for the name of the village, the X and Y coordinates, and one field per each year from 1995 to 2018, for the aggregates demand of each village (measured in the number of trucks).

2.2. Location of the active quarries and period of activity

To obtain the precise location of each quarry and the years that it has been in operation, the information obtained from the Mining Rights Cadaster, and the visual inspection of past satellite images has been combined. The location of the mining rights of Madrid region and the five neighbor provinces has been downloaded from the Mineral Rights Cadaster of the MITECO. The available information for each mining right contains: the substance exploited, coordinates of the mining right, authorization year, expiry date, and current administrative situation (mining right granted, cancelled, expired, etc.). Not in all granted mining rights there is a quarry, and in case the quarry starts extraction, the active period of the quarry may not cover the whole period granted by the mining right. Unfortunately, there is no information of the years in which the quarries have been in operation (active) in the Mining Rights Cadaster, so the active periods for each quarry have been determined by visual inspection of satellite imagery, via the historical image viewer of Google Earth© and the Historic PNOA (Plan Nacional de Ortofotografía Aérea or National Plan for Aerial Orthophotography) comparator of the Spanish Geographical Institute (IGN). Interviews with the directors of the Mining Governmental Agencies of Madrid Region, Castilla La Mancha Region (for the provinces of Cuenca, Guadalajara, and Toledo), Avila province, and Segovia Province have been made to validate the main areas of extraction and the materials extracted from each zone. In the case of Madrid Region, 132 mining rights have had a quarry with activity in one or more of the years under study (1995–2018). For the same period, in the five neighbors, a total of 445 mining rights have had mining activity for aggregates in some of these years. All 577 mining rights that have had activity have been, one by one located and by comparing satellite imagery of different years, the periods of activity have been stated. The number of active quarries each year has been matched to the figure obtained from the Minerals

Statistics, published yearly by the MITECO (Ministry of Energy, Tourism and Digital Agenda). The resulting shape file has fields for the name of the village, the X and Y coordinates, and one field per each year from 1995 to 2018, for the aggregates demand of each village (measured in the number of trucks). Twenty-four shape files (one per year from 1995 to 2018) have been created for the supply of aggregates. Each shape file is dedicated to one year and contains the quarries that were active that specific year. The fields included in each shape file are the X and Y coordinates of each quarry, the name of the owner companies, village, province, type of mining rights (A or C section), and type of rock.

2.3. Assignment of the production of aggregates to quarries

In the Minerals Statistics, there are, in addition to the total number of quarries in operation, the total tonnage exploited, and the use of each substance at regional and provincial levels for every year. This database has aggregated values with a statistical objective, not providing the individual production or the location of the quarries. Due to the lack of individual information, the provincial average per year has been equally distributed among the active quarries of that year in each province. The estimated production of the quarries of each year, measured in the number of trucks, has been imported into the supply shape files corresponding to each year.

2.4. Roads network

The road network used for the modelling has been digitized in ArcGIS from the World Streets base map of ESRI©. The highways, national, and regional roads of Madrid have been included. In the case of the neighbor provinces, for which only the information about the quarries is relevant, only the main roads and the connections from the quarries to the roads have been digitized. The roads have been split at their intersections to allow the turning of the trucks in the Network Analyst ArcGIS® tool.

2.5. Supply-demand distance estimation

A Python script has been developed to model the minimum distance from quarries to cities in ArcGIS with three nested loops (Fig. 2). In the

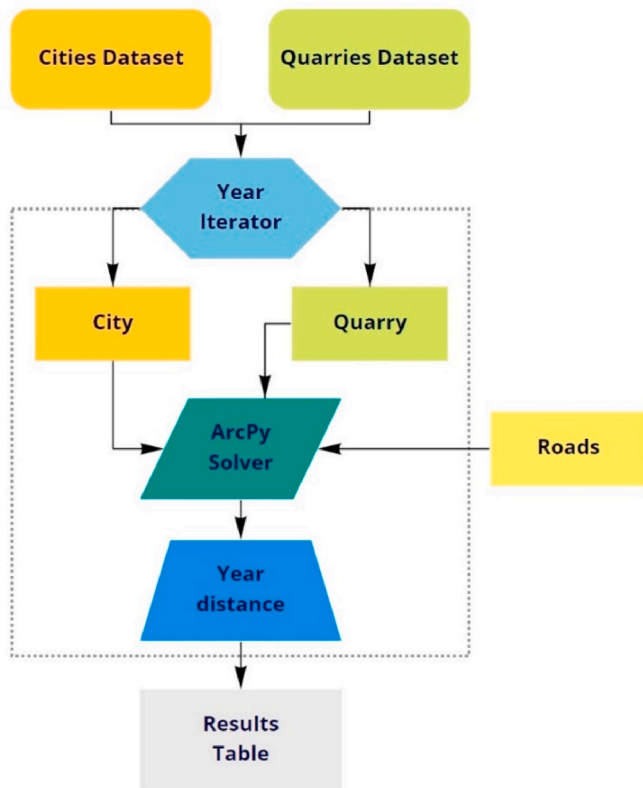


Fig. 2. Flowchart of the python script.

first loop, the script imports, for the first year, the following shape files: location of the demand points with their corresponding aggregates demand (measured in the number of trucks), location and production of the active quarries for that year (also measured in the number of trucks), and the road network. The script searches for each city, one by one, the closest quarry, it registers the distance in km for each quarry-city match, and compares the demand of the city and the production of the quarry. In the case that the capacity of the quarry is higher than the demand of the city for that year, the demand of the city becomes zero, and the amount dispatched to the city is subtracted from the production of the quarry, leaving the remaining number of trucks for that quarry. In case the demand of the city is higher than the production capacity of the quarry for that year, the production of the quarry is subtracted from the city demand, leaving that quarry with a remaining production of zero and a remaining demand of the city equal to the initial demand minus the production served by the quarry. Once the script has searched the closest quarry and operated the demand and production for each city, the first loop is finished. The distances and trucks per quarry-city match are recorded and by multiplying them for each match, the total kilometers travelled are calculated.

The minimum distance is calculated by the OD Matrix tool of the ArcGIS Network Analyst Module. The result given by the script is a conservative value, but the real distance is higher because there are some reasons that would make quarries serve demand points that are not the closest, for example, commercial contracts for different works, high demand in short periods of time being impossible to supply by a single quarry, etc.

The second loop searches for each city with a remaining demand and a quarry with a remaining production and performs the same operation than in the first loop. This procedure is followed by as many loops as necessary to fully satisfy the demand of all cities (the remaining demand equal to zero for all of them) for that specific year. The total kilometers travelled that year are the result of adding all kilometers travelled in the matches for that specific year.

