FISSAC

FOSTERING INDUSTRIAL SYMBIOSIS FOR A SUSTAINABLE RESOURCE INTENSIVE INDUSTRY ACROSS THE EXTENDED CONSTRUCTION VALUE CHAIN

Inventory of raw materials, waste, and energy flows in industrial sectors (Metallurgic, ceramic, glass, chemical, and natural stone) considered in a dynamic scenario

Executive summary

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D1.3: Inventory of raw materials, waste, and energy flows in industrial sectors (Metallurgic, ceramic, glass, chemical, and natural stone) considered in a dynamic scenario
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Through valorisation of waste streams, the FISSAC industrial symbiosis (IS) network has the potential to not only make use of waste streams generated in high amounts around Europe, but also close the material flow loop in construction value chain by utilizing construction and demolition (C&D) waste in production of construction materials.

The new industrial symbiosis model in part relies on full-scale demonstration of production of new eco-cement, green concrete, innovative ceramic tiles, and rubber-wood plastic composites through valorisation of selected industrial waste streams. These streams include:

- steel slag (electric arc furnace – EAF slag and ladle furnace – LF slag);
- waste glass from construction and demolition of buildings;
- calcined-clay wastes from ceramic brick production and C&D;
- aluminium oxide materials from secondary aluminium production;
- natural stone waste;
- scrap tyre rubber;
- wood waste from C&D;
- plastic waste from C&D.

The report summarised here aims to analyse the waste streams included in the full-scale demonstration of the FISSAC project in order to support the identification of the waste generation and valorisation potential.

The report addresses a number of topics on waste streams studied by the FISSAC project and the industrial sectors generating them. These topics include:

- Study of the **industrial sectors** in terms of a sectorial overview, distribution of production capacities in EU-28, and future trends based on historical production data,
- **Manufacturing processes**, which lead to generation of target waste streams, with their brief description, unit processes within the manufacturing line, and material/energy input and outputs,
- **Evaluation of waste streams** covering the definition of waste stream, Waste Generation Factors (WGFs) used for estimation of waste amounts, quantities generated along with their spatial distribution over the FISSAC countries and rest of the EU, future waste generation trends based on sectorial forecasts.

Methodology

- Material flow sheets were constructed in order to identify the raw material and energy inputs as well as the type of emissions and by-products created by these processes.
- The overview and definition of industrial sectors are mainly based on the Reference Documents on Best Available Techniques (BREF), reports prepared by the Integrated Pollution Prevention and Control (IPPC) Bureau functioning under the Joint Research Centre (JRC).
- For the production figures within Europe, reports prepared by sectorial associations such as Worldsteel and EuroSlag are also referred.
- All the trend analyses only consider historical data.
- The amount of waste streams are obtained through either two ways; direct information obtained from FISSAC partners and indirect data estimated through the Waste Generation Factors (WGFs).
- Recovery/recycling/reuse, incineration and final disposal are considered as the waste handling options.

Steelmaking

The steel industry is the second biggest industry in the world after oil and gas, with an estimated global turnover of 900 billion USD.

Four routes are currently used worldwide for the production of steel: the classic BF/BOF, the direct melting of scrap (electric arc furnace - EAF), smelting reduction and direct reduction 0.

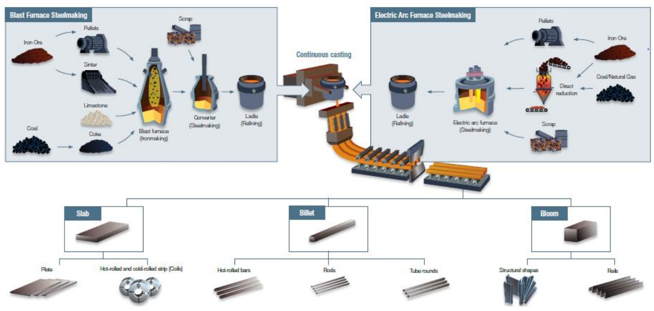

Figure 1 Overview of BF/BOF and EAF steelmaking process [2]

The main material inputs to EAF steelmaking include:

- raw materials in the form of scrap, lime, coal and iron sponge,
- auxiliaries that are alloying metals, graphite electrodes, furnace lining, inert gas, and
- process water.

