Optimization of resources and waste management in construction and quarrying chain: toward a resource efficiency plan

A. Luciano[1]*, P. Reale[1], L. Cutaia[1]

[1] ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), Department for Sustainability, Resource Valorization Laboratory- Casaccia RC, Via Anguillarese 301, Roma.

* Corresponding author antonella.luciano@enea.it

Abstract

Purpose. This paper aims to highlight the opportunities offered by the circular economy in the construction sector in terms of waste valorisation and reuse, in light of implementing a strategic resource efficiency plan within a sustainable construction waste management strategy.

Methods. A material flow analysis (MFA) has been developed on national scale and extended to the whole chain of construction and quarrying activities that encompasses all stages ranging from raw material production, through manufacture of building products, to the construction of buildings and infrastructures. Using the most recent data on production, sale and import-export, an investigation of resources' use throughout the overall chain was carried out in order to establish the domestic demand for each product and the stock stored in the production system. Wastes production and their actual management were investigated as well as the potential of reuse within the chain. Moreover, potentialities of substitution of raw materials with residues produced by other activities were evaluated, identifying their current reuse rate and the potential not yet exploited as well as the limits and the critical issues.

Results. The results highlight as the high domestic demand for raw materials is met almost exclusively by virgin materials and the substitution rate is very low. However, the potentialities in term of substitution are high thanks to the large availability of waste produced within the chain (i.e. construction and demolition waste) and outside it (e.g. bottom ashes, steel slag, and other industrial wastes used as material or traditional fuel substitution)

Conclusions. The potential in term of substitution of raw materials with residues and wastes produced within and out of the chain is not adequately exploited and further efforts, in term of national policies and strategies are needed to effectively shift towards a full resource efficiency and circular economy in the sector. Data and results of this investigation could be useful to correctly address these policies.

Keywords: building and mining chain, resource efficiency plan, material flow analysis; construction and demolition waste, circular economy.

1. Introduction

Improving resource efficiency, environmental performance and business opportunities are some of the key objectives of the EU Construction 2020 strategy [1]. Resource efficiency in the context of construction sector is envised as a broad concept aiming to reduce resources use and waste production during their lifecycle: from material extraction, though manufacture of building materials and products, resource use during occupancy and maintenance, to material recovery at demolition.

The construction sector causes the extraction of large amount of raw materials and is responsible for a consistent production of wastes throughout the building and quarrying chain.

A large amount of natural aggregates is produced and utilized every year in the construction sector: almost 3.5 billion tons in Europe and almost100 million tons are produced in Italy [2]. The substitution rate of natural aggregates with residues or valorised wastes is still low. On the other hand, large amount of wastes and residues are produced in quarrying and stone industry, manufacture of building products, construction and demolition activities. Construction and demolition waste (CDW) is one of the heaviest and most voluminous waste stream. In Europe the total production of C&D waste is equal to 870 million tons per year and in Italy it reach almost 50 million tons representing the 40% of special wastes [3] with a high percentage that is still landfilled. As the current average recycling rate of CDW for EU-27 is only 47%[4], increasing it by 70% in few years, to fulfill the 2008/98/EC Directive, is an ambitious goal, which stresses the need for enhancing the recycling strategy.

Also quarries and processing plants produce huge amounts of waste, which although showing a great potential for recovery in construction materials, are still almost entirely landfilled [5].

If we consider that in Europe every year more than 700 million tons of mining and quarrying wastes were produced [6], large are the opportunities given by the application of circular economy in the construction sector[7], in term of raw material reduction, waste valorisation and their substitution as virgin materials.
Interesting opportunities are offered by the replacement of natural aggregates with recycled waste produced within the same chain, as for example, in the case of CDW[8,9] or quarrying and stone residues [10]. Other opportunities of raw materials substitution in construction sector are offered by industrial wastes as incineration bottom ashes [11,12,13,14,15,16,17,18], steel industries slags [19,20], end of life products (e.g. crub tyre rubber [21,22] and automotive shredder residue (ASR) [23].
This paper aims to identify, through an analysis of resource flow within the overall chain the opportunities offered by the circular economy in construction sector in term of waste valorisation and reuse in order to set a strategic plan for an efficient use of resources and to develop a waste management strategy. Optimization efforts are suggested to improve recovery rates and reuse of those wastes whose production is considerable while the recovery rate still low. For this reason, this paper builds up a material flow analysis aimed at the individuation of actual demand for raw materials and construction products, of waste production and related recovery rate and highlight the potential improvements in recovery of those wastes and by-product, whose reuse is considered insufficient but could significantly reduce the raw material extraction.

2. Methodology

The investigation has covered the whole chain of construction and quarrying activities that encompasses all stages ranging from raw material production, through manufacture of building products, the construction of buildings and infrastructures up to the final demolition. The deriving material flow analysis (MFA) is extended on national scale.
Investigated sectors and materials/products have been selected on the basis of the following NACE codes: B8 "Other mining and quarrying" (B8.1, B8.9.9) for quarrying sector; C23 "Manufacture of other non-metallic mineral products" for the sector of manufacture of building products; F42 "Civil engineering" and F43 "specialised construction activities" for the construction and demolition activities.
Figure 1 reports the system boundary, the materials flows and the references to the tables within this work where the information on the resources flows, wastes production and reuse are reported in details.