This procedure is repeated by the script for each year from 1995 to 2018 (third loop), using the specific shape files (shp) of demand and production location and magnitudes for each year, giving as a result a txt file with information for each individual match (city and quarry), distance, number of trucks, etc. and the cumulated values of kilometers per year.

2.6. - Evaluation of CO₂ emissions

In Spain, aggregates are almost exclusively transported by truck. In this study, it has been taken into account just the CO₂ escaping the exhaust pipe. Other sources of CO₂ emissions related to transport by truck, which should be also included in life-cycle assessment, are those related to the production and transport of fuel, the production of vehicles (estimated in 1000 MtCO₂e), etc.

CO₂ emissions are generated in the combustion of fuel and are therefore proportional to the total fuel used by the trucks. A value of 55 L/100 km has been used in this study as the average diesel fuel consumption of the trucks transporting aggregates (30–35 tons payload) (Agioutantis et al., 2013). This figure has been validated in this study by aggregates producers. The total amount of liters consumed in the transport of aggregates each year has been calculated by dividing the total number of kilometers travelled each year by 100 (km), and by multiplying the resulting figure by 55 (L/100 km). Other contaminants are also emitted in the combustion of diesel fuel such as SO_x, NO_x, CO, and particulate matter, but they were not considered in this study. Anyhow, the actions taken to reduce the CO₂ emissions will also reduce the emissions of other pollutants.

The combustion of 1 L of diesel fuel produces 2.6 kg of CO₂ (Agioutantis et al., 2013). Once obtained the total amount of liters consumed by the trucks, the tons of CO₂ emitted each year for the transport of the aggregates have been calculated by multiplying the liters consumed in one year by 2.6 (kg/L) and dividing it by 1000 (kg/ton).

3. Results

3.1. The aggregates sector in Madrid region and neighbor provinces (1995–2018)

When studying the market of a product, both supply and demand have to be analyzed. This section describes the evolution of both parameters for the aggregates in Madrid Region and in the five neighbor provinces from 1995 to 2018. Those figures have been related to the global evolution of the Spanish aggregates market.

The demand of aggregates in Madrid (ANEFA, 2020) from 1995 to 2018 (Table 1) can be divided into three different periods: the first one, from the year 1995 to the year 2006, with a sustained growth, in which the demanded amount doubled (from 21.1 Mt to 50.7 Mt). This period was followed by a sharp fall from 2006 to 2013 (from 50.7 Mt to 5.4 Mt), that passed to a period of soft recovery of demand that lasted from 2013 to 2018 (from 5.4 Mt to 9.4 Mt). These changes in demand were driven by several factors, the most important related to demographic variables (population variation), followed by the impact of construction and economic variables (Escavy et al., 2020).

The production of aggregates in the quarries of Madrid region in the period under study has been systematically lower than the demand. This has forced to import aggregates from neighbor provinces to satisfy the needs. Analyzing the aggregates production, there appear three distinct periods (Table 1). The first period (years 1995–2006) is characterized by a production rise with one short period of decrease from 2003 to 2005. The production increase from 1995 to 2006 is high (+17.4 Mt), but lower than the increase of the demand (+29.6 Mt), resulting in the growth of the deficit of aggregates in Madrid that attained a maximum of 23.8 Mt in the year 2005. From 2006 until 2013, the production of Madrid quarries felt from 29.7 Mt to a minimum of 4 Mt in 2013

Table 1

Main figures for aggregates in Madrid region (1995–2018): demand, production, deficit, demand satisfied domestically, and productivity of the quarries.

MADRID	Demand	Production	Deficit	Demand satisfied	Productivity
Year	(Mt)	(Mt)	(Mt)	domestically (%)	(t/quarry)
1995	21,1	12,3	8,8	58	144796
1996	21,2	12,0	9,2	57	142990
1997	23,4	12,8	10,6	57	145786
1998	27,9	13,8	14,1	54	151117
1999	30,1	16,8	13,3	53	258229
2000	33,8	18,9	14,9	54	251705
2001	38,2	22,7	15,5	57	334140
2002	37,8	24,8	13,0	60	370727
2003	40,1	27,7	12,4	65	425452
2004	41,0	25,9	15,1	66	411428
2005	47,8	24,0	23,8	61	414464
2006	50,7	29,7	21,0	57	472166
2007	43,1	24,7	18,4	55	440841
2008	28,4	16,7	11,7	58	347228
2009	17,5	11,8	5,7	61	240177
2010	14,0	9,4	4,6	64	205419
2011	11,3	8,7	2,6	71	202043
2012	7,0	5,3	1,7	73	126569
2013	5,4	4,0	1,4	76	112478
2014	6,0	4,1	1,9	73	148093
2015	7,1	3,5	3,6	64	133184
2016	7,4	3,7	3,7	56	148653
2017	8,7	3,6	5,1	47	189352
2018	9,4	4,7	4,7	47	236935

(Table 1), with a sharper decrease at the beginning of the period, which progressively softened as time advanced. A higher reduction of the demand compared to that of the production resulted in the progressive reduction of the deficit of aggregates in Madrid region that attained a minimum of 1.4 Mt in 2013. The recovery in demand occurred during the period 2013–2018, and, although slight, it was not accompanied by an increase in the production of Madrid quarries, which remained in values around 4 Mt ±0.5 Mt. This production stagnation, together with the increase of demand, made the deficit to rise from 1.4 Mt in 2013 to 4.7 Mt in 2018.

In addition to the total aggregates production, it is interesting to study what happened to the number of active quarries in Madrid region and in the neighbor provinces. In the case of Madrid, the number of quarries in operation has fallen from 91 in 1988 to 20 in 2018 (MITECO,

2020). This decrease has been continuous and even in the period 1997–2007, when the demand in Madrid region for aggregates almost doubled, the number of quarries dropped from 88 to 56 (Figs. 3 and 4). From 1995 to 2006, the closure of quarries, together with the progressive increase of production, resulted in the increase of the average production that raised from 145,000 tons/quarry in 1995 to 472,000 tons/quarry in 2006. During these years, the smallest quarries closed and the bigger ones increased their production. Nevertheless, the increase of unitary production of the remaining quarries was insufficient to compensate the rise of the demand in the region, resulting in the increase of the deficit as noted previously. From the year 2006 until 2013, the demand for aggregates fell in Madrid from 57 Mt to 4 Mt (−93%), while the number of quarries was reduced from 63 to 36 (−43%). The productivity of the quarries fell 76%, from 472,000 to 112,000 tons/quarry (Table 1). The combination of all these parameters resulted in the drop of the deficit that in 2013 was only 24% of Madrid demand, while normally the deficit has ranged between 40% and 50%. From 2013 until 2018, the demand of aggregates increased while the number of active quarries dropped from 36 to 20, increasing the productivity of the remaining quarries from 112,000 to 237,000 tons/quarry. This increase was again not sufficient to compensate the increase of demand from Madrid, making the deficit raise from 1.4 Mt to 4.7 Mt (Table 1).

