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Methodological developments in the LCA of asbestos containing wastes (ACW) on the territory of eight municipalities in the Italian region of Reggio Emilia

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Sommario

Abstract

The main goal of this research project is to integrate Life Cycle Cost (LCC) with the financial and economic dimensions in order to make the Life Cycle Sustainability Assessment (LCSA) a larger instrument not only to assess the environmental impact of asbestos but also to support decision-making processes at the economic level. LCA and LCC are applied in order to evaluate the potential environmental and economic impacts of: mapping, encapsulation or remediation, collection and transportation, recycling or disposal of ACPs in the Unione Bassa Reggiana municipalities. One of the aims of the study is to identify how to improve the existing system by, for example, focusing on mapping technologies and all the possible scenarios for ACPs remediation. Relative to age and degradation status of the ACPs, this methodology is used to compare encapsulation and remediation actions in order to identify which one has the lowest environmental and economic impact. Lastly, all stakeholders' requests and expectations are addressed, in order to gain complete knowledge of the system. Through a Life Cycle Thinking approach, this study analyses some technological and plant-related aspects that have not been addressed so far. This need stems from a) inconsistent mapping methods of asbestos; b) high costs for ACM removal; c) knowledge gaps; d) shortage and uneven distribution of asbestos disposal and remediation plants. Given that any type of management choice related to asbestos can have a significant impact on the Italian national economic system, from infrastructures and services to life quality, the managing of asbestos represents one of the most important and complex issues in the country. This project addresses the complex issues related to asbestos in the following municipalities: Boretto, Brescello, Gualtieri, Guastalla, Luzzara, Novellara, Poviglio and Reggiolo (town in the lower Reggiana union) by focusing on mapping, encapsulation and confinement or remediation, collection and recycling/disposal of asbestos-containing products (ACP). First, aerial multispectral images are analysed together with low-altitude surveys, performed with drones. The aim of this stage is to map the presence of asbestos and its conservation status on the territory. Secondly, these results are overlapped with the regional technical map (CTR, Carta Tecnica Regionale), in order to build a risk map to prioritize interventions. Lastly, based on the quantity and quality (friable or compact) of the analysed ACPs, different types of remediation, such as confinement, encapsulation and removal, are analysed and compared. Private citizens are themselves able to remediate small compact quantities of asbestos (up to 30 sq. m. roofing, 3 m-long vent pipes, etc.), buying a kit which is available at affiliated hardware stores. Larger quantities of compact asbestos have to be remediated by authorised and qualified companies. Friable asbestos always has to be handled by qualified companies. When it comes to collection and transportation of asbestos waste to treatment plants, transportation directly performed by S.A.BA.R. SERVIZI S.r.l. is compared to transportation carried out by qualified companies. The last part of the study focuses on storage and recycling/disposal of ACPs. Different technologies and different types of waste treatment plants are analysed and then compared: waste disposal plants (landfills) and recycling plants (solidification and/or stabilization, chemical-physical treatments). The aim of the project is to create an economically and environmentally sustainable model which could be applied to different scenarios, both in Italy and in other EU countries. This tool enables companies, private citizens and the public administration to identify the most suitable solution to sustainably manage any asbestos related situation.

1. Introduction

For years asbestos was considered an extremely versatile material at low cost and with varied applications in industry, in construction and in other consumer products. In the mid seventies, the use of asbestos in Italy and in the world was great. Between 1976 and 1980 Italy reached the maximum in terms of extraction, production and use, beginning with the so called Italian economic and industrial miracle. From the second half of the 20th century until 1992, 3,748,500 tons of asbestos was produced (*Virta, 2006;Kim et al., 2015*) There was no sector of production which did not utilize asbestos in its work cycle, and in the building industry – residential, commercial or industrial- asbestos was used and in particular, in the form of cement fiber, in roofing and siding in insulation and sound proofing, in prefabricated buildings, in acoustical ceilings and plaster, in chimney flues, in water pipes in houses and reservoirs, in electrical wire channeling, for fireproofing and fire retardants and fire barriers for houses and warehouses, as on means of transport and car brake pads, and many other uses. About 40% of buildings constructed in Italy between 1967 and 1975, (*Marsili D., Angelini A., 2017*) have been treated with asbestos. Asbestos cement, one of the engines of expansion in the Italian construction business in the second half of the 20th century was considered the "*poor people's cement"*. In fact, entire blocks of government subsidized housing were built entirely with white asbestos panels without any protective covering. Asbestos is a silicate fiber found in nature together with other minerals in the parent rock, from which it must be separated by grinding. There are many types of asbestos but the most common type which constitutes about 95% of this mineral extracted in the world, is the chrysotile or "*white asbestos*" (*Becklake, 1976, Bourgault et al., 2014*). There are other types of asbestos which are much more cancerous like crocidolite or "*blue asbestos*", amosite, antofillite and tremolite. These are low cost materials but with great physical properties since they are heat resistant, fire resistant, long lasting, resistant to chemical and biological agents and are sound absorbent. These properties have been known since ancient times. Strabone, in his treatise Rerum Geographicarum from 25 A.C. and later Plinio the Elder (*Bonnani E.,2012*), in his Naturalis Historia from 77 B.C. tells of slaves who, working with this mineral to produce wicks for lamps, protected themselves with face masks made from sheep bladders. The two authors had seen how these forced laborers showed particular respiratory problems which led them to an early death. Marco Polo, in his book "*Milione*" tells about the great use of this mineral by the inhabitants of the Cathay Empire and it was also used by the people of northern Europe in the Viking era (*Bonnani E.,2012*). According to a legend from that age, asbestos was called *"Salamanders wool"* because it allowed that small amphibious animal to resist the damage of fire. In modern times, in a phase before the industrial revolution, asbestos was used in the textile industry. The beginning of industrial use of asbestos in contemporary times is dated to 1883 when the English magazine, *"The Engineer*" published an article entitled "*Asbestos and its applications*" in which was described the use of this material to insulate Navy steam engines in the English and German military navies. This use spread through military and civil fleets during the years leading up to the first World War. In the meantime in 1901, Ludwig Hatschet, an Austrian, patented a formula for a cement mixture made with asbestos fibers which was exceptionally light and resistant to high temperatures and fire and was very flexible in use (*Ziglioli B., 2016*). To emphasize these qualities, the product was named "*Eternit*". A Swiss patent which became the property of industrialist Alois Steinmann, and after, from 1920 the property of the Schmidheiny family and became, in a short amount of time, an industrial and multinational colossal, focused on the production of asbestos cement. In the second part of the 20th century, the use of this mineral and of its derivatives and compounds became huge in many sectors. The production of asbestos in the world was less than 250,000 metric tons in 1920, rose to almost one million and a half metric tons in 1950 and was over 4 and a half million in 1970 and in 1975, reaching its apex in 1980 with almost 5 million metric tons produced (*Minerals Yearbook, 2017*). The intensive use of this mineral first started in countries with early industrialization (England Northwest Europe, The United States), and then spread in the countries of the "*newcomers*" (Japan, Italy, The Soviet Union, and Eastern Europe). By the 1970's it was being used everywhere on the planet. "*Every country which underwent a transformation of its economy, from agricultural to industrial, at the end of the 19th century, passed through a period, more or less long, when there was in intensive use of asbestos*" (*Bianchi C., 2015*). Parallelly to the dizzying increase in production there began to emerge the first reports and research on the dangers connected to the exposure to asbestos. Already in 1899, the Annual Report of the Chief Inspector of factories and workshops, reported the possible harm from inhaling particles of the mineral. In 1900, the London doctor, M. Murray, observed the presence of profound sclerotic changes in lung function in an asbestos thread carder. A few years later, the *"British Medical Journal"* identified a new disease which the people who worked with asbestos were exposed to, namely, Asbestosis. This is a chronic and progressive disease caused by the inhaling of asbestos dust especially in those workers who inhaled it for many hours a day and for many years of their lives. Asbestos causes emphysema, a thickening of the pleura, breathlessness and heart and respiratory problems even many years after the exposure, often with lethal consequences. In Germany, in 1983, Doctor M. Nordmann (*Kratzhe&Kratzhe, 2017*), described some cases of cancer in workers who had been exposed to asbestos, so that as a consequence of this research, lung cancer was added to the register of professional diseases compiled by the insurance companies. The results of Nordmann's research showed that mesothelioma, or cancer of the pleura, theoretically can appear even after inhaling a single fiber of asbestos. For this reason, not only people who work in contact with asbestos but also those who live near the factories or who come in contact with the fibers through the products which contain them are at risk. Epidemiologists showed that in our country, the height of the pathology will be reached between 2020 and 2025 (*Robinson,2012;Park et al,2011*), since this disease has a very long incubation period, between forty and fifty years. Scientific evidence showed a correlation between asbestos and mesothelioma in the early 1970's and became evident even to the eyes of the producers. In spite of this, the working and the use of the mineral went on for many more years, before the workers, the unions and the communities where the factories were located and, in general, public opinion realized the danger connected with that type of production. Even more time had to pass before national legislations intervened to limit or ban it. Only toward the end of the 1980's some countries such as Sweden and Norway, began to take measures. In the rest of western Europe, action was taken in the mid 1990's with many delays and notable ambiguity in the community plans. The European Commission debated banning asbestos in 1999 but this went into effect only in 2005 and was partially waived in 2009. Canada, which for many decades had been the principal extractor of asbestos in the world, stopped activity in its mines in 2011 without a formal legislation. Japan, South Korea, and Hong Kong decided to effect a complete ban in 2012. In Russia, the principle exporter of the asbestos fiber, India, the principle importer of asbestos fiber, Indonesia, China, Brazil, Mexico and most of the countries in Africa and Asia still work and use asbestos legally. A series of interacting factors working on different levels, influenced the delay in banning asbestos. Without doubt, the lack of communication between the academic and scientific communities on one hand and the public on the other played a very negative role. Also, as for other industrial products which have health and community risks associated with them, the asbestos diseases seemed to be an inevitable price to pay in the name of progress. Another factor which comes into this is the fact that the incubation period is so long for these illnesses and considering the cycles of growth of world production, the mesothelioma "*bomb*" exploded between the end of the 1970's and the mid 1980's. Only in that moment did the problem of asbestos begin to "*come out of the factories*" becoming collective, common and widespread not only for the question of safety on the job and the welfare of the workers but for the entire community. No one could consider asbestos an *"extraordinary and miraculous material*" anymore. Now it is to be considered a heavy legacy in terms of human lives and the economy.

2. Asbestos

The word "*αμίαντος*" (amianto) as a noun and synonym of asbestos (even if used to indicate quicklime), as an adjective it means pure or immaculate (*α* privative μιαίνω = incontaminable, pure, incorruptable) while the word "*άσβεστος*" (in Italian, asbestos, used mostly in Anglo-Saxon countries, in Germany and in Russia) (*α* privative and *σβέννυμι*) which can be translated as unquenchable, incessant and perpetual, that in the Greek were used as adjectives (ie. 'άλς 'αμίαντος = unpolluted sea πύρ 'άσβεστος = unquenchable fire) and in the everyday scientific technical language pinpoints those minerals which have particular characteristics with which they are identifiied (αμίαντος λίθος,= uncorruptable stone = amianto) The word "*amianto*" shows up in many sources in the classical world, already in Herodotus (484-430 BC.) As a proper noun , to indicate the son of Lycurgus of Trapezunt of Arcadia: *Αμίαντος Λυκούργου 'Αρκάς 'εκ Τραπεζούντος*, even if we can't exclude that the historian also used this word in connection with the mineral. In the Latin language, amiantus i, m., and asbestinum, i, n. and asbestos, i, f., were used interchangeably and Plinio the Elder (Gaio Plinio Secondo 23-79 B.C.) in his work "*Naturalis Historia*", apparently misunderstanding the use of this word which had been used before by Greek philosophers, substituting the word άσβεστος with άσβεστινον, which translates as *"an incorruptable material*" referring to incorruptable linen, purified by fire and defined as "*quicklinen*" which was used as a funeral covering for kings or influent people, so as to prevent the contamination of their ashes, other than having described the use of asbestos cloth around the trunks of trees to muffle the sound of the tree falling and he thought that it grew in the desert and under the sun of India. In the Italian language, the term asbestos was used by Cecco d'Ascoli in his writing of 1327, while that of amianto was used for the first time in 1546-47 in a writing by M.A. Montignano, who had translated the words of Pedanius Dioscoride into common language, and which appeared again in commercial language in the second half of the XIX century. The minerals contained in asbestos are classified in to two groups. The serpentine group which is made of chrysotile (white asbestos) and amphibolus (from the Greek αμφίβολος and from the Latin amphibolus = ambiguous). Amosite, tremolite, anthophyllite, actinolite and crocidolite (blue asbestos) are also in this group. The serpentine group constituted by Chrisotile (from the Greek χρυσός = gold fiber) or white-green-grey-yellowish asbestos is a hydrated silicate of magnesium, formula $Mg_3Si_20_5(OH)_4$, with decomposure temperatures between 450-700°C. This is the type of asbestos which is most used and is the most sought after because of its fibrous property, its incombustibility and it low thermal conduction. The most important deposits are found in Canada near Quebec, in Siberia, in China, in the United States, Italy and Greece.

The amphibolous group (*Paglietti F.,2014*) is made up of:

- Acinolite or actinotus or black-green asbestos is a hydrated silicate of calcium, iron and magnesium, chemical formula $Ca_2(Mg,Fe)_5[Si_40_{11}(OH)]_2$. It is the same contained in the metamorphic rock in China, New Zealand, the United States, Europe and different areas in Asia. Its decomposition temperature is between 620-900°C.
- Amosite (an acronym for asbestos mines of South Africa) or brown-yellow-grey asbestos or cummingtonite or grunerite, is a hydrated silicate of iron and magnesium $(Mg,Fe)_7[Si_40_{11}(OH)]_2$ characterized by long, straight fibers which are rather flexible and have particular heat stability. It is common in South Africa where veins of this mineral are ash gray in color and have a decomposition temperature of between 600 and 800°C. For this reason it is used mainly as a thermal insulator.
- Crocidolite or blue asbestos, also called cape asbestos or riebeckite is a hydrated silicate formula $Na_2Fe_3Fe_2[(OH)Si_40_{11}]_2$ characterized by flexible or friable fibers having good mechanical traction resistance and chemical resistance to acids. This type is found in the Vosgi mountains in France, in the Salisburgh Alps in Austria, but even more abundant in China, South Africa and Canada. It has a decomposition temp of between 400-600°C.
- Tremolite or grey-green-yellow asbestos is a hydrated silicate of calcium and magnesium $Ca_2Mg_5[Si_40_{11}(OH)]_2$ friable with a temperature of decomposition of 950-1040°C. The name, Tremolite, refers to the place it was found, the Val Tremola in the St. Gottard mountain in Switzerland. All types of metamorphic rocks are found in China, New Zealand, the United States, Europe and different areas of Asia.
- Anthrophyllite, a name which comes from the scientific Latin "*antophyllum*" (carnation) or green-yellow-white asbestos, is a hydrated silicate of magnesium, formula, $(Mg, Fe)_7[Si_40_{11}(OH)]_2$ friable and with breakdown temp between 600-850°C. It is the most important rhombic amphibole and can be frequently found in the "*misescist*" of the Alto Adige region of northern Italy and less frequently in the western Alps and Prealps, as well as in Finland and Norway.

In the following diagram (Figure 2-1) we can see different types of Asbestos (*Kusiorowski R., 2012*):

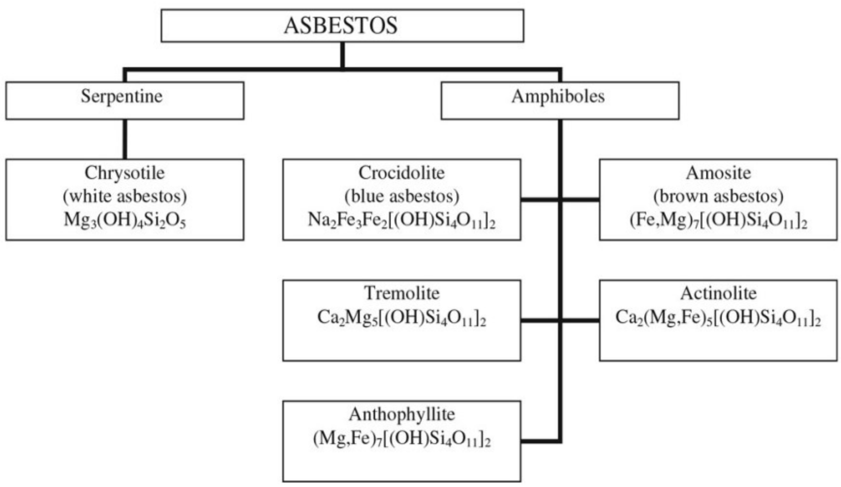


Figure 2-1: Different types of Asbestos

Once separated from the parent rock, asbestos yields a fibrous material with long, thin fibers regardless of its place of origin or composition, with parallel sides which distinguish it from the dust and from irregular fragments of minerals or materials. From the point of view of its characteristics and biological interest, and therefore of its dangers, short fibers and in particular, thick ones (non-inhalable), in the last analysis, act like the dust does (*Chiappino G., 2005*). The O.M.S. defines it in this way, "*a fiber is defined by a length equal or longer than 5um, by a diameter equal or less than 3um, and by a ratio of extension (L:D) equal or greater than 3:1"*.

- Fibers which cannot be inhaled are all those which have dimensions (100 μm) which can be blocked by the nose.
- Fibers which are respirable are all those which can be inhaled and penetrate deep into the lungs.

The following figure (Figure 2-2) shows the families of natural and artificial fibers (*Cordeiro R., 2016*).

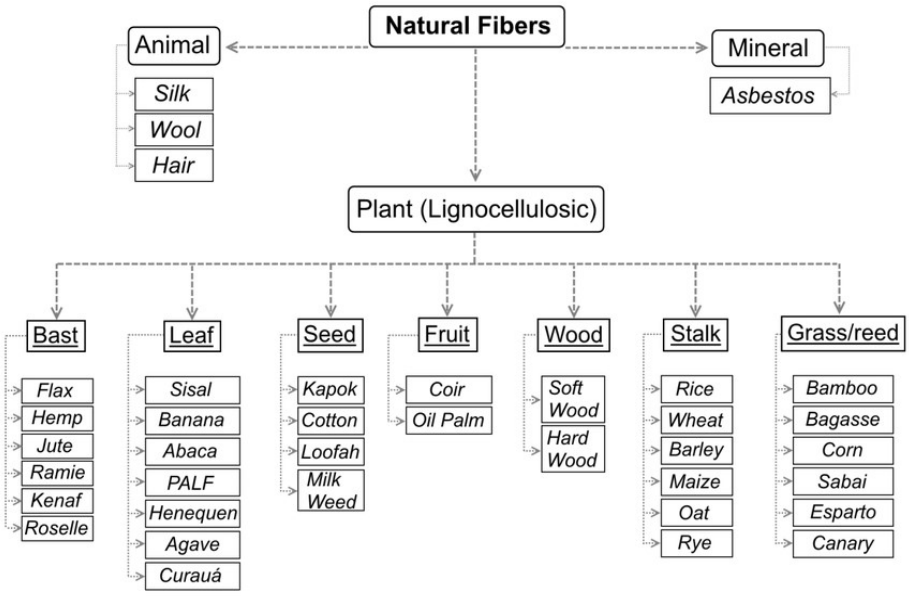


Figure 2-2: The families of natural and artificial fibers

All asbestos fibers, having a ratio of elongation (length/diameter) larger than 3 microns are considered dangerous fibers (*Lee R.J, Van Orden D.R., 2007*). Moreover, in virtue of the special disposition of chemical links, asbestos fibers separate easily in length, producing fibers which are even thinner, known as "*fibrilles*". The following table (Table 2-1) with diameters expressed in microns of mineral fibers (asbestos) natural fibers (cotton and canapé) and animal fibers (wool).

Material	Diameter (Micron)
Fibrille of chrysotile	0.02-0.04
Chrysotile fiber	0.75-1.5
Fibrille of amphiboles	0.1-0.2
Linen, canapa	12-18
Cotton	10
Wool	20-28
Human hair	40

Table 2-1: Diameter of some natural and artificial fibers

It is noted that the toxicity of fibrous material is founded on three factors, known in English as the three "*Ds*": Dose, Dimension and Durability:

- **Dose**, is the number of fibers inhaled and that deposit in the alveolar of the lungs, generally related to the development of toxic lung afflictions.
- **Dimension**, this refers to the concept that long, thin fibers are more toxic than others and remain longer in the lungs.
- **Durability** (persistence) this refers to the length of the fiber (longer fibers last longer) and to the chemical composition (resistance to deterioration in lung fluids or in the lung cells).

There is a fourth D to consider the distribution of the fibers inside the respiratory tract. It is important to know where the inhaled fibers settle. The most dangerous fibers known, after settling in the alveolar region of the lungs, migrate through the epitelio cells of the alveolar to the lung interstitium (*Tomatis L., 2006*). The possibility of subdivision in length of thousands of fibers, gives the mineral high mechanical properties and the result is that it is the only one which can be spun and knotted, leading to a massive use in different sectors such as textiles, metal works, building , paper and transport. However, these characteristics carry grave problems, namely, the release into the environment of a great number of fibers which remain suspended and become easily inhaled becoming fixed in the body with irreparable damage *(Chiappino G., 2006).* The properties of asbestos can be reassumed as following (Table 2-2).

Mineral properties	**Chrysotile**	**Amosite**	**Crocidolite**	**Anthrophylite**	**Actinolite**	**Tremolite**
Color	from white to pale green	from grey-yellowish to dark brown	Blue to grey	from white to dark green	from light green	from white to grey
T (°C) decomposition	450-700	600-800	400-600	600-850	620-960	950-1040
T (°C) fusion	1500	1400	1200	1450	1400	1325
Density (g/cm^3)	2.55	3.4-3.5	3.3-3.4	2.85-3.1	3.0-3.2	2.9-3.1
Resistance to acids	poor	average	good	very good	average	very good
Resistance to alkalis	very good	good	good	very good	good	good
Tensile resistance (Kg/csqm) to the 10^3	31	17	35	<7	5	5
Aspect	silky,flexible	fragile	fragile and hard	long and hard	--	fragile and friable
Flexibility	very good	fair	good	fair-fragile	fragile	fragile
Able to be spun	very good	fair	good	poor	poor	poor
Index of refraction	1.53-1.55	1.66-1.69	1.65-1.70	1.59-1.69	1.60-1.69	1.60-1.69

Table 2-2: Different properties of types of asbestos

3. Historical notes about asbestos

Archeological research which was conducted in 1930 near Lake Juojarvi (Finland) showed that asbestos was used, for the first time, during the Stone Age, in Western Finland. In Russia, it began to be used during the Bronze and the Iron ages. The workers added anthophollite (easily found in nearby mines) to the clay and straw mixture for stronger artifacts which were used as kitchen utensils and pots. Herodotus, in his writing, "*The Nine Muses*" tells about the use of Asbestos, in the Classical period, on the island of Cyprus, for cremation shrouds , wicks for lamps, hats and scarves. The Greek philosopher Theophrastus (c. 372-287), a disciple of Aristotle, describes asbestos as "*a stone which apparently looks like the moon, on which oil is poured, burned, but once the oil is all burned up, the stone ceases to burn as if it were responsible for the phenomena*", a circumstance confirmed by the Florentine Recipe where Allume di piuma is mentioned. Over 2000 years ago, asbestos was used in Greece to produce funeral sheets and shrouds for cremation, wicks for lamps, hats and scarves as confirmed by Pedanius Dioscorides (1 century B.C.) in his work "*De materia medica*" Strabone, a geographer and historian from 63/58 B.C. records that in the Aegean Sea, on the island of Eubea (Evia) the *"stone of Karystos"* was extracted and worked by carding and spinning and produced a textile similar to wool, that allowed them to make table coverings washed with fire. Apolonius Discolo, in the second century A.D. specifies that (again at Karystos) the people produced wicks that were indelible to flames and fabric which was even waterproof, with the use of an incorruptible stone similar to wood. Plinio the Elder, a learned Roman from the 1st century A.C. in his work Naturalis Historia described asbestos, coming from the mountains of Arcadia, as "*quicklinen*" used to make fabrics, tablecloths, and funeral tunics for the king, and shrouds in which bodies were wrapped before cremation. Other testimonies come from Anassilao from Larissa, a naturalist who followed the Pythagorian doctrine who had exalted its capacity for acoustical isolation and again in the 2nd century by Plutarch, a Greek philosopher and man of letters, who told of the vestal virgins in the Roman temples who used perpetual lamps to illuminate the sacred fire, tablecloths, nets and caps in incombustible linen from Carpasia, an antique city of Cyprus where there were asbestos quarries. We also know from Pausania, a Greek writer, that the perpetual lamps in the temple of Minerva Poliadee, in Athens, had a wick made of linen from Carpasia. In Neapolitan and Roman museums there are exhibits which prove the truth of these testimonies. After the fall of the Roman Empire and during medieval times, the use of asbestos was accompanied by fantastic legends, so much so that Charlemagne (742-814) used an asbestos tablecloth that wouldn't burn to make an impression on his guests, or to frighten his enemies in battle, and Marco Polo (1254-1324) describes for us how the alchemists and the oriental people called asbestos *"the salamander's coat"* for its fireproof properties. The Chinese define it the *"devil's stone"* because since it is resistant to fire, it evoked images of hell. Between the 14th and the 15th centuries, the mineral was used in the mining and metal working for the production of varies types of products which were in high demand for commerce and exchanges, with consequent wealth enough to economically sustain the politics of some realms. In the 6th century, asbestos was used to prepare certain medicines, also. The scientists were divided over whether to consider it a mineral or a vegetable because it was so easily made into fabric. In the Tsar's Russia, in the Central Ural region during the 17th century, asbestos was extracted and worked to make clothing and manufactured products. It was between 1860 and 1870 that the market for products made of asbestos developed notably, because the new steam technology needed a heat insulating254 material. An Italian-English association was formed by some businessmen with the reopening of the quarries in northern Italy and the discovery of vast deposits of Chrysotile in Quebec, Canada. Starting from 1890, a modern asbestos industry began in Italy with continually new applications and uses, using alpine deposits, with the improvements in the textile industry, the paper industry, panels and rope industries so much so that international attention was attracted during the universal exposition in Paris in 1878. At the beginning of the 18th century deposits of asbestos were discovered in the Urals near Ekaterinenburg and the fibers were used in the textile industry and in

1812, Crocidolite was discovered in South Africa in northern Cape province, while amosite was discovered in the Transvaal, in South Africa near the city of Penge in 1907 and production was started in 1916. As for Italy, at the time there were numerous deposits, mostly in the area called *"the green stone"* which is the area from the Pennine Alps to the Rhaetian Alps, between 500 and 3000 meters above sea level. In particular, in Valtellina and the higher Val Malenco in the province of Sondrio in Lombardy, where the annual production arrived at 700 metric tons with over 400 workers. The extraction began at the beginning of 1900 but then decreased progressively until it stopped in the early 1930's leaving its place to the extraction of talc which is active still today in the Brusada-Ponticelli mine in Val Malenco. In the region of Piemonte, Asbestos is present in the Val di Susa and in Val di Lanzo, both long and short fibered asbestos this latter being used mostly for the production of asbestos cement and is extracted from the Balangero quarry (the main asbestos mine in Europe) which began being mined in 1918 and continued until 1990. In 1992 it was inserted into the list of Sites to reclaim in the National Interest (SIN) (L. no, 257 dated 27/3/1992) and for years now work of restoration and reclamation has been going on. In 1901 "*Eternit*" (asbestos-cement) was invented by the Austrian chemist Ludwig Hatschek who patented it and let it be used in the industries of various countries. Among these is Italy and Italian Eternit was founded in Genoa and the first factory opened in 1907 in Casale Monferrato which remained the principle production plant of this type of material in Italy even if in the 1930's other plants opened in Broni, Bagnoli and Bari. In 1929, Eternit Swizerland and Eternit Belgium formed a cartel of companies which produced asbestos cement (SAIAC) with Anglo-American companies T&N, Philip Carey and Johns-Manville, which in the successive decades progressively enlarged the areas of production and sales and were able to acquire raw materials for production, create new companies in different countries reach commercial agreements for exportation and importation, to control the price and to effect great publicity to increase its use. All of this naturally, aimed at reducing the costs of production and maximizing profits (*Kazan-Allen L., 2006*). While T&N worked primarily in the countries of the British Empire, mostly in India and Africa, and Johns-Manville in the United States, Eternit became the social reason of many companies in numerous European countries (Italy, Belgium, Switzerland, France, The UK, Germany, Holland, Spain) and in Latin America. In the last century, world production reached enormous quantities totalling 174.5 million metric tons, 80% of which was produced after 1960 with the peak of world production in 1977 with 4.8 million metric tons. In the course of the centuries, the use of asbestos became so decisive, that it was used in over 3000 types of different products and its mining production reached 2.2 million metric tons still in 2008 (*Virta RL., 2008*) notwithstanding that we've known about its cancerous properties now for a long time.

4. The beginning of problems

The great versatility of asbestos due to its fibers and its very low cost have made this material amply used in different sectors: building, transport, industry and in the production of a wide range of objects and materials, creating enormous profits. So for many years the economic interests of the companies notably slowed scientific studies on asbestos and human health. Numerous court cases have seen the interests of the workers over thrown by those of the manufacturers and it was always sustained that asbestos was not harmful to health. The historical reconstruction shows clearly, however, that this is not the case and that political power, for many years, was subject to that of the big companies causing a great number of victims. Of course, this culpable delay caused damage not only to the health of the workers but also to their families, and to the inhabitants of the cities where the factories were located for decades. The people who handled the material containing asbestos were harmed but also the people who lived or stayed in rooms whose walls and roofs were made of asbestos. In 1898, Lucy Deane, an English inspector of work places, was the first to realize the grave consequences that the inhalation of the asbestos dusts had on the workers. She described an illness of the bronchial tubes and the lungs caused by the asbestos dust present in the work place. It was asbestos, although it didn't have a name back then. She defined the mineral "*evil"* and asked for a microscopic analysis which showed "*needlelike, sharp fibers similar to glass, that remaining suspended in the air in elevated quantities, haveing harmful effects*" which she wrote in her report. The next year at the Charing Cross Hospital of London, Doctor Monteque Murray, attributed the death of one of his patients, a man of 33 years, to the inhalation of asbestos dust which he had inhaled for 10 years in the textile factory where he had worked carding the fibers. This was the first time a death had been attributed to the effects of breathing asbestos dust. The Murray report which documented the death at only 30 years of age, of 10 workers who worked in that factory, came out in 1906 and lead the British government to begin an investigation, but this did not result in any concrete action. In the same year, a French inspector reported the same problem, reporting the deaths of 50 workers who worked in the industry of spinning and weaving asbestos fibers, caused by an illness which made them have grave respiratory problems. Only after two years, in Italy, a man from Turin, Luigi Scarpa, brought to the attention of the Italian congress of internal medicine, the case of 30 workers who had died because of a lung disease which was particularly aggressive and according to him justified "*the suspicion that the asbestos industry constitutes, maybe because of the special dust which it produces, to one of the most pernicious occupations (...) and special measures of hygiene and work conditions for the workers must be imposed*". In the following years, doctors who worked directly with asbestos workers denounced the problem with force, based on observations which concurred and were convincing, so that in 1918 the insurance companies in Canada and the United Stated, decided not to insure asbestos workers anymore "*because of the evidence on the harmful working conditions present in the industry"*. Moreover, The United Stated began to provide economic compensation to the workers in this sector but this was opposed to by the industry for its cost and many years were to pass before this type of action was effectively taken. Even the first official act in the UK, made on the basis of a study which showed that 66% of the workers, after 20 years in the factory, had contracted asbestosis. This was approved in 1931 and require compensation and obliged the companies to make the work place a healthier place for the workers (vacuum systems, elimination of the processes which generated the dust, more efficient cleaning systems, mechanization of the work and the exclusion of young workers), but this was enacted only in part, at least until 1969 when this rule became more strict and stringent. As the cases of asbestosis increased even for workers who did not work directly with asbestos, and were reported to the public, the industrialists began to be afraid that their profits would disappear. So, in the 30's the main companies in the sector, such as Turner & Newal, began to organize themselves to discredit the government research minimizing the risks and financing scientific studies reserved for the business owners. They chose an American doctor, Anthony Joseph Lanza, who was very competent on the effects of inhaling different kinds of dust on the lungs. In the 20's, he had left public service to work for the Metropolitan Life Insurance Company, a company which offered medical and legal advice to insurance companies and to industry. In 1929, some companies which worked with asbestos, asked the Metropolitan company to do some studies in their factories to see if asbestosis really existed and Lanza didn't need much time to see that the answer was yes. The publication of the results was delayed and after second thought, since the industry had no interest in making the findings public, the findings were published after 4 years. In 1935 in "*Public Health Reports*" the article reported that out of 121 workers analyzed, 64 had symptoms of asbestosis and suggested putting in act some simple measures to protect the workers (and protect themselves from legal action). The article had been rewritten and modified so that the data reported could not harm the companies. The next year Lanza was contacted by a doctor from the factory in Waukegan, Illinois who thought it right to warn the workers about the risks of breathing the dusts every day so that he could take measures to reduce the possibility of contracting lung diseases. Also at this time, the top managers of the Johns-Manville company decided to make periodic analyses of the concentration of dusts in their factories, *"to protect themselves in case of law suits"*. Lanza suggested that the lab Saranac, from New York, do the analyses directed by Leroy Gardner. With money provided by different companies, the center was commissioned to make studies on animals, too, on the condition that the results could be made public only if the companies agreed to it. One of these studies was to verify if asbestosis could trigger tuberculosis, but it showed a much greater effect, a very high rate of lung tumors in the mice exposed to asbestos dust; 81.8% of the mice were affected. As was in their power, the companies blocked the publication of the data and when the study was published, in 1943, no mention was made of lung tumors even if in the 1930's in England, some cases of workers stricken with asbestosis later had malignancies. Already in 1943, in Germany, the Reich, included these tumors in the list of professional illnesses caused by asbestos. These studies remained secret until after the war, but later were considered valid. At the end of that decade, there were some cases of lung tumors even in the United States, but the cases were too few to affirm that the risk was real. The English epidemiologist Richard Doll, from the London School of Hygiene, published a report in 1955 of a study made in the factory of Turner&Newal in Rochdale. This study showed that people who had worked in an asbestos factory for at least 20 years were 10 times more at risk than the general population. The long period of incubation of the illness-between 20 and 25 years had prevented the relationship to emerge clearly. Among the workers, asbestos increased the risk of lung tumors five times in non smokers and 53 times in smokers. This probe was promoted by a doctor J. Knoz, who together with Richard Doll wanted to go deeper into the question of lung tumors. When they had the results, the doctor informed the top managers at Turner & Newal, who prohibited the publication. In spite of the firm opposition of the doctors, the report was published without the data on the lung tumors. The study represented a great problem to the asbestos industry, but it was only the beginning of problems for the lobby. In 1940, in South Africa, a very rare and aggressive type of tumor was discovered by a doctor who worked in the area where blue asbestos was extracted. Many of his patients had grave symptoms. He consulted with two doctors more expert than he was, Chris Wagner and Ian Webster, who had understood that at the origin of the 47 cases of lung disease reported, the exposure to asbestos could be the cause and they decided to investigate. This proved particularly difficult because of the long incubation period of mesothelioma, sometimes 40 years and also because it seemed to affect people who didn't work with asbestos or in its extraction. The two doctors however went ahead with resolve and painstaking work and were able to prove that at least 45 of these people had been exposed to asbestos either because they had had the misfortune of playing near piles of materials discarded from the mines when they were children, or because their houses were too near to this material. This study was published in 1960 had the consequence to alert other doctors to verify whether or not patients with this rare form of lung cancer could have been exposed to asbestos. In 1964, an American doctor, Irving Selikoff, presented a study he did at a convention at the Academy of Science of New York, where he attested to a very high number of people with mesothelioma (besides asbestosis and lung tumors) who worked with asbestos. Dr. Selikoff work had continually been boycotted by the asbestos industry, but the what emerged from the conference about the problems of asbestos, frightened the asbestos lobby because it regarded the cases of people who had never worked in the factories. By tracing the medical histories of 76 people stricken with mesothelioma recovered in London Hospital, the English doctor, Muriel Newhouse, attested that almost half of them had never worked in the asbestos industry but many had relatives or others living with them who had, or they lived less than 800 meters from a factory. It was always more apparent that that terrible form of tumor could be unleashed by exposure to even a small amount of of asbestos fibers. It was Doctor Irving Selikoff of the Mount Sinai Hospital in New York who understood more quickly than others the gravity of the data being published and he immediately tried to raise an alarm that wasn't only to experts in this sector, but which could arrive to the media, to the professional organizations ,and to the industrialists of the asbestos companies. But once again, these refused to cooperate, and in fact, realizing the risks that would result to their profits from the alarm raised, they presented him with an injunction informing him that he would be sued if he gave information damaging to their interests. Moreover, someone felt it necessary to *"find a way to prevent Selikoff from causing problems and influencing our businesses"* and there was who suggested to "*keep him quiet with money*". All of these tactics failed and Selikoff went ahead researching data on these problems of health and asbestos until his death in 1992 at the age of 77. Many other doctors around the world followed his example since the research was becoming public domain and some newspapers began reporting it (in Italy in particular L'Unitá talked about it). The first restrictive measures began to be taken on this new and miraculous material which had conquered the world and public opinion, Year after year, one after another, provisions and restrictions on the use of asbestos were taken. In 1969 England prohibited the use of blue asbestos and made protection for workers obligatory, The next year Australia followed the example, while the USA made compulsory rules on the working and the transporting of the material in 1972.Once again, the industry started to find a new defensive strategy which comes out clearly reading the motivation of the sentence of first degree in the Eternit trial which concluded in Turin in 2012. "The diffusion of information always more precise on the danger of asbestos dusts induces the industries in the sector to elaborate a common strategy. In the occasion of the international conference of the organizations of information on asbestos (the Asbestos Information Committee) held in London in November of 1971 (…) the president of the Asbestos Information Committee, M.F. Howe, foreseeing that the criticism against asbestos would intensify, advised (…) to collaborate in forming a more binding legislation, and in the meantime forming a lobby which would develop a communication strategy. He observed, in fact, that *"the attacks, even those that come suddenly, could be the work of journalists in the medical sector or experts in your countries, or springing up from writings and declarations from people outside the industry such as doctor Selikoff and Rattray-Taylor, or which could be inspired by the unions. They could first strike a certain product… or go for the use of asbestos in general. In my opinion, the increasing measures will be bound to fears for the environment*". Howe incited his colleagues the examine carefully and to develop their instruments of defense based on counter-information spreading '*peaceful*' information and inviting everyone to participate, where possible, to setting down the regulations of each single government (…) to what will be published. In 1976, in the largest European newspapers, appeared some hard-hitting advertisements pointing out that "*the problems that asbestos pose are irrelevant when compared to the enormous services which it gives every day without your knowing it. These* *problems can and will be resolved*", This maneuver, centered on incorrect information and on political interference, became more decisive as time went on. In 1977, asbestos was recognized as a certain cancerous substance for man by the international agency for cancer research in Lyon (IARC) following a short study but with undeniable proof, and the lobby in order to find new counter measures organized periodic meetings (tour d'horizon). When we got to 1981, at the exhortations of the European Commission, which wanted massive diffusion of information on the danger of the mineral, to go towards professional organizations, universities and occupational physicians , the businesses decided to "*fight for asbestos in Europe, at least against the proposals and the more extreme threats (...) "was written in a reserved report.* "*The action to pursue should include looking for support from members of the European Parliament especially among those who have asbestos plants in their electoral districts*." With the great amount of money at their disposal, they did their best to bring concrete results provoking the delay of the approval to the rules for safeguarding the health of the workers and of the population also in the countries that had shown more sensitivity to the problem. Even the English law of 1969 was not resolutive nor complete in spite of all the documents already seen, it had not considered the carcinomas but only the putting in act of cautionary measures to prevent asbestosis (safeguarding English workers health concerning even tumors, came 10 years later). In Italy a story of the first studies on the pathologies of asbestos was done by Enrico Vigliani who was director for more than 30 years (1942-1977) of the clinic of occupational medicine of Milan, which was the center of studies on the harmfulness of the mineral. Vigliani remembered a study from 1908 on the incidence of tuberculosis in workers in the asbestos industry, a graduate thesis from the University of Turin from 1910 entitled *"a lethal case of pulmonary asbestosis complicated by tuberculosis"* (which made Vigliani sustain that the term "*asbestosis*" was coined in Italy and not in Great Britain) and the relation of the Occupational inspectorate of 1930. In the years 1939-1940, the question began to be treated in a systematic way thanks to different scientific publications of Vigliani and of the pathologist Mottura. A successive study of Carnevale and Chellini (1993) contributed fundamentally the overview of the studies on the asbestos pathologies in Italy bringing to light how our country during the two years of 1964-65, reached a consciousness of the cancerous risks, due to the studies of Vigliani who was the speaker at the conference at the New York Academy of Sciences in 1964. From 1965 there followed numerous reports on pleural mesothelioma: concerning pulmonary tumors, in the decade from 1955-64, significant things were published. In the Manual of Occupational medicine of Francesco Molfino (*Ed. Minerva Medica, Turin,1953*), in the chapter dedicated to asbestosis on page 31 we read that "*the cancers of the lungs ....seem to be quite frequent in asbestosis"*. In the mid sixties, the cancerous properties of asbestos were known (*Vigliani su Tempo Medico,1966 and Wagner su Abbot-Tempo del 1968*), and this brought about measures to reduce levels of exposure to asbestos in industry. In one study from 2000 of Kauppinen et.al. it was calculated that in our country in the period 1990-1993, 680,000 people were exposed to asbestos, equal to over half the total number of those exposed in the same time period in the 15 European countries taken in consideration. In fact, In Italy in the first half of the 80's there was a rise in the use of asbestos (Figure 4-1), while by then both in the USA and in other European countries, there was a reduction, due to a major awareness of the dangers of the mineral and to legislation enacted to eliminate or reduce and confine the use of asbestos (*Marinaccio et.al. 2005;Marinaccio Binazzi A.,2012).*