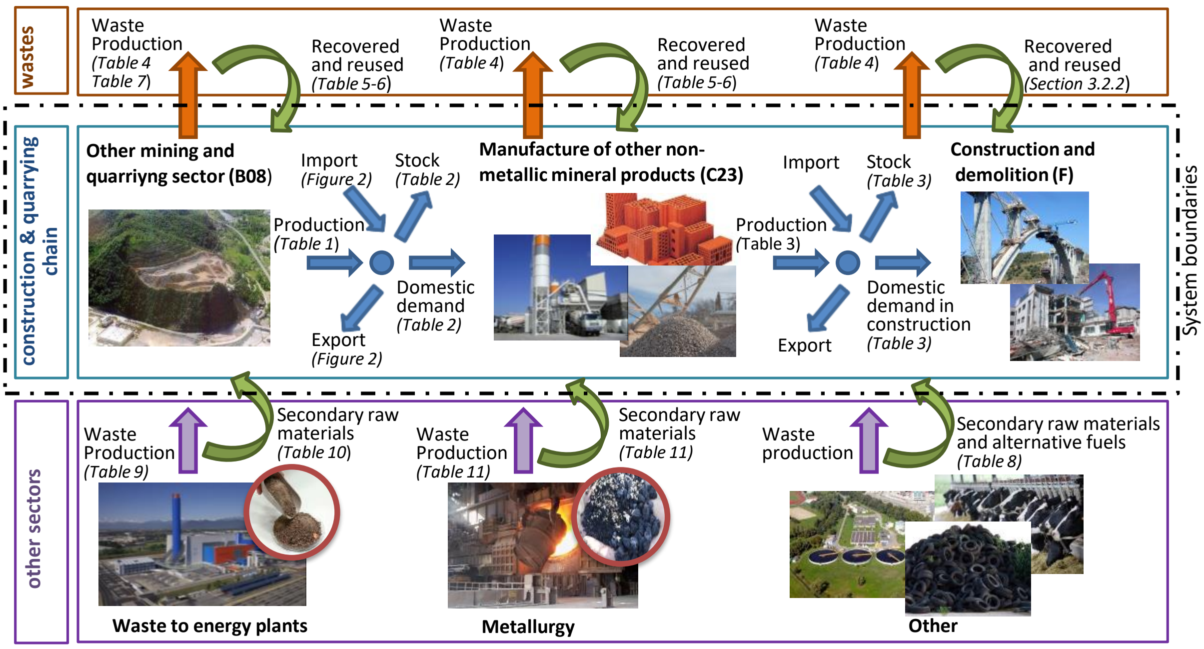

Figure 1: System boundaries, involved sectors and resorces flows (materials, wastes and secondary raw materials) within the chain and from other sectors

As reported in Figure 1, the following activities have been implemented within the MFA:
1) *Resource flow analysis*. Using the most recent available data on production, sales and import-export, an analysis of resource use throughout the chain was carried out in order to establish the domestic demand for each product and the stock stored in the production system.

2) *Evaluation of wastes production, management and reuse rate*. Waste production (i.e. wastes from the mining activity and processing of natural stones, wastes in cement and concrete production, construction and demolition wastes) and its actual management were investigated as well as the actual recycling rates and the potential not yet exploited throughout the chain.
3) *Individuation of potentials raw material substitution with residues and wastes produced in other sectors*. Potentialities of substitution of raw materials with residues produced by other activities were evaluated, identifying the current reuse rate and the potential not yet exploited as well as the limits and the critical issues.

Production and import export data were elaborated on the basis of official data of the Italian Institute of statistics (ISTAT) and information on wastes production and management were elaborated using official data of the Italian Institute for environmental Protection (ISPRA) and public reports of industry associations.
Domestic demand, evaluated for both raw materials and construction products, is evaluated as the domestic consumption (internal production sold – export + import). The difference between production and production sold represents the stock stored in the production system that have not been found placing on the market.

3. Results and discussion

3.1 Resource flow analysis and domestic demand

3.1.1 Quarrying sector

Demand for construction raw materials is closely related to the level of new house building, maintenance, renovation, and civil engineering projects. In the quarrying industry in Italy the total production in 2013, is around 167.4 x 10^6 tons of which 50.2 x 10^6 of ornamental stones, 116.2 x 10^6 of building aggregates and 0.95 x 10^6 of bitumen and natural asphalt (Table 1).
The largest production concerns aggregates such as sand and gravel (on average 69% of total production) with a significant reduction in recent years due to the industry crisis. The remaining part is made up of ornamental stones whose production was less affected by the crisis also thanks to the contribute of exportations.
Among the ornamental stones, the largest production refers to non-crushed limestone (55% in 2013), followed by constructional limestones including alabaster (20% in 2013) marble and travertine (11% in 2013).
In 2013, 88% (102.3 x 10^6 tons) of the production of aggregates and 76% (37.9 x 10^6 tons) of ornamental stones, were sold. By comparing these data with those referring to production and import-export (Figure 2) there is an evident amount of unsold stocks .
Italy, and more in general Europe, are self-sufficient in their aggregates production. Imports are limited with the exception of Belgium and the Netherlands.
Figure 2 shows the import-export data in the last years. In the course of 2014, the Italian stone industry exported more than 4 million tons of marble, granite, travertine and other stones, both raw and manufactured, for a value of almost 2 billion euro. The detail is shown in Figure 2.
The leading Italian export is that of raw marble (1,3 million tons for a total value of 331 million Euro) and manufactured marble (892 thousand tons for a total value of 936 million Euro) followed by manufactured granite (570 thousand tons for a total value of 535 million euros) and raw granite (136 million tons for a total value of 36 million euro).
However, in 2014, Italy imported almost 1,5 million tons of marble, granite and other stones for a total value of 395 million euro.
The main indicators for MFA were evaluated for the quarrying sector and reported in Table 2. Domestic demand for construction raw materials, has been calculated on the basis of data on production and sales (Table 1) and import-export (Figure 2). It was around and above 138 millions of tonnes in 2013 (almost 99 million for aggregates and 36 million for ornamental stones).
A large amount of the total production, almost 22.5 millions of tonnes (of which 13.5 million of aggregates and 9 millions of ornamental stones) have not found position on the market yet, remaining as stock stored in the production system.

