Need to Improve the Natural Aggregate Resources Supply in the City of Belgrade (Serbia)

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The City of Belgrade is the largest market for aggregates in Serbia but the production of natural aggregates is rather small, around five percent of total consumption. This reflects the geology of the City of Belgrade territory, dominated by Neogene and Quaternary sedimentary rocks. The production of crushed rock and sand and gravel on the territory of Belgrade was almost equal, while majority of imported aggregates is sand and gravel due to lower price. Consumption of crushed rocks includes around 90 % of limestone and dolomite, the rest being magmatic rocks. The main issue of using crushed rock on the territory of the City of Belgrade is the long transport routes, which are usually near or more than 100 km, creating more logistic problems and increasing cost of aggregates Therefore it is necessary to establish a good supply system with low socio-environmental impact of aggregate production and transport, and the basis for that is the analysis of actual structure of production and supply of natural aggregates and new potential quarries and/or sand and gravel pits.

Key words: *SARM, SSM, limestone, sand and gravel*

Introduction

Establishing the sustainable supply of aggregates at any administrative level is an important challenge due to their vast economic importance (in the European Union aggregates' contribution to the total mining sector was 67% by volume and 23% by value in 2006, Menegaki & Kaliampakos, 2010), but also because of the potential ecological and societal influence of their production, particularly on the local level. Aggregates are raw materials of strategic importance in modern economy due to large annual consumption mostly for infrastructure works - in the road construction and civil engineering, but also for lime and cement production, which makes the aggregates sector by far the largest amongst the non-energy extractive industries in Europe, with current production of 3 billion tonnes for EU-27 + EFTA countries in 2011, or 3.9 billion if 35 countries are included (UEPG, 2012). Therefore, their importance is constantly evaluated and carefully planned (Pfleiderer et al, 2007; Brown et al, 2011; Mankelow & Gunn, 2011; Tiess & Kriz, 2011).

In this paper the classification of aggregates proposed in the SARMa project (SARMa Glossary, 2011) will be used. Natural aggregate is aggregate from mineral resources which have been subjected to nothing more than mechanical processing, while manufactured aggregate is produced from industrial activities such as processing or re-processing of waste, by-products and residues. Aggregates industry in Serbia, and consequently in the city of Belgrade, uses almost exclusively natural aggregates – sand, gravel and crushed rock (Statistical yearbook, 2013; Simić et al, 2010; Simić et al, 2011).

Geological setting

The area of Belgrade consists of Paleozoic, Mesozoic, Tertiary, and Quaternary rocks (Marković et al., 1984; Filipović & Rodin, 1980; Pavlović, 1980; Ivković, 1975; Brković et al., 1980). Tertiary and Quaternary sediments are by far the dominant lithological members. The border and basement of this sediments consist of Devonian and Carboniferous schist, gneiss, slate and sandstone, Mesozoic carbonate and marly sediments, and Tertiary dacite–andesite rocks and pyroclastic rocks (Fig. 1).

Paleozoic rocks are made of Devonian–Carboniferous phyllite with redeposited blocks and fragments of limestone and Carboniferous terrigenous sediments (phyllite, rarely quartz sandstone with lenses of limestone). In the contact zone with granodiorite rocks of Paleozoic to Mesozoic age are metamorphosed, forming hornfels, amphibolite, mica schist and gneiss. The Paleozoic rocks occur along the southern border of the Belgrade area. Mesozoic sedimentation started in Early Triassic with bedded limestone and clastic rocks – mica-rich sandstone and shale, while during Middle and Late Triassic bedded to thick-bedded dolomite, dolomitic limestones and

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massive limestone deposited. Triassic sediments occur only along the SW border of Belgrade. Central part of the territory of Belgrade consists of Jurassic serpentinite and Late Jurassic to Upper Cretaceous rock succession, comprised of limestone and flysch (alternation of limestone, marlstone, sandstone and siltstone). Magmatic rocks of Late Oligocene and Early to Middle Miocene age were formed in the southern part of Belgrade area and as small masses within the central Belgrade Jurassic-Cretaceous succession. Volcanic rocks consist of granodiorite, phenoandesite, phenodacite, quartz-latite, latite, ignimbrite and tuff.

