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Secondary Materials in the European Aggregate Market – What is Feasible Now?

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Abstract

The take-make-waste linear economic model used across the globe for production is not sustainable considering the accepted definitions and goals for sustainable development. With sustainability goals in mind, new targets are being implemented across industries for the use of secondary materials, including in the mineral and aggregate industries. Yet, with projections for increasing demand for raw materials, there is also demand on raw material suppliers to increase production. This raises questions concerning how achievable targets are for secondary material supply, and where investments should be focused to meet targets.

With varying statistics on how much material is currently, or could be, recycled, there comes uncertainty over whether such targets are feasible. The purpose of this study is to assess the quality of data available concerning secondary material supply and where gaps exist through a mass flow analysis to identify where the largest hindrances could be, based on today's conditions.

Keywords: *Secondary Materials, Construction products, Sustainability Targets, Circular Economy*

1. Introduction

Sustainability is becoming a growing concern across the globe with more and more actors taking an interest in sustainability issues over the last 15 years (Scopus, 2023). To counteract what is seen as environmentally unsustainable practices, many organizations are advocating for a shift to a Circular Economy (CE) (Ellen MacArthur Foundation, Accessed 2023; European Commission [EC], 2021). Although the first principle of a CE is to eliminate waste, the second principle is to circulate materials at their highest value (Ellen MacArthur Foundation, Accessed 2023). This advocates for considerable growth in the utilization of secondary materials (SM) and their markets (Milios, 2018).

As the most extracted solid material, sand and gravel, collectively known as aggregates, are vital for societies. From infrastructure projects and concrete to water filtration, aggregates are versatile products with many uses that rely on local supply chains to avoid heavy costs and environmental burdens from transporting the bulky material (Blachowski, 2014). Aggregates can be sourced from natural sand and gravel deposits, crushed bedrock, by-products from other industries known as manufactured sources and recycled aggregates from wastes (UEPG, 2018). Dependent on the application of aggregates, various quality demands are placed on the material. Considering the importance of aggregates in society, concerns regarding a sustainable supply of aggregates have been raised, in particular regarding sand, and a call for more scientific input on the subject made (UNEP, 2019).

Supply concerns and a drive to reduce the amount of material ending up as waste has led to more focus on utilizing Secondary Raw Materials (SRM) (UNEP,2018; UNEP,2019). However, questions still remain as to whether SRMs can meet the quality of natural aggregates in certain applications (Cardoso et al., 2016) and a lack of trust on the demand side still exists when considering SRMs for aggregates.

On the supply side further challenges exist concerning definitions of end-of-waste and pollution levels within the materials (Malin zu Castell-Rudenhause et al., 2022).

To counteract some identified challenges for SRMs entering the market, policy makers are encouraging ambitious goals for recycling rates in supply chains to achieve higher utilization of SRMs (European Commission [EC], 2020). The aggregate industry is no exemption (Islamovic & Göransson, 2022) and more focus is being placed on mass balance within major cities (Frostell et al., 2009; Olsson & Linus, 2022). However, goals without any scientific grounding, or those that are unrealistic, can be undermining for tackling an issue.

To aid policy and decision makers, Material Flow Analysis (MFA) has been an applied method to contribute understanding on the urban metabolism of societies on a global (Giljum et al., 2014; Krausmann et al., 2018) and national level (Ren et al., 2022). In more recent studies, MFA has been used to assess circularity and challenges for achieving a CE (Haas et al., 2015). MFA is not without its challenges including issues with poor data quality, particularly for nonmetallic minerals highlighted in the literature (Schandl et al., 2018). However, with international guidelines developed, it is an established methodology used for supporting decision making (OECD, 2008).

Due to their large contribution to material consumption, aggregates have been included in several global studies but are often grouped with nonmetallic minerals that include many other substances, for example salt and minerals for fertilizer (Miatto et al., 2017) making it difficult to identify specific challenges for the aggregate industry. Studies related only to aggregates have been carried out on a global scale from a coupled human and natural systems approach (Torres et al., 2021) and on a domestic scale (Ren et al., 2022). Yet, to the best knowledge of the authors, no studies have been conducted specifically focusing on a European level which has considerably different systemic structures compared to aggregate systems on a global level; and key concerns for illegal practices, severe ecosystem impacts, and human health concerns (Torres et al., 2017) are largely addressed through regulation and permitting (European Parliament, 2011), shifting areas of concern. One such concern is SRM supply and a study of potential SRM pathways for aggregate products has not been seen in the literature.