Five provinces belonging to two Autonomous Communities surround Madrid region: Ávila and Segovia, provinces of Castilla y León, and Cuenca, Guadalajara, and Toledo, provinces of Castilla-La-Mancha. Madrid aggregates production in year 2018 was less than half of its production in year 1995, while the production of the five neighbors in year 2018 (Table 2) was similar to that of the year 1995 (10 Mt ±1 Mt). The production of the five neighbors raised from 1995 to 2003, but at a slower pace than the production of Madrid. The production in the neighbors then suffered a sharp increase until the year 2007 when they produced 41.3 Mt. Since the year 2004, the production of aggregates in the five neighbor provinces has been systematically higher than that of Madrid. From 2007 to 2013, the production suffered a drop reaching a minimum of six million tons. Since that year, the production recovered with a steeper slope than that of Madrid Region (Tables 1 and 2).

In the case of the number of active quarries, the behavior of this variable in the five provinces is different to that of Madrid, with their number following the evolution of the production: raising in the periods of increase of demand and decreasing in the periods with lower demand

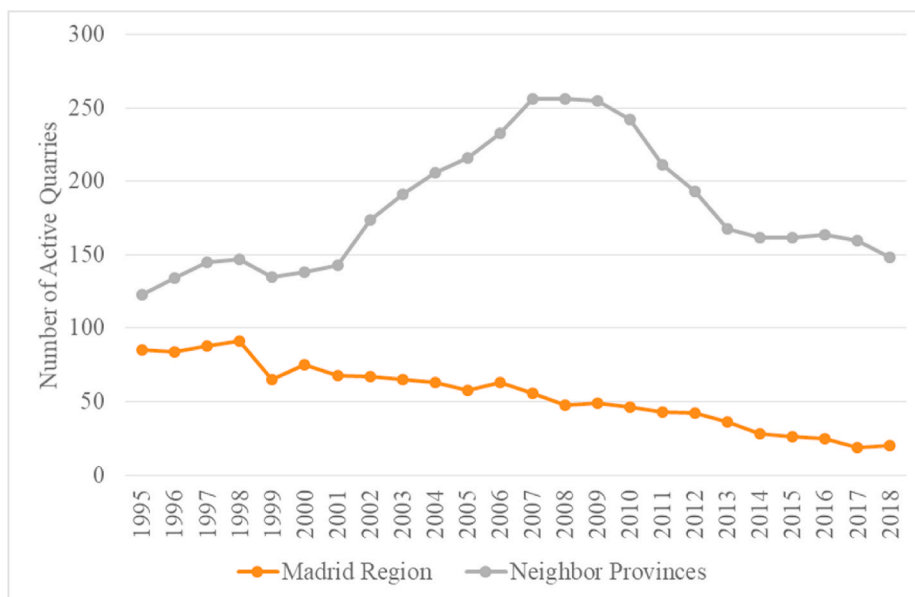


Fig. 3. Evolution of the number of active quarries in Madrid Region and in the five neighbor provinces.

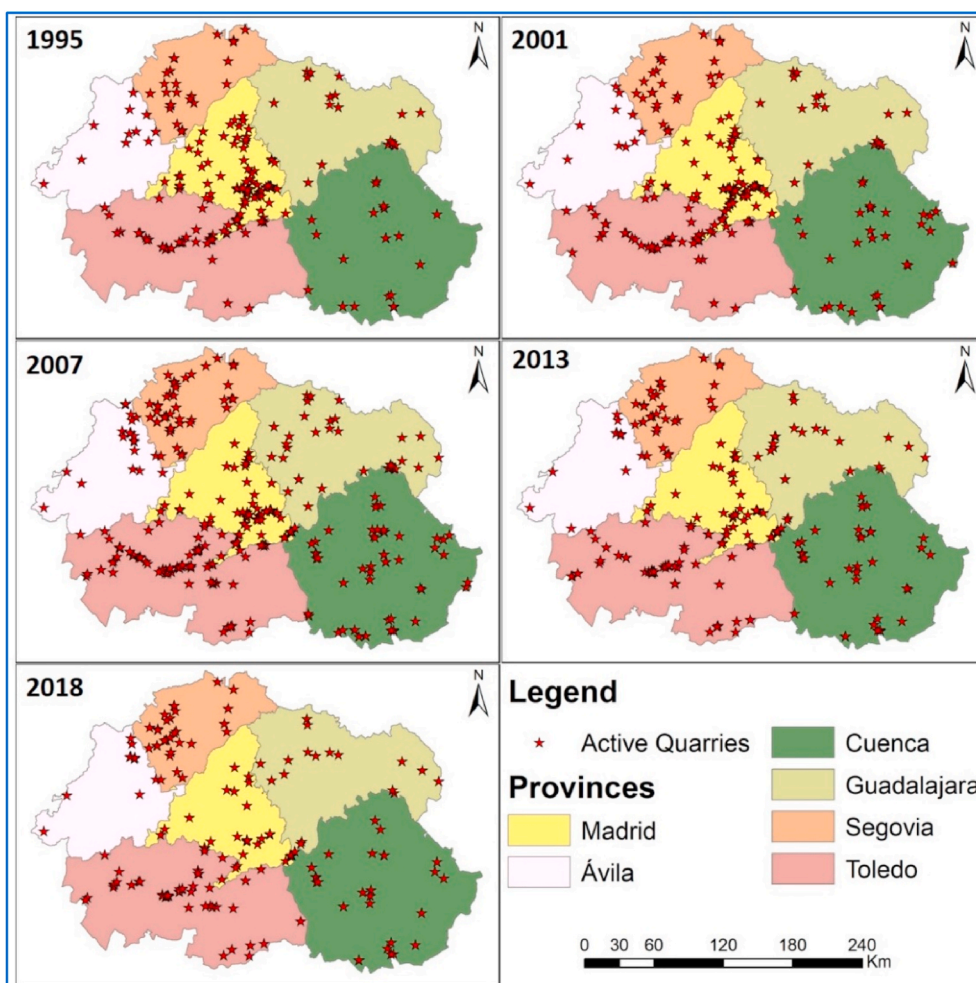


Fig. 4. Quarries location in years 1995, 2001, 2007, 2013, and 2018.