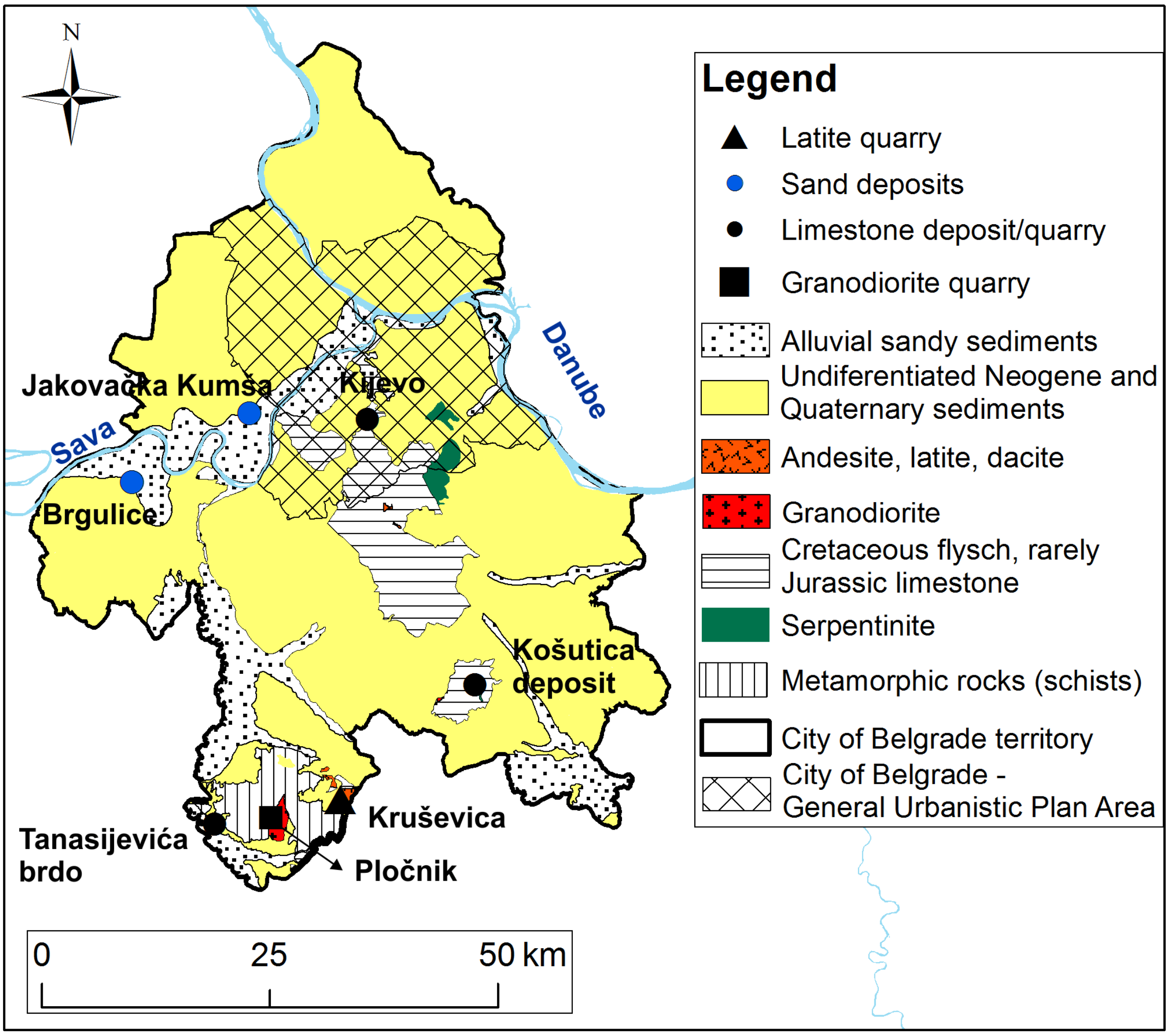

Fig. 1. Geological map of Belgrade with position of existing aggregate quarries and sand pits (after Basic Geologic Map of SFRJ, sheets Beograd, Pančevo, Obrenovac, Smederevo and Kragujevac).

Neogene sediments in Belgrade and surrounding areas consist of the following units (Životić et al., 2013): Early Miocene fresh water marlstone, tuff, and claystone; Badenian (Middle Miocene) marine sand, loosely bounded conglomerate, freshwater sand, clay and gravel; Sarmatian (Middle Miocene) brackish clayey–marly and sandy sediments and limestone; Pannonian (Upper Miocene) caspi-brackish sand, sandy clay, marly clay, silt, rarely gravel and marlstone; Pontian (Upper Miocene) fresh water clastic sediments, with three coal seams in the Kolubara coal basin. Quaternary sediments are made of fluvial gravel, sand, clay and sandy–clayey sediments.