Table 1: Production and sold product classified on the basis of typology in the "Other mining and quarrying" sector (Nace Code B.8)

NACE Code	ProdCom Code	Product type	Production (10^3t)			Product sold (10^3t)		
			2011	2012	2013	2011	2012	2013
B08.11	08.11.11.33 08.11.11.36	Marbles and travertine	5775	4207	5290	5643	3921	4917
	08 11 11 50	Limestone stones, alabaster	8207	6925	9865	5987	6760	9627
	08 11 12 33 08 11 12 36	granite	2541	1176	1305	2441	1090	1161
	08 11 12 50	sandstone	315	279	241	153	146	108
	08 11 12 90	other construction stones	1549	1281	1190	1462	1205	1112
	08 11 20 30	gypsum stone	3643	3201	3192	3491	2962	2854
	08 11 20 50	limestone (non-inert)	38159	26863	27435	22976	14291	16608
	08 11 30 10	clay			910			872
	08 11 30 30	dolomite	1422	807	735	1335	717	658
	08 11 40 00	slate	56	59	42	50	59	41
B0812	08 12 11 50	siliceous sand	14959	14123	12510	14143	12935	11783
	08 12 11 90	construction sands	80694	62296	45124	74199	54973	40732
	08 12 12 30	crushed stones for concrete, road and other constructions	86548	75406	49076	78247	66576	41735
	08 12 12 50	granules and marble powders	6717	3835	3527	5901	3410	3169
	08 12 12 90	granules and marble powders (except marble)	223	214	233	182	178	188
	08 12 13 00	Mixed waste	420	352	326	405	341	275
	08 12 21 60 08 12 22 10 08 12 22 50	clays	5544	4444	5429	4083	3262	4459
B0999	08 99 10 00	bitumen and natural asphalt	1737	1216	953	1753	1229	964
		Tot ornamental stones (B08 11)	**61 668**	**44799**	**50205**	**43539**	**31151**	**37957**
		Tot aggregates (B08 12)	**195105**	**160670**	**116225**	**177160**	**141675**	**102340**
		Tot bitumen and natural asphalt(B09 99)	**1737**	**1216**	**953**	**1753**	**1229**	**964**
		Total	**258510**	**206685**	**167383**	**222452**	**174055**	**141261**

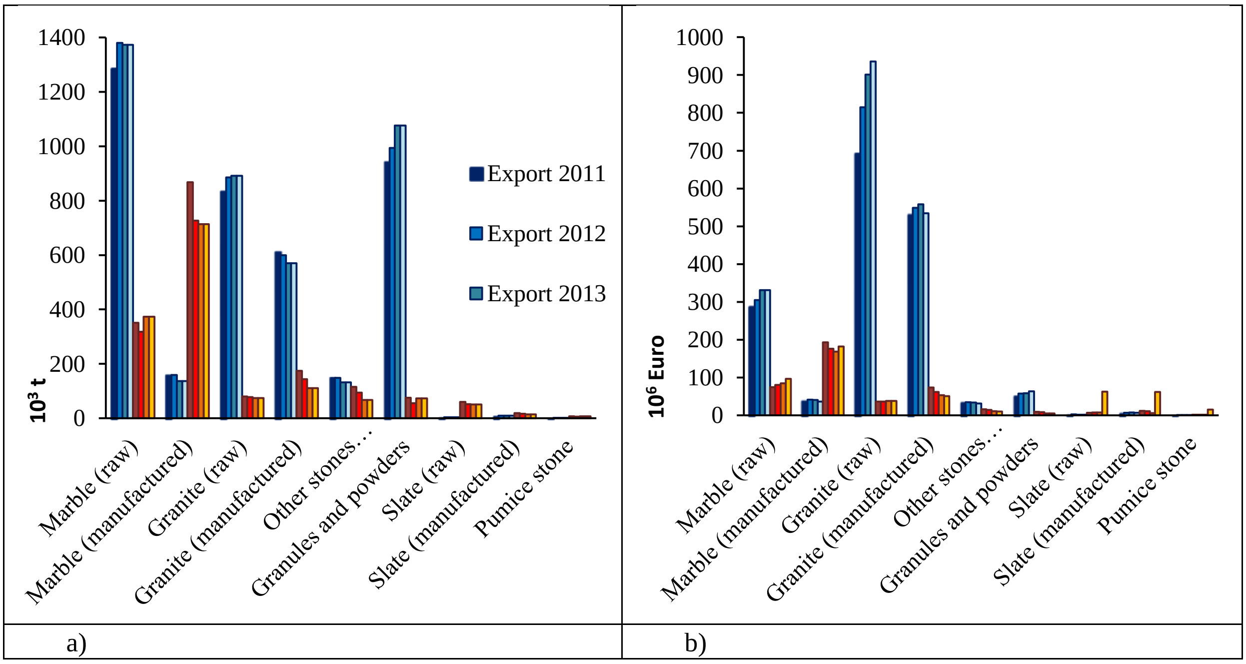

Figure 2: Import – Export for natural stones: a) weight b) value

Table 2: Domestic demand and stock stored in producion system for construction minerals and ornamental stones in 2013.

Product type	**Production**	**Production sold**	**Import**	**Export**	**Domestic demand**	**stock**
	(10^3t)	(10^3t)	(10^3t)	(10^3t)	(10^3t)	(10^3t)
Ornamental stones+	50205	37957	1340	3225	36072	9024
Aggregates (silt,sand,gravel,fract. stones, slags)++	112465	98984	0	0	98984	13481
Aggregates (Granules and pownders)+++	3761	3357	51	1047	2361	0
Bitumen and asphalt	953	964	12	0	976	0
Total	167383	141261	1403	4272	138392	22505

+ Sum of ProdCom codes 08.11.11.33; 08.11.11.36; 08 .1.11.50; 08.11.12.33; 08 11 12 36; 08.11.12 50; 08.11.12.90; 08.11.20.30; 08.11.20.50; 08.11.30.10; 08.11.30.30; 08.11.40.00
++ Sum of ProdCom codes 08.12.11.50; 08.12.11.90; 08.12.13.00;08.12.21.60; 08.12.22.10; 08.12.22.50
+++ Sumof ProdCom codes 08.12.12.50; 08.12.12.90

3.1.2 Manufacture of building products and materials

Table 3 shows the detail of production and production sold in the last years in the “Manufacture of other non-metallic mineral products” sector (C23).
The total production of the sector amounted to 164 204 thousand tonnes in 2013, with a considerable amount of ready-to-use concrete (81482x 10^3 tons) and cement (38805x 10^3 tons) followed by manufacture of other non-metallic minerals (4312 x 10^3 tons), manufacture of lime products (9518x 10^3 tons) and marble, stones and minerals processing (6424 x 10^3 tons).
The crisis in the construction sector is inevitably reflected in the productive sectors along the chain. It is dramatically evident from the trend of production in the last years (-25%) especially for primary construction materials as cement, lime and concrete. Production sold follows the same trend of production (-24%) but with an additional reduction in value (-10%).
Considering the available data of import and export, domestic demand for construction products, which represent the input required in the construction sector, has been calculated (Table 3 column 8).
Except for concrete ready to use and mortar, domestic production meets domestic demand with a slight overproduction that did not find place on the market (column 8 and 9in Table 3). The most considerable stock, instead, is referred to cement.