Therefore, this study aims to utilize a bulk-MFA analysis to aid decision makers in the aggregate industry in understanding what could be feasible today in Europe when it comes to utilization of SRMs in aggregate supply. As previous studies have already addressed underutilization in terms of downcycling of SRMs used for aggregates (European Environment Agency [EEA], 2020), the focus of this paper will be on what possibilities and challenges exist for expanding secondary material markets for aggregates. The results can contribute to building a roadmap towards a more sustainable supply chain for aggregates.

2. Materials and Method

A bulk-MFA methodology has been applied as described by Brunner and Rechberger (2003). To set the system boundary, data availability for Europe was assessed and the boundary is defined by the countries where data was available which can be seen in Figure 1. The temporal boundary has been set to 2018 as this was the most recent year for which both data on inflows and outflows was available. The main activity aggregates contribute to is to reside and work which encompasses processes for building, operating, and maintaining residential buildings and working facilities.

Data on aggregate production has been taken from the UEPG, European Aggregates Association [UEPG] (2020) to be used as the inflows for the MFA. Data is not currently available for all European countries and out of the 46 countries in Europe (including Turkey), 37 countries are represented in the

statistics and are shown in Figure 1. Exports and imports of aggregates are generally low in Europe with Norway representing the majority of exports (UEPG, 2020). However, since these are mainly exported to the UK and Germany which are within the system boundary, exports and imports are not considered with the assumption that production within the system is equal to consumption as seen in Eq. 1.

$$\text{Consumption} = \text{Domestic production.} \quad \text{Eq.1}$$

Statistics on waste have been taken from Eurostat (2018) for the mineral fraction of construction and demolition waste (C&DW), other mineral waste, soils, and combustion waste (Eurostat, 2010a) for the outflows of the model. For mass balancing, recycled aggregates are assumed to be sourced from C&DW and manufactured aggregates are assumed to be sourced from combustion waste considering the known sourcing of aggregates from slags produced in industrial combustion activities (UEPG,2020). Only non-hazardous wastes have been considered.