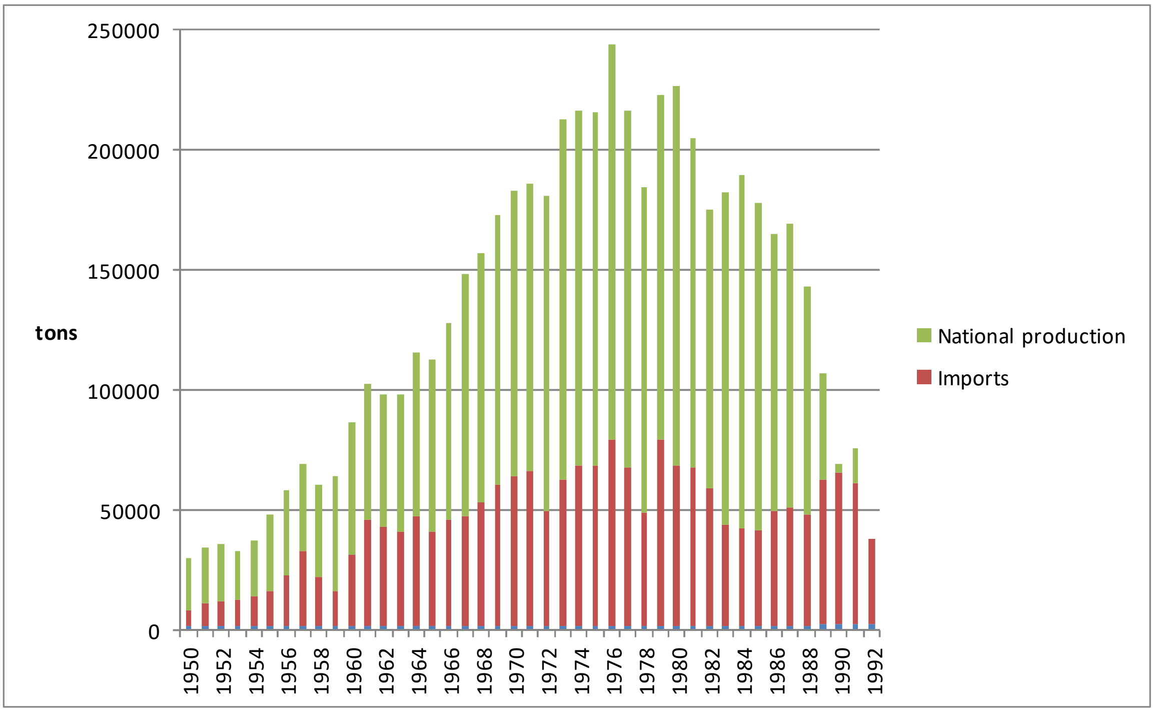


Figure 4-1:Trend of Italian production and importation of asbestos in fiber from 1950 to1992

Taking into account the time trend of the pro capita use of asbestos in Italy, seen in the past and the average period of incubation of the asbestos correlated illnesses (from 30 to 40 years) the maximum number of deaths is predicted to occur between the years 2020 and 2024 (*International Journal of Cancer, 2005;Robison,2012;Diandini et al, 2013*) Only after these years will there be an inversion of the tendency in the number of deaths due to pleural mesothelioma, at this time, still increasing *(Delgermaa et al, 2011; Park et al, 2011).*

5. The major producers and Consumers of asbestos in the world

In the following figure, (Figure 5-1) a reassuring decrease in the consumption of this mineral in the world, is seen. It passes from 1,550,000 metric tons in 2014 to 1,140,000 metric tons in 2017. In particular, we note, that in 2019, Europe, Canada and Australia, totally eliminated the use of the mineral, while in the Americas and on the African continent, its use has been strongly limited. Another positive note is the situation in South America where Brazil, Argentina and Chile in the last years, have been able to make the use of asbestos illegal. Asia, Russia ,India and China are still the major consumers of asbestos in the world (in 2000 as in 2019).

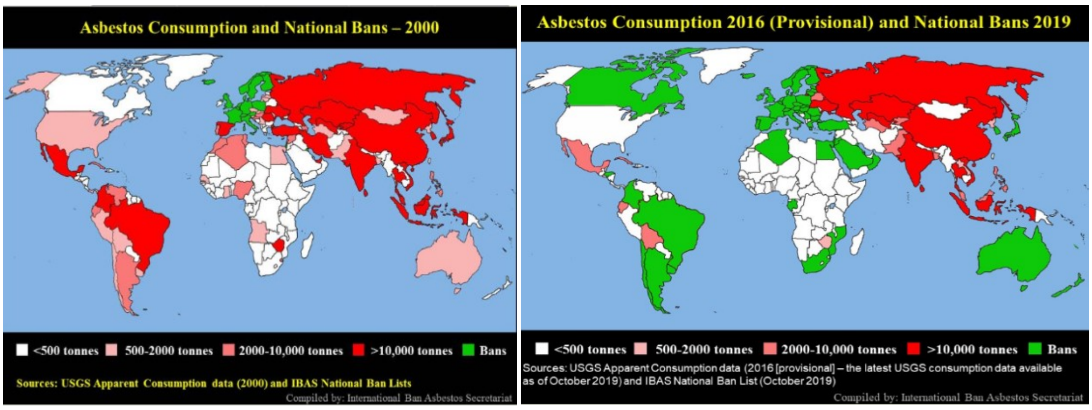


Figure 5-1: Map of the world showing the countries which have banned the use of asbestos (updated 2019)

Following is a list of 67 countries in the world (Figure 5-2) where asbestos has been banned (updated 2019):

Algeria	Czech Republic	Iraq	Mauritius	Seychelles
Argentina	Denmark	Ireland	Monaco	Slovakia
Australia	Djibouti	Israel	Mozambique	Slovenia
Austria	Egypt	Italy	Netherlands	South Africa
Bahrain	Estonia	Japan	New Caledonia	Spain
Belgium	Finland	Jordan	New Zealand	Sweden
Brazil	France	Korea (South)	Norway	Switzerland
Brunei	Gabon	Kuwait	Oman	Taiwan
Bulgaria	Germany	Latvia	Poland	Turkey
Canada	Gibraltar	Liechtenstein	Portugal	United Kingdom
Chile	Greece	Lithuania	Qatar	Uruguay
Colombia	Honduras	Luxembourg	Romania	
Croatia	Hungary	Macedonia	Saudi Arabia	
Cyprus	Iceland	Malta	Serbia	

Figure 5-2: List of countries where asbestos is banned (Geological Survey, Mineral Commodity Summaries, January 2020)

In table 5-1 above, is shown the consumption of asbestos in the world from 2014 to 2017. On the continent of Africa, Angola, Benin and Ghana have completely banned the mineral while Nigeria, and Zimbabwe are on their way to a significant reduction, while South Africa is still consuming as in 2017, about 3,180 metric tons of asbestos. In Asia and the Middle East, even though there has been as slight decrease in the four years from 2014 to 2017, their use of asbestos is still high at 92.11%. India and China, respectively with 318,000 and 235,000 metric tons used in 2017, are still far and away the two countries which use the most asbestos. After those countries comes Russia with 118,000 metric tons and Indonesia with 105,000 metric tons. In any case no country has banned asbestos. In North and Central America, the use, from 2014 to 2017, more than halved. on the contrary, Cuba increased its use. In Europe, asbestos is still used in the east block and although a slight decrease has been noted, it isn't yet significant. In South America, all of the countries interested, have reduced their use by three quarters passing from 201,000 metric tons used in 2014 to 48,100 metric tons in 2017. On the global level, the reduction although conditioned by the stalemate of use in the Asiatic countries, is at 27%, passing from 1,550,000 in 2014 to 1,140,000 metric tons of asbestos used in 2017 (*Minerals Yearbook, 2017*).

Region and country or locality	2014	2015	2016	2017
Africa:				
Angola	409	326	167	NA
Benin	NA	184	1.630	NA
Ghana	451	NA	(5)	--
Nigeria	--	35	353	18
South Africa	4	1.530	3.520	3.180
Zimbabwe	5.280	1.550	265 r	851
Other	470	578	1.030	68
Total	6.620	4.200	6.960 r	4.120
Asia and the Middle East:				
Bangladesh	12.100	10.400	11.900	18.300
China	366.000	304.000	280.000	235.000
India	379.000	370.000	308.000	318.000
Indonesia	109.000	120.000	114.000	105.000
Kazakhstan	39.500	11.400 r	25.300	10.500
Kyrgyzstan	5.630	4.450	6.800	9.170
Malaysia	3.590	2.980	2.240	2.460
North Korea	710	362	577	629
Pakistan	2.300	2.850	2.880	3.430
Philippines	2.670	1.780	3.110	2.910
Russia	156.000	124.000	101.000	118.000
Sri Lanka	42.100	34.500	47.400	35.700
Tajikistan	60	514	1.430	4.380
Thailand	41.900	36.500	32.700	42.600
Turkmenistan	4.280	4.790	4.280	6.410
Uzbekistan	76.400	56.100	70.600	97.000
Vietnam	52.900	61.300	58.100	43.100
Other	1.350	1.700	959	857
Total	1.300.000	1.150.000	1.070.000	1.050.000
Central America and North America:				
Cuba	2.890	4.100	3.080	4.610
El Salvador	723	487	365	960
Mexico	10.200	12.100	4.150	587
United States	416 r	325	747	332
Other	398	100	5	40
Total	14.600	17.100	8.350	6.530
Europe:				
Belarus	6.210	7.180	5.530	6.580
Romania	103	4.160	2.700	887
Ukraine	24.700	10.400	15.500	16.000
Other	115	161 r	306	218
Total	31.200	21.900 r	24.100	23.700
Oceania	26	109	27	163
South America:				
Bolivia	6.260	4.170	4.740	2.200
Brazil	181.000	125.000 r	89.900 r	40.300
Colombia	8.940	5.960	197	3.330
Ecuador	4.470	4.100	2.750	1.510
Other	220	1.130	690	720
Total	201.000	141.000 r	98.300 r	48.100
Grand total	1.550.000	1.330.000 r	1.210.000 r	1.140.000

Table 5-1: Use of asbestos in the world between 2014 and 2017 (Minerals Yearbook, 2017)

The following reports the course, from 2014 to 2017, of the world production of asbestos fibers (Table 5-2). From the data emerges a progressive decrease in the world production of fiber which passes from 1.520.000 metric tons in 2014 to 1,150,000 metric tons of fiber produced in 2017 (-24.34%). Russia is by far the major producer of asbestos fiber during the four year period, with 710,000 metric tons (67.74%). After years of decreased production, in 2018, the company Uralasbest, owner of a mine in Russia in the Ural Mountains, near the city of Asbest, increased its production of asbestos to up to 315,000 metric tons, of which at least 80% is exported, with a great part still sold in the USA. Brazil, during the course of 2019, definitely banned the extraction of the mineral within its borders.

Country or locality	2014	2015	2016	2017	2018
Brazil	311.227	232.052 r	170.000 r, e	135.000 r, e	110.000
China	258.632	227.073	191.632	124.723	125.000
India	227	--	--	--	--
Kazakhstan	213.100	179.800 r	192.600	192.700	202.900
Russia	733.067	650.375	691.712	710.248 r	710.000
Total	1.520.000	1.290.000 r	1.250.000 r	1.160.000 r	1.150.000

Table 5-2: The production of asbestos fiber in the world between 2014 and 2017 (Minerals Yearbook,2017)

As we can see from the following graph (Figure 5-3), the extraction in 2019 of asbestos fibers in the world has further diminished, attesting to a total of 1,090,000 metric tons. The major producer remains Russia (68.8%) followed by Kazakhstan (18.3%), China (11.5%) and Brazil (1.4%).

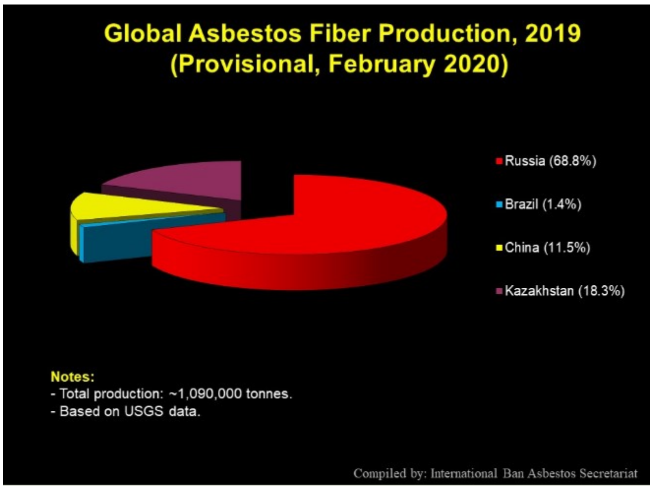


Figure 5-3: The major producers of asbestos fiber in the world (U.S. Geological Survey, Mineral -commodity Summaries,2020)

Lastly, in table 5-3, we see the major exporters of asbestos in 2017:

Russia	492,389	tons
Kazakhstan	172,621	tons
Brazil	129,767	tond
China	40,511	tond

Table 5-3: The major exporters of asbestos,2017 (United States Geological Survey USGS)

6. Classification of asbestos containing materials (ACM) and uses

The above mentioned asbestos minerals possess multiple technological properties (*Paglietti F.,2014*):

1. Soundproofing;
2. thermal insulating, resistant to high temperatures and fire;
3. elevated flexibility, elasticity, and friability;
4. resistant to acids and alkalis;
5. resistant to wear and fiction;
6. can be worked as a textile;
7. can be mixed and worked with cement based materials.

ACM or asbestos containing materials are classified according to experience, commercial practices or type of use or processing. In the present case tied to the problems inherent in the decontamination, where the potential for danger is essentially due to the release of fibers into the air, the criterion suggested by the Italian regulation for this material (D.M. 06/09/1994) regards the brittleness of the material based on the possibility that it to frees fibers into the atmosphere. Therefore, on the basis of friability, we have two categories of ACM:

1. **Friability**: or brittleness: material easily crumbled or reduced to dust with only simple hand pressure;

2. **Compact**: materials which can be easily crumbled or reduced to dust with the use of mechanical equipment and not with simple hand pressure

Products containing asbestos have different levels of danger determined by both the different compositions and by the wear that they are subjected to. Another variable is determined by where they are used and by conditions of exposure:

- outdoors or indoors;
- aggressive natural processes (acids, exposure and phenomena atmospherical in particular to intensity, sudden thermal swings, high winds etc.);
- tampering (cutting, abrasions, perforations etc.);
- high intensity accidents (fires, earthquakes, floods, tornadoes etc.);
- high probability events (hailstorms).

As seen in the table below (Table 6-1) the percent of asbestos contained in various products, depending on the material, is between 2% and 100% of the weight.

Material	Friability	Content of asbestos by weight
Spray on coverings or insulating coatings	Very friable	80-90%
Insulating coatings of pipes and heaters, panels and isolating blocks	friable	10-100%
Ropes, cords and textiles	Friabile	50-100%
Cardboard, paper and like products	Non friable	100%
Products of asbestos cement of variable density	Non friable	10-15%
Products of bitumen, brick, paving, plastic, stucco, adhesives	Non friable	2-15%

Table 6-1: Level of brittleness and the percent of weight of asbestos in different types of materials

The characteristics just sited, and the low cost of processing, facilitated the use in numerous fields and in over 3000 types of products (*Bullian, 2008*) containing asbestos amply spread over the whole nation. Table 6-2 shown a list of the main types of products containing asbestos divided into nine categories.

PHYSICAL STATE	CATEGORY	N.	TYPE OF PRODUCT CONTAINING ASBESTOS	FUNCTION OF ASBESTOS
Asbestos used as is or present as an accidental contaminant	Fibers without bonding	I	Pure asbestos in flakes, compressed cushions of raw fibers, mattresses and mats, blankets, clothing and protective accessories, couples, cords, wicks gaskets, filters, filtering swabs, felt, compressed raw fiber panels, sandwiching panels, liners and dies/shapes for foundries	Soundproofing, heat insulation, mechanical resistance, resistance to chemical, attacks anti condensation, dielectric rigidity, fireproof

	Asbestos present in mining products	II	Semi-worked Green Stone: Ballast railways, gravel for filling and for substrate roading, extraction dust and mine processing, raw sheets and blocks processed green stone: polished sheets ornamental objects, soapstone, tables tiles, shingles	Mechanical resistance resistance to chemical attacks, Ornamental, Fireproofing,
Asbestos in solid products	Asbestos textiles (threads, woven, and pressed)	III	Wicks, braids, stuffing's, blankets, cushions, protective clothing and accessories borders, movie screens, theater curtains, mats, carpets, moving conveyor belts, felt filters gaskets and fabric or braided packing upholstering fabric, linens, ironing board covers, curtains	Heat insulation, mechanical resistance, resistance to chemicals, fireproofing ornamental
	Asbestos-cement	IV	Slate, edging, slabs, tiling, shingles, fireplaces, chimneys, industrial fireplaces, flue pipes exhaust fans, chimney pots, caissons, cisterns tanks, silos, containers of various kinds, Spritzbeton columns, pillars, guard rails, building units, work planes prefabricates, cementized mortar, columns of reflux discharge and waste discharge, tubes, bulwarks gutters, rain spouts, wells, expansion tanks, couplings joints, partition walls, prefabricated building units, canalization railroad ties, electric panels, cement dust	Heat insulation, soundproofing, rust proofing, mechanical resistance, resistance to chemicals, fireproofing ornamental
	Asbestos in inert matrix (different from cement)	V	Sprayed asbestos, coppelle, fillers, materials in plaster matrix, plasterboard and drywall, plaster mortar stucco, liners and dies/forms for foundries.	Heat resistant, soundproofing, mechanical and chemical resistance, flame retardant, binding and sealing capacity
	Asbestos in cellulose matrix	VI	Paper, wall paper, plasterboard panels, cardboard panels, (for coverings, interposition, sandwiching panels, diaphragms for electrolyte processes, filters, gaskets, fire screens, sprues, gas mantles tabletops	Heat resistant, soundproofing, mechanical and chemical resistance, flame retardant, binding and sealing capacity

	Asbestos in plastic matrix resins, rubber	VII	Sprayed asbestos in vinyl matrix, glues, adhesives, sealing rings, slip proof edging, couplings, washers, stuffing-presser, asbestos-vinyl, asbestos walls, panels, belts, speed change for vehicles, clutch disks, brake linings, brake systems, synthetic stucco, various products in plastic or composites, toys, components etc.	Heat insulating, soundproof, rustproof, chemical and mechanical resistance, fire retardant, sealing and binding capability
	Asbestos in bituminose products	VIII	Glues, adhesives, asphalt covering, edgings, bituminized, board, felt mats, bituminized surface coverings, sheaths, ceramic filters, stucco surface covers, leak proof protection (for drains, tanks, canals, etc) felts, sheets of paper	Heat insulating, soundproofing, rust proof, resistant to chemical and mechanical attacks, flame retardant, sealing binding capacity
Asbestos in liquid	Asbestos in products paints and foams	IX	Paints, enamels, glaze, foams	Heat resistant, sound proof, rust resistant, resistant to mechanical and chemical attacks, flame retardant, sealing and binding capacity

Table 6-2: Types of manufactured products containing asbestos per physical state, category and function

Another classification for these materials could be made as to "*economic activity*" in which they are used. Following are some diagrams which reassume the uses in the main sectors: building, transportation, industry, and public utility.

Building Construction

- ✓ As a material sprayed on to cover metallic structures or beams;
- ✓ in prefabricated elements in plaster;
- ✓ drywall;
- ✓ in panels and lowered ceilings (soundproofing/ insulation) ;
- ✓ in paving's made with vinylvil asbestos and as subflooring flame breakers;
- ✓ in paperboard used as protection to heating plants;
- ✓ inside the doors of heaters;
- ✓ ……….

In this sector, it was used to make roofing in panels, or sheets, tiles, briquettes or flagstone for pavements, for tubes and tanks or chimney flues. In these latter cases, the asbestos is enclosed in cement so as to form a cement-asbestos composite, commonly known as Eternit. In figure 6-1 we see the more common places "*to find*" asbestos in a house.

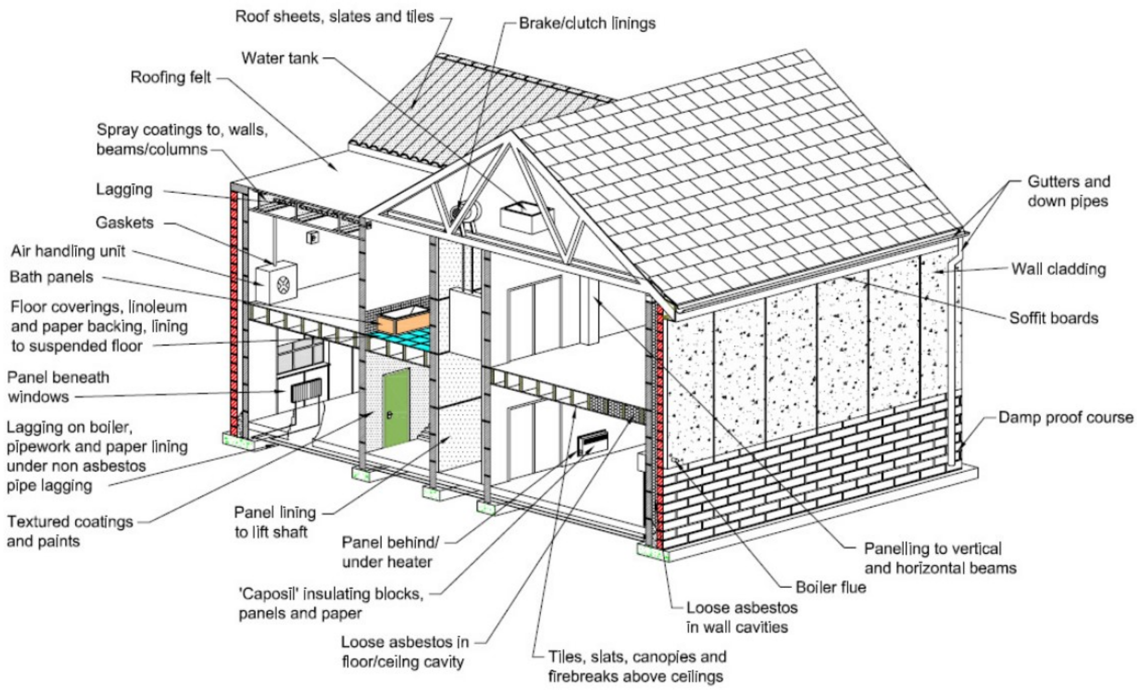


Figure 6-1: Presence of asbestos in a typical house (Bradley Environmental UK)

TRANSPORTATION

- Ships and navy yards;
- Rail rolling;
- Automobiles;
- Bodywork and metal carpentry;

INDUSTRY

- Electric Energy;
- Refineries, petrochemicals and chemicals;
- Glassworks;
- Pottery;
- Iron and steel industries and hot metal working;
- Printing and stationery;
- Textile, packaging and clothing;
- Domestic appliances;

PUBLIC UTILITY

- Military;
- Health;
- Public administration buildings.

7. Asbestos containing waste (ACW) in Italy

7.1. ACW classification

The waste classification legislation currently in force in Italy (*Italian Legislative Decree no. 152/2006*) states that waste must be classified as hazardous, in accordance with Directive 2008/98/EC, if it contains "*a substance recognised as carcinogenic (Category 1 or 2) in a concentration ≥ 0.1%" (F. Paglietti, S. Maliconico, 2016).* Given that asbestos is a Category 1 carcinogenic substance, all waste containing concentrations greater than 0.1% must be classified as hazardous. Considering that asbestos containing materials (ACMs) have concentrations averaging between 10% and 98% of hazardous substances, when they become waste, according to the definition "*any substance or object which the holder discards or intends to discard or is required to discard"* they must be classified as special hazardous waste. All special waste is classified as hazardous when it meets the criteria of Part IV of Italian Legislative Decree no. 152/2006 (replaced by Legislative Decree No. 205/2010). On the subject of classification, the recitals of Annex D are integrated into Italian Legislative Decree no. 152/2006 by art. 13(5)(b-*bis*) of Italian Law no. 116/2014. Finally, all special hazardous and special non-hazardous wastes, including asbestos waste, are classified according to origin in the European Waste Catalogue (EWC) introduced by Community Decision of the Commission no. 2000/532/EC and in force since 1 January 2002.Initially, six types of ACW were listed in the EWC, only two of which were hazardous waste (Table 7-1). Subsequently, with the amendments and additions made by Commission Decisions nos. 2001/118/EC and 2001/119/EC and Council Decision no. 2001/573/EC, implemented in Italy with Italian Legislative Decree no. 152/2006, the types of ACW increased to eight, all classified as hazardous waste and marked with an asterisk.

EWC codes	Definition
06 07 01*	Wastes containing asbestos from electrolysis
06 13 04*	Wastes from asbestos processing
10 13 09*	Wastes from asbestos-cement manufacture containing asbestos
10 13 10*	Wastes from asbestos-cement manufacture other than those mentioned in 10 13 09
15 01 11*	Metallic packaging containing a hazardous solid porous matrix (for example asbestos), including empty pressure containers
16 01 11*	Brake pads containing asbestos
16 02 12 *	Discarded equipment containing free asbestos
17 06 01*	Insulation materials containing asbestos
17 06 05*	Construction materials containing asbestos

Table 7-1: EWC codes identifying ACW

In addition to the EWC codes listed above, whose definitions specify the presence of asbestos, a further 21 codes were added which, although not explicitly including the word "asbestos" in the description, allow the classification and management of certain types of waste containing this carcinogenic substance (Table 7-2).

EWC codes	Definition
08 01 11*	Waste paint and varnish containing organic solvents or other hazardous substances
08 04 09*	Waste adhesives and sealants containing organic solvents or other hazardous substances
10 01 16*	Fly ash from co-incineration containing hazardous substances
15 02 02*	Absorbents, filter materials (including oil filters not otherwise specified), wiping cloths,

	protective clothing contaminated by hazardous substances
15 01 10*	Packaging containing residues of or contaminated by hazardous substances
16 10 01*	Aqueous liquid wastes containing hazardous substances
16 11 03*	Other linings and refractories from metallurgical processes containing hazardous substances
16 11 05*	Linings and refractories from non-metallurgical processes containing hazardous substances
17 01 06*	Mixtures of, or separate fractions of concrete, bricks, tiles and ceramics containing hazardous substances
17 02 04*	Glass, plastic and wood containing or contaminated with hazardous substances
17 04 09*	Metal waste contaminated with hazardous substances
17 05 03*	Soil and stones containing hazardous substances
17 05 07*	Track ballast containing hazardous substances
17 06 03*	Other insulation materials consisting of or containing hazardous substances
17 08 01*	Gypsum-based construction materials contaminated with hazardous substances
17 09 03*	Other construction and demolition wastes (including mixed wastes) containing hazardous substances
19 03 04*	Wastes marked as hazardous, partly stabilised other than 19 03 08
19 03 06*	Wastes marked as hazardous, solidified
19 07 02*	Landfill leachate containing hazardous substances
19 13 01*	Solid wastes from soil remediation containing hazardous substances
19 13 03*	Sludges from soil remediation containing hazardous substances

Table 7-2: Additional EWC codes identifying ACW

7.2. Data analysis: generation of ACW

From data provided by ISPRA (Italian National Institute for Environmental Protection and Research) in its 2019 Special Waste Report, 327,000 metric tons of asbestos containing waste was produced in Italy in 2017. As shown in the table below (Table 7-3), the largest quantity is represented by construction materials containing asbestos (EWC code 170605), which accounts for 94.2% of the total waste produced. Insulation materials containing asbestos (EWC code 170601) accounts for 4.9%. Compared to 2016, the total quantity produced in 2017 decreased by approximately 25,000 metric tons, or 7%. In 2017, the region in Italy with the largest amount of asbestos containing waste was Lombardy, with almost 94,000 metric tons, corresponding to 28.6% of national production, of which 92.3% was classified as construction materials containing asbestos (EWC code 170605). The other regions that contribute significantly to the production of asbestos waste are Veneto (74,000 metric tons), Emilia-Romagna (38,000 metric tons) and Piedmont (around 31,000 metric tons).

REGION	150111	160111	160212	170601	170605	TOTAL
Piedmont	26	0	39	795	29,912	307,772
Aosta Valley	0	0	0	37	287	324
Lombardy	503	2	319	6,402	86,444	93,67
Trentino-Alto Adige	30	0	0	8	1,060	1,098
Veneto	1,002	7	15	1,485	72,020	74,529
Friuli-Venezia Giulia	12	1	1	195	6,151	6,360
Liguria	13	0	19	690	2,402	3,124
Emilia-Romagna	107	0	32	178	37,509	37,826
NORTH	**1,693**	**10**	**425**	**9,790**	**235,785**	**247,703**
Tuscany	104	0	55	3,551	16,611	20,321
Umbria	308	1	0	34	5,675	6,018
The Marches	78	0	21	522	5,763	6,384
Lazio	40	0	16	1,04	11,409	12,505
CENTER	**530**	**1**	**92**	**5,147**	**39,458**	**45,228**
Abruzzo	26	0	0	12	6,216	6,254
Molise	1	0	0	0	605	606
Campania	12	0	0	184	5,236	5,432
Apulia	21	0	14	511	6,019	6,565
Basilicata	3	0	0	39	1,693	1,735
Calabria	1	0	10	61	3,774	3,846
Sicily	7	0	24	207	7,456	7,694
Sardinia	6	0	7	31	2,214	2,258
SOUTH	**77**	**0**	**55**	**1,045**	**33,213**	**34,390**
TOTAL	**2,300**	**11**	**572**	**15,982**	**308,456**	**327,321**

Table 7-3: Asbestos waste generation by type (metric tons), 2017 (ISPRA)

Figure 7-1 shows the trend in waste generation from 2007 to 2017.

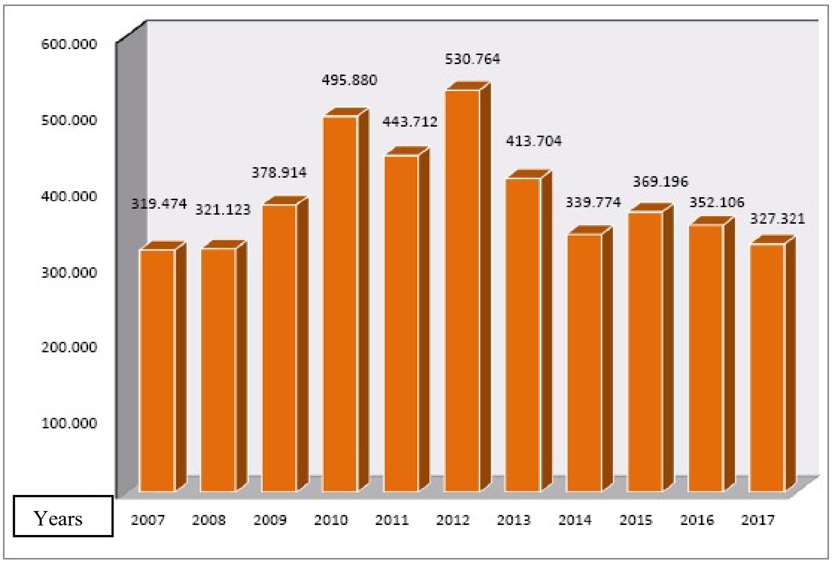


Figure 7-1: Trend in asbestos waste generation (metric tons), 2007-2017 (ISPRA 2019)

Analysis of the 2017 data, divided by macro region, shows that the highest production of ACW was recorded in the North, with 75.7% of the national total, while the Centre and South produced 13.8% and 10.5%, respectively (Figure 7-2).