Table 3: Production and sold production classified for product type in “Manufacture of other non-metallic mineral products” sector (Nace Code C.23)

Product type	**Production (10^3t)**			**Production sold (10^3t)**			**Domestic Demand (10^3t)**	**Stock (10^3t)**
(Manufacture/production of)	**2011**	**2012**	**2013**	**2011**	**2012**	**2013**	**2013**	**2013**
refractory material	852	919	801	832	900	762	762	39
bricks and tiles	647	730	576	666	691	556	556	20
ceramic sanitary ware	67	50	32	66	49	31	31	1
insulators	3	3	6	3	3	6	6	0
other ceramic prod. for technical use	0	1	1	0	1	1	1	0
other ceramic prod.	324	252	28	308	242	26	26	2
cement	56 396	46 532	38 805	35 323	28 775	24 230	24230	14576
lime	5 160	5 489	3907	4254	4354	3412	3412	496
lime products	12604	12389	9518	12423	12297	9368	9368	150
concrete ready for use	109842	99812	81482	109783	99514	82909	84337	0
mortar	4258	3752	3132	4246	3755	3150	3167	0
other prod. concrete, lime, asbestos	4279	3760	4312	3844	3445	3929	3929	383
other stones and minerals marble,	6695	6639	6424	6244	6203	6048	6048	376
other non-metallic minerals	18185	16278	15180	17048	15224	13517	13517	1664
Total	219313	196608	164204	195039	175454	147944	149389	17705

3.2 Wastes production and potential reuse within the construction and quarrying chain

Table 4shows waste production in the last years in the building and quarrying chain. The most consistent portion of waste is produced in construction and demolition activities. To date in Italy about 50 million tons of CDW (40% of special wastes) are produced every year [3]. The manufacture of other non-metallic mineral products sector (C.23) contribute with almost 3 million tons of wastes (2% of special wastes) and the quarrying sector (B.08) with almost 200 thousand tons. This last amount does not include residues (e.g. the discarded blocks with defects affecting their marketing) that are not considered waste as they are easily re-used. In the processing of ornamental stones there is a considerable production of sludge and solid waste from the finishing activities (sanding and/or polishing) that at present does not find concrete reuses despite the fact that there are several possibilities for their valorisation and reuse. The only average production of sludge in some Italian extraction basins, such as the Val d'Ossola or the Luserna, amounted to 70 and 16 thousand tons per year respectively [24]. It is therefore evident that optimization efforts must be addressed to improving recovery rates and reuse of those types of waste whose production is considerable and the recovery rate is still low (i.e. CDW, sludge from stone processing).

Table 4: Waste production in the building and quarrying chain

	Waste production (10^3t)		
Nace Code	2012	2013	2014
B.08	193.4 (3.4 HW)	139.1(2.6 HW)	197.8(4.2 HW)
C.23	2 988.7(108.6 HW)	2 842.8(66.5 HW)	2 779.5 (43.3 HW)
F (C&D waste)	51 629	47 940	51 491

3.2.1 Recovery of residual sludge from stone processing

At present the recovery rate of residual sludge from stone processing in Italy is equal to 10%. The possibilities for their valorisation and reuse depend on their specific composition (which is correlated to stones they are originated from (i.e. marble, granite, basalt etc ..), processing activities (cutting and finishing) and wastewater treatments [11].

Table 5 and Table 6 show the possibilities of recovery and reuse for different sludge, the specific standards and the required chemical-physical properties. Sludge of marble or carbonate rocks can replace the quarry limestone. The industries in which calcium carbonate is used are numerous: plastic, paper, rubber, ceramic, cement, concrete, animal feed, fertilizer, glass, steel, paints, medicines, plasters and coatings industries, and finally in agriculture as a correction of acidity.

Carbonate sludge, thanks to their chemical and mineralogical properties and their very fine granulometric distribution, may also be used as mineral fillers in order to reduce the cost of the product and to improve certain characteristics in relation to specific uses. At present it covers about 50% of the low-cost filler and reinforcing materials market and it may contribute to the composition of finished products by about 10-50% by weight in the case of thermoplastic materials. Higher percentages can be obtained for thermo-setting materials. The greatest potential for reuse are in molded or extruded products for which very high quality standards are not required; examples can be represented by PVC pipes not intended to withstand high pressures or thermal stresses, such as those used in construction, or for the protection of electrical circuits, which may contain up to 60% by weight of charge. For the same reasons, carbonate sludge is one of the first alternative raw materials for building products, such as impermeable bituminous seals and most superficial layers of bituminous conglomerate for road pavements.

Another important chance of using marble sludge is for sulfur oxide (SO_2, SO_3) abatement systems from combustion fumes. This opportunity becomes more economically interesting when the transport costs of sludge at the nearest thermal power plant are lower than the transport and disposal costs at landfills. The abatement processes are achieved by contacting the gaseous emissions with suitable reactants capable of retaining SOx by absorption or chemical reaction. Limestone, used as such, or calcined (CaO) or calcined and hydrated ($Ca(OH)_2$), lends itself to this function for its ease of combining with SOx, combining high purification efficiencies with its low cost availability.

Carrara marble sludge, made up of almost pure calcium carbonate, can be used as an integrator for animal feed, for which it is used in percentages between 7-10%.

For sludge resulting from the processing of siliceous stone, such as granite, possible re-use is related to the production of agglomerated and bricks thanks to the ability of sludge to improve the mechanical properties of brickwork. Siliceous sawing sludge can be used as silica-based smears to reduce the tendency of certain clays used in the manufacture of bricks, to have high retraction and deformation/cracking during drying operation. The sludge to be added must meet a whole range of characteristics (humidity, chromatic variation, water absorption). The biggest problem is the absorption in water that limits the use of sludge as a smear at 2%, while the withdrawal rates are always on average acceptable.