Natural Aggregates consumption in Belgrade

Aggregate consumption in Belgrade comes entirely from natural aggregates (crushed rock, sand and gravel; Fig. 2), out of which only 7 % is produced on the territory of Belgrade. This situation is even less favourable today, as the Tanasijevića Brdo quarry near Lazarevac has stopped operations in the meantime. Estimated annual consumption of all types of aggregates in Belgrade is approximately 3 tons per capita and the average annual consumption of aggregates in the EU in general amounts to 5-7 tons per capita (UEPG, 2013).

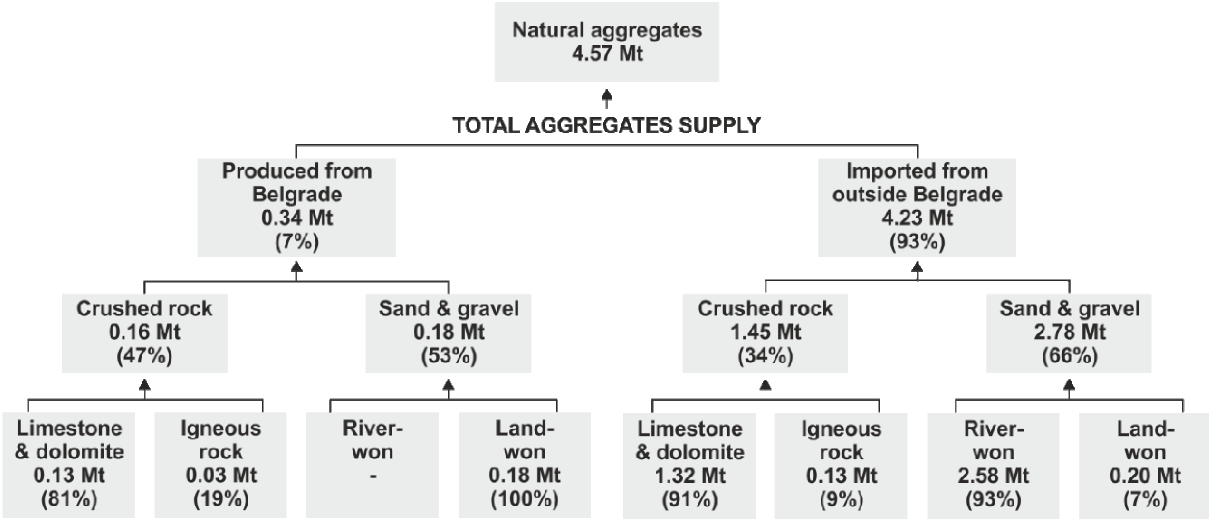

Fig. 2. Aggregates consumption in the City of Belgrade, annual average for 2008-2012. Source: Statistical Yearbook (2013). River-won sand and gravel in the City of Belgrade were not produced in the studied period, or no production was reported.

Natural crushed aggregates production in Belgrade (table 1) is at the moment limited to the Kijevo quarry, where high quality limestone aggregate is produced (table 2), and Kruševica quarry, where low quality aggregate of volcanic origin is produced mostly for Kolubara lignite basin internal consumption (Dimitrijević & Krstić, 2011). Košutica deposit, although explored according to the existing rules, has not been opened as it is within the protected area (Special Purpose Area Spatial Plan for the Avala-Kosmaj outstanding landscape, 2014).

Tab. 1. List of natural aggregate deposits on the territory of Belgrade (WEBGIS, 2015, data from producers).

Deposit/quarry	Operating status	Rock type	Usage
Kijevo	Operating	Limestone	Aggregate
Tanasijevića brdo	Closed (but operating during studied period)	Limestone	Aggregate
Košutica	Not operating	Limestone	Aggregate
Pločnik	Operating	Granodiorite	Ornamental stone, aggregate as by-product
Kruševica	Operating	Latite and latite tuff	Aggregate (low quality)
Brgulice	Operating	Sand	Aggregate
Jakovačka Kumša	Operating	Sand	Aggregate

Tab. 2. The quality of limestone in deposits on the territory of Belgrade.