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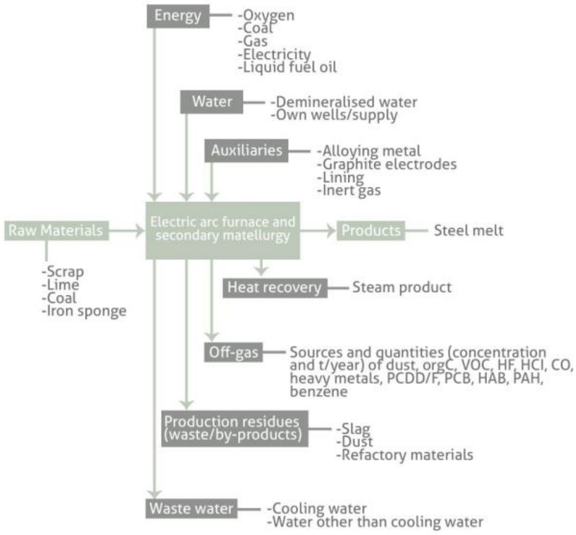

Figure 2 EAF Route for steel making (Adapted from 0)

EAF slag is generated by the fluxes and reducing agents (lime or dolomite), silicon compounds or aluminium [4]. Furthermore, some impurities in the molten metal contribute to formation of slag. **The ladle furnace (LF) basic slag**, also called the secondary refining slag or the white slag, is produced in the final stages of steelmaking, when the steel is desulfurised in the transport ladle, during what is generally known as the secondary metallurgy process [5].

The biggest crude steel and steel slag generators in the across Europe are given in Table 1.

Table 1 Top-five crude steel producers in across Europe in 2014 and their slag generation [3]

Country	Annual production (10^6 tonnes)	EAF Slag generation (10^6 tonnes)	LF Slag generation (10^6 tonnes)
Germany	42.90	1.63	0.39
Turkey	34.00	2.97	0.71
Italy	23.70	2.15	0.52
France	16.10	0.69	0.16
Spain	14.20	1.25	0.30
Based on 125 kg EAF slag/t LS and 30 kg LF slag /t LS			

The highest valorisation potential for steel slag is generated by **utilization of slag in road construction** (48%). 6% of steel was used as **secondary raw material in manufacturing of concrete**. It should be noted that the final deposit rate of 13% in 2010 is much higher than the rate observed in previous years and can be linked to the economic crisis.

Within the scope of the FISSAC project, EAF slag is envisioned to be valorised for manufacturing of new aerated autoclaved concrete (AAC) products along with LF slag and ready-mix green concrete.

When country-wise slag generation is taken into account, cement industry can benefit from EAF and LF slags particularly in Turkey, Italy and Germany.

Aluminium

Non-ferrous metal industry consumes both primary and secondary (recycled) materials. Primary raw materials are derived from ores that are mined and then further treated before they are metallurgically processed to produce crude metal. Most metal concentrates are imported into Europe from a variety of sources worldwide. Secondary raw materials are indigenous scrap and residues [6][7].

Aluminium is regarded as an endlessly recyclable material as it can be recycled without a loss in quality and current estimates suggest that 75% of the aluminium produced so far is still in use [8].

There are two production types of aluminium sector. Primary aluminium is produced from bauxite that is converted into alumina; which can then produce around aluminium. Most of the bauxite is mined outside Europe, but there are several alumina production facilities within Europe.

Scrap utilized in **secondary aluminium production** can be termed 'new scrap' which is generated during the production and fabrication of wrought and cast products or 'old scrap' which is recovered from articles at the end of their useful life. [9] [10].