The main obstacle for the enhancement in the reuse of stone processing sludge to is due to the lack of confidence in the possibilities of reuse offered by the legislation in particular regarding the definition of these residues (waste or by-product). The difficulties encountered by the small companies in demonstration of the by-product qualification still results in a high recourse to disposal.

Table 5: Recovery and reuse options for all types of sludge from stones processing

Reuse option	Standards
Fine aggregates (fillers) to be used in the production of	UNI EN 13043
Cement or bituminous conglomerates	UNI EN 13055-2
Sub-base in road contruction	Leaching test (DM 186/2006)
Environmental restoration	Leaching test (DM 186/2006)
Landfill cover	

Table 6: Recovery and reuse options of sludge from stones processing for different composition

	Reuse option	Composition	Humidity	Granulometry
white and colored marble sawmill	Agriculture, land deacidification	Appropriate	Appropriate	Appropriate
	Cement production	Appropriate	Appropriate for wet process. Required dewatering (with filter press) for dry process.	Appropriate
	Production of kitchen plans	Appropriate	< =1%	0,6-0,35 micron
	Pitches for PVC materials	CaCO3>90%	< =1% circa	Appropriate
	Absorption of acid refluxes	Appropriate	Appropriate	Appropriate
	flue-gas (with SO_2) treatment	Appropriate	Appropriate	Appropriate
White marble sawmill (high $CaCO_3$)	Paper production	$CaCO_3$>90% and without colored impurities	Appropriatefor "marmettola" < 1% for dry process	Appropriate
	Production of water-based paints and varnishes	$CaCO_3$>90% ed assenza di impurezze colorate	<1% for dry process	Appropriate
	Production of plastics in polypropylene	$CaCO_3$>90% Fe<= 0,02%	< =1%	Appropriate
	Soda production	$CaCO_3$>90% FeO_2, SiO_2, Al_2O_3<3% $MgCO_3$<6%	< =1%	10-15 mm compacted
	Metallurgical sector	Appropriate	< =1%	6-30 mm compacted
Mixed (marble, granite) sawmill	Tetrapod	Appropriate	< 15%	30%: 50-250 micron 50%: 250-500 micron 10%: <10 micron
Granite and siliceous stone sawmill	Production of agglomerated stones (cobblestones, flooring and tiles)	Appropriate	< 15%	30%: 50-250 micron 50%: 250-500 micron 10%: <10 micron
	Smelling for bricks production	Appropriate	< 15%	
	Environmental restoration, landfill coverage	Appropriate	Appropriate	Appropriate

3.2.2 Recovery of C&D

Despite an apparently virtuous picture, on the recovery percentages, drawn from the official estimates sent by individual states to the EU [3], the goal imposed by dir. Framework 2008/98 / EC, transposed by Legislative Decree 205/2010 is far from being achieved. According to estimates by ANPAR (National Association of Recycled Aggregates Manufacturers), the recovery rate is around 10% and then, the amount of recycled C&D waste amounts to around 5 million tonnes per year. If we consider that about 116 million tonnes of aggregates were produced in 2013 in Italy, and the domestic demand is almost 100 million tons (Table 2) it is understood that almost all aggregate demand is met by natural materials (about 95%) and the current rate of replacement of virgin raw materials with CDW is set around 5%.

One of the common obstacle to recycling and re-using CDW is the lack of confidence in the quality of C&D recycled materials. This lack of confidence reduces and restricts the demand for C&D recycled materials, which inhibits the development of CDW management and recycling infrastructures. The second obstacle is the lack of appropriate legislation and criteria. In Italy there are no end-of-waste criteria for CDW.

3.3 Potential for replacement of raw materials/traditional fuels with residues and wastes produced in other processes

3.3.1 Material and energy recovery in cement industry

A large amount of raw materials (25 million tons) are consumed by the cement industry every year [25] with a consequential high contribute to the environmental footprint of mining activity.

Mineral rocks can be easily partially replaced by alternative materials in the production of low clinker content cement. These materials are generally non-hazardous waste and by-products from different industrial processes, like incineration bottom ashes, waste from steelworks, rolling chips, melting slags and residues of ores used in the steel and metallurgical industry; desulphurisation chalks and heavy ash from waste incinerators; sludge from water processing and purification; pyrite ashes, inorganic waste and exhaust catalyst from chemical industry; demolition waste (without asbestos), marble and granite processing scraps, rock residues and inert waste from mining and construction; powders collected within the same cement production recycled and re-introduced into the process.

Table 7 shows the most recent data on raw materials consumption and the substitution materials utilized for cement production. In 2015 [26] more than 850 thousand tons of recovered materials, mainly constituted by coal, biomass and waste combustion ashes (418 thousand tons), steel industry waste (181 thousand tons), chemical chalks (173 thousand tons) and quarrying waste (63 thousand tons) have been used. Bearing in mind that in Italy every year more than 120 million tons of non-hazardous special waste are produced [3], cement industry employs, at the present, less than 1% of them. The actual raw material substitution rate is limited at a few percentage points (6.5% in 2015) but it could substantially raise thanks to the high availability of secondary raw materials not yet utilized as for example metallurgical waste (1600 thousand tons produced of which only 330 reused) or marble quarrying and processing wastes (10000 thousand tons of which only 18 reused) [25].