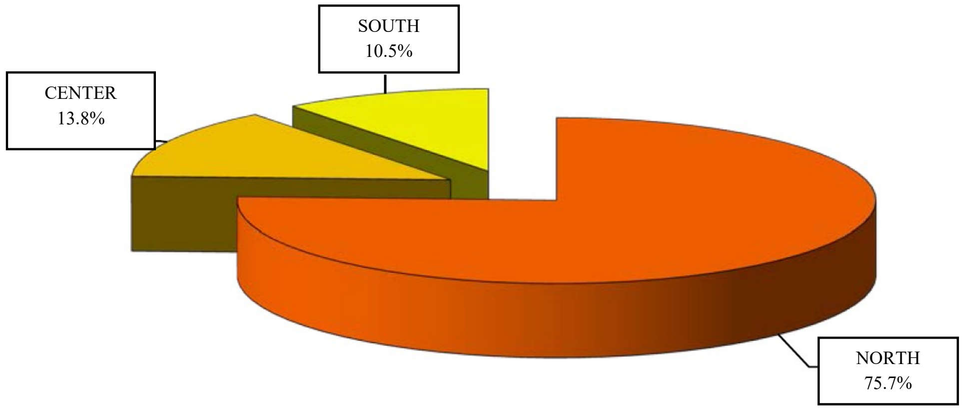
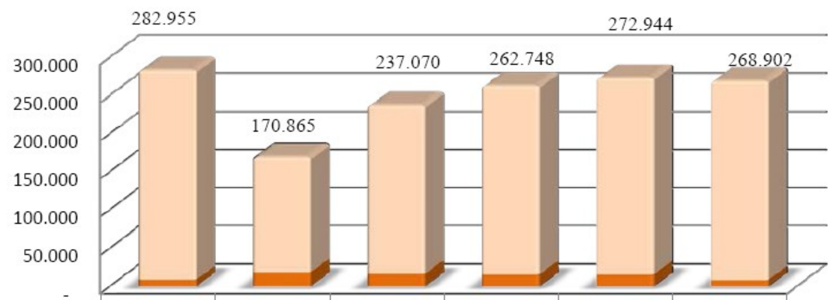


Figure 7-2:Asbestos waste generation by macro region, 2017 (ISPRA 2019)

In 2017, the total amount of ACW processed in Italy was about 269,000 metric tons, which, compared to 2016, represents a decrease of 1.5%. In addition to the waste processed in Italy, 101,000 metric tons were exported. In 2017, construction materials containing asbestos accounted for 96.5% of the total managed, and so closer attention should be paid to this type of waste. Figure 7-3 shows the quantities of each type of asbestos waste.



	2012	2013	2014	2015	2016	2017
170605	272.944	150.990	219.388	245.857	256.124	259.500
170601	8.159	18.667	16.185	14.931	14.727	7.651
160212	536	525	345	688	700	455
160111	44	13	18	29	9	7
150111	1.272	670	1.134	1.243	1.384	1.289

Figure 7-3: Asbestos waste management (metric tons), 2012 – 2017 (ISPRA 2019)

7.3. Export of asbestos containing waste (ACW)

The total amount of special hazardous waste exported in 2017 (*ISPRA 2019 Special Waste Report*) was about 1 million metric tons or 32% of the total amount of special waste exported in that year. Compared to 2016, the amount of exported special hazardous waste decreased by approximately 43.000 metric tons (-4.2%). Table 7-4 shows that the largest quantities of hazardous waste are exported to Germany, totalling 809,000 metric tons (26.5% of the total), with a decrease of 4.8% or 41,000 metric tons compared to 2016.

COUNTRIES OF DESTINATION	YEAR 2016			YEAR 2017		
	NOT HAZARDOUS	HAZARDOUS	TOTAL	NOT HAZARDOUS	HAZARDOUS	TOTAL
GERMANY	214,046	636,071	850,117	235,054	573,917	808,971
FRANCE	145,309	101,773	247,082	124,732	131,562	256,294
AUSTRIA	167,082	60,496	227,578	179,579	63,809	243,388
CHINA	260,246	0	260,246	203,925	0	203,925
HUNGARY	111,570	0	111,57	184,811	257	441,811
DENMARK	165,110	10,672	175,782	138,073	7,065	145,138
SLOVENIA	116,859	14,672	131,531	123,896	12,529	136,425
USA	171,074	14,119	185,193	99,057	0	99,057
SPAIN	65,695	9	74,695	77,469	9,116	86,585
UK	36,269	5,509	41,778	85,692	0	85,692
SWITZERLAND	38,177	7	45,177	31,617	49,223	80,84
TURKEY	36,672	38,893	75,565	75,478	0	75,478
CZECH REPUBLIC	59,027	0	59,027	73,244	0	73,244
BELGIUM	35,882	22	57,882	41,22	23,259	64,479
PORTUGAL	6,435	13,872	20,307	24,344	36,387	60,731
POLAND	15,757	85,582	101,339	24,101	24,983	49,084
ISRAEL	85,180	23,614	108,794	48,154	0	48,154
GREECE	115,780	0	115,78	45,927	36	81,927
NETHERLANDS	17,753	0	17,753	15,433	30,317	45,75
KOREA	28,924	17,288	46,212	41,433	0	41,433
SLOVAKIA	38,237	0	38,237	32,645	264	296,645
PAKISTAN	22,208	22	44,208	25,262	0	25,262
INDIA	29,814	0	29,814	23,998	0	23,998
BULGARIA	14,978	0	14,978	18,729	3,74	22,469
MOROCCO	28,675	1,765	30,44	19,129	0	19,129
SWEDEN	2,824	0	2,824	1,663	12,319	13,982
THAILAND	6,590	11,681	18,271	11,769	0	11,769
ROMANIA	5,706	0	5,706	10,914	300	310,914
VIETNAM	3,649	364	367,649	10,610	0	10,61
HONG KONG	16,040	0	16,04	8,981	0	8,981
CROATIA	6,829	0	6,829	8,796	0	8,796
MALAYSIA	2,058	53	55,058	6,664	0	6,664
NORWAY	647	0	647	5,023	0	5,023
JAPAN	2,754	0	2,754	4,926	0	4,926
INDONESIA	5,345	0	5,345	4,267	0	4,267
OTHER COUNTRIES	31,187	1	32,187	9,671	89	98,671
TOTAL	2,110,395	2,021,813	4,132,208	2,076,080	979,182	3,055,262

Table 7-4: Special waste exported by country of destination (metric tons), 2016-2017 (ISPRA 2019)

The type of waste exported to Germany, amounting to 574,000 metric tons, is mainly hazardous waste, of which 49.9%, some 287,000 metric tons, is waste classified according to EWC Chapter 17 as *"construction and demolition waste"*. Within this waste class, about 99,000 metric tons are "*insulation and construction materials containing asbestos*" (EWC codes 170601 and 170605), whose final destination is the salt mines in Germany (Figure 7-4). The Stetten salt mine, one of the most productive mines, is authorised to receive 250 types of waste, which are used to backfill the cavities created by mining.

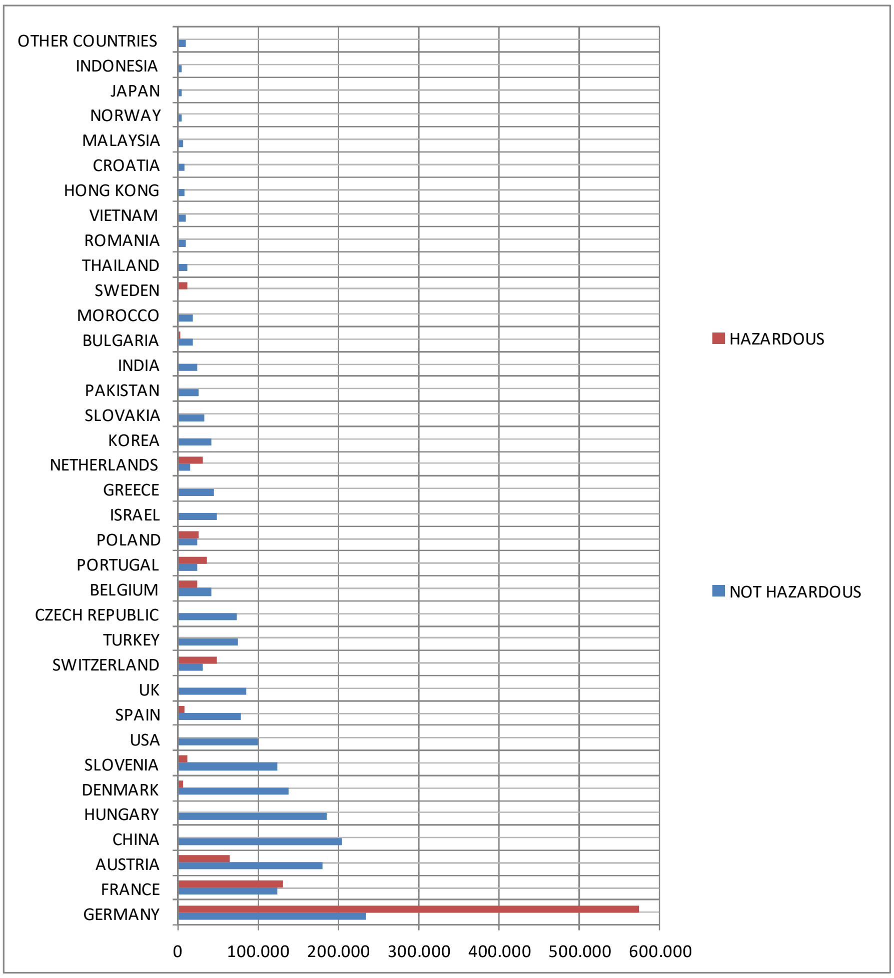


Figure 7-1: Special waste exported by country of destination (metric tons), 2017 (ISPRA 2019)

Waste with EWC code 170605 alone (construction materials containing asbestos) amounts to 90,000 metric tons (Figure 7-5), deriving from abatement and remediation activities and destined for disposal in Germany (around 89,000 metric tons) and Austria (1,289 metric tons).

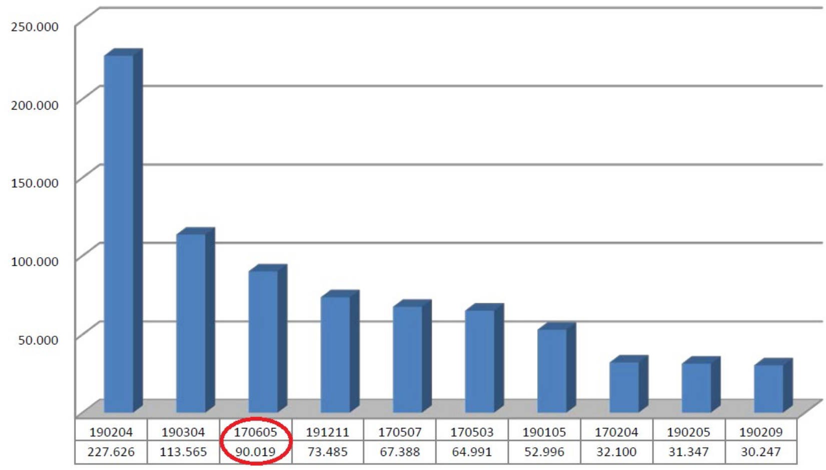


Figure 7-5: Main types of exported special hazardous waste (metric tons), 2017 (ISPRA 2019)

8. Regulatory framework

The aim of this section is to reconstruct the framework of the main provisions issued in relation to asbestos and applicable in Italy, identifying their application, and highlighting the most critical issues (*Natullo G., 2014*). Before starting a review of the legislation, it is important to note that the subject of asbestos is today regulated by a considerable number of provisions of different levels and types, which have generated a mass of legislation (there are approximately 45 Ministerial Decrees and Decrees, 32 Laws and equivalent acts, 15 Circulars, 13 Resolutions, 7 Prime Ministerial Decrees, 6 Presidential Decrees, 9 EC Directives, 1 EC Regulation, 1 Ministry of Health Order, 1 State-Regional Agreement and 1 Ministry of Health Report, in addition to 2 CJEU Decisions).
This is mainly due to:

1. the intrinsic complexity of the subject of "asbestos" due to its high degree of technicality
2. the interdisciplinary nature of the "asbestos" issue (environment, health and work) and therefore of the relevant regulations
3. the disjointed development of EU and national legislation on the subject
4. the ability to legislate on different levels.

In terms of quantity, the number of provisions on asbestos is now far greater than in any other area of law, making it difficult to apply and, in many respects, to have an in-depth knowledge of it.

Below are the main provisions relevant to asbestos in chronological order (*Italian Consolidated Asbestos Act, 2018; National Asbestos Plan, 2013*):

- Italian Royal Decree no. 1765 of 17 August 1935: compulsory insurance against occupational diseases is established;
- Italian Law no. 455 of 12 April 1943, later amended by Presidential Decree no. 648 of 20 March 1956: compulsory insurance is extended to cover silicosis and asbestosis;
- Italian Presidential Decree no. 128 of 9 April 1959 defines the standards for air monitoring in mining activities, setting maximum exposure values for workers;
- Italian Presidential Decree no. 1124 of 30 June 1965: Title I, Chapter VIII of the "Consolidated text of the provisions for compulsory insurance against accidents at work and occupational diseases" sets out further obligations with regard to silicosis and asbestosis, requiring workers to undergo a medical examination, to be repeated annually in order certify fitness to work;
- Italian Ministerial Decree of 18 April 1973, which contains a list of occupational diseases including, under letter D, asbestosis and lung cancer;
- The Italian Ministry of Health, with the Order of 26 June 1986 and then with Circular no. 42 of July 1986, imposed certain restrictions on the marketing and use of crocidolite and products containing it;
- Circular no. 45 of 10 July 1986 describes the "Action plan and technical measures for the identification and elimination of risk associated with the use of asbestos containing materials in public and private school and hospital buildings".
- Italian Decree of 16 October 1986 of the Ministry of Industry, Commerce and Crafts supplements and amends Presidential Decree 128/1959. Although limited to the specific sector (air and environmental monitoring in asbestos mining activities), for the first time, maximum exposure limits are set, thus establishing the threshold limit criterion.

- Italian Presidential Decree 215/1988 sets out nationwide restrictions on the marketing and sale of asbestos and asbestos containing products (art. 2), then specifies the exempted sectors (art. 3) and stipulates all the other cases in which there is a ban on marketing (art. 4), as well as compulsory labeling of all products excluded from the ban (art. 5).
- Italian Law 212/1990 for the first time devotes an entire section to the protection of workers exposed to asbestos and includes asbestos among the most hazardous substances (i.e. class 1).
- Italian Legislative Decree no. 277 of 15 August 1991 (now repealed) provides a number of guidelines on the health monitoring of workers.
- Italian Law no. 257 of 27 March 1992"*Regulations concerning the cessation of the use of asbestos*" prohibits the extraction, import, export, marketing and production of asbestos and asbestos containing products. The aim of the Law is not only to ban the use of asbestos, but also to regulate and manage the removal of existing asbestos and related waste. Finally, it includes support measures for workers exposed to asbestos.
- The Ministry of Industry, Commerce and Crafts Circular no. 124976 of 17 February 1993 concerns asbestos production, disposal and remediation processes.
- Italian Law no. 271 of 1993, Legislative Decree no. 269/2003 as amended by Law no. 326/2003 and Law no. 350/2003, Ministerial Decree of 27 October 2004, and Law no. 247/2007 define the compensation for workers exposed to asbestos, whether or not they are covered by INAIL insurance (National Institute for Insurance against Accidents at Work); Legislative Decree no. 626/1994 describes the main occupational safety and protection measures with particular focus on workers exposed to asbestos.
- Italian Presidential Decree of 8 August 1994 is the framework law for the Regional Governments and the Autonomous Provinces of Trento and Bolzano regarding the adoption of protection, decontamination, disposal and remediation plans for the purposes of protection against hazards arising from asbestos.
- Italian Ministerial Decree of 6 September 1994 consists of regulations and technical methods for the application of previous laws relating to the cessation of the use of asbestos, in particular regulations on risk assessment, remediation, monitoring and maintenance of existing asbestos.
- Italian Legislative Decree 114/1995 concerns the prevention and reduction of environmental pollution caused by asbestos both in the processing phase and, above all, in the remediation phase, setting the limit value for air emissions and liquid effluents;
- Italian Ministerial Decree of 14 May 1996 includes regulations and technical methods for remediation work.
- Italian Ministerial Decree of 12 February 1997 and subsequently Ministerial Decree of 26 February 1998 present the criteria for the approval of substitutes for asbestos products and the relative list.
- With Italian Law no. 426/98 and subsequent Ministerial Decree 468/01, the Ministry for Environment and Land Protection adds the most asbestos-contaminated sites to the list of sites of national interest. The Emarèse quarry is included on this list.
- Italian Ministry of the Environment Decree 471/1999, which supplements Legislative Decree 22/1997 and which will later be amended by Legislative Decree 152/2006, relates to

procedures for the environmental containment, remediation and restoration of contaminated sites.

- Italian Ministry of Health Decree of 20 August 1999, which expands on Ministerial Decree of 14 May 1996, also provides useful information on the choice of PPE and encapsulation products.
- With Italian Law of 23 March 2001 and subsequent Ministerial Decree 101/2003, funds are allocated to allow regional governments to map naturally contaminated sites and to enable the start of remediation works.
- Italian Ministerial Decree of 25 July 2001 amends the Decree of 20 August 1999.
- Italian Prime Ministerial Decree 308/2002 defines the regulations for determining the format and methods for keeping a register of asbestos-related mesothelioma cases.
- Italian Ministerial Decree no. 101 of 18 March 2003 establishes the criteria for mapping areas in Italy affected by the presence of asbestos (art. 20 Law no. 91 of 23 March 2001 sets out the aim of the mapping to produce an inventory of asbestos to target remediation actions).
- Italian Legislative Decree 36/2003 and the Decree of 13 March 2003 deal with landfills for asbestos containing waste.
- Italian Ministerial Decree 248/2004 regulates the recovery of asbestos and asbestos containing products and goods.
- The Decree of the Italian Ministry of Labour and Social Policy of 27 October 2004 concerns welfare benefits for workers exposed to asbestos.
- Italian Legislative Decree 152/2006 changes the classification of asbestos containing waste, classifying it as hazardous.
- Italian Legislative Decree no. 257 of 25 July 2006, repealed and revised by Legislative Decree no. 81 of 9 April 2008, describes the standards for the health protection of workers and introduces a register of exposed workers.
- Italian Legislative Decree 81/2008 simplifies and clarifies the legislation on occupational exposure to asbestos by bringing together all the existing regulatory provisions into a single text, the *"Health and Safety at Work Act (TULS)"*.
- Italian Legislative Decree No. 106 of 3 August 2009, a corrective decree to Legislative Decree 81/2008, defines supplementary health and safety at work measures for workers exposed to asbestos fibers.
- Italian Legislative Decree no. 205 of 3 December 2010, ("Provisions implementing Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives"), concerning waste treatment and management, includes asbestos on the lists of hazardous waste.
- Italian Ministerial Circular of 25 January 2011: regulation of sporadic and low-intensity exposure.
- State-Regional Agreement of 7 May 2015: agreement between the Government, Regional Governments and the Autonomous Provinces of Trento and Bolzano concerning the accreditation of public and private laboratories carrying out asbestos sampling and analysis based on the quality control programmes referred to in art. 5 and Annex 5 of the Decree of 14 May 1996.

- Italian Senate Act no. 2602 XVII Legislative Term of 21 November 2016: consolidated text of asbestos legislation of the Senate of the Republic of Italy (bill not yet finalised).

9. Health aspects

It is the very morphological and structural characteristics of its fibers that give asbestos such excellent technical properties, but which also make it so hazardous (*Apostoli P., Boffetta P.et al, 2019;Oksa P.,2014*). Due to their tendency to split longitudinally into increasingly fine fibrils, all asbestos fibers have sufficiently fine diameters (less than 3 microns) to be breathed in and to allow them to penetrate deep into the pulmonary alveoli. Given their high resistance to acids and alkalis, they are extraordinarily biopersistent, i.e. they remain in the alveoli for an almost indefinite period of time, even resisting attack by macrophages, especially longer fibers (over 5 microns). In fact, the macrophages die in an attempt to clear the asbestos fibers, resulting in an inflammatory reaction, causing an asbestos lesion. The ability to penetrate the lungs varies according to the type of asbestos. Amphibole asbestos, made up of needle-shaped fibers, has a higher penetration capacity than chrysotile fibers, with their "*elongated S-shape*". Once they have penetrated the body, asbestos fibers induce, by mechanisms not yet fully understood, the development of tumors that can affect the lung, the serous membranes (pleura, peritoneum, pericardium, and tunica vaginalis), the pharynx, and possibly other organs. However, one distinctive characteristic of asbestos carcinogenesis is that, unlike other chemical carcinogens, which are eliminated from the body relatively quickly, asbestos remains in the tissues for a long time and continues to act as a carcinogen throughout this time. All asbestos-related diseases occur long after the onset of exposure, with a latency period of up to 50 years (*Magnani C., Bianchi C, 2015*).

9.1. Asbestos-related diseases

9.1.1. Asbestosis

Asbestosis is a chronic and progressive respiratory disease caused by the ability of asbestos fibers to cause pulmonary fibrosis, i.e. lung scarring leading to breathing impairment. An asbestos lesion results from the onset of an inflammatory process in the pulmonary alveolus (alveolitis), which subsequently leads to fibrosis. The disease develops after a latency period of many years and starts gradually. The course of the disease is variable and, over time, leads to the spreading of fibrotic scars and worsening of respiratory disorders. Over the course of years, this can lead to very severe and eventually fatal respiratory failure. Asbestosis, a typical occupational disease of asbestos workers, was the first disease to be linked to the inhalation of asbestos fibers. It occurs for medium to high exposures of 10-15 years (dose-dependent effect). Although the level of exposure likely to cause effects is not certain, some studies (*Bianchi C.,1997;Boffetta P.,2017*) consider that a cumulative exposure of less than 25 fibers/ml/year (equivalent to 50 years of work at a concentration of 0,5 fibers/ml) does not give rise to clinical symptoms of asbestosis. According to other studies (*Dragani T., Colombo F.,2017;Ferrante D., 2017*), the no-effect threshold corresponds to a lower level of exposure (10 fibers/ml/year equivalent to 0,2 fibers/ml for 50 years of work). At these concentrations, however, the fibrous effects of asbestos are negligible compared to the much more dangerous carcinogenic effects.

9.1.2. Lung cancer

Lung cancer is one of the most common cancers in the population and cases caused by asbestos exposure are completely indistinguishable from those attributed to other causes. Exposure to any type of asbestos increases the risk of lung cancer by a factor of between 2 and 5, and there are no conclusive studies showing that one type of asbestos is more dangerous than another. The cancer develops on average 15 to 20 years after the onset of exposure. The latency period varies according to the intensity and duration of exposure, so if someone is exposed longer and more intensely, cases of lung cancer caused by asbestos can be observed as early as 10 years from the onset of exposure, whereas in those less exposed, it takes at least 20 years for the oncogenic effects to appear (*Liddel F.D.K, 2001*). Asbestos lung cancer is generally considered to be a dose-dependent neoplasia, i.e. the incidence of the disease in an exposed population increases as the dose of inhaled asbestos increases. However, the relationship between the intensity of exposure and the likelihood of the disease has not yet been fully demonstrated, and so far, no exposure threshold level below which there is no carcinogenic risk has been established.

9.1.3. Benign pleural disease

Classified under this heading are a series of benign changes to the pleura in the form of localised, sometimes calcified, thickening (plaques), recurrent pleural effusions, or other less frequent symptoms (diffuse pleural thickening, round atelectasis). They are commonly associated with asbestosis, i.e. interstitial fibrosis of the lung parenchyma, and until recently were part of the clinical picture of asbestosis. It could be said that because they can occur even after relatively low exposures, today they are by far the most common lesion observed in people exposed to asbestos (*Hillerdal, 1997*). They include the three distinct conditions described in this paragraph. **Pleural plaques** are areas of localised thickening affecting only the parietal pleura; they can be multiple, bilateral, sometimes symmetrical, and vary in extent and thickness, they tend to spare the apices and costophrenic angles, and may be calcified. They are found frequently in an occupationally exposed population, and generally the latency period between the onset of exposure and the appearance of plaques is rather long (10 to 30 years). **Diffuse pleural thickening** affects the visceral pleura and may also lead to adhesions between the two pleural layers. They can be bilateral or unilateral and may undergo calcification. Asbestos-related visceral pleural disease also includes the thickening of the interlobar fissures. In contrast to pleural plaques limited to the parietal pleura, diffuse pleural thickening is an entirely non-specific lesion, which also occurs as a consequence of common inflammatory processes. In general, **benign pleural effusions** appear in exposed persons at least 10 years from the onset of exposure and often remain the only symptom for another decade. They are usually small and can resolve in a few months without intervention, although they may recur years later. They frequently result in diffuse pleural thickening and obliteration of the costophrenic angle. They are not clinically distinguishable from effusions attributed to other causes and the differential diagnosis is essentially based on the absence of other causative factors and on a medical history involving asbestos. Benign pleural lesions cannot in themselves be interpreted as asbestosis. In reality, they do not constitute a pure asbestos-related disease, but rather an indicator of exposure.

9.1.4. Pleural mesothelioma

Mesothelioma is a malignant neoplasia that originates from mesothelial cells, the layer of cells lining the serous cavities of the body, pleura, peritoneum, pericardium, and tunica vaginalis. Almost all of the cases currently reported relate to malignant pleural mesothelioma (MPM), which originates in the pleura, both visceral and parietal, and shows a diffuse growth pattern over the pleural surface (*Travis et al, 2004*). The term used by the "*World Health Organisation Classification of Tumours of the Lung, Pleura, Thymus, and Heart*" is diffuse malignant mesothelioma, to be distinguished from other localised pleural tumours which have different characteristics and clinical course. Pleural mesothelioma is the most common primary pleural cancer, and its importance has grown in recent years due to the increased occurrence in individuals exposed to airborne asbestos fibers, with a particularly long latency period of 15-40 years, and an average course of 1-2 years. Environmental exposure, especially when added to occupational exposure, also increases the risk of contracting mesothelioma (*Hansen et al.,1998;Howel D., Arblaster L., Swinburne L., et al.,1997;Bourdes V., Boffetta P., Pisani P.,2000*). There is a correlation between the cumulative dose and disease onset (*Berman D.W., Crump K.S., 2008; Boffetta P.,2006; Hodgson J.T., Darnton A.,2000*) but a threshold level below which there is no risk of mesothelioma has not yet been determined (*Doll R., Peto J., 1999; HillerdalG.,1997;J.T.Hodgson,A.Darnton, 2000; Illgren E.B., Browne K.,1991*). Furthermore, the existence of zero cases in a dose category (human or animal) should not automatically be interpreted as zero risk. Direct validation of a threshold based on human data is virtually impossible (*ISTISAN Report,2007*).

9.2. Analysis of epidemiological data

9.2.1. Italy

Even though all asbestos extraction, production and trade was completely banned by Italian Law 257/1992, Italy is currently one of the countries in the world most affected by asbestos-related diseases. This striking fact is the direct result of a level of production, use and imports like no other country in the world, peaking in the late 1980s. Consider that between 1945 and 1992, 3,748,550 and 1,900,885 metric tons of raw asbestos were produced in and imported into Italy, respectively. With Italian Prime Ministerial Decree no. 308 of 10 December 2002, which defines regulations for determining the format and methods of keeping a register, published in Official Gazette no. 31 of 7 February 2003, a register of confirmed cases of mesothelioma was established at the INAIL Department of Occupational and Environmental Medicine, Epidemiology and Hygiene (DIMEILA), with the aim of estimating the prevalence of malignant mesothelioma in Italy, defining the methods of exposure, the impact and the spread of the disease in the population, and identifying still unknown sources of contamination. The National Mesothelioma Register (ReNaM) is organised into a regional network, with a Regional Operations Centre (COR) in every region with the task of identifying all the cases of mesothelioma occurring in that region and analysing the occupational, residential and environmental history of sufferers in order to determine how they were exposed to asbestos. Today, the network is almost complete and the whole of Italy is covered by the monitoring and registration of cases of malignant mesothelioma of the pleura, peritoneum, pericardium, and tunica vaginalis. However, monitoring is not fully established in all regions and in some cases the operations of the CORs are limited by inadequate operating conditions. The *6th ReNaM Report 2018* states that 27.356 cases of malignant mesothelioma (M.M.) were diagnosed between 1993 and 2015. The most significant data is reported below:

1. More than 90% of registered mesothelioma cases were of the pleura, with 1,769 peritoneal cases (6.5%), and 58 and 79 cases of the pericardium and tunica vaginalis, respectively.

2. The disease is very rare in the under 45 age group (only 2% of the total number of registered cases). The average age at diagnosis is 70, which does not differ significantly by gender.
3. The gender ratio (male cases for every female case: M/F) is 2,5, with 72% of cases relating to men. The percentage of women goes from 27.4% for pleural mesothelioma to 32.8% and 41.1% for pericardial and peritoneal cases, respectively.
4. The type of exposure was investigated for 21,387 cases (78.2%) and of these, 70.0% related to workplace exposure (certain, probable, possible), 4.9% to household exposure, 4.4% to environmental exposure, and 1.5% to exposure through a leisure activity or hobby. In 20% of cases, exposure is unlikely or unknown.
5. For those affected by occupational disease alone, the sectors of activity most involved are construction (15.5% of the total number of cases), heavy industry, and in particular engineering (8.6%), metallurgy (4.0%) and the manufacture of metal products (5.7%), shipbuilding (6.1%), and the asbestos cement industry (3.1%). The remaining picture is extremely varied and fragmented, with many production areas where exposure occurred due to the presence of the material in the workplace and not through direct use.

9.2.2. Emilia-Romagna

The ReM, established on 1 January 1996, is a cancer register specifically dealing with the study of the occurrence and aetiology of MM in the Emilia-Romagna region of Italy, based at the Reggio Emilia AUSL IRCCS (Local Health Authority Research Institute). The objectives of the ReM (also known as COR ReNaM Emilia-Romagna) are identical to those reported above for the ReNaM. Data analysis referring to the years between 1996 and 2019 was conducted on 2,812 cases of malignant mesothelioma occurring in citizens residing in Emilia-Romagna (*Romanelli A., Storchi C., Sala O., 2019*). The data for 2019 is incomplete, and so reference is made to 2018. The main results are as follows:

1. Regarding the diagnosis, 2,406 subjects were classified as definite cases (85.6%); 149 as probable cases, and 257 as possible cases.
2. The trend since 1996 has been increasing, from 73 cases in 1996 to 132 cases in 2018. The most common form of MM is pleural mesothelioma (91.5%), followed by peritoneal mesothelioma (7.6%), and finally pericardial and testicular mesothelioma (0.9%).
3. The gender ratio for all cases is 2.6:1. 77.2% of cases were diagnosed after the age of 64, 1.6% before 45, and the remaining 21.2% in the 45-64 age group.

As shown in the figure below (Figure 9-1), the regional incidence rate per 100,000 inhabitants, calculated for the period 2013-2017 and standardised using the direct method using the Italian population in 2000, is 3,9 in men and 1,1 in women.

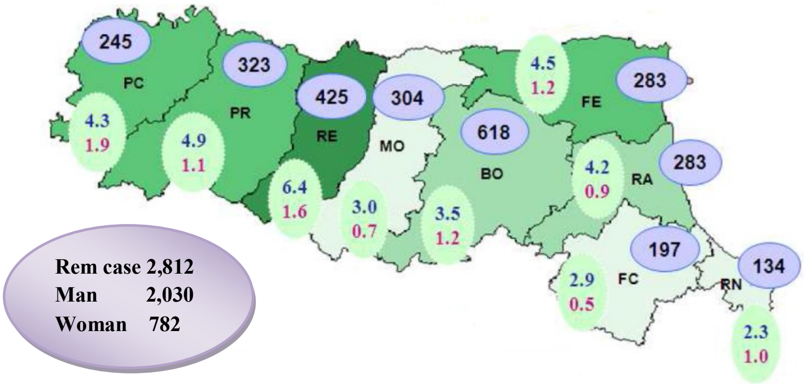


Figure 9-1: Distribution by residence: incidence rate by province from 1996-2019

10. Occupational and environmental exposure

For many years, the risk of exposure to asbestos fibers was only considered for asbestos workers, and it was only in the post-war period that attention shifted first to non-occupational exposure, but indirectly related to work (e.g. family members of workers employed in activities with the presence of asbestos or areas affected by emissions from production plants), then to the possibility of considering asbestos as an environmental pollutant normally present in anthropised areas (*Magnani C.,2013*). Workers considered as occupationally exposed to asbestos are predominantly those involved in the removal, remediation and disposal of asbestos containing materials as well as repair workers, and to a lesser extent, workers in structures, buildings and facilities where asbestos containing products were present and remained in place. According to the CAREX database, established by the International Agency for Research on Cancer (IARC), the number of workers exposed to asbestos in Italy, although down from the 353,000 in the early '90s, is still around 76,000 workers (*Ferrante D., 2017*). Implementing decrees have been issued with the aim of managing the potential risk from the presence of asbestos in the workplace, atmosphere, liquids, buildings and pipe work, and mining sites. The table below shows the limit values set out in the Italian legislation on asbestos in different contexts/environments (Table 10-1).

APPLICATION	LIMIT VALUE	ANALYTICAL METHOD	LEGISLATIVE REFERENCE
Working environments			
Action level at which certain obligations are triggered (daily average 8 hours)	0,1 fibers/ml	PCOM	Italian Legislative Decree 277/91, art. 24(3)
Action level at which certain obligations are triggered (weekly average) Cumulative dose for sporadic and low-intensity exposure with exposure to chrysotile only	0,5 fibers/ml-days	PCOM	Italian Legislative Decree 277/91, art. 24(5)
TLV-TWA exposure limit value for chrysotile (daily average)	0,6 fibers/ml	PCOM	Italian Legislative Decree 277/91, art. 31(1)(A)
TLV-TWA exposure limit value for amphiboles and mixtures containing amphiboles (daily average)	0,2 fibers/ml	PCOM	Italian Legislative Decree 277/91, art. 31(1)(B)

TLV-TWA limit value for short exposures to chrysotile (averaged over 15 minutes)	3,0 fibers/ml	PCOM	Italian Legislative Decree 277/91, art. 31(3)
TLV-TWA limit value for short exposures to amphiboles and mixtures containing amphiboles (averaged over 15 minutes)	1,0 fibers/ml	PCOM	Italian Legislative Decree 277/91, art. 31(3)
Air emissions			
Limit concentration of asbestos in exhaust pipes	0,1 mg/m^3	Gravimetric	Italian Legislative Decree 114/95 art. 1(1)-Italian Legislative Decree 114/95 Annex A
	2,0 fibers/ml	Microscopy	
Liquid effluents			
Limit concentration of total suspended matter in liquid effluent discharge	30 g/m^3	Gravimetric	Italian Legislative Decree 114/95 art. 2(1)
Asbestos in buildings			
Indicative value of current pollution in a building (average of 3 rounds of sampling)	20 fibers/l	PCOM	Italian Ministerial Decree HEALTH 06/09/94 Annex p. 2c
	2,0 fibers /l	SEM	
Remediation work			
Early warning threshold for monitoring outside a remediation site	Results indicate a clear upward trend	PCOM	Italian Ministerial Decree HEALTH 06/09/94 Annex p. 5a/11
Warning threshold for monitoring outside a reclamation site	50 fibers/l	SEM	
Reinstatement of use of remediated environments	2,0 fibers/l SEM	PCOM	Italian Ministerial Decree HEALTH 06/09/94 Annex p. 6b
Reinstatement of use of industrial environments after maintenance work with asbestos removal	Concentration value measured in the same environment before the work	SEM	Ministry of Health Circular 12/04/95, no. 7
Asbestos in pipes			
Prohibition of the use of crocidolite-containing pipes for the supply of aggressive drinking water	< 12	Water Aggressiveness Index	Ministry of Health Circular 01/07/86, no. 42
Asbestos contaminated sites			
Soil concentration limit value	1000 mg/kg	XRD-FTIR	Italian Ministerial Decree ENVIRONMENT 25/10/99 no. 471

Greenstone mining sites			
Limit value for hazardousness of extracted materials (not hazardous if less than or equal to)	0,1	Release Index	Italian Ministerial Decree HEALTH 14/05/96 Annex 4
Asbestos substitutes			
Presence of asbestos in substitute material for approval	absent	SEM	Italian Ministerial Decree INDUSTRY 12/02/97

Table 10-1: Limit values for asbestos in different environments according to Italian legislation

Data from the *6th ReNaM Report 2018* on M.M. resulting from occupational exposure (certain, possible, probable and household) or non-occupational exposure (environmental, non-work related, unlikely and unknown) is detailed below. Considering the Italian context, out of the total number of cases with known exposure (21,387 sufferers), 70% are related to workplace exposure (certain, probable, possible), 4.9% to household exposure, 4.4% to environmental exposure, and 1.5% to exposure through a leisure activity or hobby. In 20% of cases, exposure is unlikely or unknown (Table 10-2).