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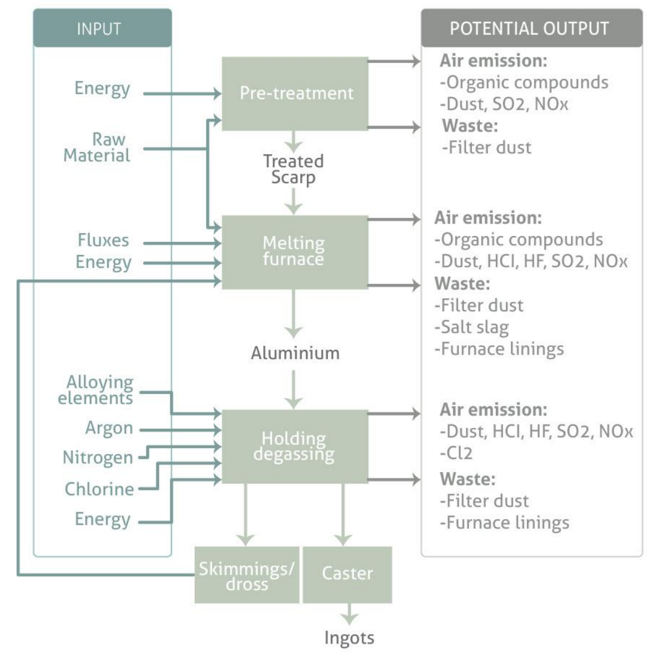

Figure 3 Secondary aluminium production [6]

Main inputs to the process include scrap metals, salt fluxes, alloying materials and energy. Potential outputs are mainly in the form of air emissions and solid wastes. Organic compounds, dust, HCl, SO_2, NO_x emissions may arise as a result of secondary production route. Also filter dust, furnace linings and **salt slag** are generated during the process (Figure 3).

The salt slag contains large amounts of aluminium oxides and various impurities that the flux has separated from the molten metal. Only around 4 – 10 % of the total weight of salt slag is metallic aluminium. The contents of salt slag can be partially or fully recovered.

BEFESA Process, which allows 100% recovery of aluminium oxides from salt, involves:

- Milling and sorting depending on the corn measure from the received residue.
- Reaction and dissolution of the hazardous components and salts.
- Separation and washing of the secondary oxide products.
- Crystallisation of salts.

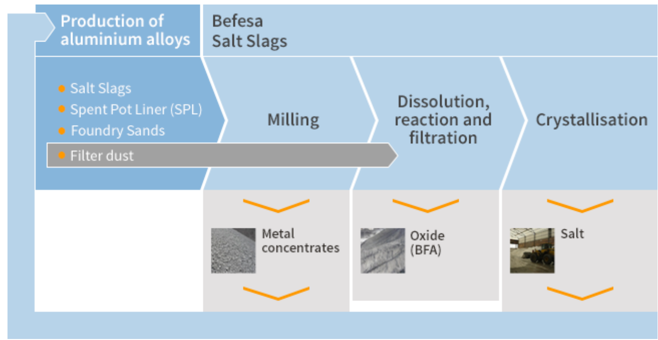

Figure 4 BEFESA Process [11]

The biggest secondary aluminium generators in the across Europe are given in Table 2.

Table 2 Top-five secondary aluminium producers in across Europe in 2006 and their slag generation [12] (Aluminium oxide recovery is based on 100% efficiency of BEFESA Process)

Country	Annual production (10^3 tonnes)	Salt Slag generation (10^3 tonnes)	Al_2O_3 recovery (10^3 tonnes)
Germany	796.00	206.96	46.57
Italy	666.00	173.16	38.96
Spain	243.00	63.18	14.22
France	222.00	57.72	12.99
UK	198	51.48	11.58

Based on WGF of 0.26t salg/t of aluminium produced and 22.5% Al_2O_3 content

Following the salt slag recovery operations, aluminium oxide is sold to suppliers and plants for re-use under different brand names including Oxiton, Noval, Paval, Serox, and Valoxy [10]. Aluminium oxides can be used as a raw material in cement clinker, mineral wool, synthetic calcium aluminates, ceramics, refractory materials, abrasives, glass and filler. In plastic industry, aluminium oxides are utilized as filler [13]. They are included in the formulations during glass manufacturing. Aluminium oxides could be blended together with other waste materials to prepare appropriate premixes for cement kilns. Feedstock materials used in clinker production consist of four major components; lime (CaO), silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3). Commonly these principal constituents are derived from primary materials however alternative materials could also be used to produce suitable feedstock [14].