Table 7: Raw materials, non-hazardous waste an by-product used in cement production and substitution rate in 2015

Item		Amount (t)	Total (t)
Mineral rocks	Clay	1911533	25487111
	Marl	9532180	
	Limestone	14017911	
	Chalk	510	
	Pozzolan	510	
	Shale	255	
	Other	24213	
Recovery materials from non-hazardous waste	Siderurgic waste	181085	860654
	Chemical waste	21326	
	Quarrying waste	63171	
	Refractory waste	2897	
	Coal, biomass and waste combustion ashes	418404	
	Desulphurisation chalks	173088	
	others	683	
Industrial by-products (not classified as waste)		667606	667606
Raw materials substitution rate		6.5%	

The cement industry is highly energy-consuming (Schneider et al., 2011). Most of the used energy (i.e. ~90%) is thermal, which is needed for raw materials drying and clinker annealing, the remaining 10% of consumed energy is electric used for grinding materials in different process steps. Italian cement industry consumes almost 2,3 million t/y of non-renewable fossil fuel. The use of alternative fuels is a valid solution to the dependence from fossil fuels, it reduces costs and contributes to the emission control [27]. Combustion ashes or residues can be incorporated into the finished product, without prejudice to the qualitative characteristics of the cement [28,29]. Today the use of residue-derived fuels (RDF), as substitute of conventional fossil fuels to feed the cement furnace is considered a best practice [30]. If the waste hierarchy is respected co-incineration has to be considered part of a modern waste management system, since it offers the community an environmentally compatible solution and an opportunity to recover and valorise those residues that can no longer be recycled or reused.

Practically a large variety of waste can become alternative fuels for the cement furnace: urban waste, end of life tyres, plasmix from recycled plastics production process, sludge from wastewater treatment plants, animal flours, non-chlorinated solvents, used oils and/or oily emulsions, etc.Table 1 reports the amount of waste incinerated in the cement plants and the rate of replacement of conventional fuels.

Most used alternative fuels were urban waste (189 thousand tons), plastic, rubbers and end of life tyres (104 thousand tons). In 2015 the substitution percentage has been 14.9% (324 thousand tons) versus 13.3% in 2014. Notwithstanding the apparent improvement, the average European substitution rate exceeds 30% and in some Nation it reaches 60% [31]. Italian plants at the present levels of production, are able to exploit almost 3 million tons per years of waste derived fuels, achieving a co-utilization rate equal to 50%, implying also a 25% reduction of the CO_2 emission [25].
Italian cement plants, at the present levels of production, are able to exploit waste volumes as high as 3'000'000 t/y to produce thermal energy, and therefore achieve a co-utilization rate equal to 50%, implying also a 25% reduction of the CO_2 emission [25].

Table 8: Fossil fuels, waste derived fuels and substitution rate

Item		Amount (t)	Substitution rate %
Fossil fuels	Methane	18'627 982 m^3	1.2
	Coal	1 431 007	81.8
	Dense burning oil	31 422	2.1
Waste derived fuels	Urban waste	188 845	14.9
	Plastic, rubber, end of life tyres	103622	
	sludge from wastewater treatment plants	17875	
	Used oils and/or oily emulsions	44	
	Other liquid fuels	13149	
	Animal flours	961	
	Hazardous waste	-	
	total	324 496	

3.3.2 Reuse of MSWI bottom ash

The recovery of wastes derived from waste-to-energy processes is one of the options that, in recent years, thanks to the interesting experiences that have been made and the continuous technological evolution, has a major strategic role to reduce drastically final disposal at landfill while at the same time increasing the amount of recyclable materials [17].
Waste treatment technology allows to reuse them almost entirely in the cement and concrete industry for use in public and private buildings [32] and to extract aluminium and other metals (Briganzoli e Grosso, 2013) as shown in Figure 27.

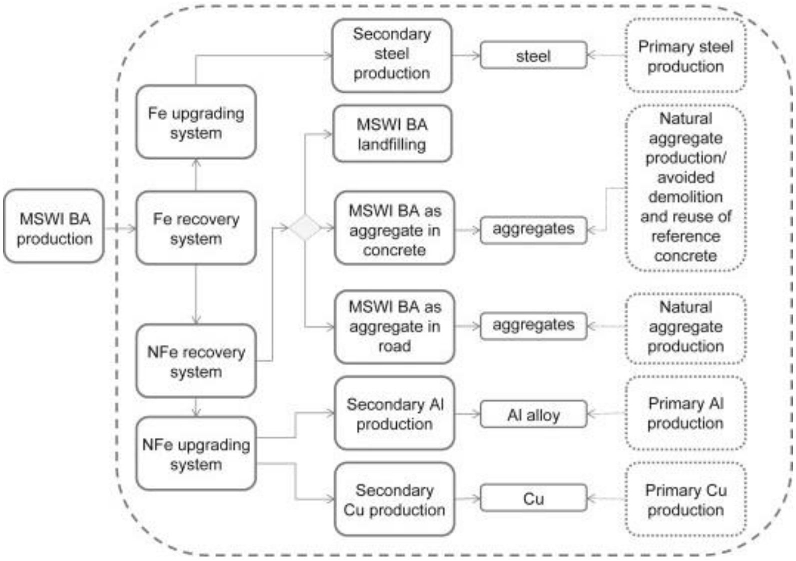

Figure 3: Full recovery scheme of MSWI bottom ashes

In Italy there are 44 incineration plants for urban residual waste and solid recovered fuel (SRF). Additionally, special waste incineration plants are added to these units. Table 9 shows recent data on incinerated wastes and wastes incineration residue in waste to energy plants in Italy.

The total waste incinerated in Italy amounts to about 6.3 million tonnes, of which almost 2.7 million RUs undifferentiated, about 1.7 million tonnes of dry fraction, more than 900 thousand tonnes of SRF, 977 thousand tons of special waste of which nearly 39 thousand tons of sanitary waste. Special hazardous wastes, mainly of health-care origin, amount to more than 52 thousand tonnes.
Wastes generated in incineration plants are about 1.4 million tonnes and accounts for 22.4% of the total amount of municipal and special waste incinerated in 2014 [3] (ISPRA 2015), of which 72.1% consists of non-hazardous waste and 27, 9 % of hazardous waste. The most commonly produced types of waste are non-hazardous bottom and ashes (69.6%) for a total of about 980 thousand tonnes which represent the recoverable fraction in construction sector. Table 10 shows the current recovery and disposal rates for this recoverable fraction.
Regarding the materials recovered from the treatment in 2010 approximately 3% is made up of ferrous metals and 0.1% by recycled non-ferrous metals. The remaining approximately 97% consists of mineral material that is mainly recovered as a cement additive or for the production of concrete instead of natural gravel.