Table 2
Main figures for aggregates in the five neighbor provinces (1995–2018): total production and quarries productivity.

5 NEIGHBORS	Production	Quarries Productivity
Year	5 Neighbors (Mt)	5 Neighbors (t/quarry)
1995	11,0	89493
1996	10,7	80005
1997	11,0	75688
1998	12,9	87784
1999	14,2	105538
2000	13,8	100130
2001	16,3	114095
2002	17,9	102868
2003	26,2	137316
2004	27,0	131048
2005	37,8	174888
2006	36,4	156103
2007	41,3	161376
2008	37,2	145252
2009	30,1	118026
2010	22,0	90929
2011	18,0	85310
2012	11,1	57404
2013	6,0	35628
2014	6,3	39116
2015	6,9	42606
2016	6,3	38170
2017	7,6	47716
2018	9,1	61217

(Figs. 3 and 4). The final number of quarries in the five neighbors in 2018 (148) is higher than the initial situation of 2016 (123) and this with a demand in Madrid that is half at the end of the period than at the beginning. This fact proves that the quarries of the neighbors compensated the loss of quarries in Madrid. The average yearly production of the quarries is lower in the five neighbors than in Madrid Region (Tables 1 and 2), one of the reasons is that in some of the quarries the aggregates (mostly sand) are a byproduct of the principal mined target of the quarries (kaolin, feldspar, etc.). Another reason is a higher proportion of small family-owned companies in the five neighbors compared to Madrid, where most of the remaining quarries belong to big corporations (LafargeHolcim, Cemex, etc.).

Mining licenses in Spain are classified into exploration (investigation) permits, and exploitation licenses. Three different types of exploitation licenses can be applied for aggregates, one for smaller operations that benefit the land controlled by the applying company (named Section A), and two others for bigger exploitations (named Section C). The first is nonderived from a preexistent exploration right (Direct Exploitation License), and the second can be obtained after succeeding in the investigation of a preexisting exploration permit (Derived Exploitation License). Fig. 5 shows the evolution of the number of mining rights, both exploration permits and exploitation licenses (all three types added) in Madrid Region. Exploitation licenses underwent a sharp fall from values above 40 licenses granted per year to six in the period 1995 to 1998, since that year until 2006 the exploitation licenses granted diminished to ca. 10 per year. In the period 2006–2014, the exploitation licenses granted per year were almost null, ranging from

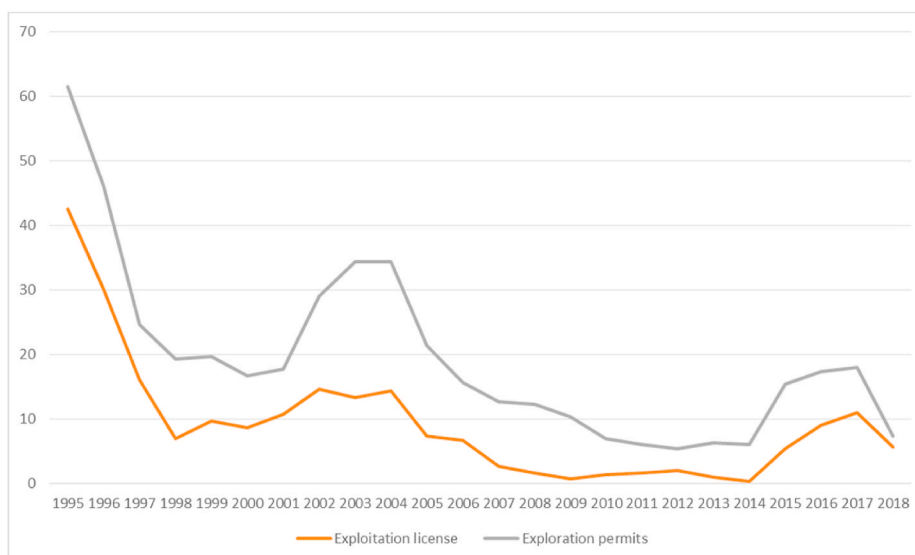


Fig. 5. Evolution of the exploitation licenses and the exploration permits in Madrid Region.

zero to three per year. In the years 2015, 2016, 2017 there was a slight recovery, rising up to 11 mining licenses granted in the year 2017, but in 2018 (and 2019) decreased the number of granted mining rights. When comparing the figures of the active quarries and the mining rights granted in this period, it can be seen that the exploitation licenses granted were not enough to replace those mining rights that expired or were exhausted.

3.2. Results of the geospatial supply-demand model

The result of the geospatial model is the total number of kilometers travelled per year to supply the aggregates required in Madrid region. This variable is highly correlated with the total demand of aggregates: the higher the number of tons traded, the higher the number of

Table 3

Total kilometers and km travelled in excess per year due to the progressive distancing of the quarries from the demand areas. Proportion of km travelled in excess over the total kilometers travelled.

Year	Total km travelled	Km travelled in excess (reference: average distances of year 1995)	% of km in excess of total km
1995	63,215,902	0	0
1996	64,526,619	843,909	1.3
1997	73,459,208	2,836,115	3.9
1998	90,401,518	3,546,099	3.9
1999	92,148,288	2,268,108	2.5
2000	100,860,505	4,203,231	4.2
2001	129,391,361	6,618,923	5.1
2002	121,267,987	11,532,261	9.5
2003	135,517,416	13,898,185	10.3
2004	143,980,277	29,879,160	20.8
2005	208,152,907	38,995,079	18.7
2006	184,578,246	39,405,744	21.3
2007	146,368,677	20,057,178	13.7
2008	97,101,129	6,469,819	6.7
2009	51,238,895	488,789	1.0
2010	39,149,401	-4,686,145	-12.0
2011	26,341,290	-5,776,756	-21.9
2012	16,789,212	-3,884,947	-23.1
2013	14,391,327	-1,619,992	-11.3
2014	18,576,416	1,180,267	6.4
2015	27,608,972	5,567,306	20.2
2016	32,762,093	9,308,398	28.4
2017	39,301,046	11,772,320	30.0
2018	39,238,732	12,464,268	31.8

kilometers travelled. The evolution of the total km travelled is shown in Table 3. It shows an initial period of increase that lasted from the year 1995–2005, raising from 64 to 208 million km travelled per year. This period was followed by a sharp decrease that lasted from the year 2005 until 2013 when a minimum of 14.4 million kilometers was reached. This drop was due to the construction crisis in Spain. From the year 2013, the kilometers travelled per year have progressively increased, reaching 39 million in 2018.