Type of exposure	Years											
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Reliable professional exposure	627	580	625	638	607	629	642	604	670	605	522	10287
	51.7%	49.7%	49.1%	50.4%	47.9%	50.4%	50.1%	48.7%	49.4%	50.9%	50.7%	48.1%
Probable occupational exposure	81	81	87	72	85	62	73	79	66	67	41	1549
	6.7%	6.9%	6.8%	5.7%	6.7%	5%	5.7%	6.4%	4.9%	5.6%	4%	7.2%
Possible occupational exposure	177	154	165	181	183	157	171	167	175	133	156	2982
	14.6%	13.2%	13,00%	14.3%	14.5%	12.3%	13.3%	13.5%	12.9%	11.2%	15.2%	13.9%
Family exposure	51	58	74	62	83	74	54	68	62	56	49	1047
	4.2%	5%	5.8%	4.9%	6.6%	5.9%	4.2%	5.5%	4.6%	4.7%	4.8%	4.9%
Environmental exposure	42	41	57	49	47	60	64	48	69	43	52	939
	3.5%	3.5%	4.5%	3.9%	3.7%	4.8%	5%	3.9%	5.1%	3.6%	5.1%	4.4%
Non-working exposure	16	25	15	23	16	22	15	20	22	12	9	322
	1.3%	2.1%	1.2%	1.8%	1.3%	1.8%	1.2%	1.6%	1.6%	1%	0.9%	1.5%
Unlikely exposure	24	30	38	34	11	29	26	24	22	18	15	576
	2%	2.6%	3%	2.7%	0.9%	2.3%	2%	1.9%	1.6%	1.5%	1.5%	2.7%
Unknown exposure	194	197	211	206	234	216	237	230	269	255	185	3685
	16,00%	16.9%	16.6%	16.3%	18.5%	17.3%	18.5%	18.5%	19.9%	51.4%	18%	17.2%
Exposure totals defined	1212	1166	1272	1265	1266	1249	1282	1240	1355	1189	1029	21387
	83.5%	82.2%	82.4%	83.8%	83.3%	77.8%	77.5%	77.2%	75.7%	76.6%	72.2%	78.2%
Exposure to be defined	168	160	175	143	171	236	249	259	311	260	317	4179
	70%	63.5%	64.3%	58.4%	67.6%	66.1%	66.8%	70.8%	71.7%	71.4%	79.8%	70%
Non-classifiable display	72	92	97	102	82	121	124	107	123	104	80	1790
	30,00%	36.5%	35.7%	41.6%	32.4%	33.9%	33.2%	29.2%	28.3%	28.6%	20.2%	30,00%
Total undefined exposures	240	252	272	245	253	357	373	366	434	364	397	5969
	16.5%	17.8%	17.6%	16.2%	16.7%	22.2%	22.5%	22.8%	24.3%	23.4%	27.8%	21.8%
Total	1452	1418	1544	1510	1519	1606	1655	1606	1789	1553	1426	27356
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 10-1: Number of malignant mesothelioma cases in Italy from 2005 to 2015 by type of exposure (6th ReNaM Report)

Regarding the Emilia-Romagna region, data from the *ReNaM* report (as of 30/06/2019) shows that out of 2812 M.M. cases, in 1,677 of those cases, exposure was classified as occupational (1,156 certain, 292 probable and 229 possible), in 228 cases as non-occupational (142 household, 56 environmental and 30 related to non-work activities), and in 495 cases, exposure was found to be unlikely or unknown (Table 10-3).

Type of exposure	Men		Women		Total	
	Cases	%	Cases	%	Cases	%
Occupational	1469	83.2	208	32.9	1677	69.9
Family	14	0.8	128	20.2	142	5.9
Environmental	27	1.5	29	4.6	56	2.3
Non-working	18	1	12	1.9	30	1.3
Unlikely	64	3.6	88	13.9	152	6.3
Unknown	175	9.9	168	26.5	343	14.4
Exposure totals defined	1767	100	633	100	2400	100
Exposure to be defined	122	6	60	7.7	182	6.5
Non-classifiable display	141	6.9	89	11.4	230	8.2
Total	**2030**		**782**		**2812**	

Table 10-3:Distribution of M.M. cases in Emilia-Romagna by type of exposure (as of 30/06/2019)

11. Census and Mapping in Italy and the Emilia Romagna region

11.1. Norms of referral

The first call to regulate the norms of mapping asbestos within the territory of the nation was from a law dated March 27,1992, relative to the cessation of the use of asbestos (published in the Suppl. Ord: of the Gazzetta Ufficiale no.87 from April 13 ,1992):

1. That the independent regions of Trento and Bolzano adopt within one hundred and eighty days from the date that the Prime Minister issues the decree in which article 6,comma5, plans for the protection of the environment, of decontamination and the disposal and restoration of it in order to defend the community from the dangers of asbestos and its derivatives.
2. The plans of which comma 1 refers stipulates that, among other things:
   a) a census of sites involved in the extraction of asbestos;
   b) the census of the companies which use or have used asbestos in their respective productive activity, as well as those companies which work in the disposal and decontamination of these materials.

   …………………

   c) the census of buildings in which are present materials or products containing free asbestos or in friable matrix with priority for public buildings and for places open to the public or used collectively and also for apartment blocks.

In comma 5 of article 12,"*the removal of asbestos and the protection of the environment of chapter 111, Conservation of the environment and health"*, we find the local health care units have a register, in which are indicated the places flaked asbestos or friable matrix of asbestos is found. The owners of these properties are held to acquire the information necessary to take cautionary measures for those working there. This information is found in the local health units who will communicate it to the independent regions and provinces of Trento and Bolzano. This data is used to make a census or to chart that which is described in article 10, comma 2 letter 1. After issuing the decree no. 101 from March 18, 2003 by the Minister of the Environment dated May 9, 2003, the regulations for the realization of a map of the areas within national borders, where the presence of asbestos was relevant, was enacted, within the terms of article 20 of the law no. 93 dated March 23,2001. This stipulates that the results of the map, the analysis relative to the work to be done and the relative priorities, as well as the data relative to measures taken, are transmitted yearly, by the 30^{th} of June. The compiled map can be seen on the institutional web site (www.bonifiche.minambiente.it).

The following are the articles and the more important attachments in the above mentioned decrees:

Article 1 Compiling the map

1. The independent regions and provinces of Trento and Bolzano are proceeding in mapping the territory based on the data collected in the monitoring activity according to the decree of March 27, 1992, no.257, following the criteria and the instruments described in articles 2 and 3.
2. The independent regions and provinces of Trento and Bolzano avail of the collaboration of the Environmental Protection Agency and its technical services (APAT), The Superior Institute of Health (ISS) and the Superior Institute for the prevention and safety at the workplace (ISPESL) which, within ninety days of the date in which this present regulation entered in force on the basis of attachment B, defined the procedure to determine the most urgent restoration works.
3. The resulting map, the analysis of the data regarding the works to be done and their priorities as well as the completed works, are transmitted yearly, by the 30^{th} of June, by the independent regions and provinces of Trento and Bolzano, to the Minister of the Environment and Protection of the Territory.
4. The Minister of the Environment and Protection of the Territory, then proceeds with his own decrees, to award resources for the mapping in favor of the independent regions and provinces of Trento and Bolzano. 50% of the available total of the sum mentioned in article 20 of the law of March 23,2001, no. 93, is destined to finance this activity of mapping, according to that indicated in attachment.

Article 2 Criteria for mapping and identifying urgent intervention

1. The following phases make up the mapping: a) the first is in identifying and delimiting the sites characterized by the presence of asbestos in the natural environs or in a building; b) a second phase makes a selection of these sites identified as in a) above in which the presence of asbestos has been ascertained either in the natural environment or in a building, which makes necessary the intervention of an urgent decontamination.
2. The first phase of mapping of which in comma 1, letter a) is done according to categories of research and the parameters defined in the attachment A, keeping in mind that in the mapping, all the sites must be included, even those for which data has already been collected by surveys, notifications, onsite inspections, and in which there has actually been ascertained the presence of asbestos, as well as other locations which can be identified in the independent regions and provinces of Trento and Bolzano.
3. The second phase of mapping, (comma 1 letter b) is done based on criteria and procedures identified according to article 1 comma 2. Statistical data available and epidemiological studies relative to asbestos-correlated pathologies can be attached to give support to the findings.

Article 3 Instruments used for mapping

1. The making of a map of the areas relevant to the presence of asbestos must be done using the computer systems preset and based in the nation's territory (SIT) integrated by specific software for the elaborations and interrogations according to the standards of the National

Environmental Computer Systems (SINANET) and organized in the following way: a) chronological managing of points, b) managing of data from the site and monitoring done according to the explanation in article 2; c) geographic representations of the territorial diffusion of the sites where asbestos or materials or products containing asbestos are located, complete with data on the quantities, subdivided between friable and compact materials and where they exist, also by information concerning the percentage in the various environmental origins

2. When the mapping is complete, the sites must be geo referenced.

ATTACHMENT A
CRITERIA FOR MAPPING THE PRESENCE OF ASBESTOS

Mapping has the aim of making evident sites where there is the presence of asbestos, that is, of materials that contain it, including places where it appears in nature, the data for the mapping can also be had from the asbestos census done according to article 10 of the law no. 257 dated 27 March 1992. To make the map we must keep in mind the following. Categories of research

- **Category 1**, active or inactive industrial plants.
- **Category 2**, Public or Private buildings.
- **Category 3**, Presence in nature.
- **Category 4**, Other presence of asbestos by human activity.

We will now look at categories 1 and 2.

Category 1 Active or inactive industrial plants

In this category we distinguish between plants where asbestos was worked (plants where asbestos was used as a raw material in the production process) and plants where asbestos was not worked (plants where asbestos was or is present in the building itself as part of the machinery, pipes, facilities, etc. For that which concerns the types of plants which can be put in the urgent list, referring to that defined in attachment B letter a) (businesses majorly concerned) of the decree issued by the President of the Republic on August 8,1994, and taking account of the technological and structural evolution which can determine modifications which could exclude a business which has changed type of work. Plants built after April 1994 are excluded.

Category 2 Public or Private buildings

Buildings are of following types: a) schools of every grade and order, b) hospitals and care homes, c) public administration buildings, d) sport facilities, e) shopping centers, f) correction institutes (jails), g) movie theaters, theaters, convention centers, h) libraries, i) houses of worship, l) residential buildings, m) agricultural buildings and those pertaining to them, n) industrial buildings and those pertaining to them.

ATTACHMENT B
CRITERIA FOR DETERMINING URGENT RESTORATION WORKS: THE CREATION OF A MAP SHOWING RISK AREAS

1. The definition of the procedure to determine urgent restoration works will attain to these criteria

PRIORITY CRITERIA OF INTERVENTIONS

- extensive area of the site;
- type of activity (type of production) ;
- activity in function;
- discontinued activity;
- length of time the activity has been discontinued;
- state of the building structure;
- distance from residential center;
- density of the interested population;
- type of asbestos present as raw material;
- types of materials containing asbestos;
- estimated quantity of materials;
- surface area in open air;
- presence of confinement or closed area;
- presence of control or maintenance programmes;
- concentration and diffusion in the environment;
- involvement of the site in works of urbanization;
- presence of causes which create or favor the dispersion of fibers;
- epidemiological data indicating the increase of illnesses correlated to the exposure to asbestos in the mapped area.

2. In evaluating the criteria in point 1, it will be taken into account that which is required by the ministerial decree of 6 September, 1994 which specifies "*Standards and technical methods of application of article 6, comma 3, and of article 12, comma 2, of the law of 27 March 1992, no. 257, relative to the ceasing of the use of asbestos*" and of the standards in force.

In the following image (Figure 11-1) we see the mathematical criteria for the creation of a map showing risks and the relative priority of intervention. Having defined the probability (P) and severity (S) of the damage, the risk R is calculated with the formula R = P X S and can be represented in a matrix, having the severity on the abscissas and the expected probability of its occurrence on the ordinates. This representation is the starting point for defining the priorities of the prevention and protection interventions to be adopted. The numerical and chromatic evaluation of the risk level allows to identify the priority of the interventions to be carried out.

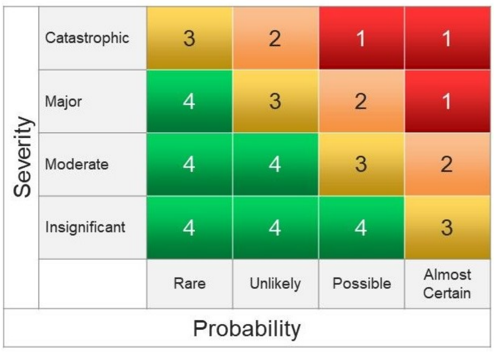


Figure 11-1: Map of risks and priority of intervention (Asbestos Free AeroDron)

11.2. Analysis of Data

The Minister of the Environment and of the protection and preservation of the sea, in 2020 made a map of the national territory regarding the presence of asbestos.(*Minambiente, 2020*). The efforts made by many regions to verify the presence of asbestos have availed of specific plans and programmes, and have seen a continual increase in sites found with the presence of materials containing asbestos (ACM). In fact, the number of sites with asbestos on the maps passed from 44,000 in 2014 to 86,000 in 2016 and reached 108,000 in 2019 (Figure 11-2).

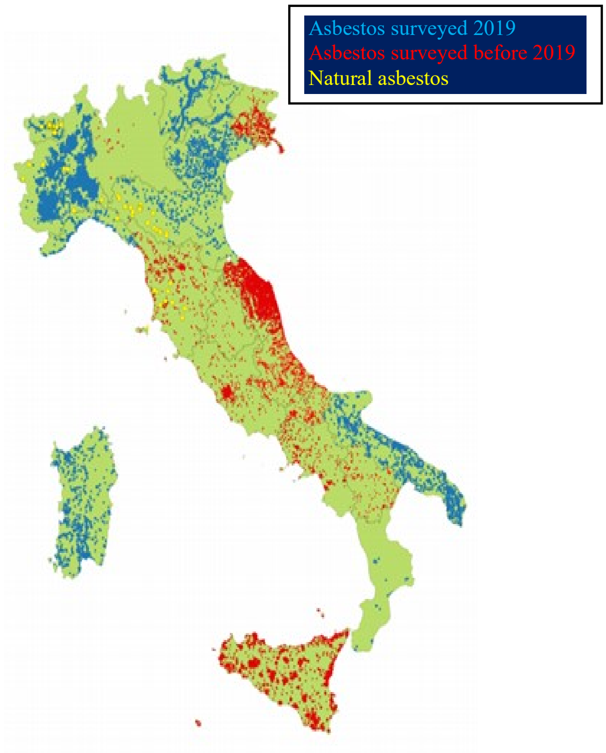


Figure 11-2: The 2020 map of the Minister of the Environment showing sites with the presence of Asbestos

Within these numbers are included all the industrial sites counted, whether active or discontinued, and the 10 Sites of National Interest (SIN) involved in this difficult problem of asbestos. We can see on the map the positive increase in the numbers of sites cleaned of asbestos which on the basis of data provided by the Regions, passed from 22,240 in 2014 to 7,740 in 2019 (Figure 11-3). We must add to this number the sites which were partially cleaned, intending, sites where all the material containing asbestos were removed, that in 2019 were a good 4,261. On the other hand, there is the low percent, only 11.1% of sites totally or partially cleaned in respect to the total of the sites mapped (108,000 sites mapped against 12,000 sites partially or totally cleaned). It is evident that these data must be read in the light of the notable lack of homogeneity in the readings which still characterize the mapping activity and of the low levels of computerization and updating the data that doesn't allow an efficient programming of the mapping nor a complete picture of the quantity of asbestos actually present on the national territory, also as the marked differences in the data presented by associations and technical organizations show.

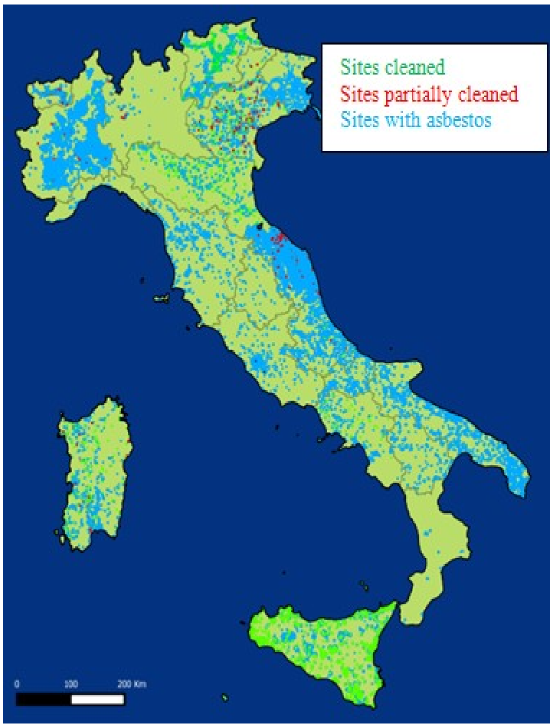


Figure 11-3: Map from year 2020 of the Minister of the environment showings sites restored and sites not yet restored

Every year, the Legambiente (an organization for the protection and conservation of the environment) undertakes a survey which it sends to the regional offices about the regional plans for the state of asbestos in each region and from which we get information about the problem of asbestos on a national level. The last compilation of this information underlined the alarming situation which afflicts our country (*Legambiente,2018*). In fact, after 28 years that law no. 257 went into effect, the Regional Asbestos Plan has still not been approved by all the Italian regions (Figure 11-4).

Figure 11-4: Map from year 2020 of the Minister of the Environment updated for asbestos by region

Going into detail of the information regarding the survey that the administrations provided, the questionnaire submitted to the appropriate authorities asking them to be specific about the types of places that contained asbestos, (sites extracting it, industrial plants, public buildings, private buildings, siding and roofing made with asbestos cement and sites contaminated in other ways) and their size (sqm) of the structures surveyed. For the regions which did not respond (Abruzzo, Calabria, Liguria, Molise, Toscana, and Umbria), where possible, data from the previous survey of 2015 was used. As we can see in the following table (Table 11-1), the results obtained by the Legambiente dated 28th of April 2018, show a total of 370,000 buildings (for a total of almost 58,000,000 sqm) both public and private, present in the national territory, contain material made with asbestos. 58% of the buildings mapped are private ones.

Region	Industrial sites	Public buildings	Private buildings	Sheet in C.A.	Other contaminated sites	Total sqm surveyed
Abruzzo	614,000	4,369	5,54	0	0	221,817
Basilicata	1	-	-	-	-	-
Calabria	-	-	1,20	1,013	0	130,045
Campania	3	85,000	955,00	3,043	0	3,011,500
Emilia-Romagna	100	1,020	0,00	0	58,00	0,00
Friuli-Venezia Giulia	637	150	0,00	752	0	2,271,660
Lazio	0	1,638	0,00	0	0	880,000
Liguria	-	-	-	-	-	-
Lombardy	0	24,979	180,01	0	0	4,988,590
The Marches	8	13,611		11,857	0	13,630,854
Molise	55	30	236,00	0,00	23	-
Piedmont	13,207	835	8,67	39,066	16,351	24,898,574
Apulia	3,894	61	5,17	4,457	1,191	2,151,010
Sardinia	756	1,377	-	662	0	8,034,858
Sicily	471	615	9,38	0	1,203	0,00
Tuscany	161	806	-	-	119	0,00
Umbria	16	117	428,00	545	0	645,288
Aosta Valley	84	235	1,31	1,544	0	985,568
Veneto	245	738	329,00	0	0	0,00
Autonomous province of Bolzano	44	78	1237,00	1,053	0	513,049
Autonomous province of Trento	0	0	0	1,601	0	515,765
Total	20,296	50,744	214,469	65,593	18,945	57,889,988

Table 11-1: Survey of 2018 by Legambiente, the presence of asbestos in the regions of Italy

To show how great the extent and the presence of asbestos in Italy, and how it has been largely been underestimated, and how the ongoing surveys, even if slowly, are fundamental in order to know the exact state of the art in our country, the data gathered in 2018 concerns private buildings which have increased 50% respect to the census report of 2015 (Table 11-2).

Building typology	2015	2018	% increase
Private buildings	143,543	214,469	50%
Public buildings	50,744	45,808	10%
Industrial sites	6,913	20,296	4%
Other contaminated sites	1,393	18,945	14%
Sheet in C.A.	33,527	65,593	6%

Table 11-2: The difference between the data gathered by the National census bureau on buildings containing asbestos in 2015 and 2018 (Legambiente, April 2018)

The region of Emilia-Romagna, in a ruling of the regional junta, no. 1302 on 5th of July, 2004, approved the project, "*The mapping of the regional territorial zone for the presence of asbestos*" which was updated on 31/12/2018. The aim of this project was to choose public and private buildings which were open to the public to guarantee the health of the people who worked in these buildings and also the general public, eliminating the exposition to asbestos fibers completely or reducing them as much as possible. The list includes working plants and extraction sites, too. The map is updated periodically on the basis of projected inspections carried out by the USL agency. Every site is indicated with its name, address, its priority class and the points it has attained, considering the use it has, its accessibility and the type of asbestos material it contains. The restoration activity for the complete removal of the materials containing asbestos, reached 932 sites, or about 78% as of 31/12/2018, on a total of 1198 initially reported by owners and mapped. Moreover, 39 sites mentioned in the list are not used anymore or are not open to the public anymore. The list includes 20 "*sites of extraction where a natural presence of asbestos is present*" of which only 4 are active now (Figure 11-5).

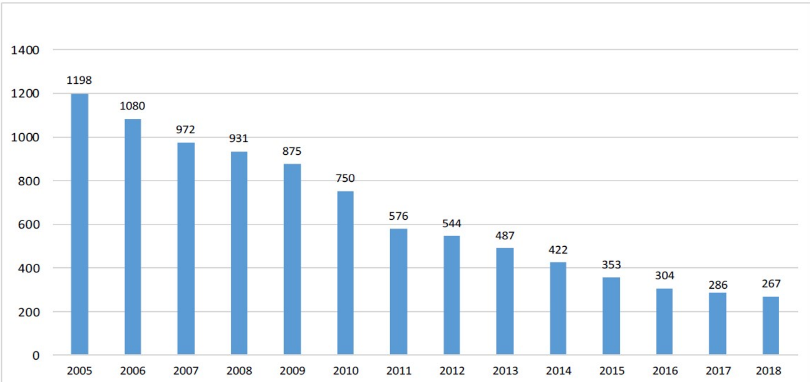


Figure 11-5: Number of sites in Emilia Romagna containing asbestos from 2005 to 2018

The activity of prevention and removal have been concentrated on the priority classes and those of elevated risk. The following table (Table 11-3) shows the priority interventions.

Priority class	Conditions necessary to be assigned priority class
5	ACM friable or compact confined
4	ACM friable or compact, not confined; non accessible site
3	ACM friable or compact, not confined, accessible site, not for public use
2	2a) ACM friable, not confined, accessible site, not for public use 2b) ACM compact not confined, accessible site, for public use
1	ACM friable, not confined, accessible site, for public use

Table 11-3: Priority interventions for the removal of asbestos

As we can see for the graph below (Figure 11-6), there aren't any more sites in the priority class 1 and the reduction of sites in priority class 2 is about 86%.

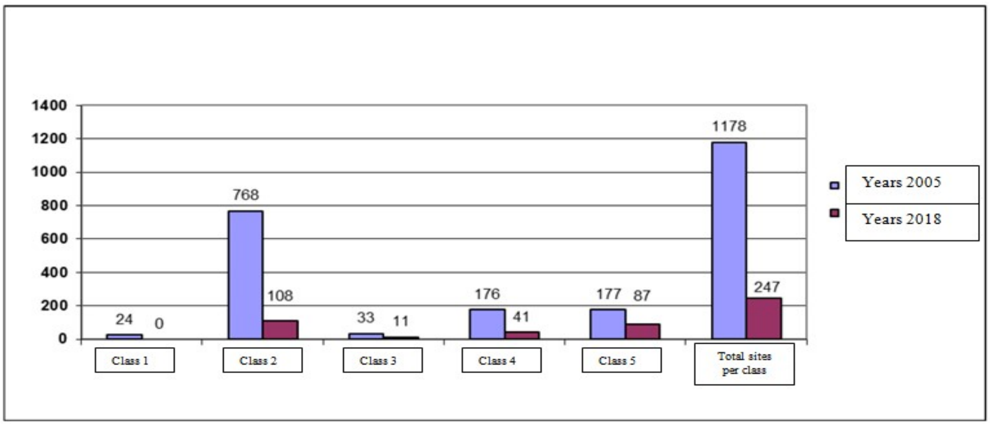


Figure 11-6:Number of sites with the presence of asbestos in the Emilia Romagna region for priority of intervention 2005-2018

The reduction is very high in certain types of sites in particular in schools where it is about 90% (Figure 11-7).

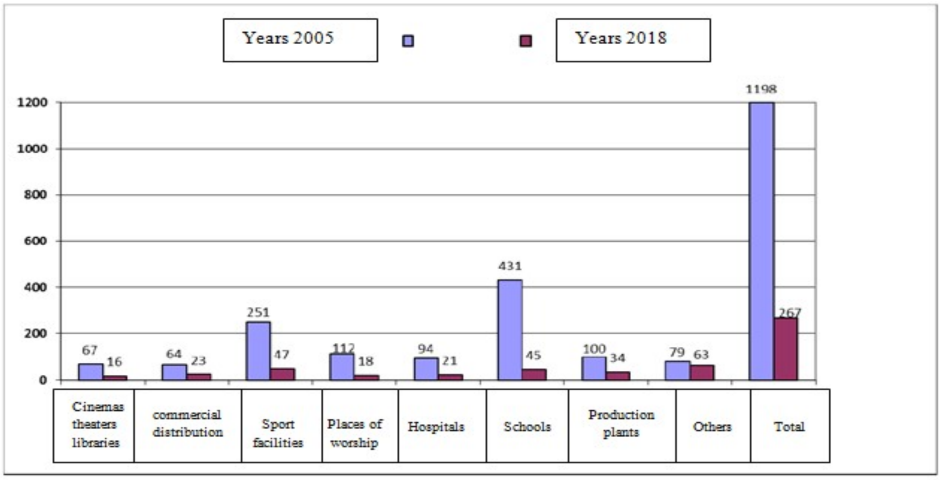


Figure 11-7: Number of sites with the presence of asbestos in the Emilia Romagna region as to type of buillding 2005–2018

12. Planning the decontamination operations

12.1. Methods of decontamination

The methods of decontamination used and set down by the standards in force (D.M. 06/09/1994) are essentially three: the removal, the confinement and the in encapsulation (*Bullian,2008*). These systems can be implemented either in the case circumscribed, limited operation, or in the case of a general operation. These procedures are:

- **Decontamination by removal**: consists in the total elimination of materials containing asbestos.
- **Decontamination by encapsulation**: consists in treating the materials containing asbestos with products which penetrate or cover them having the capacity of encompassing the fibers of asbestos restoring its adherence to the support and creating a protective film on the exterior surface.
- **Decontamination by confinement**: consists in forming a barrier, which is resistant to impacts so as to seal the asbestos containing material from the rest of the surrounding environment.

12.1.1. Removal

This is without doubt the mostly widely used procedure which consists in the elimination of any source of exposure to the population and abolishing any future precautions necessary for activities conducted inside the building (Figure 12-1). Before removal, a paint like film is applied to the material (not long lasting) type D (encapsulation of products in asbestos cement to remove following the D.M. From 20/08/1999). After decontamination, it is no longer necessary to formalize a program of maintenance and inspection with someone responsible.

Figure 12-1: Method of decontamination: removal

12.1.2. Confinement

The system of covering the materials consists in confining them by installing a new covering over that in asbestos-cement, which is left in its place when the supporting structure is able to uphold a permanent added load (Figure 12-2). To make this decision the builder or the contractor must provide the calculations of the extra weight the structure can bear. The installation usually consists in drilling holes in the asbestos material so that a new covering can be fixed to it and to the internal weight bearing structures which determines the freedom from the asbestos fibers. The inferior part of the covering in asbestos-cement does not get confined and remains therefore accessible from inside the building, in respect to the constructive characteristics of the roof. Before positioning the covering, the entire surface is treated with penetrating or covering products type C (encapsulation of products made in asbestos-cement of compact matrix not visible according to the D.M. of 20/08/1999) which tends to encompass the asbestos fibers. The thickness of the dry encapsulating cover should not be less than 200 μm, and no measurement should be less than that. The operation must be performed in conformity with the D.M. of 20/08/1999, and in particular, the contractor must require from the company who does the work, a certificate showing the conformity of the encapsulating product applied, and a certificate of the conformity of the work (one color, thickness, minimal duration of treatment). When the decontamination is complete, a program of maintenance and inspection with an nominated responsible person must be made.

Figure 12-2: Method of decontamination: confinement

12.1.3. Encapsulation

This type of intervention consists in treating the surface of the products containing asbestos with at least 2 hands of an appropriate covering or penetrating product, type A (or B if the product in asbestos-cement is in a building), which can block the asbestos fibers giving the system more stability and create an elastomeric film of protection on the exposed surface (Figure 123).

Figure 12-3: Method of decontamination: encapsulation

The work must be done in conformity of the D.M. of August 1999, and in particular the contractor must require of the company doing the work, a certificate attesting to the product used and the work done in regards to thickness, colors different from the last two hands and the minimum duration of the treatment. For encapsulating covers of type A (encapsulating products in asbestos-cement of compact matrix visible externally according to the D.M. of 20/08/1999) the average density of the encapsulating cover, dry, shouldn't be less than 300 mm, and in no point be less than 250 mm. As shown in the figure below (Figure 12-4), the two products in the encapsulation cycle should be two products that form a covering and are of two different and contrasting colors. In order to have this encapsulating product adhere better, a coat of primer can be used.

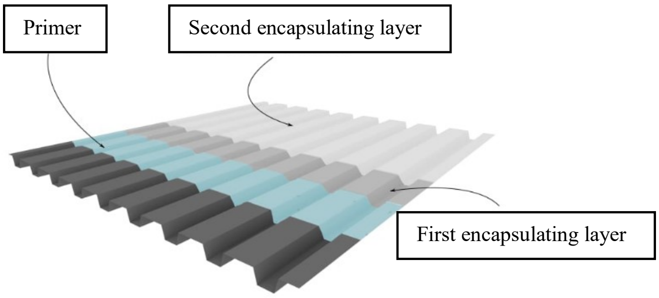


Figure 12-4: Encapsulation of a sheet of asbestos cement with a double layer of an encapsulating product and a layer of primer

The encapsulating cover type B (encapsulation of products in asbestos-cement of compact matrix visible eternally, according to D.M. of 20/08/1999), the average density of the dry encapsulating cover shouldn't be less than 250 mm and in no point should be less than 200 mm. The last two products of the encapsulating cycle should be two products that cover in two different and contrasting colors. The encapsulation requires necessarily a primary treatment of the surface in order to clean it and to guarantee adherence of the encapsulating product. The treatment must be done with the appropriate tools which avoid the dispersion of the asbestos fibers into the environment and which allow the water used to be recuperated and treated. After the work is done, a program of maintenance and inspection with a nominated person responsible should be formalized.

12.2. Samples and analysis of manufactured products

The analysis or testing of materials containing asbestos are of two types and precisely.

- the analysis of the mass samples;

- the analysis of airborne fibers.

The analysis of mass samples is carried out in order to characterized both the quality and the quantity of asbestos in the material thought to contain it in work places no longer in use. When the evaluation of the type and morphology is finished, a microscopic analysis is done which can tell the degree of asbestos or the absence of it in the material. It can also determine the type of fiber it is made of. The most common techniques used are the microscopic in contrast phase (MOCF) and the electronic microscope scanner (SEM) (Figure 12-5).

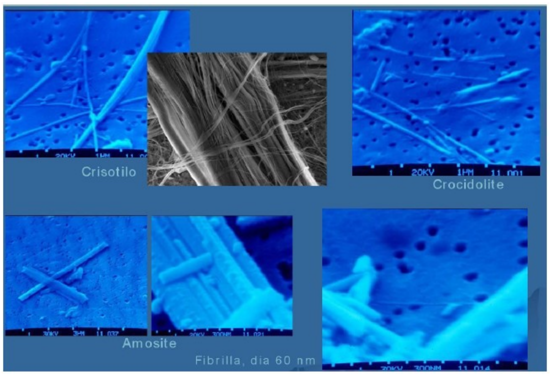


Figure 12-5: Electronic microscope scanner (SEM) showing different asbestos fibers

The MOCF (Figure 12-6) is the most used technique both because it is very fast and because it costs less although it is less conclusive, has less depth and it is impossible to recognize the fibers unequivocally since this technique is largely determined by the technician who must be able to visibly recognize the dimensions and the shapes.

Figure 12-6: MOCF of fibers of chrysotile seen by the chromatic dispersion method

The necessity of measuring the quantitative concentration of asbestos in a mass sample entails the use of other analytic techniques such as: x-ray diffraction (XRD) and infrared spectrum analysis with converted Fourier (FTIR). These analytic techniques, with mass samples, are the most used because they allow a better mineralogical characterization of the asbestos contained in the sample. In summary we can say:

- The MOCF test is sufficient to verify the presence of asbestos in any material;
- in order to determine the concentration, it is necessary to use the XRD and the FTIR tests;
- In order to have the absolute certainty of the absence of asbestos, the microscopic SEM test is used.

The way the samples are collected is very important, even before any analysis is done. Mass samples are to be gathered according to the procedure outlined in the D.M. Dated 06/09/1994 and reassumed in in the following points:

- acquiring representative photographic documentation;
- the use of adequate DPI (devised for individual protection) during the gathering of samples;
- the use of less invasive ways possible of collecting the samples so as to limit as much as possible airborne fibers;
- gathering small quantities which do not cause significant alterations in the production;
- inserting the sample in an airtight container, marking the point of collection and the compilation of a collection form;
- sending the sample and its documentation to the lab responsible for the analysis.

The analysis of the airborne fibers is carried out in order to determine the concentration of the asbestos fibers in the air (0.001 fiber/ml = 1 fiber/1=1000 fibers/m^3). In other words, the sample is taken by collecting known volumes of air using a pump which is specifically gauged having the air pass through a filter membrane on which the solid particles in suspension, will deposit. In this case, the analytic techniques used are those using a microscope either the MOCF or the SEM. AS already pointed out, the MOCF is easier to do but the results are less precise and dependable in comparison to the SEM technique which allows an unequivocal and certain recognition of the asbestos fibers present. For this reason, the type of technique used is chosen on the basis of the type of environment, (work place, living area or external space) and in the context in which the work must be done (estimation of the state of pollution, the duration of the work of recovery, phases of restoring the cleaned area). The current norm requires the use of both analytical techniques defining, however, the limits of the diverse readings if they are done by the MOCF or the SEM. The limit in the relationship between the two methods has been set at 1 to 10 between the SEM and the MOCF since the latter (MOCF) often counts all the visible fibers even if they aren't asbestos The D.M. 06/09/1994, states that for 2 fiber/1 counted in SEM. corresponds an (overestimated) concentration in MOCF of 20 fiber/1. In short, the choice of an analytic technique best able to measure airborne asbestos fibers can be seen in the following table (Table 12-1) referring expressly to the legislation in act.

TYPE OF ENVIRONMENT	COLLECTION METHOD	NOTE
Work place, exposure to workers	Personnel/ MOCF	D.Lgs 81/08
Living area (indoor)	Environmental/ SEM (advised) MOCF	D.M.06/09/1994
Monitoring of the workplace of decontamination	Environmental/MOCF	D.M.06/09/1994
Reclamation of environs cleaned by confinement	Environmental/SEM	D.M. 06/09/1994
External areas	Environmental/SEM	not required

Table 12-1: Methods of collecting samples on the basis of type of area

12.3. Evaluation of the state of affairs

The presence of materials containing asbestos in a building or in roofing is not per se a danger for the health of the occupants because the risk depends on the probability that the products in asbestos release fibers and this comes from the state of conservation of the materials, correlated to all the

potential factors which can modify the integrity of the materials, such as accessibility, danger of damage by impact, vibrations, atmospheric pollutants. A very important phase in evaluating the presence and danger of asbestos s represented by recognizing the state of a site, through inspections and evaluations of the state of conservation of the infrastructure and the things which can or could contain asbestos.
To verify the state of affairs, the following actions are usually taken:

- verification and visual identification of materials potentially containing asbestos aimed at examining the conditions in which the plants and infrastructures are found;
- research and verification documented by the technical data compiled accessible and traceable in order to make a first study of the materials used in the construction of the plant;
- collection of mass samples to verify analytically the quality and quantity of the presence of asbestos in the collected material;
- distinction between friable and non;
- metric findings aimed at calculating the quantity of the various products;
- monitoring the areas where the fibers are airborne so as to determine the starting point for a future clean-up;
- scheduling and registering all the technical information collected.