Stone property	Kijevo limestone, average for last 6-8 years (data from producer)	Košutica limestone, average for the deposit (data from Ministry of Mining and Energy)
Bulk density [kg/m3]	2657	2660
Porosity [%]	1,09	2,20
Water absorption [%]	0,26	0,49
UCS, dry stone [MPa]	140	92
UCS, water-saturated stone [MPa]	125	
UCS after 25 freezing cycles [MPa]	122	
Abrasion resistance [$cm^3/50cm^2$]	19,27	25,30
Los Angeles [%], gradation "B"	24,6	24,6
Los Angeles [%], gradation "C"	23,2	23,1

Granodiorite from the Pločnik deposit near Lazarevac is used as ornamental stone, and by-products can be used in the future in small quantity as aggregate. There are at the moment two pits from which sand is excavated and used as low quality aggregate (table 3), mostly for road subbase layer, structural and non-structural fill.

Tab. 3. Typical quality of sand in land-won deposits (Milićević & Pavlović, 2009).

Aggregate property	**Value**
Bulk density []kg/m^3]	1312
Bulk density, compacted [kg/m^3]	1528
Clay lumps content [%]	32
Particles <0.09 mm [%]	13
Particles <0.063 mm [%]	10
Particles <0.02 mm [%]	7.5
Fineness modulus	10
Sand equivalent	38

Comparing properties of sand and gravel from four rivers (table 4; Fig. 3) the similarity between Dunav and Velika Morava are obvious, reflecting that all studied locations from the Danube are located downstream the Velika Morava and Danube confluence. Aggregate from the Sava river has the finest granulation, while Drina aggregate has the coarsest one and the best LA (Los Angeles) value, but as well the largest percent of elongated grains.

Tab. 4. Average quality of riverbed sand and gravel (based on numerous producers data, number of studied locations is given in brackets).

Aggregate property	**Dunav (25)**	**Sava (4)**	**Velika Morava (8)**	**Drina (12)**
Water absorption, < 4 mm [%]	1.1	2.1	1.0	0.8
Water absorption, > 4 mm [%]	0.9	3.9	0.7	0.6
Grain shape 3:1 [%]	9.7	6.3	9.8	12.0
Clay lumps [%]	0.0	0.0	0.0	0.1
Weak grains [%]	0.0	0.5	0.0	0.0
Los Angeles test [%]	29.2	29.0	29.0	25.0
Bulk density [kg/m^3]	1886	1650	1798	1816
Bulk density, compacted [kg/m^3]	2022	1803	1963	1982
Organic particles [%]	0.0	0.0	0.0	0.0
Particles < 0.09 [mm]	1.3	2.1	1.3	3.1
Granulometry, 0-4 [mm]	49.0	48.6	45.9	38.9
Granulometry, 4-8 [mm]	15.7	17.6	17.8	15.6
Granulometry, 8-16 [mm]	17.7	23.0	20.3	23.5
Granulometry, 16-31.5 [mm]	12.8	8.5	11.6	16.5
Granulometry, > 31.5 [mm]	4.8	2.4	4.4	5.6

Historical quarries and new potential aggregate deposits

On the territory of city of Belgrade there are numerous aggregate rock (mostly limestone) deposits and/or quarries, where exploitation has been stopped at different time periods. All data on those deposits of limestone, i.e. quality and the remaining resources of stone are tentative and must be considered just as an indication (table 5).

Tab. 5. List of aggregate rock locations (Cmiljanić, 1983; for Kolubara basin Vučković & Nešić, 2011).

Deposit	Location (town/village)	Rock type	Resources [m3]
Petka	Lazarevac	Limestone	2,500,000
Beli kamen	Velika Moštanica	Limestone	25,000
Bela reka	Ripanj	Limestone	100,000
Grabovac	Ripanj	Limestone	30,000
Trešnja	Ripanj	Limestone	80,000
Blaško brdo	Ralja	Marlstone-limestone	120,000
Klisura	Ralja	Limestone	25,000
Koviona	Ralja	Limestone	150,000
Vekinac	Ralja	Limestone	60,000
Đubrine	Parcani	Limestone	150,000
Grab	Koraćica	Limestone	100,000
Oglavci	Koraćica	Limestone breccia	150,000
Kolbine	Rušanj	Limestone	200,000
Zbegovište	Rušanj	Limestone	2,500,000
Vukšića majdan	Barajevo	Limestone	120,000
Bučje-Prečica	Ripanj	Sandstone	75.000
Hajdukovac	Velika Moštanica	Sandstone	400.000
Veliki Crljeni coal field	Kolubara basin	Sand and gravel	5,000,000
Coal field E, F and G	Kolubara basin	Sand and gravel	95,000,000

Supply routes of natural aggregates

Most crushed rock aggregates (predominantly limestone, some dolomite and diabase) necessary for the City of Belgrade are coming from deposits in central Serbia, i.e. from the area marked with the 100 km radius from the centre of Belgrade (Fig. 3). There is at the moment only one limestone quarry on the territory of Belgrade – Kijevo, which is located quite close to the city centre, so in the future Belgrade cannot expect to enlarge the production of aggregate on it's own territory.