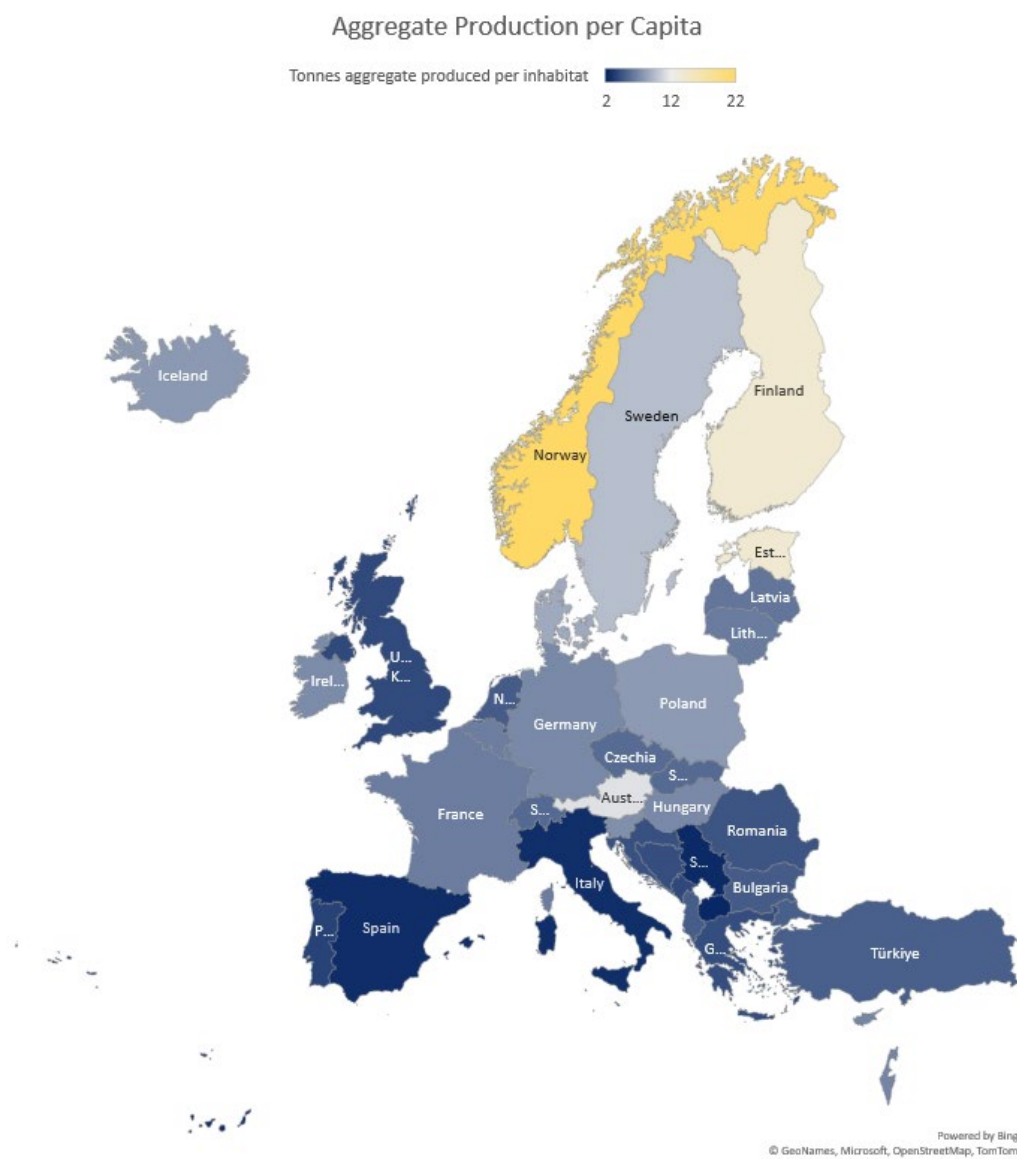


FIGURE 1: MAP OF INCLUDED COUNTRIES WITHIN EUROPE FOR THE STUDY WITH THEIR DOMESTIC PRODUCTION PER CAPITA.

To model aggregate stocks, stock estimates have been taken from Krausmann et al. (2018) for global stocks and scaled to the populations of the included countries up until 2015. Stocks for concrete, asphalt, and aggregates were included and modelled as 100% aggregate by mass, considering the small amount, by mass, of bitumen and additives for cement and asphalt (under 5 %). Bricks were excluded due to the uncertainty surrounding aggregate content (sand bricks vs. clay bricks). For 2016 & 2017, UEPG production values were used to determine the stock additions and C&DW statistics from Eurostat were used for outflows to give a final estimate of aggregate stock levels as of 2018. Eurostat data collection is every 2 years and, therefore, an average of the 2016 and 2018 data was used for 2017.

End-uses for aggregates are taken from (UEPG, 2020), all of which represent stock building applications, and each material stream is assumed to contribute proportionally to each application. Similarly, each application is assumed to have a proportionally equal contribution to waste streams. Total material consumption is estimated using consumption per capita for high-income countries from 2017 (United Nations [UN], 2018).

Potential SRM sources from waste were identified through known source waste streams (C&DW and combustion waste) and through estimated compositional similarities of waste streams given in the statistics (Eurostat, 2010a).

3. Results

For the described system in Europe, consumption is estimated at 4.3 billion tonnes for 2018 with 92% of aggregate material adding to stocks and only 8% replacing existing stocks. The results indicate that only 9% of the aggregate market came from secondary materials and the largest source of aggregates is currently crushed rock constituting 50% of supply. A model of the mass flows can be seen in Figure 2 and highlight the small proportion of circularity in the current system. From the model, it is estimated that 58% of all material consumption for 2018 in Europe was aggregate consumption. Furthermore, the model illustrates the large amount of aggregates that are accumulating in stocks, as well as highlighting that utilization rates of C&DW for aggregate products are already high, approaching 90%. For combustion wastes, utilization rates are still below 50%,

The movement of aggregates in 2018 through the economy is highlighted in a Sankey diagram in Figure 3 showing the main end-uses for aggregates. A simple overview of the main processes associated with aggregates is shown above and include manufacturing, transportation, use and waste management at end-of-life. Since extraction of virgin aggregates often takes place at the same location as the manufacturing, this process is excluded.