These findings are necessary to draw the map of the area in question and must contain all the information about materials used, the types, friability, position, type of application and accessibility. The map therefore gathers a series of technical and environmental information designed to define the state of the area where it may be necessary to intervene in decontamination. These documents, moreover, are very useful to periodically monitor the areas and the products according to the laws in force (D.M. 06/09/1994).

12.4. Evaluation of risk in areas indoors

In order to evaluate the risk of asbestos, the map and the study made to verify things mentioned in the above paragraph, are very important. The D.M. 06/09/1994 brings out the particular importance of basing the evaluation of risk on the verification and findings of the conditions and characteristics relative to the materials containing asbestos by using the inspection sheets contained in attachment V of the same decree. For the evaluation of risk from the potential exposure to asbestos fibers to the people in the building, the following types of criteria are used:

- ✓ the examination of the conditions of installation in order to estimate the danger of material fibers released into the area;
- ✓ measurement of the concentration of airborne asbestos fibers (by monitoring the area).

Monitoring the area isn't the only criterium adopted to evaluate the release of fibers because it measures the concentration present in the air at the moment of measuring, without obtaining information on the danger that the asbestos could deteriorate or be damaged during normal activities. In particular, in case of damage, accidental or not, elevated quantities can be released which however would be only occasional and brief and which aren't collected as samples. In the phase of visual inspections of the installation, the following must be carefully evaluated:

- the type and condition of the materials;

- factors which could determine future damage or disrepair;
- factors which influence the diffusion of fibers and the exposure to individuals.

Therefore the compilation of the forms for the onsite inspection (attachment V of D.M.06/09/1994) of the building where materials containing asbestos are found must be completed. The factors to be considered must consent to evaluate any possible future damage or deterioration of the material and the fact that the material itself could be damaged or deteriorate. On this basis we can see three types of situations:

- intact materials not susceptible to damage;
- intact material susceptible to damage;
- damaged material.

Using the outline of evaluation suggested by D.M. 06/09/1994 hereunder we arrive at the decision whether or not to undertake an operation of decontamination of ACM in question (Figure 12-7).

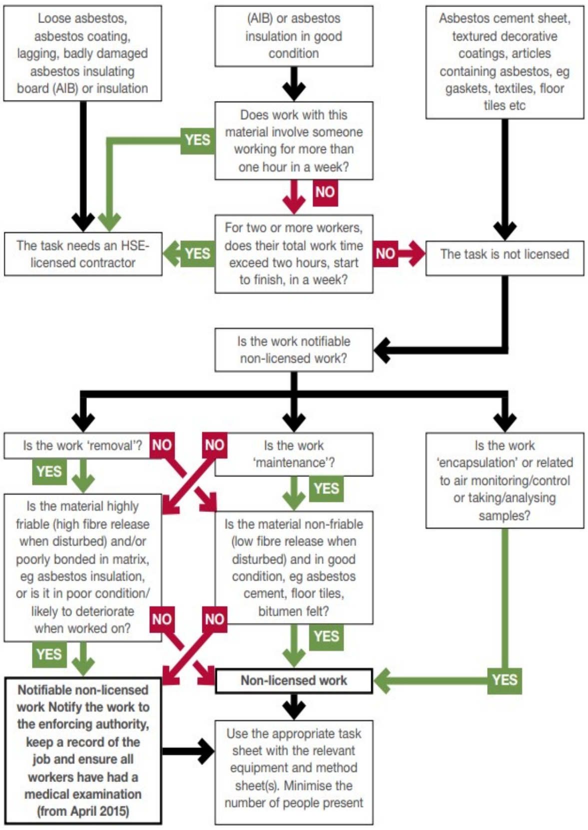


Figure 12-7: Diagram of the flow of the process chosen for the decontamination ACM (HSE, 2001)

The current legislation however does not stipulate precise systems of evaluation of risk on points, (algorithms) leaving to the technician the decision whether to use these algorithm systems in use for years in various western countries. These methods aim to limit the variables of judgment stating the conclusions of the evaluation of risk in an unequivocal and concise way. The algorithms are methods through which a "*weight*" is assigned to factors thought to be relevant to a probable release of fibers into the air; these figures are compiled in a simple mathematical quotation which provides a numerical index which then allows the comparison of different situations and to put them in order according to priority. One of the algorithms most use is the "*criterion of risk evaluation of Versar*" introduced by the American company of the same name in 1987 and essentially based on a two dimensional model by the definition of priority of intervention on the product in question. This method was subsequently adopted by the E.P.A. In alternative to the above named criterion, there also exists an Index of Ferris, an E.P.A. Index (proposed by the Environmental Protection Agency U.S.A. 1992) and a German index (elaborated in 1989 by the Internal ministry of Germany) Some Regions such as Piedmont, Lombardy, Veneto, Abruzzo, Lazio, Tuscany, and Emilia Romagna have developed their own algorithms using the guide for the evaluation of the state of conservation of coverings in asbestos cement and to evaluate the risk. Here below, we see a description of the criterion of evaluation of risk using the Versar method invented by the American Company Versar in 1987. As we see from the graph (Figure 12-8), the indicators show two distinct orders of factors:

- ✓ Damage factors;
- ✓ Exposure factors.

Each parameter is assigned a score established in order to limit the variability due to the subjectivity of the detector.

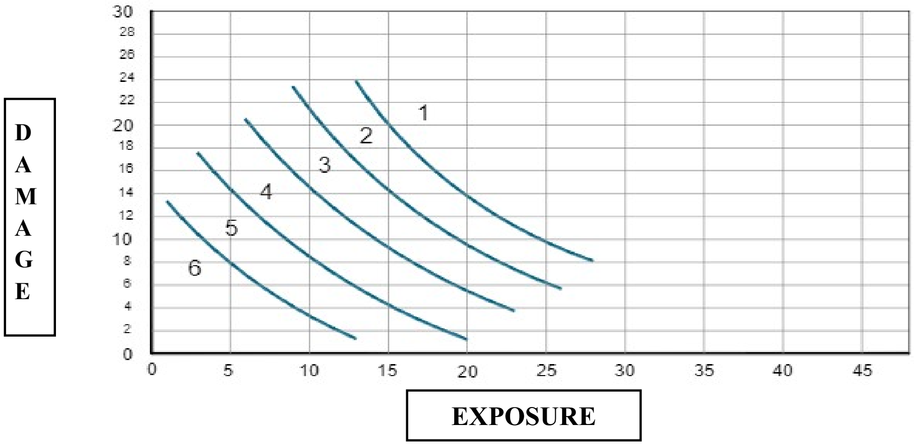


Figure 12-8: Graph of the index of Versar for risks

Here is the key to understanding the above drawn graph:

- ➢ **Zone 1** immediate removal;
- ➢ **Zone 2** removal as soon a possible. It can be postponed to the next date possible for example, school vacations, but without waiting for the occasion to restructure or of extraordinary maintenance of the building;
- ➢ **Zone 3** programmed removal, the removal can be done when maintenance or remodeling is programmed;
- ➢ **Zone 4** reparation. Areas that are damaged should be fixed with work limited to confinement or encapsulation;
- ➢ **Zone 5** periodic monitoring and inspections. Periodic checks of the area to assure that there is no ulterior damage;
- ➢ **Zone 6** No immediate action necessary improbable release of fibers. No work is needed.

In any situation in which materials containing asbestos are present, it is a good rule in any case, to have a program of checks and maintenance which in many cases represents the best solution to prevent risks derived from the presence of asbestos. Concluding the decontamination intervention is indicated in the following cases:

- The plant which contains the ACM should be demolished;
- In interventions of maintenance and remodeling;
- In large plants where the ACM can deteriorate with time or be subject to vandals;

- Where extensive damage exists and work of restoration is not convenient (more than 10% damage);
- When the source of the damage cannot be eliminated;
- When ventilating systems are present capable of increasing the airborne fibers;
- When environmental monitoring shows that airborne fibers are polluting the area (>2 fiber/1 in SEM or >20 fiber/1 in MOCF – D.M. 06/09/1994.

12.5. Evaluation of outdoor risks

The flat or wavy sheets of asbestos cement, used to cover buildings are made of non friable material which when new or well conserved, do not tend to release fibers spontaneously. When asbestos cement is found inside buildings, even after a long time, it is not significantly subjected to alterations which determine a release of fibers if it isn't tampered with. Instead, the same material on the outside of a building exposed to the atmospheric conditions undergoes a progressive deterioration because of acid rains, temperatures swings, wind erosion and microorganisms in plants. Consequently, after being installed for years corrosive alterations can take place releasing the fibers. The main indicators useful to evaluate the state of deterioration of the asbestos-cement cover in relation to the possible release of fibers are:

- ➢ The friability of the material;
- ➢ The state of the surface and in particular evidence of fibers showing through the cover;
- ➢ The presence of cracks, breakage or flaking;
- ➢ The presence of friable or powdery material corresponding to water grouts, or drains etc.;
- ➢ The presence of powdery material englobed in little dripstones near places where water drips.

To determine the presence of a risk it is necessary to consider, other than the state of conservation of the material, the context in which the building is set which has a covering made of asbestos cement. Terraces, balconies and windows which border on sheets of asbestos cement can be important in defining the presence of risk for those who live or work in the vicinity because fibers can be released from these places and when it is windy, can easily enter the building. On the other hand, schools or hospitals near buildings with the presence of these materials determines the opportunity to intervene since they can be a hazard to people who are more vulnerable. In fact, data shows that samples taken from the environment near buildings with roofing in asbestos-cement, have low airborne fibers; in these cases an operation of removal can increase the risk because during the manipulation of the sheets, fibers are released. Therefore the decision to do this work or not, and the choice of times and ways, must take into consideration on one hand the state of deterioration of the materials and the factor of dispersion, and on the other the presence in the nearby area of very young people for example students or people with health problems like hospitals or care homes. Redoing the covering in asbestos-cement is necessarily carried out in an open area and not in a restricted one. And in any case done in such a way as to release a very limited amount of fibers. Monitoring of the area is not the only system to verify the release because the powdery material produced by deterioration is transported by the wind because of the limited capacity of the fibers to deposit and because of their aerodynamic properties. Having said this, a punctual evaluation by itself is not sufficient but should be accompanied by an evaluation of the overall risks which take into account mechanisms of dispersion and airborne fibers in external areas (Figure 12-9).

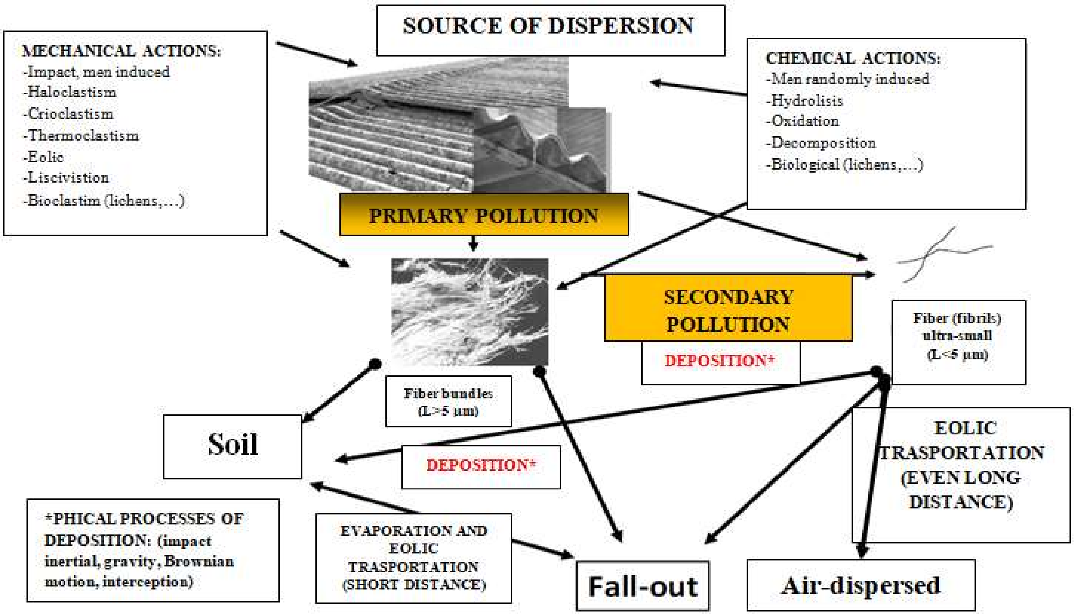


Figure 12-9: Diagram of the process of release and suspension of the asbestos fibers in the atmosphere from roofing made of asbestos cement (O. Sala, 2014)

In order to evaluate the state of conservation of roofing in asbestos-cement, and to evaluate the risks, we'll take as a referral the guide lines of the Emilia Romagna region. The following table shows the findings of the state of conservation of the roofing. The cards shown below (Figure 12-10) describe the location and context in which the product is found (shows windows and balconies or places where people are present) and the state of conservation of the roof by assigning a score to the various parameters which describe it.

FORM NO.1
DESCRIPTION OF THE ROOFING AND CONTEXT

Owner:__________________________
Address:__________________________
Date:____________________________
Roof:
Corrugated sheets □ Flat sheets □ Other_________________________
Covering or surface treatment____________________________________
Size:_____m^2
Gutters: present □ absent □ Distance from ground:_____m^2
Gradient:____% Layers no.______
Year completed: certain □ presumed: □
Description of openings:_________________
Near schools or hospitals: yes □ no □
Damage to roof/damage found:
Damaged sheets □ Broken sheets □ Repaired sheets □
Cause of damage:
Maintenance work: □ Age of materials□ Vandalism: □
Exceptional atmospheric events: □ Other: □

FORM NO. 2
FINDINGS OF THE STATE OF CONSERVATION OF THE ROOF

North side □ South side □ East side □ West side □

When the state of repair of the roofing is not uniform, fill out the following form for each side

No.	Parameter	Observations	Points for each item	Points assigned
1	Consistency of materials	using a tool, the angles and edges of the	1	
		using a tool, the angles and edges of the sheet tend to bend and layer	3	
		layer easily	9	
2	Surfacing of fibers	with a magnifying glass groups of fibers surrounded by cement can be seen	1	
		with a magnifying glass groups of fibers can be seen partially surrounded by cement	3	
		fibers seen with a magnifying glass are easily plucked with a tweezer	9	
3	Layering, cracks, breakage	absent	1	
		little	2	
		numerous	3	
4	Friable or powdery material in the rain gutters	absent	1	
		little	2	
		consistent	3	
5	Dripstones	absent	1	
		very small	2	
		of notable size	3	
Assessment of the state of conservation of the roofing			Total	

Figure 12-10: Forms for the evaluation of the state of conservation of the roof in asbestos-cement

The Following is a table (Table 12-2) showing procedures to follow consequent to the assessment of the state of conservation of the roof and to the context in which it is situated.

Total	Assessment	Consequent procedures
5-10	good	Evaluate the state of the roof at least every three years and adopt specific procedures for maintenance work, both ordinary and extraordinary, and in general for all access to the roof in order to avoid disturbing the sheeting
11-20	poor	Evaluate the state of the roof annually and schedule restoring work every 3 years. If there is a school nearby or there are people in the vicinity, the work should be done within a year
21-27	very poor	Schedule a restoration within 18 months, removal being the best solution. In case the material is near the presence of people or schools or hospitals, schedule the removal within 6 months, unless the inspection council asks for less time, in which case it is proposed to appeal to the ordinance of the local health authority

Table 12-2: Table of ratings evaluating the roofing in asbestos cement

12.6. Implementing plans: the work plan

The work plan when speaking of asbestos decontamination, is a document, by which an executive company lays out all the procedures and techniques that will be put into effect in order to perform the work according to current laws. (D.M. 06/09/94). It is drafted according to the D. Lgs. 257/2006 entirely accepted as a unified text on safety D. Lgs. 82/2008. It is a document which must be notified to the security agency competent for the area, (local ASL) at least 30 days before beginning the work. In that period of time, thanks to the collaboration of technicians and the inspection office, who usually give their opinions and requests in order to better the work. The work plan is a true project of restoration and decontamination through which tools, procedures and the organization of the work will be adopted for the safety of the workers and to avoid risks to the environs based on a documented primary evaluation of the risks. In this, the area to reclaim is accurately analyzed adapting the type of work intended, carefully describing the various phases of work starting from the lay-out of the work site, up to the authorized disposal of the waste; and contains, moreover, the requirements and the consequent measures to take on the subject of hygiene and safety common to all work sites, and as already mentioned, an analysis of the risks which could occur during the intervention and identifying the provisions to be taken. The work plan must be rigorously respected during the work phase because, correctly following the plan, guarantees that the work will be done so as to avoid risk of exposure to asbestos by the workers and pollution of the external area. A plan of work for the reclamation and removal of asbestos, in nature, friable and compact, must contain the following guide lines:

1. Information about the company doing the work;
2. Information about the contractor of the work;
3. Information about the work site:
    - exact location in "*toto*" (including blueprints, designs, photographic documentation etc.)
    - nature of the remedial work to perform,
    - approximate dates of beginning and ending of the work measured to take for the separation of the area to decontaminate and/or for the removal of asbestos containing material from the work site *"en toto",*
    - the type and characteristics of the material which is the object of the decontamination: friable or compact asbestos-cement,
    - an estimate of the amount of material to removed.
4. Information regarding the personnel working at the work site:
    - technical director of the work site,
    - assistant to the technical director,
    - operational personnel,
    - physical and professional suitability of the workers.
5. Information relative to the organization and the methods of working at the work site:
    - daily and weekly working hours,
    - work stages and operative procedures,
6. Information relative to hygiene in the workplace and in the environs:
    - specific means of protection,
    - ways of use and maintenance of the means of individual means of protection,
    - posters relating to hygiene hung in the work place,
    - description of methods of confinement of the work area,
    - operative systems of controlling airborne asbestos fibers and ways of applying them,
    - evaluation of the presumable level of exposure during the removal of asbestos,
    - measures to adopt in case these levels are greater than presumed (in the case of friable asbestos),
    - characteristics and location of the "*structure*" prepared for decontaminating the personnel (in case of friable asbestos),
    - procedures to adopt to monitor the environment and technique of collecting samples (for friable asbestos),

- documentation of the lab carrying out the analysis of the samples (for friable asbestos),
- Type, number, and characteristics of the vacuuming system for powders used on the work site,
- equipment and means used at the work site.

7. Information relating to safety measures used at the work site:
    - number, type and characteristics of the personal means of protection required to eliminate risks of falling,
    - characteristics of the mechanisms required to eliminate the risk of falling,
    - personal means of protection to eliminate other risks present at the work place,
    - characteristics of safety posters,
8. Information relating to the storing of waste materials:
    - type and ways of baling,
    - ways of temporary amassing waste materials,
9. Information relating to the transport and disposal treatment of waste materials:
    - transport,
    - disposal treatment.
10. Attachments.

The work plan is written by the employer of the company doing the work or by his delegate possessing the requirements according to current law (an administrative course qualifying him to remove materials containing asbestos). It shouldn't be a simple description of a standard operation but detailed analysis of problems relating to the type of environment and plants to treat and of the work done there, describing the procedures to be done in order to respect regulations the theoretic principles of decontamination suitable to the situation. Furthermore, it must foresee , as much as possible, the difficulties which could emerge during the work, and the solutions in order to avoid them not to mention the measures to take in an emergency and the required assessment procedures. The contents of the work plan for that which regards the phases of work and important jobs, are usually agreed on before presenting the official notification, to the person responsible in the inspection office, competent for the area, to which the law leaves the evaluation to his discretion.

12.7. Operative procedure for work sites with asbestos-cement sheets

Sheets and other products of roofing in asbestos-cement must be adequately wet before any handling or movement. In the case that the roof must be walked on, specific adhesive, paint or encapsulating products which do not allow for sliding must be used. The wetting must be done by spraying or pouring with low pressure pumps. Under no circumstance should a high pressure stream of water be used. If the asbestos fibers are found accumulated in the rain gutters, they should be treated by dampening them with water so that a dense mud is formed which should be put in plastic bags with scoops which can be disposed of also. These plastic bags sealed with adhesive tape, are then disposed of as is asbestos. The sheets must be removed without breaking them avoiding the use of demolition tools. They must be disassembles by removing the clamps, screws or nails which fix them, being careful not to damage the sheet itself. Drills, saws, flexible or abrasives of high velocity must not be used. If necessary, only hand tools should be used or mechanical equipment with vacuum systems suitable for use with asbestos-cement, having absolute filters at the end. The vacuumed material must in no way be splintered after removal. They must not be allowed to fall to the ground. A suitable way of lifting them must be used to lower the sheets to the ground. The disassembled sheets, wet on both sides, must be put one on top of the other and wrapped in a way to make moving easier by the lifting machines available on the work site. The asbestos material removed must be closed in packaging which does not deteriorate or wrapped in plastic sheets and then sealed. Any pointed cutting pieces must be discarded as to avoid tearing the packaging. Waste in very small pieces must be collected as soon as they form and closed in bags made of impermeable material that doesn't deteriorate, and immediately sealed. All waste materials must be tagged required by law, and they must be taken away from the work place as soon as possible. Temporarily piling them must be done separate from other trash, preferably in containers for transport or in a special area just for them, but not in the way of traffic which could provoke breaking up. Daily cleaning must be done by wetting or vacuuming with absolute filters of the work site where it could be contaminated by asbestos fibers.

12.8. Requirements of companies and qualified personnel

The companies which do the work of decontamination and restoration of goods containing asbestos, must be registered in Category 10 – reclamation of goods containing asbestos of the list of environmental managers of the capital of their region. The documents to present are:

- a bank trust which can be issued by a bank according to memo no.150 from 2008;
- a copy of IVA charges, of balances, of income declaration (volume of affairs, real estate) of the last financial year.

The activity of removal and restoration are put in two sub-categories, in relation to the degree of danger to the environment and human health and to the complexity of the work of removal (Deliberation no. 1/2004 of the National committee):

- **Category 10A** – for activity of reclamation done on building materials containing asbestos tied in cement matrix or retinoid
- **Category 10B** – for activity of reclamation done on friction materials, insulation materials, (panels, couples, paper and card sprayed materials, stucco, enamels, tar, glue, gaskets, and other insulating materials), pressurized containers, outdated equipment or other materials containing asbestos.

Registration in the subcategory 10B is valid also to do work in category 10A respecting the category of registration. Within category 10A and 10B, there are different classes according to the amount it costs to do the work (Table 12-3):

CLASSES	Amount of money for the reclamation work
A	over 9,000,000 euro
B	up to 9,000,000 euro
C	up to 2,500,000 euro
D	up to 1,000,000 euro
E	up to 200,000 euro

Table 12-3: Classes of category 10 by amount of Euros for reclamation work

The companies which intend to register in category 10 must demonstrate that they have the following requisites:

1. **Subjective requisites, including moral requisites:**

In order to respect these requisites, the owner (in the case of an individual company) or the legal representatives (in all other cases):

- Must be Italian citizens or citizens of the EU or of another country but resident in Italy, as long as this other country gives the same rights to Italian citizens in their country;
- They are not prohibited or unable to do the work or are temporarily prohibited by the legal directives for individuals and companies;
- Were not subject to judicial conviction according to article 444 of the penal code, and even if this has been extinguished of every effect or if he was pardoned of the conviction in the following cases: sentenced to prison for crimes against the environment, including laws for safeguarding health, or the laws regarding building or urbanistics, having been sentenced to over one year in jail. The conviction is not counted if ten years have passed from the date of the conviction to the sentencing, or if he was granted a suspended sentence and in the meantime the crime was discharged as in art. 167 of the penal code, or if he was rehabilitated;
- In their regards, there don't exist causes for prohibiting the work, for cancellation, or suspension of which art. 67 D.Lgs 159/2001;
- They never declared falsely or falsified information required to be registered.

2. **Technical suitability: technician Cat. 10, minimum equipment and value of equipment**

The companies and the agencies engaged in this work of decontaminating things containing asbestos must nominate a technician in Cat. 10 who will be the person responsible for the work whose professional qualifications must include a suitable diploma, experience in the sector and exams which prove his suitability according to the deliberation no.6/2017 of the national committee for the category chosen. The minimum technical requirements are set down by the deliberation no.1/2004. For each of these categories, 10A and 10B, there is a list of the minimum amount of equipment the company must have and the how much this equipment is worth for each class registration.

List of equipment necessary (minimum) for category 10A:

1) Vacuum cleaner with absolute filters;
2) Individual protection devise for breathing (masks);
3) Airless (a pump to spray encapsulants).

List of equipment necessary (minimum) for category 10B:

- extraction plants and air extractors with absolute filters;
- a unit of decontamination even if modular or prefabricated;
- water filtration unit;
- aspirators (or exhaust fans) with absolute filters;
- individual breathing protection devise (masks);
- airless (pump to spray encapsulants);
- personal and environmental air samplers;
- devise for measuring depression;
- smoke generator;

- unit to heat water.

There must also be presented, a declaration which substitutes for a notary act which attests for the type of equipment, the worth of the equipment the availability and the state of repair of the equipment which the person must own in order to do this work. This substitute declaration of a notary act varies according to the category because the equipment in each category is different. The whole and exclusive availability of the minimum amount of equipment (Table 12-4) can also be demonstrated by a contract or lease of location, as long as it respects the requirements listed in art. 2 of the deliberation no.2 of 10/07/2006 (National committee register for environmental operators).

ATTACHMENT "A" (art.2,comma 1)					
THE VALUE OF THE MINIMUM AMOUNT OF EQUIPMENT, CATEGORY 10					
	Class E up to 51,645.69 €	**Class D** up to 413,165.52 €	**Class C** up to 1,549,370.70 €	**Class B** up to 7,746,853.49 €	**Class A** up to 7,746,853.49 €
Cat.10A	2,600.00 €	2,600.00 €	7,799.00€	36,700.00 €	51,600.00 €
Cat. 10B	12,900.00 €	12,900.00 €	31,000.00 €	154,900.00 €	180,800.00 €

Table 12-4: The minimum value of the minimum amount of equipment required for category 10A or 10B

1) Financial capability

The companies which have the intention of registering in both categories 10A and 10B must have the financial requisites (Table 12-5) and must accept the amounts set down by the National committee (D.no.1/2004).

ATTACHMENT "D" (ART.4,COMMA1)					
FINANCIAL CAPABILITY CATEGORY 10					
	Class E up to 51,645.69 €	**Class D** up to 413,165.52 €	**Class C** up to 1,549,370.70 €	**Class B** up to 7,746,853.49 €	**Class A** up to 7,746,853.49 €
Cat.10A	23,200.00 €	43,900.00 €	152,400.00 €	803,100.00 €	1,084,600.00 €
Cat. 10B	33,600.00 €	54,200.00 €	175,600.00 €	919,300.00 €	1,213,700.00 €

Table 12-5: Financial capability for categories 10 A and 10 B

For the people who work in the decontamination of asbestos there are two requirements (*Grandi M., Magri M.,2012*) necessary for all levels:

- a regional certificate of authorization for the decontamination and removal of materials containing asbestos (commonly called a license for asbestos);
- medical certificate of health.

For the aforementioned works of decontamination of asbestos, the people engaged in this work both technicians and workers, must be adequately and constantly informed and trained on the inherent problems of this work both on temporary work sites and mobile work sites as well as the risks of handling asbestos continually, even if they have the regional certificate of authorization. For everyone who works there from the managers to the laborers, there is the obligation to attend qualification courses for the decontamination and removal of material containing asbestos according to art. 10 D.P.R. 08 august 1994 and s.m.i. (*Cavarini F., 2014*). The courses are organized by the regions and are on two levels:

- Operational, consists of 30 hours of lessons of theory and practice with a qualifying final exam;

- Administrative, consists in 50 hours of lessons, theory and practice, with a qualifying final exam.

The workers are given information by the health agency according to the D.Lgs. 81/2008, about the risks of exposure to asbestos as well as to periodic preventive health check-ups in order to ascertain their physical suitability to the work of removing asbestos containing material. The check-ups usually take place every year even if the law regulating them requests them every 3 years. The law states that the health monitoring of the workers be done by "*competent doctor*", that is, one who specialized in occupational medicine. This doctor must judge the suitability of the workers and to inform them on the significance of the monitoring and on the outcome of it. He must visit the sites at least twice a year. Lastly, the check-ups are occasions to personalize the information on the risks, on the use of protective measures and on the necessity to avoid smoking tobacco.

12.9. Individual protection devices

The Individual Protection Devices (D.P.I.) are all those things that make up the personal work kit and guarantee the safety of the individual, limiting or eliminating risks of injury or of professional illness. They must be available in the same number as the number of workers involved in the work, getting replacements necessary for normal use. The employer has the obligation to make available suitable DPI whenever, during the work, the inherent risks cannot be sufficiently limited by technical measures of prevention or by collective protection means. If during the operation of decontamination of asbestos, an elevated concentration of airborne fibers is ascertained, the protection of the workers must include both respirators and special protective clothing to wear exclusively during work (as required by the current legislation on the subject of safety D.Lgs. 81/2008) which should then be taken off respecting the procedure of decontamination described in the precedent chapters. Since asbestos is harmful if breathed in, it is of fundamental importance to use something to protect the respiratory tract. In case of exposure to asbestos fibers all devices of the respiratory tract protection belong to the third category DPI and are intended to save lives or to protect from grave, permanent injury. An adequate training program is obligatory for the workers to attend over and above the information and training they have had in order to use the individual protection devices in line with art. 43 of the legislation no. 626/1994 now abrogated and introduced with D.Lgs. 81/2008. The choice of respirators must be made taking into account the present degree of protection required in relation to the concentration of pollution possible through the assessment of risks depending on the level of protection desired. Except for exceptional cases, the respirators usually used are those with high efficiency filters type P3. These respirators can be of various types and the principle characteristics are two, the factor of Nominal Protection (FPN) which shows the effectiveness of the filters measured in a lab and attested to by the manufacturer and by the factor of Operative Protection (FPO) which shows the real effectiveness measured experimentally on the field, and that is on the work site. From these tests the choice of respirators is made on the basis of the risk situation possible in terms of fibers/liter of airborne fibers.

On the basis of the capacity of penetration of an aerosol, the filters are classified as follows:

- P1- penetration inferior to 20% (low efficiency);
- P2- penetration inferior to 6% (average efficiency);
- P3- penetration inferior to 0.05% (high efficiency).

Regarding Art. 251 of the legislative decree 81/2008, keep in mind that these devices must have a protection factor adequate to the concentration of asbestos fibers possible so as to guarantee always and in any case, that the air filtered inside the mask isn't superior to 10 fibers/liter. We refer in particular to the factor of nominal protection (FPN which is the relationship between the concentration of pollution in the area and that present in the mask, at the level of the respiratory tract of the user, the higher, the more protective). Moreover, the obligation to use these devices is emphasized in Art. 254, comma 4, when the exposure cannot be reduced by other methods. " *In any case, if the exposure cannot be reduced with other methods it is necessary to use an individual protection device of the respiratory tract with a factor of protection to guarantee all the conditions stated in article 251, comma 1, letter b*".

Concerning the types of masks, the different types are (Figure 12-11):

- Entire, that is that covers the whole face and must be used with filters which do not weigh > 600 gr. and <0.2% loss of tightness or seal;
- Half mask which covers the nose and mouth and must be used with filters <300 gr. with a total loss of tightness or seal of <0.2%;
- Mouthpiece which consists of a device held between the lips, which is not suitable to a complete prosthesis, associated with a nose clip and with a loss if tightness or seal of <0.2%,
- Facial filter with a filter together with a half mask, total loss <3% per FFP3.

Obviously, these types of masks have a FPN and FPO value different to that reported in the following table (Table 12-6) and so their use should be assessed each time according to the situation on the work site.

RESPIRATOR	FPN	FPO
Half mask with P3 filter (or facial filter FFP3)	50	30
Whole face mask with P3 filter	1000	400
Electro-respirator class 3 for use with a helmet or hood (THP3)	500	100
Electro-respirator class 3 for use with mask (TMP3)	2000	400

Table 12-6: Values of FPN and FPO for different types of respirators

Figure 12-11: Different types of respirators

To choose the correct respirator, use the following method-example (Figure 12-12).

Pollution present in the air: airborne fibers average considered concentration of asbestos Maximum exposure to asbestos downstream of protection 10 fiber/liter Level of protection necessary: *1000 fiber/liter:10 fiber/liter=100* Decision: It is necessary to use aa respirator which has an FPO equal of superior to 100

The choice of the type of protection device depends not only on the protection factor, but also on other factors such as:

- Duration and frequency of work,
- respiratory fatigue,
- microclimate,
- presence of other risks,
- levels of work organization,
- ergonomics of work,
- specific needs of the user.

The use of a half mask and a facial filter FFP3 in general, is reserved for operations of maintenance or removal of material in asbestos-cement, or while laying out the work site. A very important aspect that should never be neglected is the correct maintenance of the respirators. To do this, the person responsible for the work site must keep these DPI in good working order following the directions in the instruction manual. The filters or the masks directly must be substituted following the manufacturers indications or when the user feels that it is hard to breathe which happens when three is too much dust in the filter. It is a good thing to remember, before beginning a job, that the workers need to be taught and informed on the techniques of removing asbestos and on the use of the respirator masks, on the procedure of decontaminating and cleaning themselves and the cleaning and maintenance of the DPI.

For body protection, cotton coveralls are not suitable because the fibers enter in the weave of the fabric and are hard to wash out. Presently, two types of coveralls are used when working with asbestos:

- disposable coveralls with a hood;
- waterproof coveralls with a hood.

Coveralls must be made of a smooth fabric so as to not retain the fibers (coveralls in porous material are advised against), with a hood, should not have external pockets, should be closed at the wrists and ankles (or be able to be closed), with elastic or tape.

- Disposable coveralls are made in non woven fabric (like Tyvek) and even if they are good hygienically and suitable for decontamination, they have other characteristics;
- little transpiration;
- little insulation against the cold;
- need to be substituted every time one enters or leaves the work site;
- need to wear disposable underwear under the coveralls;

- are easily torn.

Waterproof coveralls (in fabric like Goretex or PCS) can be used more than once and after careful cleaning done under a shower, must be put away at the end of the work shift in a protected box inside the work site. These have the following characteristics:

- can be reused after careful cleaning and upkeep;
- can be worn under the shower with clothes worn underneath because they are waterproof;
- let transpire they are thermal;
- insulating.

It should be pointed out that the underwear worn under the coveralls should only be the necessary underpants, socks and undershirt possibly disposable. Rubber boots or non slip shoes that are used must be easily washed and high enough to cover the bottoms of the coveralls. The alternative are disposable shoes which however can slip on wet surfaces, this danger can be reduced by overshoes with the sole in polyethylene. The gloves to wear to remove asbestos must be waterproof and long enough to resist revealing the wrists when working and under the gloves it is advisable to wear cotton gloves. Except for the masks and the shoes, all other clothing worn during the removal of asbestos is treated as contaminated trash and is thrown away every time one leaves the work site.

13. The transport of special dangerous waste

Just as the work of decontamination of goods containing asbestos require the registration in the list of Environmental Managers, so does the transport of special dangerous wastes. The category which permits the transport these wastes is Cat. 5 – collection and transport of dangerous special waste. The documents to present are:

- a bank credit (Deliberation no. 5/2016 art. 4 of the National Committee) which can be issued by the bank or be a financial institute with a share capital not inferior to 2,582,284 €;
- a copy of VAT report, of balance sheets, income tax report (business volume, material assets) of the last fiscal year.

As well as having to respect a series of subjective requirements common to all categories, the companies and the agencies which intend to register in the list of Category 5 of Environmental Managers must also respect specific requirements of technical competence (availability of the means of transport and personnel) and to demonstrate their financial standing by means of a bank credit.

- **Responsible technician for Category 5**

  The companies and the agencies whose work is to transport and/or manage special dangerous and non dangerous waste, must nominate a technician responsible for this category whose professional qualifications must be proven by a diploma, by experience in the sector and by the tests of suitability required by the Deliberation no.6/2017 of the National Committee.
- **Requirements of technical competence**

  The minimum requirements of technical competence relative to the availability of vehicles and personnel are set by the Deliberation no. 8/2017 which has completed the Deliberation no. 5/2016 and has abrogated D. no.1/2003 and no.6/2012. The vehicle must be completely at the disposal of the company according to the rules of the street code and the legislation on trucking , in one of the following forms: ownership, leasing, hiring without driver, on loan without driver, confidentiality pact, usufruct. In order to validate this requirement an affidavit must be presented in lieu of a notary deed which declares the possession of the minimum requirements of the vehicles and of the personnel (the calculation of the permissible load of the vehicles must be made based on the category and class for which the registration is requested and in case of renewal, on the basis of the category and the class in which the company is already registered).