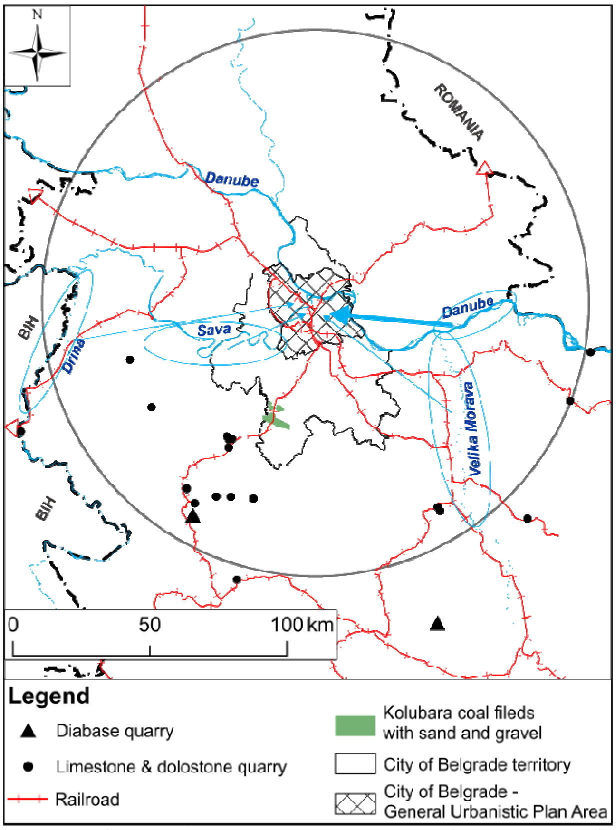

Fig. 3. Aggregates supply routes to the City of Belgrade. Grey circle – 100 km radius from the centre of Belgrade. Blue ellipses and arrows indicate the river-won aggregate sources, the Danube river bed being the most important for aggregate supply to Belgrade.

Sand and gravel is mostly excavated from riverbeds of Danube (around 90% of total amount) and Sava, Drina and Morava rivers (the remaining 10 %) outside the city boundary. Sand and gravel deposits from "Kolubara" basin are not currently used and are deposited on the waste dump at the mine site, while coal is extracted.

Discussion

The aggregate industry differs in at least two important aspects from most other industrial sectors (Bleischwitz & Bahn-Walkowiak, 2007). First, the location of the quarries and the quality of the material produced are determined by geology of an area, but the industry that uses aggregates is spatially related to areas of high demand, i.e. large cities, as aggregates are high-bulk, low unit value commodities that derive (or lose) much of their value from being located near the market. Secondly, the success of the aggregate sector is dependent on the success and competitiveness of the downstream industries – construction, manufacturers of mineral commodities, cement and concrete. All this means that aggregate quarrying will try to continue production in the vicinity of urban centres, close to the consumption sites, thus causing a lot of conflicts of interest. Therefore, it is necessary to begin with aggregate planning in Serbia and Belgrade, as summarised by Simić et al (2014).

Transportation is a major cost driver and a critical parameter for aggregates market prices (Menegaki & Kaliampakos, 2010). In general 80-90% of production is transported by lorries (Bloodworth et al, 2004; Tepordei, 2005; Bolen, 2005; Kaliampakos & Benardos, 1999) estimated that delivering to a radius of 15 km from the quarry leads to a 30% price increase. A delivery distance of more than 40 km is therefore unusual (Drew et al., 2002), but in case of the city of Belgrade it is usually near or more than 100 km for crushed rock, creating more logistic problems and increasing cost of aggregates.

From all those reasons, it is necessary to introduce the Sustainable aggregates resource management (SARM) and Sustainable supply mix (SSM) principles in aggregates supply planning. SARM is efficient, low socio-environmental impact quarrying and waste management, while SSM uses multiple sources, including recycled wastes and industrial by-products (slag) that together maximize net benefits of aggregate supply across generations (SARMa Glossary, 2011). With those two principles it is much easier to organize and plan sustainable supply of aggregates for industry, particularly in large cities and areas deficient in natural aggregates (Blengini & Garbarino, 2011, Cibin & Furin, 2011). Unfortunately, Serbia has neither Mineral Policy/Plan, nor Strategy of Mineral Resources Management, which should define the basic and sustainable roadmap to better aggregate supply and management, not only in Belgrade, but also in other aggregate-deficient areas. Preparation and adoption of those documents should be the first step in increasing the efficiency of aggregate supply.