C&DW and combustion wastes are the only identified contributors from waste streams to aggregate production in 2018. However, there is high uncertainty as to whether other waste streams are used, or if industrial by-products that have not entered the waste system are also a notable source material not seen in the data. Similarly, any excavation wastes that are used in the same project never reach a waste classification and so are unlikely to be accounted for in the production or waste statistics, and uncertainty remains on how these are classified or accounted for.

Further potential SRM sources from waste were identified as soils and other mineral wastes. Assuming a 100% utilization rate for these potential SRMs still leaves a nearly 60% deficit for current demand based on consumption rates, and sees achieving a completely circular market for aggregates as unfeasible considering the current situation as illustrated in Figure 4. Excluding the potential SRM sources identified, yet still assuming 100% utilization of C&DW and combustion waste, the deficit between SRM supply and demand from consumption increases to nearly 90%.

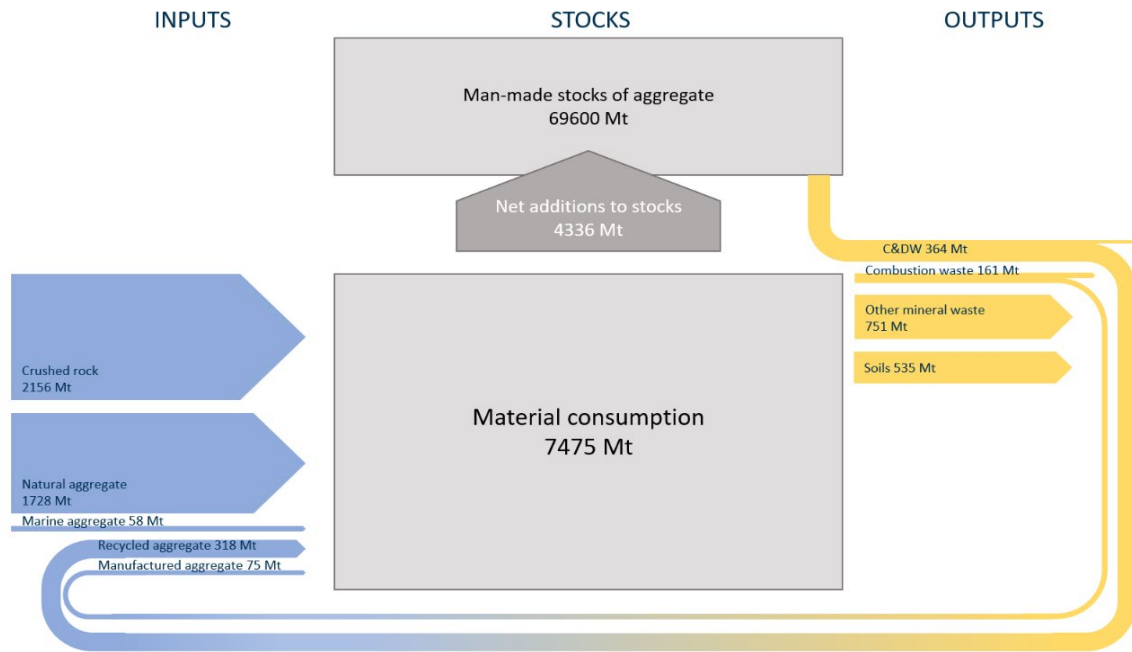


FIGURE 2: SCHEMATIC REPRESENTATION OF MASS FLOWS THROUGH EUROPE IN 2018.