Similarly, aluminium oxides recovered from salt slags can be utilized as a source of alumina in ceramics industry. Besides, some manufacturers of technical ceramics offer metallised ceramics. Aluminium oxide is available as substrate material for such special types of ceramic products. As a result of providing good electrical insulation, suitable thermal conductivity and high mechanical strength, aluminium oxides is used in advanced ceramic materials named oxide ceramics.

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Within the FISSAC industrial symbiosis case, aluminium oxide based materials recovered from secondary aluminium salt slag will be used for production of ceramic tiles.

Ceramic

Generally the term 'ceramics' (ceramic products) is used for inorganic materials (with possibly some organic content), made up of non-metallic compounds and made permanent by a firing process. In addition to clay-based materials, today ceramics include a multitude of products with a small fraction of clay or none at all.

Following production steps are followed for production of ceramic tiles:

- Raw materials preparation
- Milling and spray drying
- Pressing
- Drying
- Glazing and decoration
- Firing

Two main groups of raw materials used for ceramic wall and floor tiles are body raw materials, which are mainly clays and glaze raw materials including frits, kaolin, sand, pigments and opacifiers (Figure 5). As a result of the process, wastewater, excess heat, and air emissions are generated. Process losses or solid wastes include used filters, used sorption agents, sludge, packaging waste, cuttings, defective tiles and broken ware.

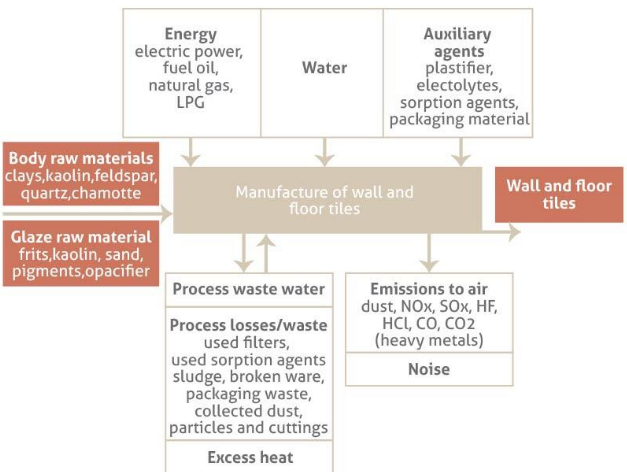

Figure 5 Input and output in the manufacture of bricks and roof tiles

Table 3 Top-five ceramic producers in across Europe in 2011 and their calcined clay waste generation [15]

Country	Annual production (10^3 m²)	Calcined clay generation (10^3 tonnes)
Italy	368.00	257.60
Spain	324.00	227.08
Turkey	205.00	143.50
Poland	113.00	79.10
Portugal	63.00	44.10

Based on a WGF of 0.7 kg calcined clay per m² tile

Pozzolan is defined as 'a siliceous and aluminous material, which in itself possesses little or no cementing property, but will in a finely divided form - and in the presence of moisture - chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. *Pozzolans not only strengthen the concrete, they have many other beneficial features.*

Calcined clay wastes present great opportunities to be valorised in cement industry due to their pozzolanic properties. The use of materials with such properties reduce the need for clinker production and lower energy consumption, which in turn reduce the carbon footprint of cement manufacturing. Also pozzolanic materials provide technical improvements in the end product such as long-term mechanical strength, stable resistance to expansion, durable resistance and reduced hydration heat [16].

In Spain and Italy, due to their high production volumes, the amount of calcined clay waste generated by industry is close to or above the maximum amount of potential natural calcined pozzolana demand of cement products. However, in Turkey, although ceramic tile production is very high, it is still below the level to satisfy the potential demand from the cement industry. Cement manufacturers in Germany, France, and Poland, where the pozzolanic material consumption can exceed 200 kilo tonnes per year, need to use virgin pozzolanic materials or find another source of raw materials.

The **calcined clay** from ceramic tile production is expected to be valorised **for the purpose of eco-cement production** within the FISSAC industrial symbiosis framework.

Natural stone

During cutting, shaping and finishing of natural stone, appropriate stone blocks are selected, they are cut down into slabs and later they are sized according to product specifications. The intermediate products are then finished by polishing. During cutting and sizing of natural stone blocks and slabs, considerable amount of water is required, which acts as a lubricant. The wastewater leaving the cutting and sizing equipment is collected and diverted to a pond where the fine

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sized natural stone material is separated through flocculation. A second flocculation step is applied in the decantation cone following the pond. Water is recirculated back to the cutting process and the slurry that contains stone particles are passed through a press filter. The residual water is also sent back to the process. After filter-press, the slurry is composed by fine particles and water with a relationship on weight 80% particles / 20 % water [17].