One of the targets of this study was to test the hypothesis of the increase of the distance from quarries to demand areas and, if so, quantify the distancing of the active quarries from the demand points. For this, the average kilometers each ton travelled each year, and the average distance that a truck had to travel from the quarry to the demand point have been estimated. These two variables are independent of the total traded aggregates in the year. Fig. 6 shows these two variables, with a three-year moving average to smooth their variability. From 1995 to 2004, the average km travelled per ton raised 24%, from 3.02 to 3.75 km/t. With 25.5 tons average haulage load of trucks, the mean distance from the quarries to the demand points raised from 38.5 to 47.8 km (77–96 km taking into account the way back to the quarries). A relatively flat period went from 2004 to 2007 in which the values remained close to 3.8 km/t and 49 km of average distance between the quarries and the demand points. From 2007 to 2012, Spain suffered a building crisis that reduced the building activity to marginal figures. For instance, the number of new homes that were built in this period decreased from 651,427 in 2007 to 44,190 in 2012 (Escavy et al., 2020). During this construction standoff period, both variables decreased (from 3.8 km/t and 48 km in the year 2006 to 2.46 km/t and 31 km in year 2012). The last period of the study (2012–2018) was characterized by a strong increase of the values of both variables (76%), from 2.46 km/t and 31 km–4.35 km/t and 55.4 km. In the year 2018 a truck had to travel in average about 110 km from the quarry to the demand point and return, while in 2012 this distance was only 62 km.

4. - Discussion

4.1. Emissions due to the increase of transport distance

Taking as reference values the number and distribution of quarries in the year 1995, that had an average travel distance of 3.02 km/ton, in the period 1996–2018, only four years (2010–2013) had traveling distances lower than those of the year 1995 (Fig. 6). These years with lower distances coincide with a period of extremely low demand of aggregates

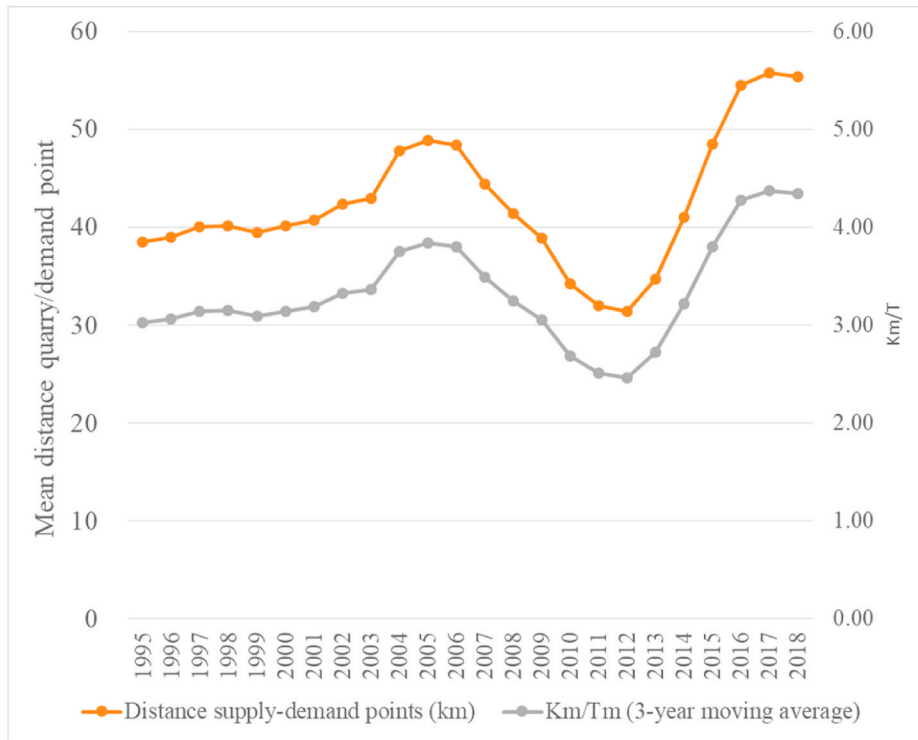


Fig. 6. Mean distance from the quarries to the demand points and km travelled per ton, one-way trip only (three-year moving average).

due to the deep building crisis that almost stopped construction in Spain. In these years, 70% of the limited demand of Madrid region was satisfied by domestic quarries (Table 1).

In the remaining 17 years covered by this study, the km/ton has been higher than the value of the year 1995, showing an overall rising trend. The average distance from the aggregate quarries to the demand points followed a similar trend: a growth period from 1995 until 2006 followed by a decrease, reaching a minimum in the year 2012. From that year, a rapid rise is observed, which almost doubled the distance in 5 years. This increase is the consequence of a growing demand, a reduced number of active quarries in Madrid, and the inelasticity of the aggregates production, mostly due to the long periods required to obtain new mining permits, and the dismantling and abandonment of some of the quarries

that had been inactive for several years.

The evolution of the number of quarries and aggregates production in the five neighbor provinces is different to those of Madrid region. The curves of the aggregates deficit in Madrid and the number of quarries and productivity in the five neighbor provinces followed a very similar pattern (Fig. 7), showing the dependence of the aggregates production in the neighbor provinces on Madrid needs for construction raw materials.

Based on the previously calculated parameters, the kilometers travelled in excess due to the progressive increase of the distance from the supply areas to the demand points have been estimated (Table 3). In all years in the period under study, except in the four corresponding to the deepest part of the building crisis, there have been an excess of kilometers travelled. The year with the maximum of kilometers travelled in

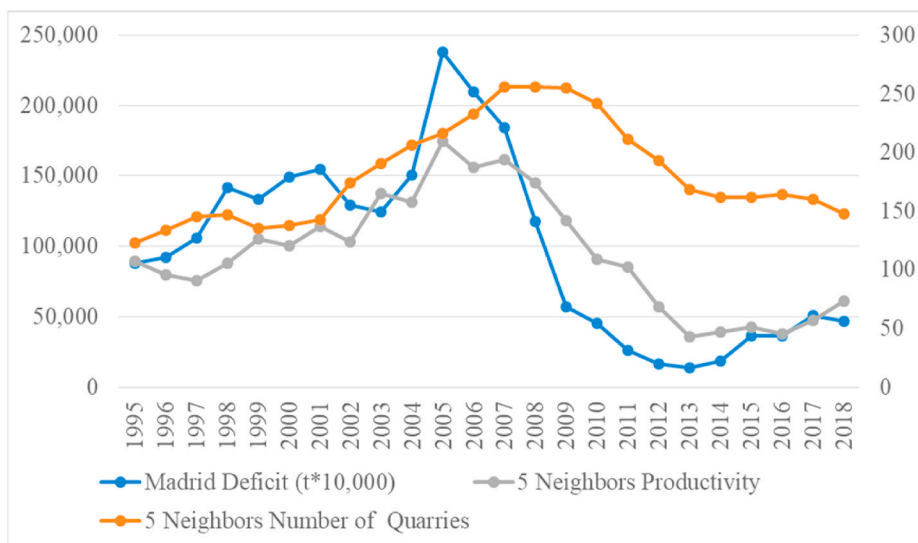


Fig. 7. Comparison of Madrid Aggregates deficit and the productivity and number of quarries in the five neighbor provinces.