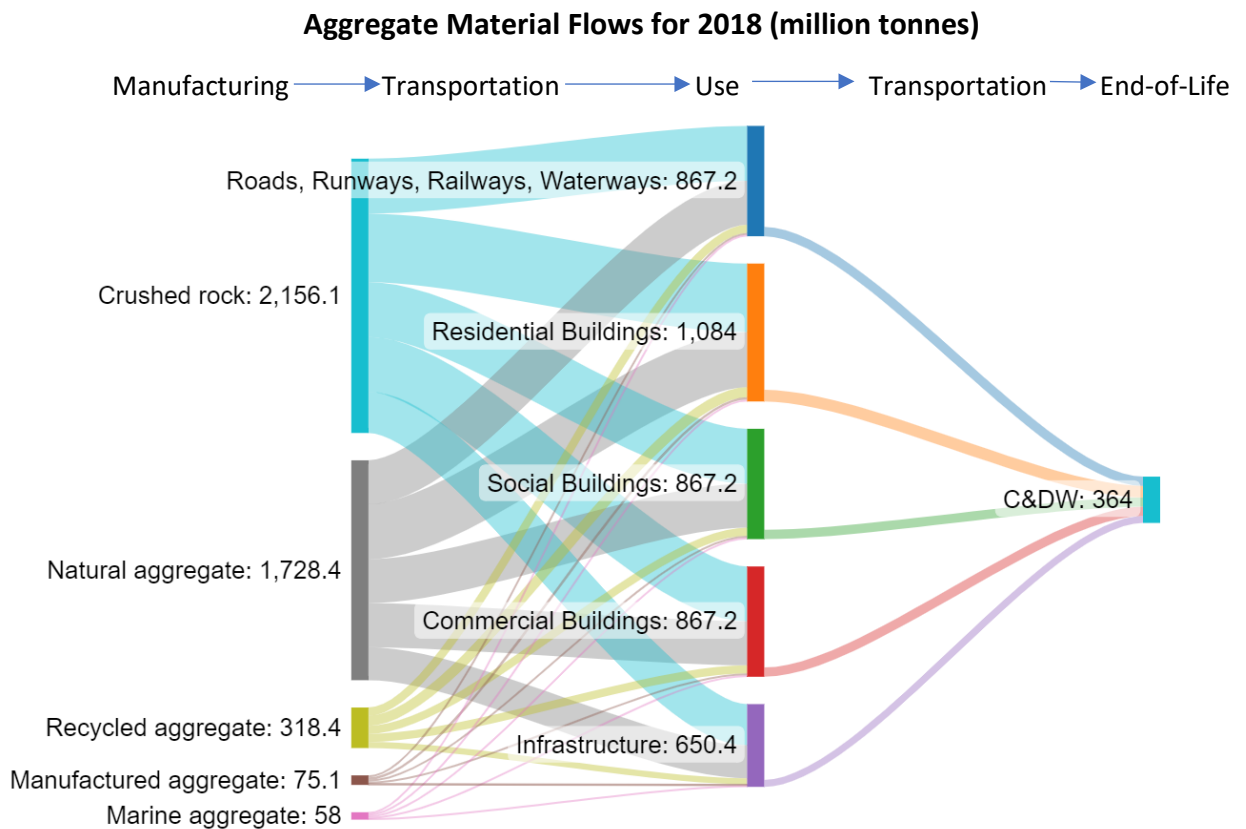


FIGURE 3: SANKY DIAGRAM ILLUSTRATING THE FLOW OF AGGREGATES THROUGH THE EUROPEAN ECONOMY IN 2018.