- **Requirements of financial standing**

To collect and transport wastes the companies must demonstrate their financial standing (Deliberation no. 3 from 14 March 2012) with an amount of:

- 9,000 € for the first vehicle,
- 5,000 € for every added vehicle.

The demonstration of possessing the required financial standing is not necessary if the company has already showed this in the register of truckers third parties.

14. Preliminary storage and storage facilities for asbestos containing waste (ACW)

Asbestos containing waste, duly sealed according to the regulations, is subsequently managed in two different ways:

- establishment of an on-site temporary storage facility to optimise subsequent transport to a final disposal facility (e.g. landfill);
- direct transport to an authorised storage facility.

Temporary waste storage is the accumulation of waste, prior to collection, in the place where the waste is produced, under the following conditions:

1) the waste must be stored in compliance with the technical standards regulating the storage and packaging of waste containing dangerous substances and managed in accordance with the regulations;

2) the waste must be collected and sent for recovery or disposal in one of the following alternative ways, at the discretion of the waste producer:

- at least every three months, irrespective of the quantities stored; when the total quantity of waste stored reaches 30 cubic meters, of which a maximum of 10 cubic meters is hazardous waste.
- in any case, where the quantity of waste does not exceed the above-mentioned limit per year, temporary storage must not exceed one year;

3) "*temporary storage*" must be carried out according to uniform waste categories and in compliance with the relevant technical standards and, in the case of hazardous waste, in compliance with the standards regulating the storage of the hazardous substances contained therein;

4) the regulations governing the packaging and labelling of hazardous substances must be complied with (Italian Legislative Decree 152/06, art. 183(c)(1)(bb).

Storage facilities for hazardous and non-hazardous special waste are defined in art. 183 of Italian Legislative Decree 152/2006, as amended, as "*disposal activities comprising the preliminary storage of waste referred to in point D15 of Annex B to the fourth part of this decree, as well as recovery activities involving the storage of waste referred to in point R13 of Annex C to the same fourth part*".
The disposal activities in this legislation (Annex B) include:

- D15. Storage prior to any of the operations numbered D1 to D14 (excluding temporary storage, prior to collection, on the site where the waste is produced).

The recovery activities in this legislation (Annex C) include:

- R13. Storage of waste for the purpose of carrying out any of the operations numbered R1 to R12 (excluding temporary storage, prior to collection, on the site where the waste is produced).

The typical final destination of ACW is landfills for non-hazardous waste with a mono-cell for asbestos (D1). Much less frequent are cases of specially engineered landfills (D5) and permanent storage facilities (D12). However, it is possible that prior to final disposal in a landfill, preliminary activities will be carried out, such as:

1. Grouping (D13) of waste into uniform classes;
2. Reconditioning (D14) (e.g. packaging of waste for optimisation of final transfer);
3. Preliminary storage (D15).

Storage pending treatment (R13), which is only feasible if the final destination is R5, ("recycling/recovery of other inorganic substances"), is currently only permitted under German law (*ISPRA 2019 Special Waste Report*). In such facilities, the ACW is stored and accumulated before final disposal or recovery. In some of these facilities, in addition to storage, ACW may undergo preliminary disposal operations. However, these operations cannot in any way modify the chemical-physical and/or product characteristics of the waste or lead to the assignment of a different EWC code. Table 14-1 shows the quantities sent for physical-chemical treatment (D9), preliminary grouping (D13), preliminary reconditioning (D14), as well as the quantities remaining in stock in the reporting year (D15), both at the management facilities and with the producers, to be sent for disposal the following year. Table 14-1 below shows the tonnages of EWC 17 06 05 waste sent for disposal operations by type in 2017.

Region	Year 2017				
	D9	D13	D14	D15	Total
Piedmont	2	30	3	966	1,001
Aosta Valley	-	-	-	-	-
Lombardy	1	3,993	2,081	2,520	8,595
Trentino-Alto Adige	-	73	-	260	333
Veneto	-	2,532	12,969	3,375	18,876
Friuli-Venezia Giulia	-	-	-	116	116
Liguria	1	-	-	101	102
Emilia-Romagna	-	924	76	3,056	1003
Tuscany	-	24	-	637	661
Umbria	-	-	-	339	339
The Marches	73	38	15	113	239
Lazio	-	1,151	22	518	1,691
Abruzzo	-	-	-	193	193
Molise	-	-	-	-	-
Campania	-	60	-	437	497
Apulia	-	-	-	132	132
Basilicata	-	-	-	29	29
Calabria	-	-	7	914	921
Sicily	-	32	48	1,510	1,590
Sardinia	-	-	-	77	77
TOTAL	77	8,857	15,221	15,293	39,448

Table 14-1: Quantity of construction materials containing asbestos (EWC 17 06 05) sent for disposal operations by type (metric tons), 2017 (Source: ISPRA Special Waste Report 2019)

As regards the management of other types of asbestos waste (EWC codes 150111, 160111, 160212, 170601), the quantity sent for chemical-physical treatment (D9) was 813 metric tons. 2,883 metric tons and 1,457 metric tons were sent for preliminary grouping (D13) and preliminary reconditioning (D14), respectively, mostly consisting of insulation materials containing asbestos (EWC code 170601).

15. Treatment: asbestos disposal and recovery

15.1. Landfill disposal

Italian Ministerial Decree 27 September 2010 defines the waste acceptance criteria for landfill, replacing those contained in the Ministry for Environment and Land Protection Decree of 3 August 2005.

Annex 2

Principles

Asbestos waste or asbestos containing waste can be transferred to the following types of landfill sites:

a) landfill for hazardous waste, specially engineered or with a mono-cell;
b) landfill for non-hazardous waste, specially engineered or with a mono-cell;

- ➢ landfill for non-hazardous waste, specially engineered or with a mono-cell for waste identified by the European Waste Catalogue Code 170605*;
- ➢ for other types of asbestos containing waste, provided that it has undergone treatment processes in accordance with the provisions of Italian Ministerial Decree no. 248 of 29 July 2004 and with values conforming to Table 15-1 below, verified at a frequency established by the competent authority at the treatment plant.

PARAMETER	Values
Asbestos content (% by weight)	≤ 30
Apparent density (g/cm^3)	> 2
Relative density (%)	> 50
Release index	< 0.5

Table 15-1: Acceptance criteria for treated asbestos containing waste at non-hazardous waste landfills

In addition to the general criteria and requirements for landfills for hazardous and non-hazardous waste, the transfer of asbestos or asbestos containing waste to the landfills identified in points a) and b) above must comply with the disposal methods and criteria, equipment and personnel, and measures to protect personnel from contamination by asbestos fibers indicated in point 2 below.

Methods and criteria for storing asbestos containing waste.

The storage of asbestos containing waste must occur directly in landfill cells specifically and exclusively engineering for this purpose, and must be carried out in such a way as to avoid the breaking up of the materials. Cells must be created using systems that involve the construction of zones or trenches. They must be spaced in such a way as to allow the transit of vehicles without causing the breaking up of the asbestos containing waste. To avoid fiber dispersion, the storage area must be covered with appropriate material on a daily basis and before each compaction operation, and if the waste is not packaged, it must be regularly sprinkled with water. The materials used for daily coverage must have a plastic consistency so as to adapt to the shape and volumes of the materials to be covered and to provide adequate protection against the dispersion of fibers, with a soil layer at least 20 cm thick. No activities that may result in the dispersion of fibers, such as drilling, should be carried out at the landfill or in the vicinity. A map showing the location of asbestos containing waste within the landfill or site must be prepared and retained. If the site is used after closure, appropriate measures must be taken to prevent human contact with the waste. For the final top cover, the landfill area must be reclaimed as a green area, which must not be disturbed by excavation works, even superficial. For the management of landfills where asbestos containing waste may be disposed of, the provisions of Title IX, Chapter III of Italian Legislative Decree no. 81 of 9 April 2008 shall apply.

Annex 3

Sampling and analysis of asbestos containing waste

For landfills where asbestos containing waste may be disposed of, the analysis must be supplemented as follows.

Waste analysis

Without prejudice to the provisions of art. 6(6)(c), the asbestos content by weight must be determined analytically using one of the quantitative analytical methods provided for in Italian Ministerial Decree of 6 September 1994 of the Ministry of Health; the percentage of asbestos present by weight, calculated on the waste after treatment, will be reduced by the dilution effect of the encapsulating matrix in relation to the value of the initial waste. The bulk density is determined according to standardised laboratory procedures, using specific instrumentation (hydrostatic balance, pycnometer). The absolute density is determined as a weighted average of the absolute densities of the individual components used in the asbestos waste treatment processes and present in the final material. The relative density, on the other hand, is calculated as the ratio of the bulk density to absolute density. The Release Index (R.I.) is defined as the asbestos weight fraction/relative density (the asbestos weight fraction being the % by weight of asbestos/100). The Release Index must be measured on the treated waste, after it has acquired the properties of compactness and solidity (Figure 15-1). The test must be carried out on samples weighing not less than 1 kg in total, without any container or packaging and the assessment of the Release Index should be carried out as indicated in the monitoring and control plan.

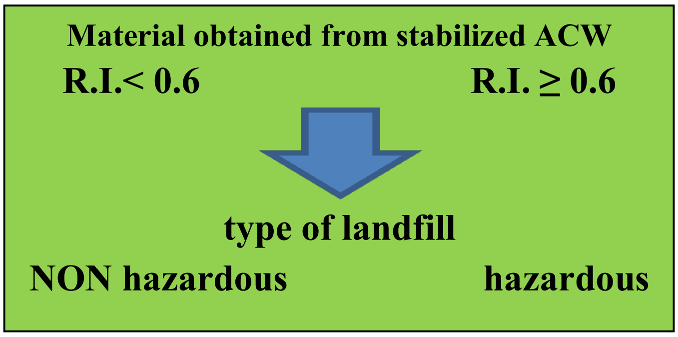


Figure 15-1: Acceptability of treated ACW in landfills based on the Release Index

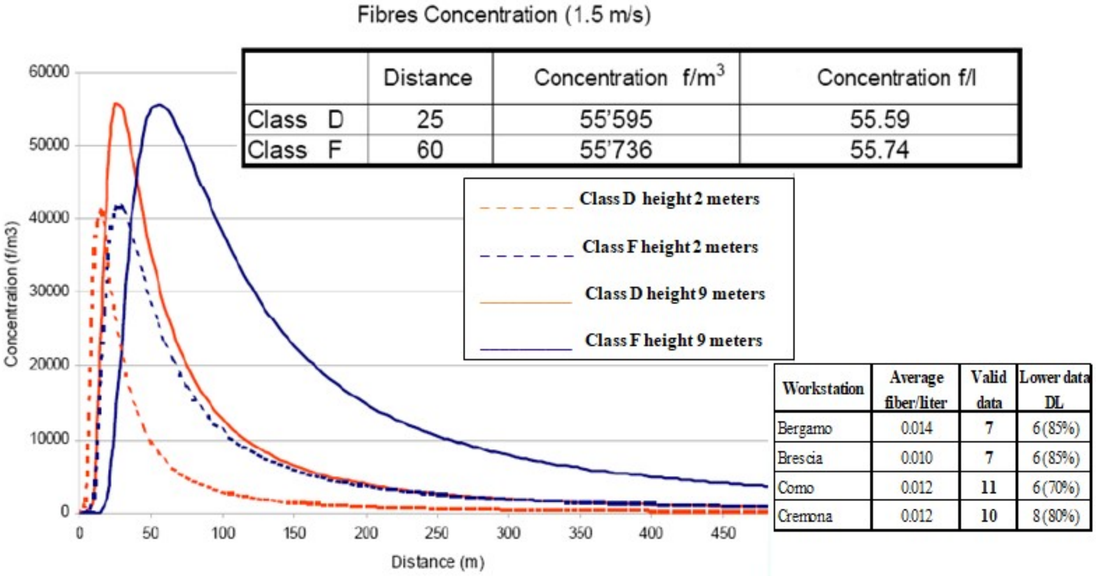
Analysis of airborne particulate matter containing asbestos

Phase-contrast optical microscopy (PCOM) techniques should be used. Reference should be made to the monitoring criteria specified in Italian Ministerial Decree of 6 September 1994 of the Ministry of Health when assessing the analytical results. A list of the various problems that may arise over time from the transfer of ACW to a landfill facility is given below.

1) <u>Short-term dispersion of asbestos fibers</u>: landfills are possible sources of emission. During disposal, damaged and broken packages may release fibers into the air (Figure 15-2).

Figure 15-2: ACW unloading stage at an asbestos cement landfill site

The following figure (Figure 15-3) shows the assessment of the impact on air quality of the accidental dispersion of fibers at the Treviglio landfill in the province of Bergamo (*Somigliana, 2008*). As can be seen, the fiber/liter concentration level in the vicinity of the landfill is well above the environmental background value.



	Distance	Concentration f/m^3	Concentration f/l
Class D	25	55'595	55.59
Class F	60	55'736	55.74

Workstation	Average fiber/liter	Valid data	Lower data DL
Bergamo	0.014	7	6(85%)
Brescia	0.010	7	6(85%)
Como	0.012	11	6(70%)
Cremona	0.012	10	8(80%)

Figure 15-3: Assessment of the impact on air quality of accidental fiber dispersion at a landfill site (Somigliana,2008)

2) Medium to long-term dispersion (5-15 years): The most common way of controlling leaching is to minimise the amount of rainwater (Figure 15-4) infiltrating the site by encapsulating the waste in impermeable materials (*Bell G., 2001*).

Figure 15-4: Asbestos cement packages transferred to special landfill

Analysis carried out on leachate from the Barricalla S.p.A. landfill in Turin in 2002 revealed the presence of a significant number of asbestos fibers (*Paglietti F,2002*; *Zamengo L.,2004*). This situation is due to the structural decay of the packaging containing the waste caused by wear and tear over time and the degradation conditions that develop within the body of the landfill following burial. The only effective leachate treatment method is the use of innovative on-site techniques. In the article "*On-site microwave-assisted pilot-scale plant for treating hazardous waste landfill leachate: a new European LIFE project for asbestos prevention and monitoring*" by L. Zamengo, S. Polizzi, F. Paglietti and G. Fasciani, 2004, a pilot-scale plant for filtering landfill leachate containing asbestos fibers at the Barricalla S.p.A. landfill is described and shown schematically (Figure 15-5).

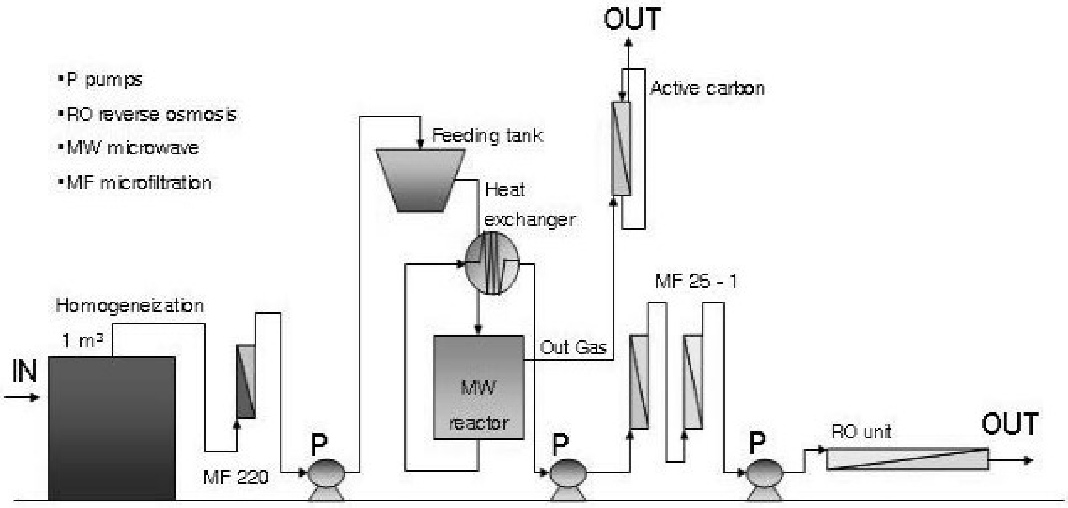


Figure 15-5: pilot plant for filtering landfill leachate containing asbestos fibers

3) Long-term dispersion (over 15 years): potential contamination of the surface water system. In the long run, no lining system, no matter how perfectly designed and constructed, will prevent filtration losses (*G.Bell,2001*).

One of the factors leading to the formation of open discontinuities that can leave a leachate unaltered for several kilometers is fissuring due to desiccation or differential settlement (*Hagerty and Pavoni, 1973*). Rainwater infiltrates the no longer sealed storage area and leads to the continuous leaching of asbestos cement with fiber concentration in the leachate. The rate of the process is likely to increase over time due to the gradual disintegration of the cement matrix, leading to a greater release of fibers. Leachate leakage from the no longer sealed containment system can cause contamination of the surface water system even in the absence of groundwater emergence. The problem is not in itself the presence of asbestos in the water, but rather that the fibers can become airborne as the aqueous solution evaporates.

4) Long-term dispersion (over 15 years): potential groundwater contamination. Suspended particles may also be present in large quantities in the leachate. If these particles enter the phreatic zone, they mix and move with the groundwater (*Bell G., 2001*). Under the right hydrogeological conditions (groundwater table very close to ground level), asbestos fibers can move from the surface water system to groundwater. The mobility of fibers in the groundwater depends on the permeability and hydraulic conductivity of the host rock lithology. The scientific literature describes cases of fiber migration through the aquifer, even far from the dispersion site (*Buzio S.,Pesando G.,2000; Emmanouila K.,Kalliopi A.,2009)*.

15.1.1. Data analysis: ACW disposed of in landfills and their location

As shown in Table 15-2, compared to 2016, the number of facilities increased by 2 units in 2017, both located in the north of Italy. In particular, in the North there are 9 facilities (6 for non-hazardous waste and 3 for hazardous waste), in the Centre there are 5 facilities (4 for non-hazardous waste and 1 for hazardous waste), and in the South there are 9 (8 for non-hazardous waste and 1 for hazardous waste).

Region	Year 2016			Year 2017		
	No. of landfills for non hazardous waste	No. of landfills for hazardous waste	Total	No. of landfills for non hazardous waste	No. of landfills for hazardous waste	Total
Piedmont	1	2	3	2	3	5
Aosta Valley	0	0	0	0	0	0
Lombardy	1	0	1	1	0	1
Trentino-Alto Adige	0	0	0	0	0	0
Veneto	0	0	0	0	0	0
Friuli-Venezia Giulia	1	0	1	1	0	1
Liguria	0	0	0	0	0	0
Emilia-Romagna	2	0	2	2	0	2
NORTH	5	2	7	6	3	9
Tuscany	3	1	4	3	1	4
Umbria	0	0	0	0	0	0
The Marches	1	0	1	1	0	1
Lazio	0	0	0	0	0	0
CENTER	4	1	5	4	1	5
Abruzzo	1	0	1	1	0	1
Molise	0	0	0	0	0	0
Campania	0	0	0	0	0	0
Apulia	1	1	2	1	1	2
Basilicata	2	0	2	2	0	2
Calabria	0	0	0	0	0	0
Sicily	0	0	0	0	0	0
Sardinia	4	0	4	4	0	4
SOUTH	8	1	9	8	1	9
TOTAL	17	4	21	18	5	23

Table 15-2: Number of landfills handling ACW, by category and region, 2016 - 2017 (ISPRA 2019)

Figure 15-7 below shows the geographical location of landfills handling ACW in Italy in 2017.

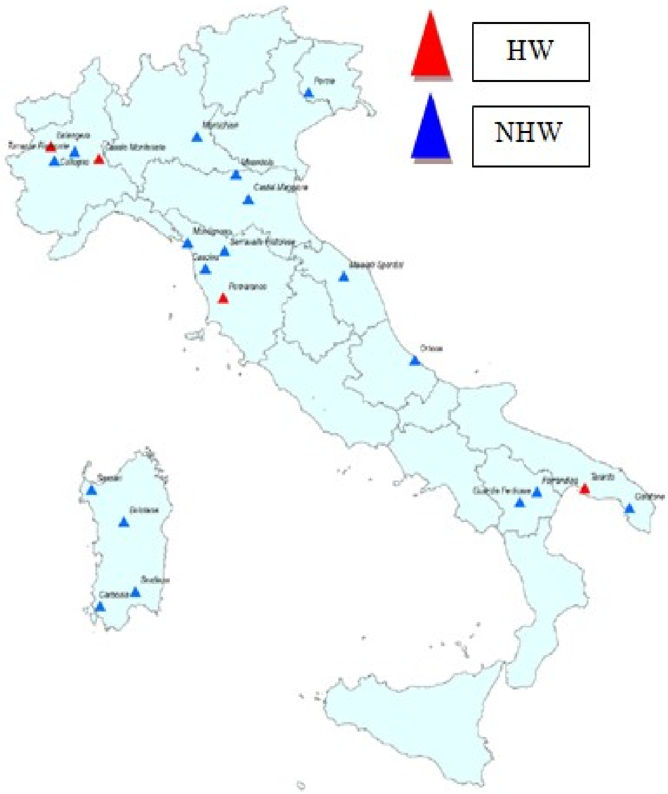


Figure 15-6: Geographical location and category of operational landfills handling asbestos containing waste (ACW), 2017- NHW non-hazardous waste landfills; HW: hazardous waste landfills. (ISPRA 2019)

The quantity of ACW disposed of in 2017 amounted to 223,000 metric tons, representing 1.9% of the total sent to landfill and 19.4% of total hazardous waste. 94.2% of ACW was disposed of in specially engineered cells/mono-cells at non-hazardous waste landfills (210,000 metric tons, 18 facilities), while the remaining 5.8% was disposed of at hazardous waste landfills (13,000 metric tons, 5 facilities). 68.7% of the total ACW disposed of in 2017 was handled in the North (153,000 metric tons), 11.2% in the Centre (25,000 metric tons), and 20.1% in the South (about 45,000 metric tons). Compared to 2016 (231,000 metric tons), there was a decrease of approximately 8,000 metric tons (-3.4%) for this type of waste (Figure 15-8).

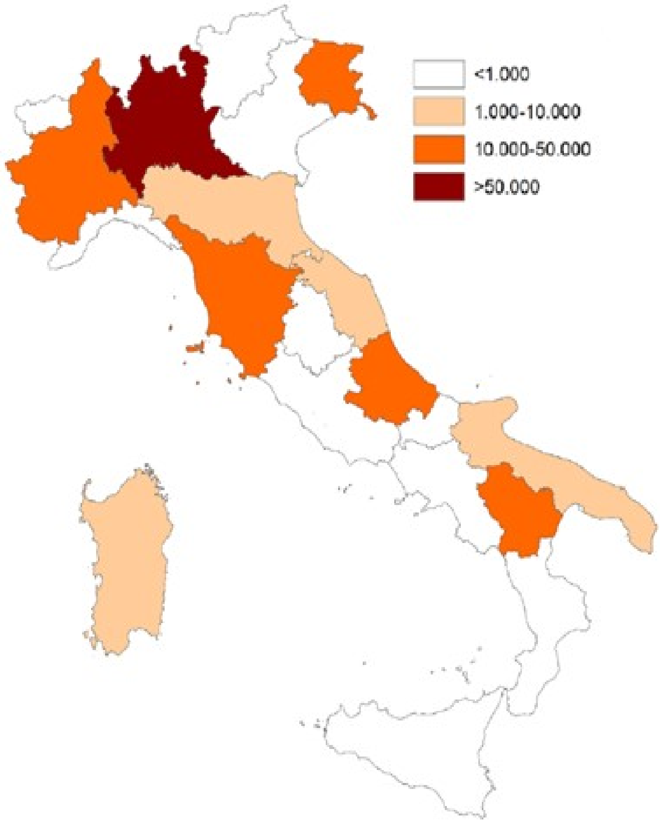


Figure 15-7: Asbestos containing waste (ACW) disposed of in landfills (metric tons), 2017 (ISPRA 2019)

Analysis of the data by macro region (Table 15-3) shows an increase in the quantities disposed in the North (+19,000 metric tons or +14.5%). The largest increase in this macro region was in Friuli-Venezia Giulia, where the quantities disposed of rose from 23,000 metric tons to 48.000 metric tons. Lombardy, which is the region with the highest quantities of ACW disposal, also shows a growth of 13.1% (+9,000 metric tons) compared to 2016. In the South, the total quantity of disposed ACW was about 5,000 metric tons, equal to +11.8%, concerning, in particular, Abruzzo (+7.6%). The regions in the Centre, on the other hand, show a reduction of 32,000 metric tons or 56.2% (Figure 15-9).

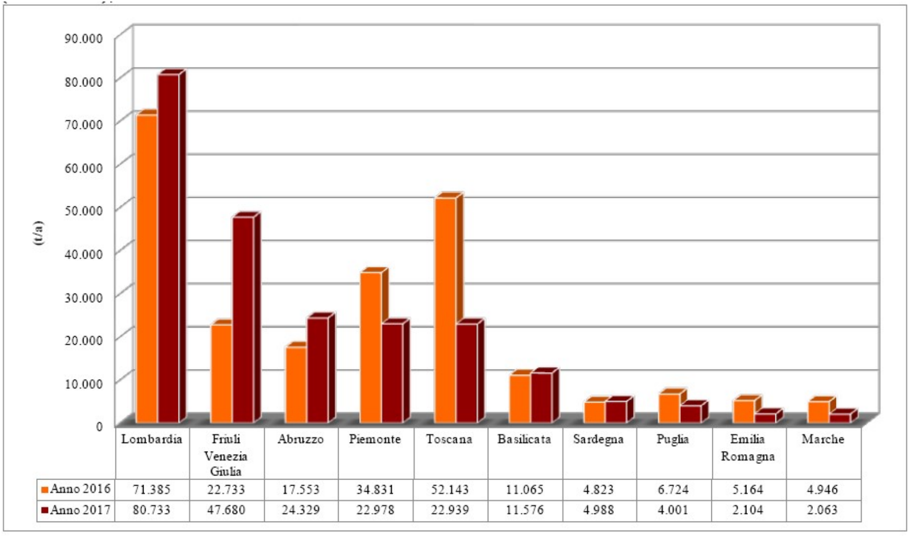


Figure 158: ACW disposed of in landfills, by region (metric tons), 2016 - 2017 (ISPRA 2019)

This trend is seen in particular for construction materials containing asbestos (170605*), for which the quantity, which fell from around 46,000 metric tons to around 24,000 metric tons, appears to have halved compared with 2016, in both regions that dispose of this type of waste (Tuscany and Marche). The quantities of insulation materials containing asbestos (170601*), which are entirely disposed of in Tuscany, also show a significant reduction, from 11,000 metric tons in 2016 to 1,100 metric tons in 2017.

Region	Year 2016			Year 2017		
	ACW disposed of in landfills for NHW (tons/year)	ACW disposed of in landfills for HW (tons/year)	Total ACW disposed (tons/year)	ACW disposed of in landfills for NHW (tons/year)	ACW disposed of in landfills for HW (tons/year)	Total ACW disposed (tons/year)
Piedmont	16,570	18,261	34,831	11,051	11,927	22,978
Aosta Valley	0	0	0	0	0	0
Lombardy	71,385	0	71,385	80,733	0	80,733
Trentino-Alto Adige	0	0	0	0	0	0
Veneto	0	0	0	0	0	0
Friuli-Venezia Giulia	22,733	0	22,733	47,680	0	47,680
Liguria	0	0	0	0	0	0
Emilia-Romagna	5,164	0	5,164	2,104	0	2,104
NORTH	115,852	18,261	134,113	141,568	11,927	153,495
Tuscany	40,799	11,344	52,143	21,835	1,104	22,939
Umbria	0	0	0	0	0	0
The Marches	4,946	0	4,946	2,603	0	2,603
Lazio	0	0	0	0	0	0
CENTER	45,745	11,344	57,089	23,898	1,104	25,002
Abruzzo	17,553	0	17,553	24,329	0,000	24,329
Molise	0	0	0	0	0	0
Campania	0	0	0	0	0	0
Apulia	6,685	39,000	45,685	3,992	9	12,992
Basilicata	11,065	0	11,065	11,576	0	11,576
Calabria	0	0	0	0	0	0
Sicily	0	0	0	0	0	0
Sardinia	4,823	0	4,823	4,988	0	4,988
SOUTH	40,126	39,000	79,126	44,885	9	53,885
TOTAL	201,723	29,644	231,367	210,351	13,040	223,391

Table 15-3: Landfill disposal of ACW, by category and region, 2016 -2017 (Source: ISPRA 2019)

Table 15-4 below shows the list of landfills that handled asbestos containing waste in 2017 and the quantities involved. The quantity of waste disposed of, the authorised volume (cubic meters) of the specially engineered cell/mono-cell, and the year-end residual capacity (cubic meters), referring only to the specially engineered cell/mono-cell, are reported for each facility. In order to acquire more information on landfill facilities receiving asbestos containing waste, ISPRA prepared and sent a questionnaire to facility operators. The information requested concerned, among other things, the authorised volume of specially engineered cells for the disposal of asbestos waste and the remaining capacity as of 31/12/2017. The authorised volume supplied by 16 of the 23 surveyed facilities was approximately 4 million cubic meters, while the residual capacity as of 31/12/2017, available for 12 of the 23 facilities, was over 1 million cubic meters. The analysis of the data cannot, therefore, be considered exhaustive, but it does provide useful information to help draw a picture of the capacity of landfills available for the disposal of this type of waste. The following figures show the quantities of ACW disposed of in landfills in the two-year period 2016-2017, by region and by European Waste Catalogue Code, respectively.

Region	District	City	Authorized cell volume (m^3)	Residual capacity of the cell 31/12/2017 (m^3)	Codes EWC of ACW (tons/year)			
					160212*	170601*	170605*	Total ACW
Landfills for NHW								
Piedmont	TO	Collegno	-	-	-	-	1,037	1,037
Piedmont	TO	Torrazza Piemonte	-	-	-	-	10,014	10,014
Lombardy	BS	Montichiari	696,000	-	-	-	80,733	80,733
Friuli-Venezia Giulia	PN	Porcia	386,989	245,159	-	-	47,68	47,68
Emilia-Romagna	BO	Castel Maggiore	-	-	-	-	1,204	1,204
Emilia-Romagna	MO	Mirandola	49,080	23,310	-	-	900	900
Tuscany	MS	Montignoso	260,000	70,000	-	-	15,102	15,102
Tuscany	PI	Cascina	183,200	-	-	-	6,719	6,719
Tuscany	PT	Serravalle Pistoiese	-	-	-	-	14	14
The Marches	AN	Maiolati Spontini	33,800	12,578	10	-	2,053	12,053
Abruzzo	CH	Ortona	270,000	49,000	-	-	24,329	24,329
Apulia	LE	Galatone	80,403	38,811	-	-	3,992	3,992
Basilicata	MT	Ferrandina	101,914	-	13	195	10,972	218,972
Basilicata	PZ	Guardia Perticara	8,800	2,357	-	-	396	396
Sardinia	CA	Serdiana	-	-	-	-	1,421	1,421
Sardinia	NU	Bolotona	200,000	-	-	-	1,618	1,618
Sardinia	SS	Sassari	10,000	8,985	-	-	166	166
Sardinia	SU	Carbonia	-	-	-	-	1,783	1,783
Total			2280,186	450,20	-	-	210,133	210,133
Landfills for HW								
Piedmont	AL	Casale Monferrato	63,000	-	-	46	3,213	49,213
Piedmont	TO	Balangero	-	-	1	886	567	1454
Piedmont	TO	Collegno	1,486,650	542,85	-	914	6,129	920,129
Tuscany	PI	Pomarance	49,000	-	-	1,104	-	1,104
Apulia	TA	Taranto	84,850	47,48	-	-	9	9
Total			**1,683,500**	**590,33**	-	**2,95**	**9,918**	**12,868**
ITALY			**3,963,686**	**1040,528**	-	**3,145**	**220,051**	**223,196**

Table 15-4: Landfill sites disposing of ACW, by category, region and European Waste Catalogue Code, 2017

The amount of waste consisting of construction materials containing asbestos (EWC code 170605*), amounting to 220,000 metric tons, represents 98.5% of the total. The remaining 1.5% is made up of other types of asbestos containing waste identified by the European Waste Catalogue Codes 061304*, 101309*, 160111*, 160212*, and 170601*. Analysis of the data on the management of construction materials containing asbestos only (EWC code 170605) shows that this is almost exclusively disposed of in landfills, or sent for preliminary storage. As shown in Table 15-5 below, the total amount landfilled in 2017 corresponding to this code was 220,051 metric tons (1,000 metric tons more than in 2016). The regions that disposed of the most were Lombardy (with 80,733 metric tons) and Friuli-Venezia Giulia (with 47,680 metric tons).

Region	Quantity
	2017
Piedmont	20,96
Lombardy	80,733
Friuli-Venezia Giulia	47,68
Emilia-Romagna	2,104
Tuscany	21,835
The Marches	2,053
Abruzzo	24,329
Apulia	4,001
Basilicata	11,369
Sardinia	4,988
ITALY	220,051

Table 15-5: Quantity of EWC code 17 06 05 waste disposed of in landfills (metric tons), 2017 (Source: ISPRA 2019)

15.2. Recovery methods

Methods for treating ACW fall into two categories:

- Treatments that reduce fiber release from ACW without completely or partially altering the chemical and crystalline structure of the asbestos (Table A). These include treatments applied to obtain stabilised or partially stabilised materials. They do not include stabilisation-solidification treatments, as referred to in Table A, packaging in rigid or flexible containers, as referred to in the Decree of the Italian Ministry of Health of 6 September 1994 chapter 5, paragraphs 6 and 7 as amended pursuant to article 6(3) and article 12(2) of Italian law 257/92, as well as treatments usually applied during remediation activities for the protection of operators and the environment. Encapsulation does not change the original waste code.
- Treatments that completely change the chemical and crystalline structure of the asbestos and thus negate the hazard associated with asbestos minerals (Table B). The end materials derived from these treatments are intended for re-use as raw materials.

In Table A, the treatment processes for asbestos containing waste that reduce fiber release from ACW without altering (or partially altering) the chemical and crystalline structure of the asbestos include:

- ➢ Stabilisation/solidification in a stable non-reactive organic or inorganic matrix;
- ➢ Encapsulation;
- ➢ Partial alteration of the chemical and crystalline structure.

<u>Destination of treated material: landfill.</u>

In Table B, treatments for asbestos containing waste that completely change the chemical and crystalline structure of the asbestos and thus negate the hazard associated with asbestos minerals include:

- ➢ Chemical modification;
- ➢ Mechanochemical modification;
- ➢ Lithification;
- ➢ Vitrification;

- ➢ Vitrification-ceramisation;
- ➢ Pyrolytic lithification;
- ➢ Clinker production;
- ➢ Ceramisation.

<u>Use of the end product: reuse as a secondary raw material (SRM)</u>

If the asbestos containing waste undergoes stabilisation treatments (that do not modify its chemical and crystalline structure), it is necessary to check the value of the Release Index (R.I.) in Annex 1 of Italian Ministerial Decree 248/04 in order to determine the type of landfill the treated waste should be sent to. Indeed, this waste, reclassified with the EWC codes 190304* (partly stabilised) and 190306* (stabilised), both classified as hazardous, is respectively destined for hazardous waste landfills, with an R.I. of > 0,6 (EWC code 190304*), and to non-hazardous waste landfills, with R.I. < 0,6 (EWC code 190306*).

For the sake of simplicity, all the treatments listed above have been grouped into the following three macro-categories:

- Thermal treatments
- Chemical treatments
- Mechanochemical treatments

15.2.1. Thermal treatments

Thermal treatments consist of the alteration of the chemical and crystalline structure of asbestos silicates, which occurs spontaneously at high temperatures. The resulting materials are free from the initial toxicity and hazardous nature. This category of treatments is very diverse and is also where the most real-world industry experience is concentrated. Almost all the applications identified and the studies analysed involve the use of temperatures close to or above 1200 °C. The issue common to all thermal treatments is the high energy required to heat a thermally inert material such as asbestos. Other issues relate to the formation of air pollutants during the heating phases, and from this point of view a particularly problematic material is vinyl asbestos, since the thermal treatment of halogenated polymers can lead to the formation of persistent organic pollutants such as dioxins and polychlorinated biphenyls. There are various subcategories of thermal treatment, which can be classified according to the heating technology, the possible presence of additives, and the thermal processes that follow heating (recrystallisation).