excess (near 40 million km) has been 2006. About 20% of the km travelled would have been avoided if the average distance quarry-demand areas would have remained similar to that of 1995. In 2018, about 12.5 million km have been travelled in excess, representing about 30% of the total km travelled. The sum of the yearly amounts in the period 1995–2018 gives a total of 205.37 million km travelled in excess, due to the increase of average distance from demand to supply areas. With an average consumption of 55 L/100 km, the liters of diesel fuel consumed in excess were around 112.95 million L that emitted more than 293,675 tons of CO₂ to the atmosphere.

The results of this study confirm the progressive distancing of the quarries from the demand areas, whichever the causing forces are. This increase of the average distance has a direct impact on fuel consumption and in greenhouse gas emissions to the atmosphere.

4.2. Potential causes of moving aggregate quarries away from demand areas in Madrid region

Several causes could explain the progressive distancing of the quarries away from the construction areas and the relocation of most of the production to the neighbor provinces. The most relevant could be the NIMBY phenomenon, institutional NIMBY, land competition between different economic sectors, depletion of resources, increasing limitations to exploitation due to environmental or heritage protections, or by the combination of some of the previous ones that made mining companies avoid the most conflictive areas.

4.2.1. The NIMBY phenomenon

When a new project is proposed to a community, it is perceived and evaluated in terms of its functional utility, risks to the population, and environmental impact. This drives the population to think about their role in the ecosystem and in the society and to reflect on territory values such as landscape, protection of the territory and public health, converting these topics into key points for discussion (Messina, 2015). The acronym NIMBY, first proposed by O'Hare (1977), stands for "not in my backyard" and is related to facilities that, despite the overall benefits to society, they have negative impacts on a reduced number of people (Zhang, 2020). The people potentially affected may create local movements to resist the siting of the obnoxious activity or land use in their proximity (Driscoll, 2013). The term employed to define unwanted facilities is LULU "locally unwanted land use" (Popper, 1987). The public opposition is ascribed to the NIMBY syndrome (Lake, 1993). Another term related to NIMBY is NIABY (Not in anyone's backyard) that represents a total opposition to the building of the facility anywhere (Feldman and Turner, 2010). The background of the NIMBY issue with aggregate quarries is that people complaining about quarries near their neighborhoods could not have neighborhoods without these quarries (Drew et al., 2002).

NIMBY groups have acted on environmentally and socially hazardous activities such as landfills, waste incinerators, mines, prisons, etc. and activities with visual impact such as wind turbines, airports, etc. (Driscoll, 2013). In the case of mining, social value conflict usually focuses on the externalities of material extraction versus economic benefits such as income and employment generation (Brown et al., 2017). One effect of the resistance in certain areas to the siting of undesired activities is the concentration of these activities in poorer areas causing an environmental injustice (Bullard, 1990). NIMBY movements are sometimes seen as selfish local parochialism attitudes that prevent societal benefits (Mazmanian and Morell, 1990), while others see the opposition to LULUs positive because instead of the simple relocation of the facility, they oblige to think about the origin of the problem and about other possible solutions (Lake, 1993). In mature societies, NIMBY phenomenon is evolving to an increased public participation in the decision process, moving from an initial position of the displacement of the facility to the negotiation of compensation and safety measures to permit the facility. The compensations for obnoxious activities are

variable; depending, for example, on the number of people affected by the activity (Gallo, 2019). In a different typical NIMBY activity, shale gas development, Zanocco et al. (2020) have analyzed the different perceptions and degree of opposition to the activity based on the distance. Despite the general thinking of the closest the facility, the stronger the opposition (NIMBY phenomenon), some studies have found that in some cases the most proximate to the development are more supportive YIMBY (yes in my backyard) or PIMBY (please in my backyard). The main reason behind the support of people living close to the establishment of a facility is related to the creation of jobs and the increase in business opportunities. Another important explanation is that the perceived benefits of the development outweigh its costs.

In the case of Madrid province, with 840 persons/km², it is a very densely populated territory compared to an average of 24 persons/km² of its five neighbors (INE, 2020). According to Corine Land Cover 2018 (Pérez-Quintana, 2019), the artificial surface (urban, industrial, commercial, etc.) in Madrid region is about 14.9% of its territory while only 1.5% of the territory in the five neighbor provinces is artificial surface. Madrid has 8% of its territory occupied by urban areas. This figure highly contrasts with the surface occupied by urban areas in the five neighbor provinces that average 1%, with a maximum of 1.5% in Toledo province and a minimum of 0.5% in Cuenca province. This high level of constructed surface in Madrid makes it difficult to find a wild area with potential aggregates far from residential areas.

In addition to the extensive land constructed, Madrid region is the administrative and economic center of Spain and industrial activity remains marginal. For example, in 2018, 88% of employed people in Madrid region worked in the services sector and only 7% in the industry sector. Mining, despite being included in the primary sector, is considered an industrial activity by the population, and the low impact of the industry in Madrid economy and job market, makes citizens to give more value to the environment than to the economic and social benefits of mining. NIMBY activities in Madrid have been conducted via Environmental NGOs or neighborhood associations created ad hoc for each case, but their activity has been very limited and their results almost null. After a search in the newspaper library, only one area of crushed rock aggregates exploitation, and another one exploited for sand and gravel, have been subjected to opposition by the neighbors. The first one organized demonstrations against the authorization of two limestone aggregate quarries in 2003 and 2008 in their area (La Alcarria de Madrid), promoted by Ecologistas en Acción, an environmental organization (canteras, 2008). The sand and gravel exploitation opposition focused on the Jarama River area and has been promoted by another environmental organization (Asociación Ecologista del Jarama el Soto (2014). These NIMBY groups ended their activities in 2008 and 2014 respectively, and their impacts were very limited. One of the initial hypotheses, when starting this study, was that the NIMBY phenomenon would be the main cause of the quarries moving to the neighbor provinces, but it has turned out to be a variable with a low impact in the case of Madrid region.