As previously presented, the territory of the City of Belgrade is rather sensitive to aggregate supply, as it produces only 5% of natural aggregates on its own territory, with trends to go down to only few percents. At the same time, we can assume that in the next ten years the consumption of aggregates in Belgrade will rise to 4 t/per capita. Therefore, the authorities in Belgrade already started to prepare for future by adoption of several crucial documents on the city level, based on the State regulations.

General Urbanistic Plan of Belgrade until 2021 (GUP, 2003) does not specifically forbid new exploitation but says "It is general intention that exploitation of non-metallic mineral resources is not welcome on the territory of GUP of Belgrade", which in fact means that it is almost impossible to get the exploitation license. The Law on waters (2010) generally forbids exploitation of mineral commodities in the narrow protection zones around water springs (sources). The Law on mining and geological explorations (2011) has authorized local administrative units (towns and municipalities) to give permits for exploitation of aggregates. Therefore, administration of the City of Belgrade is responsible for issuing permits for riverbed excavation and for issuing permits for extraction of limestone, sand and gravel within the territory of the city. All projects and plans which involve extraction, processing and transport of minerals or recycling and use of recycled aggregates must have approval from the City Secretariat for environmental protection. Approval is given after all conditions requested by the law are met and environmental impact assessment has been fulfilled, reviewed and accepted.

The analysis of the actual supply chain clearly shows that Belgrade cannot expect increased production of natural aggregates on its own territory due to geologic background and environmental protection, except low-quality sand for road subbase layer, structural and non-structural fill. All other natural aggregates will be transported from existing and/or new sources. As consumption of river-won sand and gravel will be the most important aggregate resource shipped to Belgrade, a Study on determination of locations for sand and gravel stockpiles along the river banks in Belgrade has been prepared (Tahov & Trivan, 2013) in order to organize the sustainable supply of sand and gravel. The other potential resource of sand and gravel are Kolubara basin coal fields, from which aggregate can be used in Belgrade, but this would require geological exploration according to the regulations (Law on mining and geological exploration, 2011), and careful planning of exploitation in order not to disturb the future production of lignite for thermal power plants. Sand and gravel from those locations could be produced with the least impact on the environment and focus should be on improving the efficiency of exploitation of all possible commodities.

When crushed stone aggregates are considered, there are plenty of quarries within or close to 100 km diameter around Belgrade (Fig. 3). Only one quarry is located near the Danube river, allowing the most ecologically acceptable transport, but it is within the National park and limited area for exploitation. Besides that, there are several large quarries located near the railroad, some of them with their own loading ramps. With good sustainable planning, aggregate from those quarries can be used with lesser environmental impact, i.e. lower CO_2 emission, less road damages and potential traffic jams and accidents, combined with lower transport cost.

Considering recycling of aggregates, none of construction and demolition waste is currently being recycled, which is one of the important topics for future, although it will not significantly improve aggregate supply as typical building constructions in Serbia include a lot of clay-based brick products and much less concrete.

The problem of aggregate supply in large cities across Europe has been, at least partially, solved by either using marine aggregates (UK, Netherland, Belgium France and Germany), or recycled aggregates (UK, Germany, Netherland, France, Belgium and Switzerland), as reported by UEPG (2015).

Conclusion

The availability of primary aggregate resources in the wider region of the City of Belgrade is sufficient for current needs. However, in case of increasing demand of aggregates it will be necessary to establish a good, sustainable system to supply the Belgrade market with both natural and manufactured aggregates. Therefore it is important to maximize efficiency of aggregate extraction on active quarries to maximize net benefits and achieve sustainable quarry life-cycle, adoption of best practices, more rigorous control of stone quality, increased extraction and construction waste/by-products recycling to be used as aggregates, and wide use of whole aggregate life-cycle analysis.

Use of SSM of natural (primary) and manufactured (secondary) aggregates should be the strategic orientation of the city of Belgrade in order to achieve the goal of a sustainable use of aggregates. The European experience shows that with complete recycling of construction and demolition waste (CDW) industry meets only around 10% of total demand for aggregates. For the City of Belgrade it will be necessary to use CDW to the possible maximum given future needs of the city for aggregates, but also to reduce the environmental impact and pressure for new locations of waste dumps.

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