Table 9: Incinerated wastes and waste production in incineration plants in 2014

plants	treated waste (10^3 t)	Waste incineration residues (10^3 t)							
		from flue gas treatment section	hazardous bottom ash, fly ash and slag	Non-hazardous bottom ash, fly ash and slag	sand	Liquid wastes and sludge	Ferrous metals	total	% on incinerated waste
44	6278	197	183	980	14	14	19	1407	22.4

Table 10: Slag and bottom ash recovery rate and typologies of the recovery products

	Disposal+		**Recovery**+		**Type of recovered materials (%)**++		
Geographic area	**(10^3 t)**	**(%)**	**(10^3 t)**	**(%)**	**inert**	**Ferrous metals**	**Non-ferrous metals**
Nord	105.6	14.6	615.2	85.3	96.4	3.5	0.1
Centre	30.6	30.8	68.6	69.2	97.9	2.0	0
South	44.9	26.0	129.6	75.0	97.8	2.0	0.2
Total in Italy	181.0	18.2	813.4	81.9	96.7	3.2	0,1

+ Elaboration from ISPRA 2015 [3]
++ ENEA 2012 [33]

3.3.3 Reuse of steel slag

The Best Available Techniques Reference Document for Iron and Steel Production [34] emphasizes the importance of the reuse of steel slag in the field of civil works and road constructions.
In order to identify possible re-use in the construction sector, one should note the type of scrapping available, the different fields of application (cement, cement conglomerates, bituminous conglomerates, road signs, etc.) and the qualification regulations (waste, by-product, end of waste) and industry technical standards.
Steel is basically produced by two distinct production processes: the whole cycle, which makes use of raw materials such as mineral iron and carbon fossil and the electrical arc furnace cycle (EAF), which fuses iron scrap, exploiting the features of complete steel recyclability. The whole cycle for steel production (integrated works) essentially produces 4 types of steel scrap: granulated blast furnace slag (GBS); air-cooled Blast furnace Slag(ABS); Basic Oxygen furnace Slag (BOS); Steelmaking slag (SMS). Table 11 shows the slag production and the recovery percentage for each destination (i.e. cement, environmental restoration, internal use, concrete, asphalt, road ballast and base).
The analysis of the data (2010) shows an average production of more than 3,5 million tons per year of slag deriving from integrated works completely absorbed by the construction industry (less than 1% is disposed of). Most of the production consists of GBF which is reused prevalently for cement production and BOF used prevalently for road ballast. EAF slag amount at about 3 million tons per year, of which 75% has been reused for road pavements (38%) and concrete (28%), while residual quantities for the construction of bituminous conglomerates (13%) and road ballast (12%). There are further opportunities for improvement in the reuse rate due to residual and unused utilization capacity of about 750 thousand tons of EAF slag per year.

Table 11: Slag production and the recovery percentages for each destination.

slag	production (10^3t)	recovered (%)	cement (%)	environ. restoration (%)	internal reuse (%)	concrete (%)	asphalt (%)	road ballast (%)	road base (%)
GBS	2150	100	99.7	0.3	0	0	0	0	0
ABS	50	100							
BOS	1050	100	0	0	20	0	0	80	0
EAF–C	1900	75	0	3	0	27	11	15	44
EAF–S	400	75	13	1	0	29	53	0	4
SMS from EAF	700	75	9	3	30	33	5	2	18
SMS integrated works	330	100							
Tot. integrated works	3580	100	67	8	6	0	0	19	0
Tot. EAF	3000	75	2	3	3	28	13	12	38

4. Conclusions

The construction sector determines the extraction of large amount of raw materials and it is responsible for a consistent production of wastes throughout the life cycle. Improving resource efficiency will allow a reduction in environmental pressure and an increase of business opportunities. This paper through a material flow analysis at national level, extended to the whole life cycle, from the production of raw materials to the construction of buildings and infrastructure, presents an evaluation of the actual state of natural resource utilization (raw materials) and waste production, as well as its disposal and reuse rate as substitution of natural raw materials. The results highlight the high domestic demand both for raw materials (138 million tons of construction minerals and ornamental stones of which almost 100 million of aggregates and 36 million of ornamental stones) and for manufactured building products (149 million tons of which 81 million of ready-to-use concrete and 39 million of cement).

Results also demonstrate that waste production in the overall construction and quarrying chain is considerable. The most consistent amount of waste is produced in the course of construction and demolition activities (about 50 million tons of CDW every year), whereas the manufacture of building products and materials contributes with almost 3 million tons and the quarrying sector with almost 200 thousand tons. The evaluated rate of substitution of virgin raw materials with valorised waste produced within the chain, is still low. For example, the amount of recycled C&D waste amounts to around 5 million tonnes per year and considering the domestic demand for aggregate of almost 100 million tons, it is understood that almost all aggregate demand is met by natural materials (about 95%) with a current rate of replacement of virgin raw materials stops at 5%.

Because other opportunities of raw materials substitution in construction sector were offered by industrial wastes produced in activities outside the construction chain, this paper have investigated some of these routes through MFA. Interesting opportunities emerge from the material and energy recovery in cement industry, MSWI bottom ashes and steel slag. Very high reuse rates are achieved for the 6,5 million tons per year of steel slag (100% for integrated works slag) for the 980 thousand tons of non-hazardous fly and bottom ash (81%). In cement industry, 850 thousand tons of recovered wastes were yearly used, employing 1% of the total amount of special waste. The actual raw material substitution rate stops at a few percentage points (6.5% in 2015) but it could substantially raise thanks to the high availability of secondary raw materials not yet utilized. On the same industry, alternative fuels were utilized in substitution of traditional one with a substitution rate of almost 15%, still too low if compared with the European average of 30% and the value of 60%in some nations.

It is therefore evident that the potential in term of substitution of raw materials with residues and wastes produced within the chain is not adequately exploited and further efforts, in term of national policies and strategies are needed to effectively move towards the full application of the circular economy in the sector.

The results of this study could be useful to address national policies and strategies in those sectors where further efforts are needed.

References

[1] European Commission, 31.7.2012: Strategy for the sustainable competitiveness of the construction sector and its enterprises COM (2012) 433 .