Demand vs. Potential Secondary Material Supply for 2018 in Europe for Aggregates

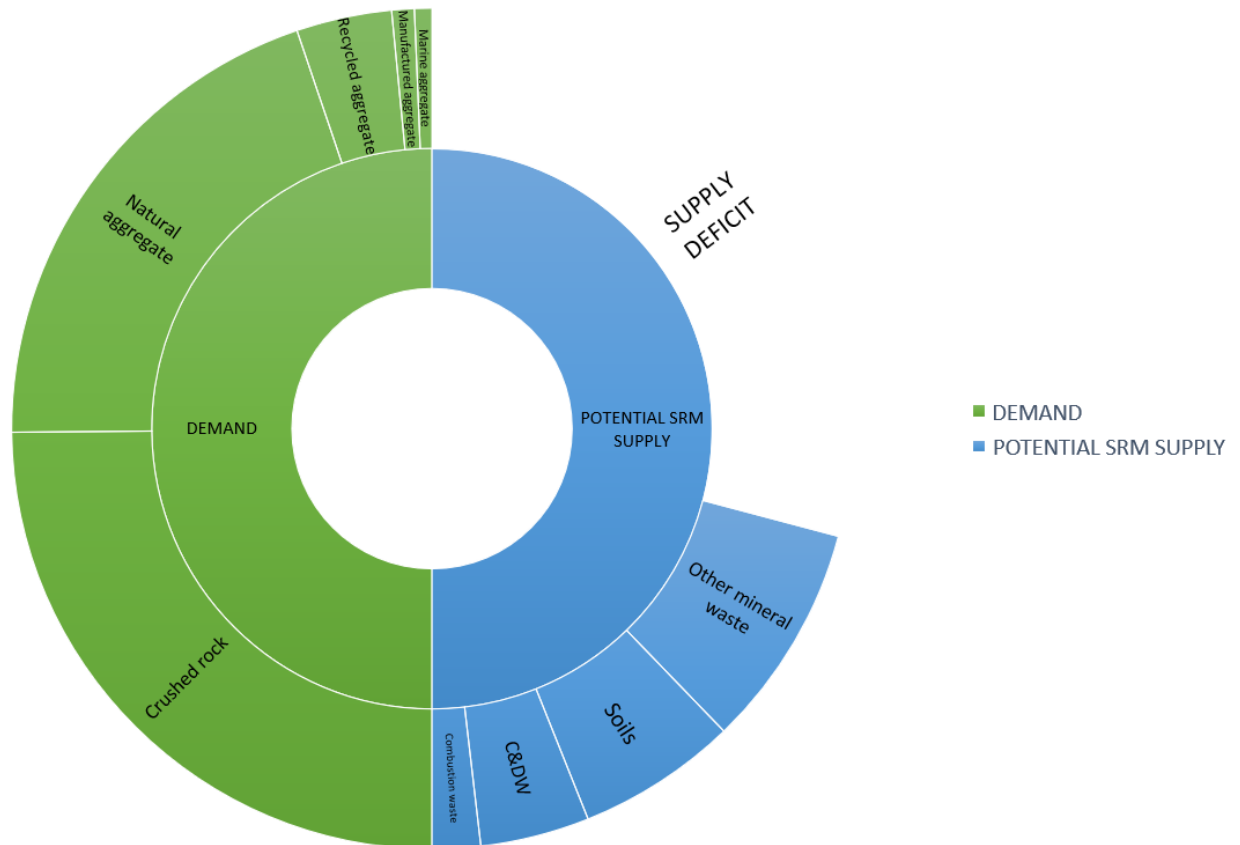


FIGURE 4: COMPARISON OF CONSUMPTION TO POTENTIAL SRM SUPPLY SOURCES BASED ON WASTE STATISTICS.

4. Discussion

The aim of this study was to identify challenges and possibilities for SRMs in the current aggregate market and assess the quality of data currently available. The results show that only 9% of the current aggregate market is circular and achieving a closed-loop CE for aggregates is not feasible within the boundaries of the model. Therefore, considerable action is needed to increase circularity which can include reducing aggregate demand and identifying new potential SRM flows for aggregate products. As the model indicates we will not be able to meet all aggregate demands from SRM for the foreseeable future, it also highlights how important it is to work with current aggregate producers in improving the sustainability of virgin production.

There are several uncertainties within the model linked to data quality and knowledge gaps that should be considered when analyzing the results. Firstly, some uncertainties lie with the data collection for relevant statistics. Eurostat (2010b) have published details on how the data on waste is collected which helps in assessing uncertainty surrounding the statistics; similar work is encouraged for other data set providers like the UEPG to help improve transparency surrounding data collection. As some of the statistics are collected through surveys, an understanding of variation between contributors can also help assess accuracy of the data, as well as help identify how different practices in waste management from organizations impacts the availability and quality of waste streams for future predictions of potential SRM flows.

The current study has been conducted on a bulk level, but substances are important when considering new sources from waste, especially when considering potential emissions into the surrounding environment, be that land, water, or air. This means the potential utilization from waste streams is

highly uncertain. As quality varies significantly between aggregate products, the substances involved are also important when considering which aggregate products can be replaced by SRMs. Better quality statistics with a higher granularity concerning content in waste streams might be important to identify new utilization opportunities in the future.

Soils and other mineral wastes have very unknown utilization rates in aggregate application and 100% utilization is very unlikely in reality. One source for other mineral waste is quarries & mines so a question is raised as to why it is not utilized today. As transport is a significant contributor to the environmental and economic costs for aggregates, it is often inefficient, both environmentally and economically to move these wastes to urban hubs where the demand for aggregates is highest. Soil utilization rates can be 0% for clay soils and so are highly influenced by the local conditions, therefore, a better understanding of realistic utilization rates at a European level would be needed to assess what contribution they could make to the aggregate market in the future.