Simple thermal treatments

In vitrification processes, ACMs are generally heated to temperatures above 1000 °C in order to obtain an inert silica material free from asbestos fibers. At temperatures above 700 °C, the desorption of crystallisation (structural) water leads to the breakdown of the fibrous crystalline structure, resulting in the production of an inert glassy material. Based on this phenomenon, some vitrification processes apply a temperature of around 900°C to ACMs, while in other cases melting is carried out at temperatures of up to 1300°C in order to obtain a molten mass of silicates which, on cooling, form a glassy compound (largely with amorphous structures and free from asbestos fibers). In general, the main issue of all thermal treatments relates to the way the material is heated. Electric and natural gas furnaces are generally used to achieve the desired temperatures. A very efficient but very expensive alternative heating method is the INERTAM process (European Patent no. EP 3 175 932 A1), developed by the French company INERTAM of the EUROPLASMA group. This process uses a plasma torch (arc discharge type) to melt the ACMs. Currently owned by EDF and Prométhée, it is used at the Morcenx operating plant in the Landes Department (south west France) and has been in operation since 1996. It is the only authorised operational ACW inertisation plant in France (the first country to ban the use of asbestos from 1 January 1997) and the largest permanent continuous cycle ACW treatment plant operating in Europe. On the subject of special heating methods applied to vitrification, it is also worth mentioning the process devised by CEA, developed in France in 1992 (French patent no. FR 2 668 726 A1; the patent licence was transferred to the ONETT industrial group). The process consists of a simple vitrification mechanism by melting using an electric furnace with a cold crucible and high-frequency direct induction. The inductors consist of a solenoid powered by a high-frequency current (200 to 600 kHz) obtained from an 80-kW generator for a 300 mm-diameter container. The end product of the vitrification process (commercially known as Cofalit) is essentially a basalt and is used as an aggregate in public works. Another type of heating technology was devised by INPG Entreprise and the Grenoble Institute of Technology, which have developed a prototype for asbestos treatment that induces "high-frequency magnetic fusion": the prototype has a 600 mm-diameter tank, 100 kV power and 100 kHz frequency. The glassy inert material produced can be used to build roads and reinstate quarries. Vitrification processes may or may not include pre-treatments such as grinding and crushing, aimed at reducing the size in order to facilitate the melting of the treated materials. Generally, there are also abatement systems for the gases produced in order to reduce polluting air emissions. A case in point is the pilot unit installed in 1996 near Nuremberg (Germany) by VERT (Vitrification and Environmental Recycling Technology Limited), which developed the McNeill Vitrification Process (MVP), marketed through Chemical Exchange Directory s.a. This pilot plant is interesting because it has an emission filtering system consisting of ceramic filters and scrubbers with acidic, alkaline and neutral pH. The VITRIFIX process (European Patent no. EP 0 145 350 A2 published in 1985) is a similar example, where asbestos is treated at 1350-1380 °C with flue gas treatment (filtering and condensation). A major disadvantage of simple fusion vitrification is the high cost of disposing of the material produced, which, although no longer harmful, has few applications and must often be treated as waste (non-hazardous). The identification of an application for this material could therefore contribute significantly to reducing the costs of the overall process. In this context, the asbestos thermal treatment process designed by ITALCEMENTI (Italian Patent no. MI 92 A 001803 developed by Cucitore and Gilioli, 1992) should be mentioned, involving treatment at 600-800 °C with the subsequent reintroduction into the cement production cycle as a raw material or corrective additive for clinker production. In some cases, thermal treatments can be carried out with the possible addition of additives or low-melting agents, in different percentages and generally alkaline, such as caustic soda (NaOH) or potassium hydroxide (KOH), with the aim of lowering the melting point of the asbestos minerals.

Thermal treatments with controlled recrystallisation

If, after melting, the material is subjected to a controlled temperature, it is possible to obtain products with good mechanical properties that can be used in construction or civil engineering works. Depending on the specific thermal treatment, these can involve vitrification-ceramisation and lithification. Vitrification-ceramisation thermal treatments are based on a high-temperature melting process. This takes place at a temperature of between 1350 and 1550 °C, followed by a phase of homogenisation of the molten material, a so-called nucleation phase, at a lower temperature than the previous phase of between 700 and 900 °C, and a final crystallisation phase, during which the crystalline component of the glass-ceramic is formed, at temperatures of between 750 and 950 °C. The melting, nucleation and crystallisation times are long and depend on the fluidity of the molten material, the degassing conditions of the starting material, and the workability of the end material. In lithification processes, the melting phase is followed by a phase of partial crystallisation through slow cooling, which results in the production of a hard material with a high specific weight and excellent compressive and tensile strength, 75% glassy in nature and 25% crystalline. Typically, in lithification, melting takes place at temperatures of between 1300-1450 °C. The materials produced by vitrification-ceramisation/lithification processes are themselves materials with interesting mechanical properties, such as cordierite, a highly prized ceramic material used as a refractory and ceramic support for the manufacture of catalytic converters and catalytic filters for industrial use. The ceramic materials formed have a low coefficient of thermal expansion and are totally free from asbestos fibers. Rather than the initial fibrous structure, they have a columnar structure, which can no longer be inhaled. The best-known technology belonging to this category of treatments is the KRYAS process developed in 2007 by Professors Alessandro Francesco Gualtieri and Ivano Zanotto of the Department of Earth Sciences at the University of Modena and Reggio Emilia in partnership with the company ZETADI S.r.l. With Italian Patent no. MO2006A000205 and European Patent no. EP2027943B1, the process involves the thermal conversion of ACW by ceramisation using a continuous furnace.

Thermal treatment in the presence of other inorganic materials
In order to improve the properties and usability of the inert material produced, in addition to the controlled recrystallisation described above, inorganic materials such as clay can be added. However, this approach should not be confused with the addition of chemical agents intended to react directly with asbestos fibers. The so-called "pyrolytic lithification" (different from the lithification described above) involves the mixing of the ACM with clay as part of the production of expanded clay: a drying phase at 300 °C with loss of formation water, followed by combustion phases at 1000 °C (in the presence of organic substances), partial melting at 1300 °C and subsequent vitrification only of the external parts of the clay-based granules, which do not melt completely due to the low thermal conductivity of the material, leaving sufficient porosity inside. The high reactivity of clay at 650-950 °C facilitates the integration of the silicate phases coming from the ACMs. This subcategory of processes includes the CORDIAM process (*Patent no. RM96A000782*), developed by the Institute of Mineral Processing at the National Research Council. As an alternative to clay, ENEL's Waste Management Research Centre (*Centro Ricerche e Valorizzazione Residui*) (*Patent no. MI98A002194*) proposed the use of coal fly ash in a thermal cycle with melting at about 1200 °C for one hour.

Microwave treatments
The possibility of using microwaves for more efficient heat transmission has been investigated. It has been shown (*Leonelli et al., 2006*) that it is possible to add ACMs to ceramics (up to 5%) and subsequently convert the mixture into forsterite by heating using microwaves. Microwaves can also be used to generate an air plasma capable of reaching 3000 °C with the consequent inertisation of asbestos through melting and subsequent vitrification; the efficiency of the process appears to increase as the alumina/silicon ratio increases (*Averroes et al., 2011*). As suggested by *Horikoshi et*

al. (2014), the efficiency of microwaves in the treatment of asbestos can be attributed to the greater heat penetration and increased electric field strength between the fibers. Although scientific evidence demonstrates the feasibility of the microwave-based inertisation of asbestos, there are no significant uses for this technique on an industrial scale. ATON HT (Poland, http://aton.com.pl/) holds an international patent application (US2012/0024990) for the use of microwaves in the presence of additives such as sodium and/or potassium silicate, caustic soda and borax. Developed in 2008 by Ryszard Parosa, Supervising Board President at the Polish company Aton-HT S.A., the technology involves transporting ACMs, previously ground and reduced to minute particles and then mixed with a low-melting agent, to a microwave thermal reactor, where they are heated to between 900 and 1100 °C for 2 to 15 minutes, depending on the type of ACM. Both the compact and friable treated materials undergo a two-stage mixing in an aqueous solution during grinding and are then transferred into the reactor. The crushed material is transformed into particles no larger than 5 mm in size. After their introduction into the reactor, these particles are brought to the transformation temperature at which the transition from a fibrous to a non-fibrous habit takes place through the application of a polarised beam of electromagnetic waves, with a frequency of between 2,45 GHz and 915 MHz. The wave beam is used to induce fast and uniform heating of the treated material. The final product can be used to repair roads or can be mixed with cement to make bricks.

Treatments with oxyhydrogen

An alternative strategy is the use of a stoichiometric gas mixture of 1:2 oxygen and hydrogen (oxyhydrogen) from the electrolysis of water. The subsequent reaction between the two components starts spontaneously at 570 °C and releases an energy of 241,8 kJ per mole of hydrogen. A temperature of 2800 °C can be reached using this technology. However, the disadvantage is the low energy efficiency of the process, during which electrical power is consumed for the electrolysis of water to produce the gas mixture. This methodology allows the degradation of asbestos with an efficiency of up to 99% (*Min et al., 2008*). An example of a real-life application of oxyhydrogen in asbestos degradation is the CYNERGI process: friable and solid ACMs must first be ground in special crushers before being fed into the plant. The ACW is fed into a rotary kiln and preheated to facilitate grinding in the crusher.

15.2.2. Chemical treatments

The aim of chemical treatments is to destroy the asbestos fibers through chemical attack using concentrated strong acids or bases and subsequent neutralisation of the resulting mixture to extract products that can be reused as inert materials. These applications generally require lower process temperatures than thermal processes but still higher than ambient temperatures. The risk associated with chemical treatments is that inertisation occurs only at the surface and does not affect the fibers located in the innermost part of the structure, which could be released if the end material is broken up.

Traditional chemical treatments (subcritical)

Since hydrolysis of the oxygen-silicon bond is required, the two main strategies are:

- use of highly basic pHs (or less commonly acids) that degrade the asbestos structure, generating free silanols;
- use of hydrofluoric acid to form silicon fluoride.

In general, it is necessary to operate at temperatures close to 100 °C to achieve satisfactory results. The disadvantages of both techniques are related to the costs of reagent consumption and subsequent wastewater disposal. In the case of both basic treatments and hydrofluoric acid processes, there are patents for their use, but no real industrial applications are known. One example of a process using strongly basic solutions is the TRESENERIE process of the Belgian company WASTE TREATMENT BELGIUM (WTB) developed by Gérard Debailleul with European Patent no. WO199700099A1. The process, which takes 20 to 30 minutes, is based on dissolving the asbestos fibers in a concentrated basic aqueous solution (> 25 mol/litre, 25 M) of sodium hydroxide (NaOH) or potassium hydroxide (KOH). Up to now, the procedure has only been tested on small, transportable, low-capacity pilot plants, and the construction of industrial plants is the subject of feasibility studies (*Debailleul G.,1997*). A technology that refers to the use of hydrofluoric acid is the SOLVAS process proposed by the German company SOLVAY UMWELTTECHNIK Gmbh. The principle is based on the dissolution of asbestos fibers by a solution of hydrofluoric acid (HF) and the subsequent neutralisation of the acid solution with calcium hydroxide, also known as slaked lime ($Ca(OH)_2$). The neutralisation of excess acid leads to the precipitation of various compounds of the chemical elements present in ACMs (magnesium, iron, etc.) such as calcium fluorides, oxides and hydroxides. This separates the liquid and solid phases and produces a fine, inert powder that can be used in concrete. This technique requires careful monitoring and a large number of precautions due to the highly hazardous nature of hydrofluoric acid. Furthermore, industrial plants are not yet available for this technology.

Hydrothermal treatment (supercritical)

A chemical treatment that eliminates the problem of handling corrosive/hazardous reagents is the “hydrothermal treatment” (*Anastasiadou et al., 2010*) developed in 2005 by Alberto Servida of S-Sistemi S.A.S. of Monza in collaboration with Alessandro Servida and Simona Grassi of the University of Genoa and Giuseppe Nano of the Polytechnic University of Milan, with Italian Patent no. VI2005A000174, European Patent no. EP2038019A1, and US Patent no. US20100234667A1. The waste is first subjected to a preparatory step of coarse comminution in water in order to obtain a paste preferably with a solid matter content of no more than 30% by weight. The method also involves the addition of an oxidising compound, such as hydrogen peroxide, to the aqueous phase until a specific concentration is reached. The materials treated and analysed by SEM are totally free from fibrous habit. The method benefits from being low cost and simple, and works at low temperatures. A further advantage is that the process takes place in a single cycle and generates solid inert materials, such as Mg and/or Ca silicates, silica, water and carbon dioxide without the use of harmful reagents, and the plant can be mobile or stationary (*Grassi S. et al., 2010*). The main issues related to the process are the particularly high pressures and the filtration of the resulting water. Regarding the need to add an additional hydrolytic agent, it is worth mentioning the CHEMICAL CENTER process devised in 2010 by Norberto Roveri of the University of Bologna, owned by the Bologna-based company Chemical Center S.r.l. This process, with Italian Patent no. ITMI2010A001443 and European Patent no. EP2428254B1, combines a hydrothermal treatment with an acid treatment using an acidic industrial waste product, “spent whey”. Although it does not contain toxic agents, it cannot be discharged into water bodies due to its high organic content and the presence of a complex bacterial flora. The treatment with spent whey leads to the formation of an acidic liquid phase and a solid phase containing asbestos fibrils. The amount of whey used varies from 2 to 100 times by weight, preferably 20 to 40, compared to the total weight of the material to be treated. The patent is particularly innovative and significant because it uses two hazardous wastes, i.e. asbestos cement and spent whey (a serious environmental problem for the dairy industry), and thus treats one waste with another to obtain commercially viable products.

Treatment with reducing agents

Silicates, such as asbestos, can be degraded by reaction with a suitable reducing agent, such as a metal in its elemental form. One issue related to these processes is the triggering of the reaction. On the other hand, the advantage of this approach is that redox reactions are facilitated and once started they self-propagate. This is referred to as self-propagating high-temperature syntheses. One example of such technology is the LIFE FIBERS-LIFE12 project ENV/IT/000295 "Fibers innovative burning and reuse by Self-propagating High temperature Synthesis (SHS)" developed in 2010 by Claudio Belfortini, Laura Gaggero, Evelina Isola and Maurizio Ferretti with Italian Patent no. ITGE2010A000032A1, in collaboration between the Department of Earth, Environmental and Life Sciences (DISTAV) and the Department of Chemistry and Industrial Chemistry (DCCI) at the University of Genoa. This consists of the rapid transformation of asbestos fibers through a highly exothermic redox reaction, through which aluminium, by means of an alumino-thermic reaction, or by means of another metal reducing agent, reduces the metal oxides, transforming them into a molten and pure state. The reaction, triggered by an electrical impulse, i.e. from a low-energy source for a few seconds, proceeds as a combustion wave through the reactant volume without any additional energy input and therefore the process is self-sustaining. Compared with other traditional thermal methods, the process is very fast, requiring just a few seconds and a small amount of activation energy, as well as relatively simple equipment. The products obtained can be used as a secondary raw material and constitute an inert material or silicate with very good thermal and hardness properties, therefore suitable for use as a refractory and/or an abrasive.

15.2.3. Mechanochemical treatments

Mechanochemical treatments involve the use of mechanical energy transmitted to the ACM by grinding machines to destroy the crystalline lattices and molecular bonds present in the asbestos, the cause of its hazardous nature (*Plescia et al., 2003*). High-energy grinding or ultra-fine grinding processes have been proposed and successfully used on a laboratory and industrial scale. Specifically, it has been demonstrated that the grinding of phyllosilicates in mills using a variety of methods results in their gradual amorphisation through the release of the hydroxyl ions needed to maintain their crystalline structure (this is also known as "cold vitrification"). Mechanical stress, caused by compression and friction, leads to rapid lattice distortion, the expulsion of water, OH and CO2 molecules, and the formation of an isotropic, amorphous material. One example of this technology is the HEM (High Energy Milling) process developed by F. Colangelo of the Department of Technology at the Parthenope University of Naples and R. Cioffi, M. Lavorgna and L. Verdolotti of the Institute for Composite and Biomedical Materials (IMCB) at the National Research Council of Naples, and L. De Stefano of the Institute for Microelectronics and Microsystems, also at the National Research Council of Naples. The results of X-ray spectroscopy and diffraction analyses carried out on asbestos containing waste show a total transformation of the chemical and crystalline structure of the asbestos. The resulting fine powders can be reused in numerous civil engineering applications such as the production of building materials like cement and mortar, as these powders have excellent pozzolanic activity. The mechanical properties of mortars prepared with such mixtures are better than those prepared using lime and pozzolan.

Finally, this method is efficient and less expensive than the chemical and thermal asbestos treatments described above (*Cioffi R. et al., 2011*).

16. The non removal: the process of deterioration in asbestos cement (CA)

16.1. Dispersion into the atmosphere

Cement matrix deteriorates after years of rain and wind. Acid rain is especially damaging to cement surfaces and asbestos-cement in particular deteriorates when exposed to the weather. This is particularly true if calcium hydroxide in the cement comes in contact with the acid rain. This causes it to dissolve slowly in the water (*Dyczek, 2006*). When this happens the chrysotile fibers which are more resistant to the weather than the cement matrix, appear on the surface of the cement, (*Burdett 2007*). Asbestos fibers which are not tightly bound to the cement, can be carried by the wind into the environment or can be washed away by the rain. Increased airborne asbestos is seen near buildings with asbestos cement roofs and panels (*Spurny, 1989; Krakowiak et al, 2009*) This is caused by the breakdown of the cement matrix which was found to deteriorate at a speed of 0.024 mm/year in clean environments. *Campopiano* et al. in 2009 found that rain and wind caused the asbestos fibers to be washed into rain gutters corrugated asbestos roofs seem to release fibers in an impressive way. In the table below, (Table 16-1) are shown the results of a study by Chiappino and Venerandi, which, based on the position, (whether inside or outside a building) and on the period in which the sheets of asbestos cement were laid, points out the level of deterioration of the sheets with the consequent release of fibers into the atmosphere.

SHEETS	SURFACE IN CEMENT	FIBER
NEW	Very small shallow cavity (intrinsic porosity)	Not visible
INDOORS BUILDINGS after 10 years	Slightly thinned	Just visible tightly englobed
EXPOSED TO ATMOSPHERIC AGENTS		
After 2 months	Small cavity increased	Layer tufts of fiber visible but held in place by cement of cement partially eroded
After 1 year	Alterations by corrosion superficially evident	Generalized surfacing of fibers which are beginning to be released
After 2 years	Surface layer corroded, under layer still uniform	The fibers are released visibly
After 5 years	Deep and converging holes	Tufts of fibers both compact and frayed by the wind make clumps of fibers ,even fine
≥10 years	Impressive corrosion	Vast loss of fiber with indistinct borders with large areas of fiber lost into the environment

Tabella 16-1: Table elaborated by " The study on samples of wavy sheets of asbestos.cement" Chiappino and Venerandi in Med. Lavoro 1991; 82.2: 99-191

The microscopic analysis of the coverings in asbestos-cement exposed to atmospheric agents for variable amounts of time, from 2 months to over 15 years, show that the corrosive phenomena which release fibers, begin after just a few months and are quite evident after a few years. They become impressive between 5 and 10 years. Acid rain is the principal factor in the deterioration of the surfaces. In South Africa the fibers were found in the soil around houses with corrugated asbestos roofs (*Phillips et.al, 2009*). Not only the weather, but also using high pressure water pumps can be a factor in deterioration. In a nine month study, (*Oberti et.al., 2018*) the roofs which were exposed to atmospheric conditions, released fiber and showed that fibers can be released from dry cement, also. This study shows that the binding force of the cement with the asbestos diminishes as time passes and after about 3 years it can decrease to 40% in respect to what it was at the beginning. After 10 years, the sheets which are not protected from exposure to the atmospheric conditions can be definitively damaged so as not to be able to withstand their own weight, with the danger of material falling from the roof. Drinking drain water which comes from asbestos cement roofing can be a risk for stomach cancer (*Anderson et.al. 1994; Kjaerheim et al. 2005*). In summary the process of deterioration of the coverings in asbestos cement, happens according to the following phases:

- Rain dissolves the soluble components on the surface of the cement of the sheets which are already intrinsically porous;
- Acid rain, swings in temperature, combustible products accelerate the dissolution which removes successive and deeper layers;
- The mechanical effect of the rain and wind, micro-fractures caused by freezing, and mold, make the detachment of coarse tufts of fiber complete.

Once the fibers detach from the covering, dispersion happens in these phases: the course heavy tufts of fibers detach from the sheet and fall to the ground all around the building. When they are on the ground, the crushing action of traffic and the lifting action of the wind and other atmospheric agents, makes the fibers finer and breathable, and transports them to even great distances. Asbestos fibers which are deposited on the roofs are, instead easily dispersed into the air when the roof is dry and there is wind. The part that remains in the rain gutters should not be forgotten because inevitably it becomes a source of secondary airborne fiber. Airborne fibers, in fact, can bz transported far away from the source. *K.R. Spurny* in 1989 showed the synergistic effect which the fibers, as they are released into the atmosphere following the deterioration of the covering or roof, bind to cancerous substances (heavy metals, hydrocarbons, polycyclic aromatics) and are a source of further risk of cancer. Also organic growths on roofs, such as moss, lichens or fungi, can condition the asbestos fibers. These organisms react with the exposed chrysotile fibers decreasing the content of MgO which is a modification of surface charge from positive to negative. This was observed with the dissolution of the outer brucite layer (Mg(OH)2). These organisms can extract iron from the fiber leading to a reduction in the free radical generation shown in a lab (*Daghino et al. 2005; Favero-Longo et al.2005*). Both of these conditions, surface charge and reduction of free radicals are linked to fiber toxicity. Organisms on the asbestos roofs, prevent the release of fibers into the air. The concentration of fibers in a city environment has been reported to be as high as 0.0198 fibers/cm³ (*Krakowiak et al. 2009*) This was seen in an area with many houses built with material containing asbestos. However, no fibers were found in a sample of the air which means that airborne fibers were few. *Krakowiak et al.* (2009) found that a slight breeze of 1 m/s can carry asbestos fibers as far as a few hundred meters. Lichens are considered to be responsible for much surface corrosion (*Chen et al., 2000*) since they are known to release oxalic acid. Moss also influences damage caused by the weather since it holds the fibers in place and therefore keeps the roof intact.

16.2. Dispersion in water

Asbestos has been used extensively over the past decades on a global level as a construction material for drinking water tanks and pipelines. In Italy, there are an estimated 80.000 km of asbestos cement pipes, most of which were installed between the 1960s and 1970s *(3rd Consensus*

Conference on malignant mesothelioma - Bari, 29-30 January 2015). This raises the question of whether the water contained and transported in these pipes could contain asbestos fibers and whether these fibers could be carcinogenic if ingested. The reference document determining the limit value for asbestos in water for Italy is "*Asbestos - Summary of knowledge on exposure and toxicological profile*", issued by the Italian Ministry of Health in 2015. This publication provides a comprehensive review of the state of the art in relation to World Health Organisation (WHO) studies on the epidemiological and toxicological effects and on the effects of exposure to asbestos through drinking water. With the risk of benign gastrointestinal cancer per 100,000 inhabitants at a concentration of about 7x10E-6 fibers/l, the U.S. EPA has set a maximum limit of contamination in water intended for human consumption of 7 million fibers/l, with a fiber length greater than 10 μm. Sweden and the UK, on the other hand, specify values above 3x10E-6 fibers/l, while the Netherlands, Germany, Austria and Russia refer to values 1-2 orders of magnitude lower, between 10E-5 fibers/l and 10E-4 fibers/l, (*Sala and AA.VVV,2005*). Based on the information reported in the document published by the Italian Ministry of Health, recent studies conducted in the USA have shown no correlation between exposure to asbestos fibers in drinking water and carcinogenic diseases, with concentrations above one million fibers per liter (MFL), nor any interactions between them linked to oral exposure. With regard to the contamination threshold concentration (CTC), provided for by current Italian legislation on remediation (Legislative Decree no. 152/06), the limit for asbestos fibers in water is yet to be defined. To date, the only regulatory reference in Italy regarding the presence of asbestos in water concerns pipes, namely Ministry of Health Circular no. 42 of 1 July 1986, which introduced the Aggressiveness Index for drinking water. In fact, the alkalinity of the water, the concentration of calcium carbonate (which over time produces a protective film that effectively isolates the asbestos cement), and varying pH can increase or decrease the release of fibers into pipes. The concentration of iron can also significantly affect the aggressiveness of the water, given that the metal binds the fibers and inhibits corrosion of the pipes. Through Directive 98/83/EC, the European Community does not consider asbestos as a parameter to be monitored and does not set limits for it. In Italy, this Directive has been transposed by Legislative Decree 31/2001, which regulates the conditions necessary to guarantee the supply of drinking water, without mentioning monitoring for asbestos. Although not a hazard, the possibility that asbestos in water may contribute to an increase in the background level of dispersed airborne fibers and thus the risk of inhalation should be considered. From 1998 to 2014, the Italian National Institute of Health, in collaboration with seven regions, including Emilia-Romagna, collected a number of samples (samples taken at points considered most at risk, in older pipes) from asbestos cement pipes (*Pirani G.,2017*). The results shown in Table 16-2 below show that, although the problem of contamination of drinking water is real, the concentrations of asbestos fibers found are always below the value of 0,1-0,2 MFL1, which is the concentration considered a risk by the Safe Drinking Water Committee.

Region	City	No. sample	Range of values (fiber/liter)	Period
Emilia Romagna	Bologna	416	Not detectable -2,550	1988-2013
Emilia Romagna	Modena	58	Not detectable -130,000	2006-2013
Emilia Romagna	Carpi	50	Not detectable -105,780	2014-2015
Toscana	-	50	Not detectable -4	201-2015
Piedmont	Torino	5	Not detectable	1998
Marche	Senigallia	-	Not detectable -2,680	2013

Table 16-2: Analytical results for asbestos in drinking water: source article of ECOSCIENZA N. 6/2016, (B. Bruni, M. Cerroni, P. Comba, L. Lucentini, L. Musmeci, E. Testai)

While waiting for new developments, as suggested by both national and international studies, it is necessary to deepen our knowledge of the average concentration levels of asbestos in drinking water in order to determine its danger to health and assess the level of contamination on a large scale, using specific area indicators, in order to produce a hierarchy of priority actions in areas recognised as being at risk.

17. LCA analysis of the mapping, removal and treatment using an inertization plant of asbestos containing materials (ACM) within the eight municipalities of the Lower Reggiana area

17.1. Objectives and field of application

17.1.1. Objectives

The aim of the study is to perform an environmental impact assessment of the drone surveying, removal, remediation and disposal of asbestos containing materials (ACM) using a crystallization plant within the eight municipalities of the Lower Reggiana area using the Life Cycle Assessment (LCA) methodology.

17.1.2. Field of application

17.1.2.1. System purpose

The purpose of the system is the management of asbestos containing products in the area of Lower Reggiana.

17.1.2.2. The analysed system

The system being analysed is the management of asbestos containing products in the municipalities of the Lower Reggiana area using a continuous furnace inertisation plant.

17.1.2.3. Functional unit

The functional unit is the amount of ACM treated from 01/04/2016 to 31/12/2017: 150,000 kg.

17.1.2.4. System boundaries

The system boundaries range from ACM mapping to treatment using a continuous furnace inertisation plant.

17.1.2.5. Data quality

SimaPro7.3.3 is used for the study. The data used to define the Functional Units of the sub-processes of the main process is primary data. Much of the data on the construction of the sub-processes come from estimates or the literature. For many processes, such as energy and transport, database processes are used, where present, even if they do not represent the actual processes. IMPACT 2002+ is used as a method for assessing environmental damage.

17.1.2.5.1. New asbestos indicator

The number of LCA studies applied to the different management options for asbestos containing waste is surprisingly low (*Terazono A. et al.2000*), mainly due to the fact that there is no impact assessment method for asbestos emissions into soil, water or air (*Loss A., Toniolo A.,2018*). However, some strategies have been proposed to at least partially address this limitation. In particular, the pioneering work by Terazono et al., although limited to the disposal stage of the asbestos life cycle, for the first time attempted to quantify the health risk of inhaling asbestos fibers, by proposing a solution through an accurate estimation of the asbestos exposure dose and the calculation of the conversion factor, expressing the relationship between the exposure dose and health risk. However, the different environmental issues considered in that study (i.e. health risk and energy consumption) were not weighted since, at that time, transparent and unbiased methods of weighting to compare their effects were still missing from most of the impact assessment methods used in LCA. More recently, Loss et al. introduced inventory indicators that take into account the airborne dispersion of asbestos fibers as well as their deposit on the ground, quantifying the amounts (*ReCiPe 2008 H / H Europe M. Goedkoop,2008*). This study proposes a first attempt at calculating the human health characterisation factor for asbestos fibers for the purposes of carrying out environmental impact assessments in different scenarios such as ACW remediation by removal and treatment. The new "asbestos" indicator is represented by cases of malignant mesothelioma and is related to the percentage of asbestos fiber air dispersion as a result of the degradation of asbestos sheeting mainly due to failure to remove the sheeting, no definitive end-of-life treatments and inappropriate remediation by operators in the sector.

17.1.2.5.1.1. IMPACT method

Here are a few considerations for creating the indicator:

- Substance: *Asbestos fiber;*
- Source: ONA APS Mesothelioma Report "*Data from the II ONA APS Mesothelioma Report*". In 2015, asbestos-related deaths in Italy amounted to 6,000 people/year, comprising 3,000 lung cancer deaths, 1.500 due to miscellaneous cancers, and 1,500 due to malignant mesothelioma;
- Source: ONA APS Mesothelioma Report "*Data from the II ONA APS Mesothelioma Report*". In 2019, asbestos-related deaths in Italy amounted to 6,000 people/year, comprising 3,600 lung cancer deaths, 600 due to asbestosis, and 1,800 due to malignant mesothelioma;
- To develop the indicator, deaths from malignant mesothelioma (M.M.) in 2015 (1,500 cases of mesothelioma/year) were considered, as the disease can also occur at low concentrations of asbestos fibers in the air (not dose-dependent);
- Year in which the use, marketing and production of asbestos and all asbestos containing products are banned: 1992;
- Average M.M. incubation period taken as reference: 25 years (minimum latency period 10 years and maximum latency period 40 years);
- Amount of asbestos cement mapped in the eight municipalities under consideration: 33.000 metric tons=33.000E3 kg;
- Asbestos content in sheeting is on average 10% = 0.1*33000E3 kg;
- Number of inhabitants of Italy: 60,000,000 inhabitants;

- Number of inhabitants of the 8 municipalities of Lower Reggiana: 72,000 people;
- Number of deaths in the 8 municipalities of Lower Reggiana: 1,500/60E6*72,000= 1.8 cases (people);
- 2019 is considered for the calculation of airborne fibers;
- In 2019, existing asbestos sheeting was at least 27 years old.

Table 17-1 shows the production (P), import (I), export (E) and consumption (C) of asbestos in Italy from 1946 to 1992 (*2nd ReNaM Report*). Values are expressed in metric tons.

Year	Imports (I)	Exports (E)	National production (P)	Consumption (I-E+P)
1949	2799	4037	15877	14640
1950	6271	2891	21433	24813
1951	9435	1421	22612	30625
1952	9588	1577	23938	31948
1953	10378	2407	20397	28368
1954	11795	2325	23784	33254
1955	13828	4636	32101	41293
1956	20644	6070	35785	50359
1957	30652	4802	36615	62466
1958	19667	6242	38555	51980
1959	14536	9587	47662	52611
1960	29606	7176	54914	77344
1961	43892	9209	56975	91658
1962	40842	7891	55211	88162
1963	38760	6412	57167	89515
1964	45219	9033	68556	104742
1965	38649	26247	71928	84330
1966	43764	35965	82325	90124
1967	45529	34173	101062	112419
1968	51554	41847	103437	113143
1969	58229	46075	112526	124680
1970	62402	48662	118536	132276
1971	64257	48971	119568	134854
1972	47753	54668	131272	124357
1973	60288	63181	150256	147364
1974	66373	67067	148099	147406
1975	66457	82749	146995	130703
1976	77179	83752	164788	158215
1977	65468	67106	149327	147690
1978	47189	68958	135402	113633
1979	77151	74479	143931	146603
1980	66545	63815	157794	160525
1981	65942	51438	137086	151591
1982	56884	48624	116410	124671
1983	41620	61164	139054	119510
1984	40127	57540	147272	129859
1985	39737	65502	136006	110241
1986	47895	45187	115208	117916
1987	48864	51541	118352	115674
1988	46315	50936	94549	89928
1989	60687	37532	44348	67503
1990	63438	4825	3860	62473
1991	58906	1156	15000	72750
1992	36205	1686	0	34519

Table 17-1: Import, Export, Production and Consumption of asbestos in Italy from 1946 to 1992 (Second ReNaM report)

Table 17-2 shows the percentage breakdown of asbestos consumption by decade.

Years	Tons (I-E+P)	%
49-59	422,357	10.205
60-69	976,117	23.585
70-79	1,383,101	33.418
80-92	1,357,160	32.792
	4,138,735	100

Table 17-2: Percentage breakdown of asbestos consumption in Italy (1946-1992)

- Of the 33,000 metric tons of asbestos sheeting (561,000,000 sqm), it is assumed that 10% dates back to the 1950s, 20% to the 1960s, 30% to the 1970s, and 30% to the 1980s. The calculation was made from the actual production/import of asbestos in Italy from the 1950s to the 1980s.
- It is assumed that the cement structure of asbestos cement sheeting has a duration of 30 years before it starts to deteriorate (0% release). (Source *Table prepared by "Study of samples of corrugated asbestos cement sheeting" - Chiappino and Venerandi in Med. Lavoro 1991; 82.2: 99-191)*.
- It is assumed that the degradation takes place linearly over the period of time considered.
- It is assumed that the degradation is gradual and ends after 50 years with the complete release of fibers (100% release).
- In 2019, the airborne fibers by the years of installation reported above are (Table 17-3):
  - for sheeting installed in the 1950s: 100%/(2030-1980)=x/(2019-1980) x=78%
  - for sheeting installed in the 1960s: 100%/(2040-1990)=x/(2019-1990) x=58%
  - for sheeting installed in the 1970s: 100%/(2050-2000)=x/(2019-2000) x=38%
  - for sheeting installed in the 1980s: 100%/(2060-2010)=x/(2019-2005) x=18%

Years	Tons (I-E+P)	Weight	% degradation
49-59	422,357	10.205	78
60-69	976,117	23.585	58
70-79	1,383,101	33.418	38
80-92	1,357,160	32.792	18
	4,138,735	100	

Table 17-3: Percentage of airborne fibers dispersed over the decades

- Considering the weighted average between the percentage installation in the various decades analysed and the degradation times of the sheeting, the percentage of asbestos fibers dispersed in the air in 2019 is 40% (Table 17-3). If it is then assumed that only 0.1% of this percentage of fibers can potentially be inhaled by humans (*Merler E.,2006; Albin M., 1994;Anderson* A.*,1991;Berry G.,1999; Hisanga N.,1988; Kauppinen T. ,2000;Mirabelli D.,2005;Mirabelli D.,2008; Gylseth B.,1981; Magnani. C.,1998*), then the quantity of asbestos fibers dispersed in the air and which can be inhaled by humans is calculated as follows:

$$0.001*0.4*0.1*33{,}000E3=1.320 \text{ kg}$$

The characterisation factor of the substance "*Asbestos fiber*" is calculated via the following expression:

$$cf = 1.8 \text{ cases (people)}/1.320 \text{ kg} = 0.001364 \text{ cases/kg asbestos/year}$$

The damage assessment factor of the category is:

$$df = (80\text{-}50) \text{ DALY/cases}$$

The factor used to obtain the damage assessment relating to the substance considered is:

$$cf*df=0.001364\text{cases/kg asbestos/year}*(80\text{-}50) \text{ DALY/cases}=4.091E\text{-}2 \text{ DALY/kg asbestos.}$$

The damage assessment factor of the damage category is 30 DALY/cases. It should be borne in mind that the effect of dispersed asbestos will continue and that the new asbestos that will disperse (60%) will be added to this.

17.2. Inventory

17.2.1. General flowchart and inventory table

In order to describe the system as a whole, Figure 17-1 shows the general flowchart of the process and Table 17-4 reports the extraction of the main process modelled with the SimaPro calculation code, with the related parameters shown in Table 17-5 and Table 17-6. The following paragraphs detail the various sub-processes related to drone surveying, and remediation by removal, transport, storage and treatment using an inertisation plant of 150 metric tons of asbestos containing materials (ACM).