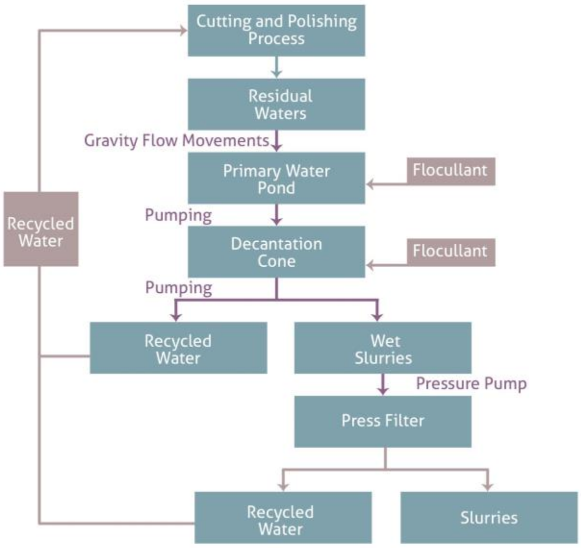

Figure 6 Cutting and Polishing Process [17]

Approximately 35% of global natural stone production is in Europe, of which over 80% is in Italy, Greece, Spain, and Portugal. The natural stone production in Turkey is equivalent to 60% of total EU production, which was approximately 24 million tonnes in 2008 (Table 4).

Table 4 Top-five natural stone producers in across Europe in 2008 and their waste slurry generation [18]

	Annual production (10^3 tonnes)	Waste slurry (10^3 tonnes)
Turkey	15,323.00	2,461.76
Italy	12,197.00	2,439.40
Spain	4,583.00	916.60
Germany	4,099.00	819.80
Portugal	985.00	197.00

In the scope of FISSAC, **slurries will be utilized in improved ceramic products.**

Tyre rubber

Life cycle of scrap tyres are shown in .Disposal of large numbers of scrap tyres becomes problematic, as scrap tyres are non-biodegradable, non-compactable, and they float to the surface in landfills. Unregulated stockpiling of tyres can lead to (i) fire hazard and toxic emissions (PAHs, metallic oxides etc.), and (ii) health hazards by providing an ideal breeding habitat for mosquitos that transmit serious diseases [19].

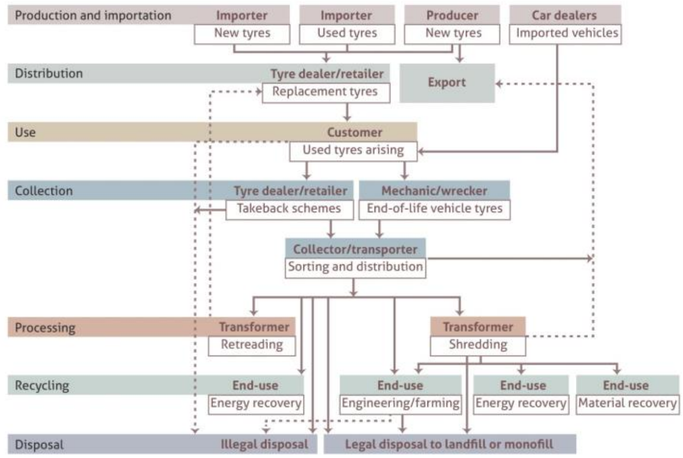

Figure 7 Life cycle phases of tyre rubber

The largest volumes of used tyres arise from Germany, UK, France, Italy, Spain and Poland (Table 5).

Table 5 Top-five waste tyre generators [15]

Country	Annual production (10^3 tonnes/year)
Germany	475.00
Italy	371.00
UK	335.00
France	302.00
Poland	219.00

FISSAC aims to use this waste in production of rubber wood plastic composites. *Rubber wood plastic composite is the new type of wood plastic composite (WPC) using tyre rubber as raw material.* This product has new additional properties beyond the WPC. There is high volume consumption of tyre and this production can eliminate the burden for the disposal of used tyre waste. Besides that, used tyre rubber provides improved wear resistance and vibration damping to the new type of composite by its chemical and mechanical characteristics.