4.2.2. Institutional NIMBY

NIMBY movements are present at different scales, from small movements to the siting of a facility near a certain neighborhood to institutional country-level actions. In developed countries, some environmental policies can be viewed as macro-level NIMBY phenomena, promoting the siting of hazardous or polluting facilities in poorer nations (Pellow, 2007). Different degrees of protection or increased barriers to the siting of facilities can be noted between regions in decentralized countries such as Spain. Scally (2013) has broken down the NIMBY syndrome into a personal attitude and institutionalized action via regulatory barriers. Both sides, personal and institutional, seem to be highly correlated, meaning that in areas with high public contestation, the siting of undesired facilities and regulatory barriers tends to be stricter.

In our case of study, mining legislation is common for all regions, but

environmental laws are a region competency (Autonomous Regions). Each region can legislate particularly for environment protection, but the common frame of the European and country-level legislation makes the regional environmental protection norms similar. Anyhow, the application of the laws can differ from one region to another and in the case of Madrid, mining seems not to be a priority sector for the regional government, despite some world-class deposits of industrial minerals and rocks are being exploited in this region (i.e. sepiolite, sodium sulfate, and gypsum). Madrid neighbor regions (Castilla y León and Castilla La Mancha) seem to be more mining friendly. Castilla y Leon Region has a minerals resource strategy (2017–2021), a regional commission for mining, and a region-owned company for the finding and development of mineral deposits, and the promotion and development of the mining sector (Siemcalsa). Castilla la Mancha region has a web page where mining activity in the region is advertised and promoted, and leads research projects about ecological restoration of mining areas (Mancha, 2021). The different perception of mining by the regional governments certainly has an impact in the delocalization of the Madrid quarries to the neighbor regions.

4.2.3. Depletion of resources

A Mineral Resource is a concentration or occurrence of a solid material of economic interest in or on the Earth’s crust in such form, grade

(or quality), and quantity that there are reasonable prospects for eventual economic extraction (JORC, 2012). Mineral resources for aggregates in Madrid region can be considered unlimited. The north and north west of the region is a mountainous range formed by granite and metamorphic rocks, the southeast is a paramount formed by Miocene limestone, and sand and gravel are ubiquitous in the river valleys that cross the region, and in the Quaternary fluvial terraces. Some areas have been extensively mined in the past, but resources are still abundant and varied, and the depletion of resources is not the main cause of the progressive transfer of quarries outside Madrid region.

4.2.4. Limitations to mining due to environmental protection, water course protection, and protection buffer around urban areas

Ore Reserve is the economically mineable part of a Mineral Resource that includes the application of Modifying Factors. Modifying Factors are considerations used to convert Mineral Resources to Ore Reserves, including legal, environmental, mining, processing, metallurgical, infrastructure, marketing, economic, social, and governmental factors (JORC, 2012). These are all restrictions and conditions that make an exploitation feasible. In the case of Madrid region, the most relevant limitations to mining are the built areas and their protection buffer, environmental protection, and water course protection.

The Dangerous and Noxious Activities Spanish Act (1961), states that

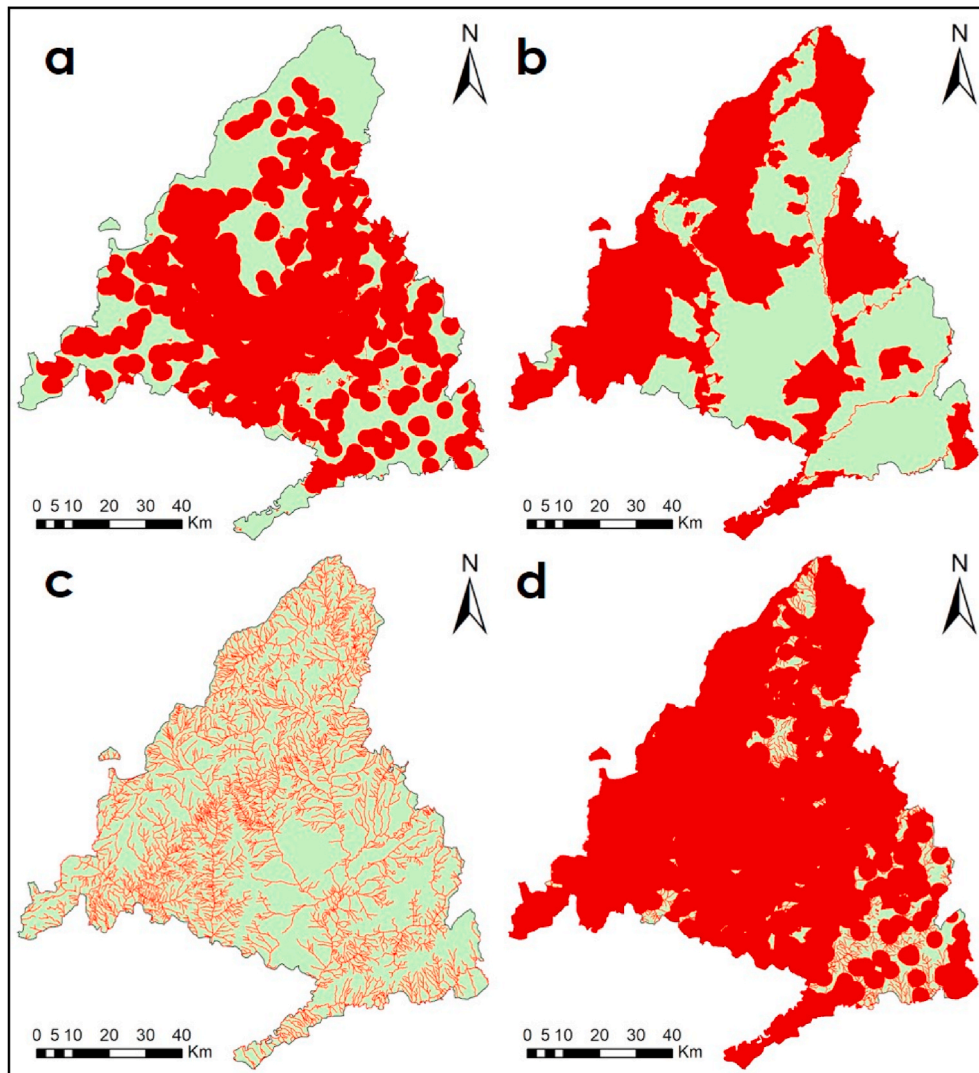


Fig. 8. Restrictions on mining in Madrid Region (in red). a.- Urbanized area and buffer from residential zones; b.- Environmentally protected area; c.- Watercourse protection buffer; d.- Combination of the three main limitations (green color: areas without restrictions).

the minimum distance to an urbanized area to establish an activity considered dangerous or noxious is 2 km. Municipalities could voluntarily reduce this distance but is not a frequent situation due to potential citizen opposition. Those mining rights that were granted before the entry into force of this norm or those quarries that were out of the 2 km buffer, but, because of the growth of the urban area, they are now at less than 2 km to urban areas, can continue quarrying, but new mining rights should keep the buffer distance or try to negotiate with municipalities the reduction of that distance. In total, 65% of the surface of Madrid region lies within the 2 km buffer around urban areas or is built for industrial or commercial activities (Fig. 8a).