[2] UEPG, 2009-2010: Sustainable Development in the European Aggregates Industry - Annual Review

[3] ISPRA: Rapporto Rifiuti speciali (2015)

[4] Pacheco-Torgal, F., Labrincha, J.A., Jalali, S., John, V.M.: Eco-efficient concrete. Cambridge, UK: Woodhead Publishing Limited Abington Hall (2013)

[5] Luodes, H., Kauppila P.M., Luodes N.,Aatos S., Kallioinen J., Luukkanen S., Aalt J.: Characteristics and the environmental acceptability of the natural stone quarrying waste rocks. B. Eng. Geol. Environ. 71(2), 257-261 (2012)
[6] Pacheco-Torgal, F.: Eco-efficient construction and building materials research under the EU Framework Programme Horizon 2020. Constr. Build. Mater. 51, 151–162 (2014)
[7] European Commission. 1.7.2014: Resource efficiency opportunities in the building sector COM (2014) 445
[8] Rao A., Jha, K.N., Misra, S.: Use of aggregates from recycled construction and demolition waste in concrete. Resour. Conserv. Recy. 50, 71–81 (2007)
[9] Martín-Morales, M., Zamoranob, M., Ruiz-Moyanoa, A., Valverde-Espinosa, I.: Characterization of recycled aggregates construction and demolition waste for concrete production following the Spanish Structural Concrete Code EHE-08. Constr. Build. Mater. 25 (2), 742–748 (2011)
[10] Careddu, N., Dino, G.A.: Reuse of residual sludge from stone processing: differences and similarities between sludge coming from carbonate and silicate stones: Italian experiences. Environ. Earth Sci. 75:1075 (2016)
[11] Bassani, M., Bertola, F., Bianchi, M., Canonico, F., Marian, M.: Environmental assessment and geomechanical properties of controlled low-strength materials with recycled and alternative components for cements and aggregates. Cement and Concrete Comp. 80, 143-156 (2017)
[12] Tasneem, K.M., Eun, J., Nam, B.: Leaching behaviour of municipal solid waste incineration bottom ash mixed with Hot-Mix Asphalt and Portland cement concrete used as road construction materials. Road Mater. Pavement. 18(3), 687-712 (2017)
[13] Mancini, G., Viotti, P., Luciano A., Fino, D.: On the ASR and ASR thermal residues characterization of full scale treatment plant. Waste Manage. 34, 448–457 (2014)
[14] Bertolini L., Carsana M., Cassago, D., Quadrio Curzio, A., Collepardi, M: MSWI ashes as mineral additions in concrete. Cement Concrete Res. 34 (2004) 1899 – 1906
[15] Lin, C.F. Wu, C.H., Ho, H.M.: Recovery of municipal waste incineration bottom ash and water treatment sludge to water permeable pavement materials. Waste Manage. 26, 970–978 (2006)
[16] Kokalj, F., Samec, N. Jurič, B.: Utilization of bottom ash from the incineration of separated wastes as a cement substitute. Waste Manage. Res. 23 (5), 468-472 (2005)
[17] Allegrini, E., Vadenbo, C., Boldrin, A., Astrup, T.F.: Life cycle assessment of resource recovery from municipal solid waste incineration bottom ash. J.Environ.Manage.151, 132-143 (2015)
[18] Toraldo, E., Saponaro, S., Careghini, A., Mariani, E.: Use of stabilized bottom ash for bound layers of road pavements.J. Environ. Manage. 121, 117-123 (2013)
[19] Gonçalves, D.R.R., Fontes, W.C., Mendes, J.C., Silva, G.J.B., Peixoto, R.A.F.: Evaluation of the economic feasibility of a processing plant for steelmaking slag. Waste Manage. Res. 34(2), 107-112 (2016)
[20] Kehagia, F.: Skid resistance performance of asphalt wearing courses with electric arc furnace slag aggregates. Waste Manage. Res. 27(3), 288-294 (2009)
[21] Lintz, R.C.C., Seydell, M.R.R.: Evaluation of tire rubber disposal in concrete for pavements. Journal of Urban and Environmental Engineering. 3(2), 52-57 (2009)
[22] Tiwari, B., Ajmera, B., Moubayed, S., Lemmon, A., Styler, K., Martinez, J.G.: Improving geotechnical behavior of clayey soils with shredded rubber tires: Preliminary study. Geotech Sp. 234, 3734-3743 (2014)
[23] Cossu, R., Fiore, S., Lai, T., Luciano, A., Mancini, G., Ruffino, B., Viotti, P., Zanetti, M.C.: Review of Italian experience on automotive shredder residue characterization and management. Waste Manage. 34, 1752–1762 (2014)
[24] Dino, G.A., Fornaro, M.: L'utilizzo integrale delle risorse lapidee negli aspetti estrattivi, di lavorazione e di recupero ambientale dei siti. Giornale di Geologia Applicata. 2, 320-327 (2005).
[25] AITEC, Rapporto di Sostenibilità 2015
[26] AITEC, Relazione Annuale 2015
[27] Genon, G., Brizio, E.: Perspectives and limits for cement kilns as a destination for RDF. Waste Manage. 28, 2375-2385 (2008)
[28] Schneider, M., Romer, M., Tschudin, M., Bolio, H.: Sustainable cement production: present and future. Cement Concrete Res. 41, 642-650(2011)
[29] van Oss, H.G., Padovani, A.C.: Cement Manufacture and the Environment.Part II: Environmental Challenges and Opportunities. J. Ind. Ecol. 7(1), 93-126 (2003)
[30] European Union, Decision 2013/163/EU: Commission Implementing Decision establishing the best available techniques (BAT) conclusions under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions for the production of cement, lime and magnesium oxide. (C(2013)1728/F1). Official Journal of the European Union. 56, 1-52 (2013).
[31] CEMBUREAU, Activity report 2015

[32] Zhang, T., Zhao, Z.: Optimal use of MSWI bottom ash in concrete. Int. J. Concr. Struct. Mater. 8, 173-182 (2014)
[33] ENEA, Federambiente: Rapporto sul recupero energetico da rifiuti urbani in Italia, 3rd edition, (2012).
[34] Remus, R., Aguado-Monsonet M.A., Roudier, S., Sancio, L.D.: The Best Available Techniques Reference Document for Iron and Steel Production. JRC Reference Report (2013)