Construction and demolition waste

Construction and demolition activities can be associated with a number of environmental impacts in the form of high amounts of solid waste generation, air emissions, water use and emissions as well as energy consumption [20].

Construction and demolition waste (C&DW) exhibits great variation in terms of both amount and content according to the nature of C&D projects as well as the characteristics of the structure (Table 6).

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Table 6 Ranges of constituents of C&DW for the EU (except Estonia and Finland) [21]

Type	% - Min	% - Max	10^6 tonnes - Min	10^6 tonnes - max
Concrete and Masonry - total	40,0%	84,0%	184	387
Concrete	12,0%	40,0%	55	184
Masonry[a]	8,0%	54,0%	37	249
Asphalt	4,0%	26,0%	18	120
Other mineral waste	2,0%	9,0%	9	41
Wood	2,0%	4,0%	9	18
Metal	0,2%	4,0%	1	18
Gypsum	0,2%	0,4%	1	2
Plastics	0,1%	2,0%	0	9
Miscellaneous	2,0%	36,0%	9	166

Due to the large amounts of waste generated, C&DW has been identified as a priority waste stream for reuse and recycling. The EU Waste Framework Directive (WFD) (Directive 2008/98/EC) requires the Member States of the EU to take the necessary measures to achieve a minimum of 70% (by weight) target of re-use, recycling and other material recovery (including backfilling) of non-hazardous construction and demolition waste by 2020.

Table 7 Top-five C&DW generators [21]

Country	Annual production (10^3 tonnes/year)	% Reused or recyled
UK	99.10	75%
France	85.65	45%
Germany	72.40	86%
Turkey	68.64	0%
Italy	46.31	0%

Waste streams from C&DW covered under FISSAC project include

- Plastics
- Glass
- Ceramics
- Concrete
- Wood

Conclusion

FISSAC project aims to valorise a number of waste streams originating from steel, secondary aluminium, ceramic, natural stone, and construction demolition sectors in a symbiotic network for production of eco-cement, green concrete, innovative ceramic tiles, and rubber-wood plastic composites. The establishment of such a network contributes to circular economy and supports End-of-Waste approach.

FISSAC aims to establish a sound valorisation scheme for EAF and LF slag similar to blast furnace slag. If EAF and LF slag can be incorporated into cement in a similar manner to blast furnace slag, potentially 8 – 24 million tonnes per year of slag would be necessary for cement products according to 2012 data. EAF slag generation almost in all EU States are sufficient to satisfy the minimum demand.

In comparison to steel making slag, salt slags in secondary aluminium industry is generated in much smaller amounts. The salt slag generation is expected to rise in the next decade and exceed 3 million tonnes per year, 15 – 30% of which are aluminium oxides.

Production losses in the form of calcined clay amounts to 1.3 million tonnes in the EU and Turkey based on 2009 data. Although calcined clay generation potential is estimated to rise in upcoming years, it is not entirely sufficient to meet the natural calcined pozzolana demand for cement industry that is between 1.3 – 3.7 million tonnes. As a result of natural stone processing, 7.3 million tonnes of slurry was generated in 2008. Italy and Turkey have the highest potential to become suppliers of this secondary raw material.

The components of used tyres present a high potential for valorisation at their end-of-life. Recovery rates of used tyres are rising over the years reaching up to 96% in 2010. FISSAC aims to incorporate rubber portion of used tyres in wood-plastic composite products.

Total amounts of C&DW in Europe was approximately 600 million tonnes in 2010. Although construction sector went through a decline in next few years, the amount of C&DW is expected to increase to 2010 level around the year of 2020. FISSAC Project aims to valorise plastic, glass, ceramic, and wood waste from C&DW for different products. Plastic and wood portions are going to be used for production of wood-plastic composites whereas the rest will be utilized in eco-cement and green concrete manufacturing. According to the estimations, highest amount of C&DW generation occurs in United Kingdom, which is followed by France, Germany, Turkey, and Italy.

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