Utilization rates are already high for C&DW leaving only a small possibility for improvements, however, as seen by previous studies, there is potential to recycle it to a higher value instead of downcycling it as often happens today (EEA, 2020). A possible contribution to increasing the utilization of minerals from combustion waste could lie in the efficiency of current recycling processes. An example of technology that could increase recycling of materials from combustion waste can be found in Switzerland, where the company, Selfrag, selectively fragments combustion waste with high voltage pulse power (Selfrag, Accessed 2023a). The treatment recovers metals and minerals, decreasing the fraction condemned to landfills by up to 50% (Selfrag, Accessed 2023b). The technology indicates a possibility to increase the recovery of minerals from combustion waste, instead of landfilling the material and the applicability of the technology to other European countries is being investigated (Femgo AB et al., 2023).

In Sweden, combustion waste can be used as construction material for final coverage at landfills after metals recovery has been carried out (Naturvårdsverket, 2022). As there exists tax deduction for materials that can be used for these approaches (Riksdag, 2020), it might be of economic interest to refrain from recovering more materials from the combustion waste as the process could affect the physical characteristics of the material. To have incentives for mineral recovery from the combustion waste, the recycling must either be cost-competitive compared to the tax deduction or not inhibit the combustion wastes' property as construction material. This indicates that current regulations might prevent recycling to their highest value, as it might not be the most economically feasible option.

As the European Union has concluded that landfilling of materials that are possible to recycle must be restricted from 2030 (EC, Accessed 2023), materials for final coverage at landfills ought to decrease. A coming reduction of this landfill construction material indicates that combustion waste must be handled differently in the coming years. Technologies that increase recovery from this material should therefore be investigated, to enable an increased use of secondary aggregates in society.

Demand for aggregates is predicted to continue increasing to 2060 (OECD, 2019) and is likely higher than what is shown in the model as the use of excavation material that is used on the same site does not class as waste, nor is bought, (Environmental Protection Agency [EPA], 2019) so does not appear in the data. This indicates that reducing aggregate demand will be a large challenge, and collaboration with aggregate users is suggested to identify possibilities for increased efficiencies in aggregate use. Excavation material is known to be used in construction projects for backfilling or landscaping purposes and there may be overconsumption in these uses to reduce the amount of waste leaving a site, which could be one possible area to identify efficiency increases. A better understanding of these onsite flows can help in freeing up more SRMs for aggregate use elsewhere.

Geographical limitations for transporting materials to where they are needed are not the only logistical challenge for SRMs, but also the temporal factor of when a waste is produced to when it can be utilized. This is highlighted by recent efforts for mass balance and identifying storage areas in cities for SRMs (Frostell et al., 2009; Olsson & Linus, 2022) which has not been addressed in this study but should be considered by decision makers when deciding strategies for improving circularity of the aggregates market.

Lastly, it is important to note that only resource efficiency has been considered in the MFA and there may be trade-offs with other environmental impacts in a transition towards higher SRM utilization, which could include higher contamination levels, increased water consumption and energy consumption leading to higher carbon emissions. Social sustainability aspects have also not been considered and should be explored to see if there are social gains or losses from SRM utilization in Europe.

5. Conclusion

The results of this MFA show that achieving a closed-loop CE for aggregates is not currently feasible considering current knowledge on the potential waste streams available and projections for growth in demand. While ambitious goals can drive more innovation in an area, unrealistic goals can have negative consequences. To move towards meeting ambitious goals on the circularity of aggregates, more work should be focused on reducing the demand for aggregates and identifying new source material, alongside the current work focused on increasing utilization of known waste streams for aggregate production. This could be done by identifying waste from overuse in the construction process; increasing the utilization rates for potential sources which are deemed highly uncertain in the current study; and identifying new materials through novel testing on waste streams or by-products not currently associated with aggregates. The results also highlight the importance in supporting virgin aggregate suppliers in sustainable practices as it is likely virgin materials will continue to play a significant role in the aggregate market for the foreseeable future.

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