Officially, about 15% of the region surface is environmentally protected (1210 km² out of 8028 km²), but when including all protection figures (Habitats European Directive Sites, Birds European Directive Sites, National Parks, Regional parks, wetlands, etc.) about 54% of Madrid region is affected by environmental protection norms (Fig. 8b). The quarries already permitted before the date of entry into force of the environmental protection could continue with their activities, but they have to adapt to the new protection rules at the time of the renewal of their respective mining rights (every 30 years). For the demand of new exploitation rights, mining activity in protected areas is prohibited in some of them, and allowed with different levels of restrictions in the rest. In those protected areas where mining activity is theoretically tolerated, the protection measures in place make the permitting process longer, more expensive due to the in-depth additional studies required, and uncertain of the results.

In addition to these protected areas, the Spanish Water Law regulates human activities, including the extraction of aggregates near the watercourses. This law states that the extraction of aggregates closer to 105 m from a watercourse requires a special permit from the hydrographic authority. This protection complicates obtaining new mining permits, sterilizing a relevant portion of the Quaternary sand and gravel deposits. About 17% of Madrid surface falls inside this buffer distance (Fig. 8c).

When merging all these three legal limitations for mining, about 91.5% of the surface of the region of Madrid has limitations or restrictions that impede or complicate and lengthen the obtaining of mining rights (Fig. 8d).

4.2.5. Other limiting factors

Other factors limiting the establishment of new aggregates quarries in Madrid region are the presence of large mining rights and a higher land price due to land competition with other sectors. Some companies, mainly cement producers, accumulate considerable areas with mining rights to warranty their production in the long term, and this prevents the opening of aggregates quarries in these areas.

The price of land in Madrid region is higher than in the neighbor provinces. For example, 1 ha of land used for cultivation costs on average in Madrid 7.100 €, 8% more than in Cuenca, Guadalajara, and Toledo, and 17% more than Ávila and Segovia (MAPA, 2020). This can be a relevant factor for low-thickness deposits (in our area of study the Quaternary deposits) because the surface required to exploit a certain volume of aggregates is higher than for thick deposits.

4.2.6. Mining companies requesting mining licenses in more favorable areas

The consequence of the exposed limiting factors is that companies may be prone to propose developments in areas that would support them (Zanocco et al., 2020). In the case of aggregate quarries, usually small and highly mechanized activities, which exploit nonrenewable resources, and that have an impact on the environment, they have difficulty to convince the population around a positive benefit/cost balance. In the case of Madrid region, with most of its territory affected by restrictions, a higher price of land, and a high population density, the mining companies find easier to apply for mining rights in other provinces with less limiting factors than in Madrid.

4.3. The importance of including mining activity in land planning

In economic and or demographic growing areas, intensive extraction of construction minerals is required, but the growth itself competes for land with mining activities (Wernstedt, 2000). The growth sterilizes mineral resources and mining can generate negative aesthetic and environmental effects. When competing with other high-value uses of land, many communities have viewed the extraction of aggregates negatively (Wernstedt, 2000). When land planning in intensively developing areas has considered the zones for aggregates extraction, the mining is usually at a disadvantage and there is a high risk that the deposits could not be exploited. Planners, therefore, should reserve areas rich in raw materials for construction in enough quantity while minimizing adverse effects and considering the needs of the local communities, regional governments, and construction industries (Philpot et al., 2019). Brown et al. (2017) highlighted the importance of participatory mapping in the identification of potential conflicts in natural resources management in land planning.

This study shows the consequences of not including in land planning the areas that would supply the raw materials to the construction industry. In the case of the Madrid region, this lack of planning has caused, among many other negative effects, the unnecessary emission of more than 294,000 tons of CO₂ to the atmosphere.

5. Conclusions

It has been confirmed that, in developed areas such as Madrid region, there is a progressive distancing between the sources of raw materials for construction and the demand areas. By considering the location of the quarries and the location of the demand areas and their demanded tonnage, it has been possible to estimate the kilometers that the aggregates travelled in Madrid Region from the year 1995–2018. A truck delivering aggregates in Madrid region in 1995 travelled in average 77 km from the quarry to the delivery area and return. This represented 6.04 km per ton. The distance increased every year, except during the deepest part of the building crisis of Spain, reaching a maximum of 111 km in 2018 (8.7 km per ton). Due to the increase of the distance, a relevant portion of the demand of Aggregates in Madrid region is satisfied by importing the material from the neighbor provinces. In 2018, imports of aggregates attained 50% of the tonnage consumed in Madrid region.

The increase of the distance results in major environmental and safety impacts, being the increase of the CO₂ emissions one of the most important. Due to the increase of the distances, a minimum of 294,000 tons of CO₂ have been emitted to the atmosphere in excess in the period under study in Madrid region.

The initial hypothesis when the study started was that the distancing of the quarries from the demand areas in Madrid region was due to the NIMBY effect, but after the analysis, it has been concluded that other factors play a more prominent role in the distancing of the quarries (the amount of surface built or with a type of protection). Near 92% of the surface of Madrid region has limitations or protections that complicate obtaining the permits acquisition. This makes the aggregates companies to move the production areas to the five neighbor provinces with more potentially minable land.

As it has been proved, the areas with raw materials for construction extraction have to be taken into account in the land planning to avoid the increase of transport distances and the associated negative effects. Authorities should quantify and locate the short, medium, and long-term needs of construction raw materials. This demand should be integrated in the land planning taking into account the geology and the social, economic, and environmental limiting factors. The delineation and protection from other uses of the required extraction sites would avoid distancing from the quarries, with associated economic, environmental, and safety benefits.

Author statement

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