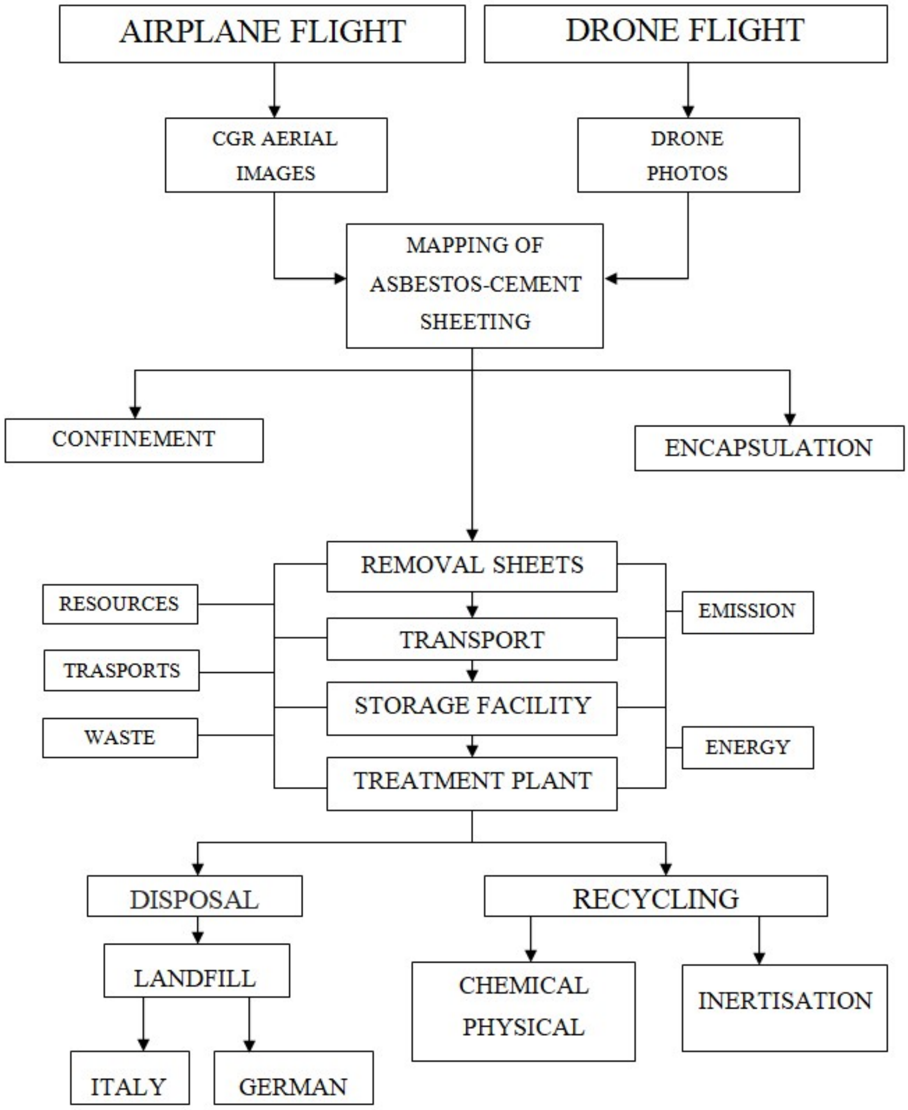


Figure 17-1: General flowchart of asbestos containing material (ACM) management

ACM treatment with inertisation by firing	MACMsmalt	metric tons	MACMsmalt /(MACMsmalt*(1+0,75))*100	The following phases are considered: - asbestos sheeting survey - removal - collection - storage - disposal Functional Unit: 150000kg of ACMs disposed of until December 2018 Mass allocation MACMsmalt/(MACMsmalt*(1+0,75))*100
Secondary building material from inertised ACM	MACMsmalt* 0.75	metric tons	0,75*MACMsmalt/(MACMsmalt*(1+0.75))*100	0,75*MACMsmalt/(MACMsmalt*(1+0,75))*100
Electricity/heat				
CGR aerial footage	1/Areacensita*AreaUnione/MACMcens*MACMsmalt	p	The following assumptions are made: the flights were carried out using a two-seater aircraft the km travelled were Limp=1000km hours spent timp=100h The Functional Unit refers to 1000ksqm surveyed Allocation according to the area surveyed 1/Areacensita*AreaUnione Allocation according to the treated mass 1/MACMcens*MACMsmalt	
Surveying by AeroDron	MACMsmalt	metric tons		
Drone flight for the 8 municipalities of the Bassa Reggiana area	1/33000*MACMsmalt	p	Drone flight to photograph the 8 municipalities of the Bassa Reggiana area: the FU of the process refers to 33000t of identified asbestos sheets	
Cross-checking of drone photos with CGR aerial images	1/33000*MACMsmalt	p	Cross-checking of drone photos with aerial images: the FU of the process refers to 33000t of identified asbestos sheets	
Removal of asbestos cement sheet	MACMsmalt	metric tons	Area of sheets removed: t	
Storage facility	MACMsmalt/(Plastra/1000+Ptelo/nlastre+Area*Spesprim*Densprim+Areabul*Spesprim*Densprim*nbul)*Arealastrunit	sqm	Storage facility: sqm	
ACM treatment by inertisation rev3	MACMsmalt	metric tons	Inertisation treatment: t	

Table 17-4: Extraction of the main "ACM treatment with inertisation by firing" process

Input parameters	Value	Comments
Areacensita	1000	area surveyed: ksqm
AreaUnione	313.9	area of the 8 Municipalities of the Bassa Reggiana area: ksqm
MACMsmalt	150	mass of ACM disposed of by the end of 2018: t
MACMcens	33048	mass of ACM surveyed: t
Mlastrunit	25.5	mass of a 1,5sqm asbestos cement sheet: kg
Arealastrunit	1.5	area of a 25,5kg asbestos cement sheet: sqm
ttagl	2	Cutting time: sec cutting time: sec
cemamasp	5	Asbestos cement removed during a single bolt cut: g
nbul	4	Number of bolts per 1,5sqm of sheet
Lunglastra	1.5	Sheet length: m
Larglastra	1	Sheet width: m
Spesprim	0.001	Protective primer thickness: m
Densprim	1.1	Primer density: t/m^3
nlastre	10	Number of sheet
stelo	0.0002	Film thickness: m
speslastra	0.0175	Sheet thickness: m thickness=0,015-0,02=0,0175m
Ronda	0,03	Sheet radius: m
densPE	0.925	PE density: 0,91-0,94 t/m^3
Areatetto	100	Roof area: sqm

Table 17-5: Input parameters of the "ACM treatment with inertisation by firing" process

Calculated parameters	Value	Comments
Area	Lunglastra*Larglastra	Sheet area: sqm
Areabul	0.05^2	Area surrounding the bolt: sqm
Ptelo	densPE*2*((Lunglastra*larglastra)+(Lunglastra+10*(speslastra+Ronda))+(Larglastra+10*(speslastra+Ronda)))*stelo	Weight of film wrapping 10 sheets: t
Plastra	17*1*1.5	Sheet weight: kg
Nlastretetto	Areatetto/1.5	number of roof sheets
Npac	Nlastretetto/nlastre	number of packages of sheets

Table 17-6: Calculated parameters for the "ACM treatment with inertisation by firing" process

17.2.2. ACM roof survey using drones within the municipalities of the Lower Reggiana area

The following describes the process regarding the surveying of asbestos cement (AC) sheeting, within the municipalities of the Lower Reggiana area, through the use of drones. Figure 17-2 shows the relative flowchart.

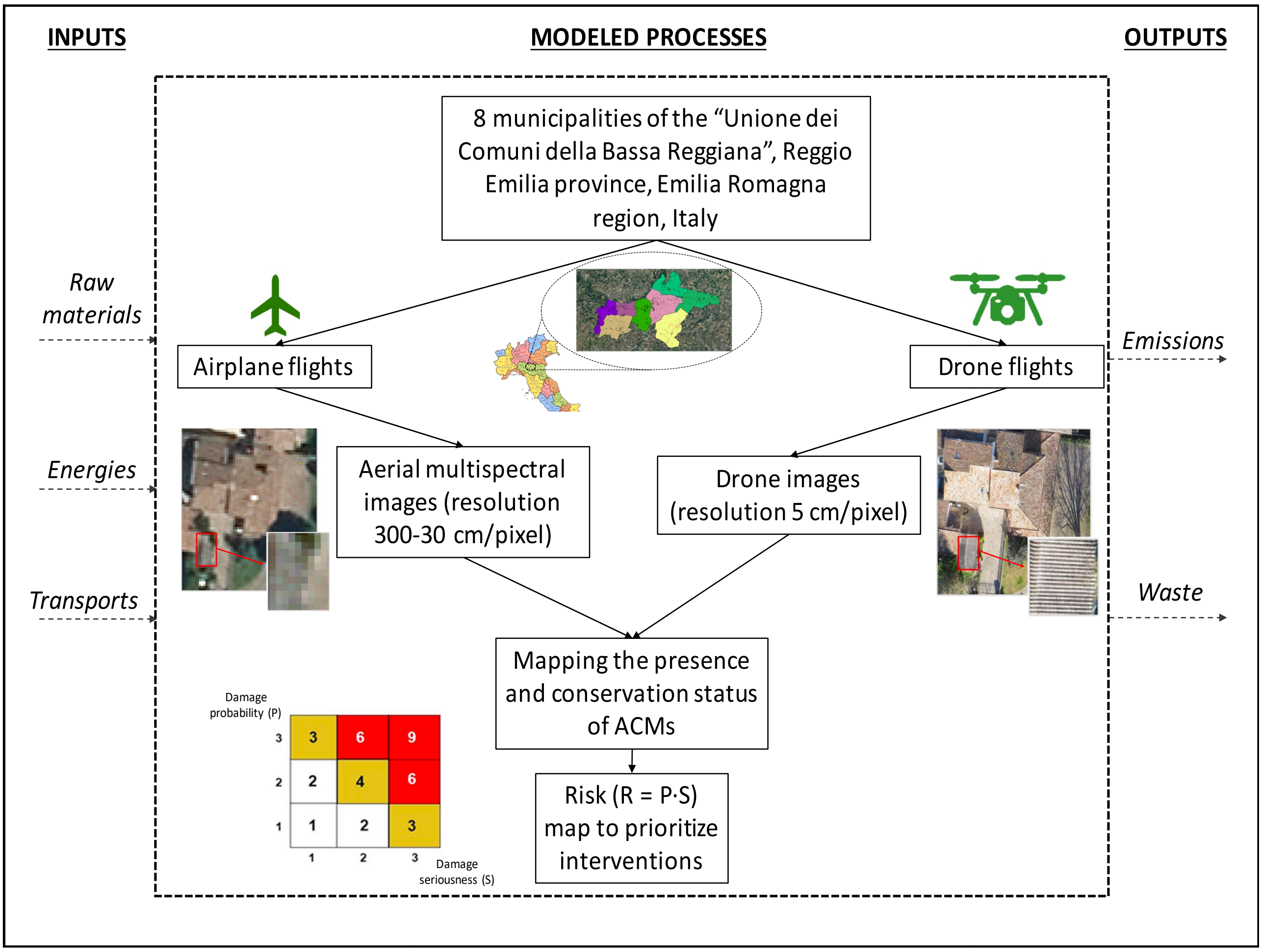


Figure 17-2: Flowchart showing the system boundaries considered in the LCA of the ACM mapping and prioritisation of actions (AeroDron AsbestosFree)

Numerous techniques can be used for the indirect mapping of AC sheeting. These techniques are characterised by varying degrees of statistical accuracy and resolution, but no methodology is able to identify the presence of asbestos in small areas of sheeting as well as classify its condition. In this project, a methodology for classifying the condition of AC sheeting was analysed and applied, using high-definition images obtained from drone flights over the eight municipalities of the Lower Reggiana area (Figure 17-3).

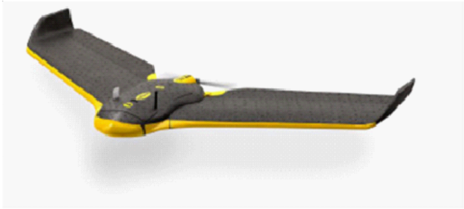


Figure 17-3: Drone used to survey the Lower Reggiana area (AeroDron AsbestosFree)

This methodology includes a series of analytical techniques which combine the interpretation of aerial multispectral images with the study of information collected from low-altitude surveys performed using drones. The integration of these techniques has allowed the development of a system which can not only map very small areas of AC sheeting but also classify the condition of the surveyed sheeting (Figure 17-4).

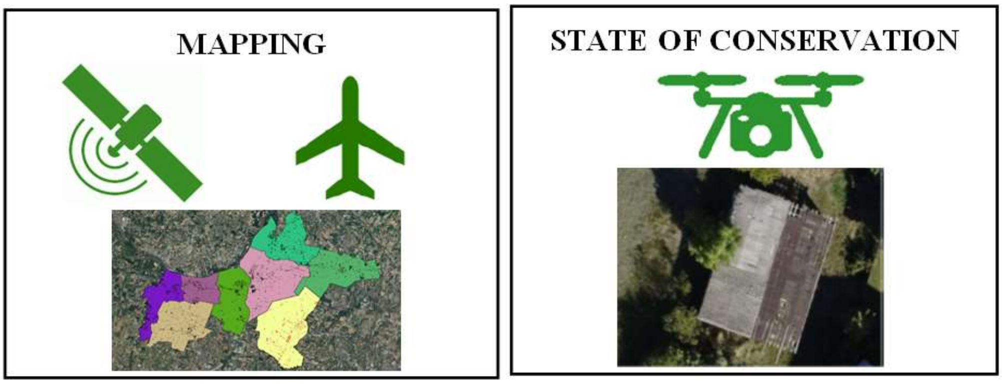


Figure 17-4: Integration between mapping and classification of the condition of surveyed AC sheeting (AeroDron AsbestosFree)

In fact, the interpretation of the images taken by drones makes it possible to detect any flaking, cracks and breakages of the AC sheeting. Assessment of the condition depends on signs of degradation and the relative percentage of deteriorated roofing with respect to the total surface area. The flights are carried out using fixed-wing drones, at an operating altitude of up to 150 meters. Flights over inhabited areas are subject to authorisation granted by ENAC, the national civil aviation body. The function performed by drones in this methodology is crucial because it allows the classification of the condition of the AC sheeting and ensures the effectiveness of the mapping. In fact, the resolution of multispectral aerial images (about 3 m per pixel), although higher than that of satellite images, is not sufficient to identify the texture of the sheeting (Figure 17-5). For example, it is impossible to distinguish with certainty grey concrete roofing from a fiber cement sheet, especially when it is partially covered with lichens or in a shaded area.

Figure 17-5: Comparison of multispectral aerial images with drone images (AeroDron AsbestosFree)

Drones, on the other hand, allow images to be taken with a resolution in the order of 5 cm per pixel, a resolution suitable for obtaining more information on the characteristics and condition of the sheeting (Figure 17-6).

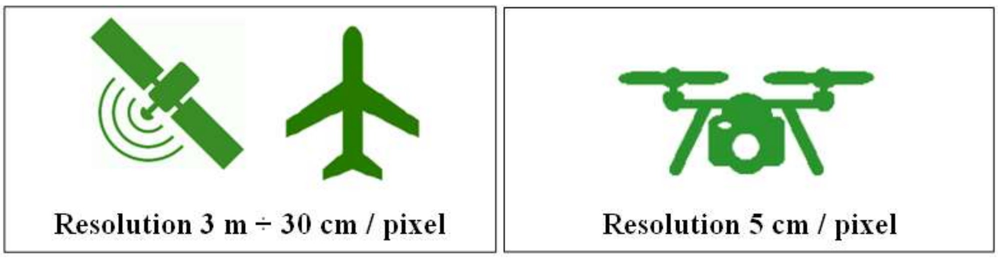


Figure 17-6: Comparison of the resolution of multispectral aerial images with drone images (AeroDron AsbestosFree)

Each pixel of the drone images is analysed individually and compared with a constantly updated database, which searches for the presence of textures, colours and shapes typical of those that characterise AC sheeting. The information collected is superimposed on the Cadastral Map (Figure 17-7), to be used to draw up risk management plans and match the location of the AC sheeting with the Cadastral information.

Figure 17-7: Vector mapping of AC sheeting superimposed on the Cadastral Map (AeroDron AsbestosFree)

Due to their lower resolution, methods that rely exclusively on multispectral aerial image analysis, while providing reliable information on the total amount of ACM present in an area, cannot be accurate in resolving uncertainties or exhaustive in terms of the amount of AC sheeting identified. The chosen methodology, on the other hand, is able to identify coverage as small as 2 sqm thanks to the use of drones. Drones are crucial because by flying at low altitudes over the sheeting identified by the analysis of multispectral images, they are able to acquire high-resolution images (Figure 17-8) whose analysis allows the elimination of false positives and verification in the case of uncertainties regarding the type of sheeting.

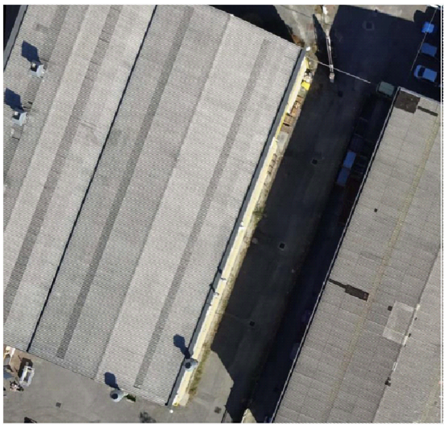


Figure 17-8: High-resolution drone images (AeroDron AsbestosFree)

Like all methods based on remote sensing, the developed methodology also has an inherent error: the images analysed can be disturbed by light phenomena that reduce their sharpness and definition. In general, the classification of some sheeting may remain undetermined when the surveyed areas are covered by lichens, common paints and, in general, in all cases of poor visibility. Visual verification through drone footage minimizes the “statistical” error, but it is not always possible to fly over all areas where there is sheeting of uncertain classification for regulatory reasons related to the flight or operational context.

17.2.2.1. Methodology

The methodology described above is divided into three stages: initial identification, refinement by drone surveying, and cross-checking of the drone images with multispectral aerial images. The *initial identification* involved the acquisition of multispectral aerial images by Compagnia Generali Riprese Aeree S.p.A. (C.G.R. S.p.A.) and the subsequent superimposing of these images on the Cadastral Maps. The aim is to identify the sheeting within the municipality that have spectral characteristics compatible with ACM products, with differing degrees of probability. The processes are reported in Table 17-7 and Table 17-9, with the related parameters in Table 17-8, Table 17-10 and Table 17-11. These were modelled using the calculation code for this initial stage, divided into the following two sub-processes:

✓ <u>*Process: CGR aerial footage*</u>, whose functional unit refers to 1,000 ksqm surveyed (F.U. = 1p)

Inputs from technosphere: electricity/heat	**Amount**	**Unit**	**Comments**
Transport, helicopter {GLO}| processing | APOS, U	timp/tvita = 0.1	hr	Two-seater aircraft weight: 1t
Electronic component, active, unspecified {GLO}| production | APOS, U	1/tvitamfoto*timp = 0,001	kg	Camera
CI_Hangar production (3) (b)/with electrowelded mesh update (multi-output)	1/1575*1000*1/(55*365)*timp/9*1/1575*6 = 1.338727149E-6	p	Hangar area where the aircraft is located: 1575sqm Hangar area allocation p/1575*1000 Time allocation: hours needed for filming: timp it is assumed that the aircraft operates in the summer from 8am to 5pm (9 hours) days of filming: timp/9 p/(55*365)*timp/9 Allocation of area occupied by the aircraft: area occupied by the aircraft: 2*3=6sqm p/1575*6
Transport, freight, lorry 16-32 metric ton, EURO6 {RoW}| transport, freight, lorry 16-32 metric ton, EURO6 | APOS, U	(Paereo*timp/tvita+Pfotocam/1E3/tvitamfoto*timp)*100 = 10.0001	tkm	Two-seater aircraft transport: 100km
^Aluminium recycling (from Ecoinvent 3) multi-output (Allocation 50%)	500*timp/tvita = 50	kg	End of life of two-seater aircraft (aluminium)
^Steel recycling (from Ecoinvent 3) multi-output (Allocation 50%)	500*timp/tvita = 50	kg	End of life of two-seater aircraft (iron)
Outputs to technosphere: Waste treatment	**Amount**	**Unit**	**Comments**
Used industrial electronic device {GLO}| treatment of, mechanical treatment | APOS, U	Pfotocam/tvitamfoto*timp = 0.001	g	Camera end of life

Table 17-7: Extraction of the "CGR aerial footage" process

Input parameters	Values	Comments
Limp	1000	Distance travelled by aircraft for filming: km
Lvita	100000	Distance travelled during the life of the aircraft: km
timp	100	Flight time for filming: h
tvita	1000	Flight time during the life of the aircraft: h
tvitamfoto	100000	Camera lifetime: h
Paereo	1	Aircraft weight: t
Pfotocam	1	Camera weight: kg

Table 17-8: "CGR aerial footage" process input parameters

✓ *Process: Surveying by AeroDron*, whose functional unit is the mass of asbestos cement sheeting mapped within the 8 municipalities of the Bassa Reggiana area (F.U. = 33,048 metric tons).

Inputs from technosphere: materials/fuels	**Amount**	**Unit**	**Comments**
Computer, laptop {GLO}| production | APOS, U	1/(tvitacomp*8*5*52) *tcomp = 1.317175975E-7	p	Computer for interpreting multispectral aerial images
Inputs from technosphere: electricity/heat	**Amount**	**Unit**	**Comments**
Electricity, low voltage {IT}| electricity voltage transformation from medium to low voltage | APOS, U	Pcomp*tcomp = 3.2	kWh	Electricity for interpreting multispectral aerial images Computer power: 0,8kW
AeroDron algorithm for interpreting CGR images	1/Tvitaalgor*tincr = 0.0033	p	Use of the algorithm for image interpretation The process includes: -Computer for interpreting multispectral aerial images: Computer, laptop {GLO}| production | APOS, U: 1/(tvitacomp*8*5*52)*tcomp -Electricity for interpreting multispectral aerial images (Computer power: 0,8kW): Electricity, low voltage {IT}| electricity voltage transformation from medium to low voltage | APOS, U: Pcomp*tcomp

Table 17-9: Extraction of the "Surveying by AeroDron" process

Input parameters	Values	Comments
tcomp	4	computer usage time: h
Pcomp	0.8	computer power: kW
tincr	100	Usage time for aerial image interpretation: h

Table 17-10: "Surveying by AeroDron" process input parameters

Calculated parameters	Values	Comments
tvitacomp	5*365*8 = 14600	computer lifetime: h 5 years at 8 hours a day
Tvitaalgor	30000 = 30000	algorithm usage time: h

Table 17-11: "Surveying by AeroDron" process calculation parameters

The subsequent *refinement activity* involves the use of drones flying at low altitude to survey sheeting of uncertain classification, which does not have a uniform distribution of the spectral signature. Table 17-12 reports the process created for drone flights in the Lower Reggiana area, with related parameters in Table 17-13 and Table 17-14.

✓ *Process: drone flight over the 8 municipalities of Lower Reggiana*, whose functional unit is the mass of asbestos cement sheeting mapped within the 8 municipalities of the Lower Reggiana area (F.U. = 1p).

Inputs from technosphere: materials/fuels	Amount	Unit	Comments
Polypropylene, granulate {RER}| production | APOS, U	Mdrone = 0,7	kg	
Computer, laptop {GLO}| production | APOS, U	1/Tvitacomp*tprog = 0.0005494505495	p	Computer for programming drone settings
Inputs from technosphere: electricity/heat	**Amount**	**Unit**	**Comments**
Electricity, low voltage {IT}| electricity voltage transformation from medium to low voltage | APOS, U	Qbat*tvolo = 192.03	Wh	Electricity used for the drone battery
Battery, Li-ion, rechargeable, prismatic {GLO}| production | APOS, U	Pesobat/Tvitabat*tvolo = 17.3	g	battery
Electricity, low voltage {IT}| electricity voltage transformation from medium to low voltage | APOS, U	Pcomp*tprog = 6.4	kWh	Electricity for the computer for drone settings Computer power: 0,8kW
Electronic component, active, unspecified {GLO}| production | APOS, U	Pfotocam/tvitamfoto*tvolo = 0.000173	kg	Camera

AeroDron algorithm for analysing the drone images	1/Tvitacomp*tAlgfotdrone = 0.0343	p	Use of the algorithm for image interpretation The process includes: -Computer for interpreting multispectral aerial images: Computer, laptop {GLO}| production | APOS, U: 1/(tvitacomp*8*5*52)*tcomp -Electricity for interpreting multispectral aerial images (Computer power: 0,8kW): Electricity, low voltage {IT}| electricity voltage transformation from medium to low voltage | APOS, U: Pcomp*tcomp
Outputs to technosphere: Waste treatment	**Amount**	**Unit**	**Comments**
Used Li-ion battery {GLO}| treatment of used Li-ion battery, hydrometallurgical treatment | APOS, U	Pesobat/Tvitabat*tvolo = 17.3	g	Drone battery end of life
Used industrial electronic device {GLO}| treatment of, mechanical treatment | APOS, U	Pfotocam/tvitamfoto*tvolo = 0.000173	kg	Camera end of life

Table 17-12: Extraction of the "Drone flight for the 8 municipalities of the Bassa Reggiana area" process

Input parameters	**Values**	**Comments**
Mdrone	0.7	drone weight: kg
Tvitadrone	100000	drone lifetime
Qbat	11.1	battery power V*A W A=2ampere V=3*3,7Volt range 40min
tvolo	17.30	flight time: h
Pesobat	50	battery weight: g
Tvitabat	50	battery lifetime: h
Pcomp	0,8	computer power: kW
tprog	8	computer programming time for drone settings: h
tvitamfoto	100000	Camera lifetime: h
Pfotocam	1	Camera weight: kg
tAlgfotdrone	500	time required for algorithm programming for drone photo analysis: h

Table 17-13: "Drone flight for the 8 municipalities of the Bassa Reggiana area" process input parameters

Calculated parameters	**Values**	**Comments**
ncaricabat	tvolo/(40/60)	Number of battery recharges
tvitacomp	7*52*5*8	computer lifetime: h 7 years for 8 hours a day *5 days a week* 52 weeks: h

Table 17-14: "Drone flight for the 8 municipalities of the Lower Reggiana area" process calculation parameters

At the end of the refinement phase, the images collected during the flights are analysed and *cross-checked* with the previous multispectral images. The process (Table17-15), with related parameters

(Table 17-16 and Table 17-17), related to the cross-checking of the images mentioned above is reported below.

✓ *Process: Cross-checking of drone photos with CGR aerial images*, whose functional unit is the mass of asbestos cement sheeting mapped within the 8 municipalities of the Lower Reggiana area (F.U. = 1p).

Inputs from technosphere: materials/fuels	**Amount**	**Unit**	**Comments**
Computer, laptop {GLO}| production | APOS, U	1/(tvitacomp*8*5*52) *tcomp = 5,268703899E-6	p	Computer for interpreting multispectral aerial images
Inputs from technosphere: electricity/heat	Amount	Unit	Comments
Electricity, low voltage {IT}| electricity voltage transformation from medium to low voltage | APOS, U	Pcomp*tcomp = 128	kWh	Electricity for interpreting multispectral aerial images Computer power: 0,8kW
AeroDron algorithm for interpreting CGR images	1/Tvitaalgor*tincr = 0,003333333333	p	Use of the cross-checking algorithm

Table 17-15: Extraction of the "Cross-checking of drone photos with CGR aerial images" process

Input parameters	**Values**	**Comments**
tcomp	4	computer usage time: h
Pcomp	0,8	computer power: kW
tincr	100	Usage time for aerial image interpretation: h

Table 17-16: "Cross-checking of drone photos with CGR aerial images" process input parameters

Calculated parameters	**Values**	**Comments**
tvitacomp	5*365*8 = 14600	computer lifetime: h 5 years at 8 hours a day
Tvitaalgor	30000 = 30000	algorithm usage time: h

Table 17-17: "Cross-checking of drone photos with CGR aerial images" process calculation parameters

17.2.2.2. Results of the mapping of the municipalities of the Lower Reggiana area and subsequent use

Below is a map of the eight municipalities surveyed (Table 17-18).

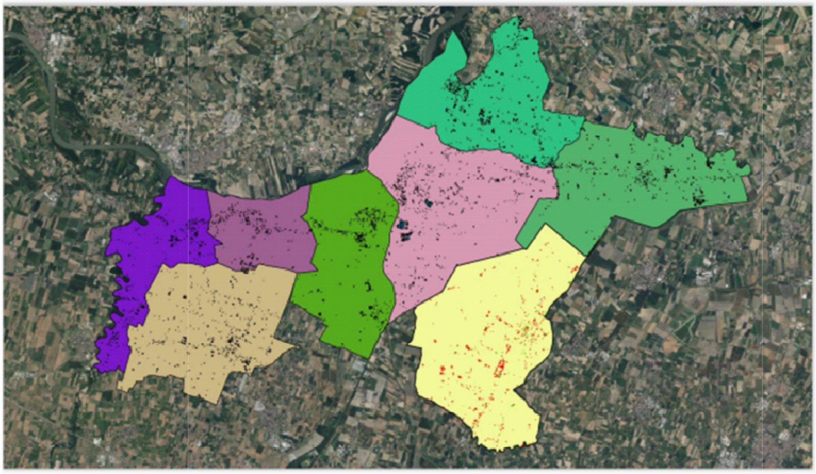


Table 17-18: Map of the eight municipalities of Lower Reggiana following the mapping of asbestos cement sheeting (AeroDron AsbestosFree)

Table 17-19 shows the results regarding the municipalities with 2,203,174 sqm and 33,048 metric tons of AC sheeting mapped.

Description	Total Unione	Average Unione
Total surface area of the city in ksqm	313.9	39.24
Inhabitants	72,048	9,006
Population density per ksqm	229.53	-
Total surface ACM in sqm	2,203,174	275,397
Number of coverings in ACM	6,184	773
Tonnes of ACM	33,048	4,131
ACM per inhabitant sqm	30.58	30.58
Sqm ACM per ksqm of surface area	7,018.71	7,018.71

Table 17-19: Mapping results for the eight municipalities

Table 17-20 shows the results for each municipality. The municipality with the greatest presence of AC sheeting (within the 8 municipalities) is the Municipality of Luzzara with 394,911 sqm, 1,045 areas of sheeting and 5,924 tons identified. Considering the 9,318 inhabitants and 38.5 ksqm of surface area, there are 42.4 sqm/inhabitant and 10,257 sqm/ksqm of surface area.

Description	Boretto	Brescello	Gualtieri	Guastalla	Luzzara	Novellara	Poviglio	Reggiolo
Total surface area of the city in ksqm	18.1	24.4	35.6	53	38.5	58	43.6	42.7
Inhabitants	5,315	5.623	6,576	15,053	9,318	13,761	7,226	9,176
Population density per ksqm	294	230	185	284	242	237	166	215
Total surface ACM in sqm	123,115	150,100	233,747	469,083	394,911	279,281	232,282	320,655
Number of coverings in ACM	401	509	185	1,047	1,045	828,000	855,000	798,000
Tonnes of ACM	1,847	2,525	3,506	7,036	5,924	4,189	3,484	4,810
ACM per inhabitant sqm	23.2	26.7	35.5	31.2	42.4	20.3	32.1	34.9
Sqm ACM per ksqm of surface area	6,802	6,152	6,566	8,851	10,257	4,815	5,334	7,509

Table 17-20: Mapping results by individual municipality

Once the mapping results were obtained, the following activities were carried out:

1. Cross-checking of the mapping results with cadastral, tax and registry information of the eight municipalities;
2. Creation of a georeferenced database on QGIS;

3. Data extrapolation in Excel format;
4. Creation of Nova Streets, a software dedicated to managing ACM mapping data.

As an example, the statistical data for the Municipality of Poviglio is reported by sheeting area (sqm) and types of users (domestic and non-domestic). Within the municipality in question, 855 users were positively cross-checked for a total of 232,828 sqm of which:

- Domestic users under 30 sqm of roofing: 250 records for a total of 5,012 sqm
- Domestic users over 30 sqm of roofing: 384 records for a total of 12,596 sqm
- Non-domestic users (with VAT no.): 221 records for a total of 215,220 sqm

Finally, a special software was developed by NovaLab of Correggio (https://novalabstudio.it/) dedicated to the management of data obtained from the mapping described above. With this software, it is possible to:

❖ Build a "dynamic" list of information (Figure 17-19) of users associated with georeferenced sheeting, available to all interested stakeholders (municipal technical offices, local police, local health authority).

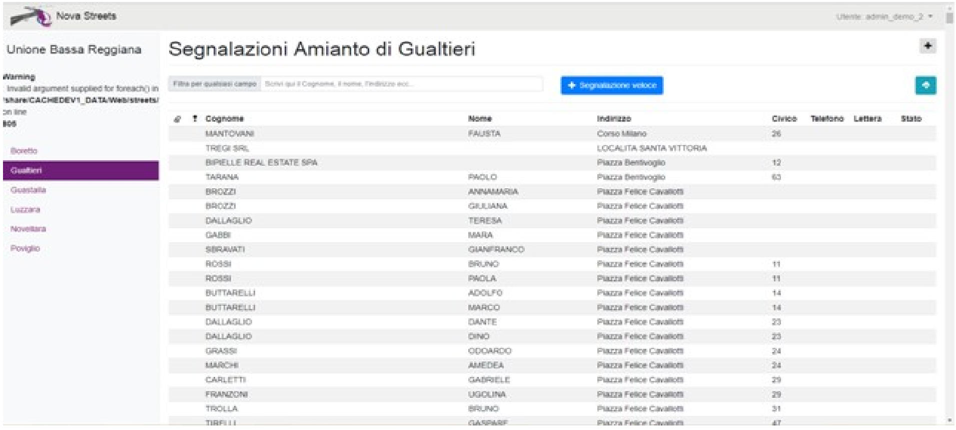


Figure 17-9: Screenshot from Nova Streets asbestos management software

❖ Enter reports of ACM presence or removal (Figure 17-10).

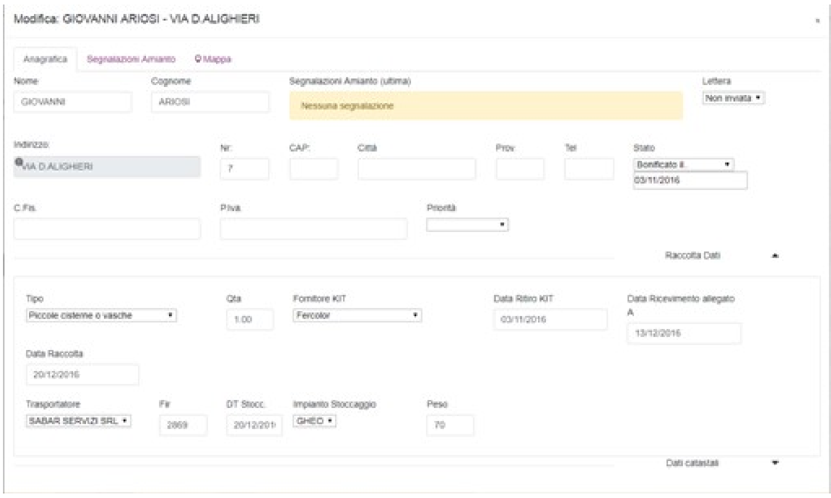


Figure 17-10: Screenshot from Nova Streets asbestos management software

❖ Superimpose several layers (Figure 17-11) for subsequent risk map construction (to establish action priorities).

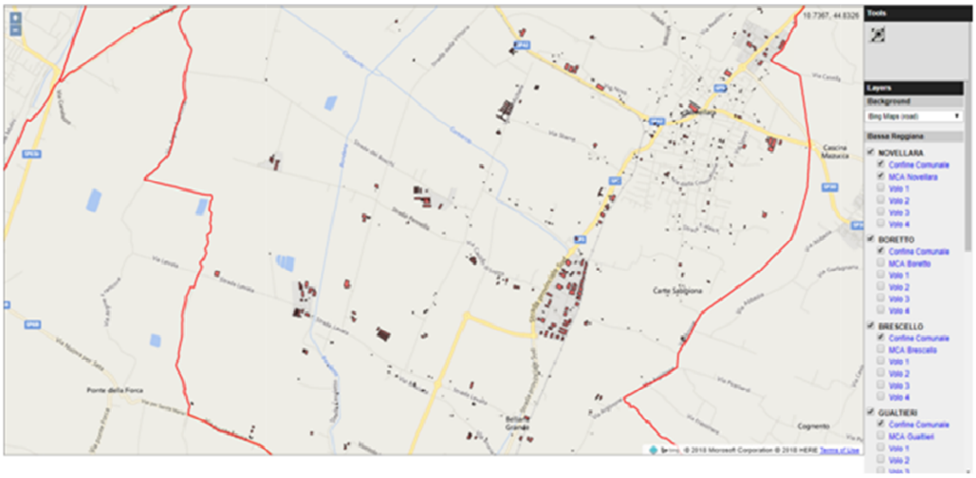


Figure 17-11: Screenshot from Nova Streets asbestos management software

❖ Check drone flights conducted (Figure 17-12).

Figure 17-12: Screenshot from Nova Streets asbestos management software

❖ View high-resolution photographs taken by the drone (Figure 17-13).

Figure 17-13: Drone photograph

17.2.3. Remediation by removal of asbestos cement sheets

In this process, an asbestos cement sheet (1.5 sqm area and weight of 25.5 kg) is remediated through removal. The site in question was assumed to be in the Municipality of Guastalla. Figure 17-14 shows the relative flowchart.

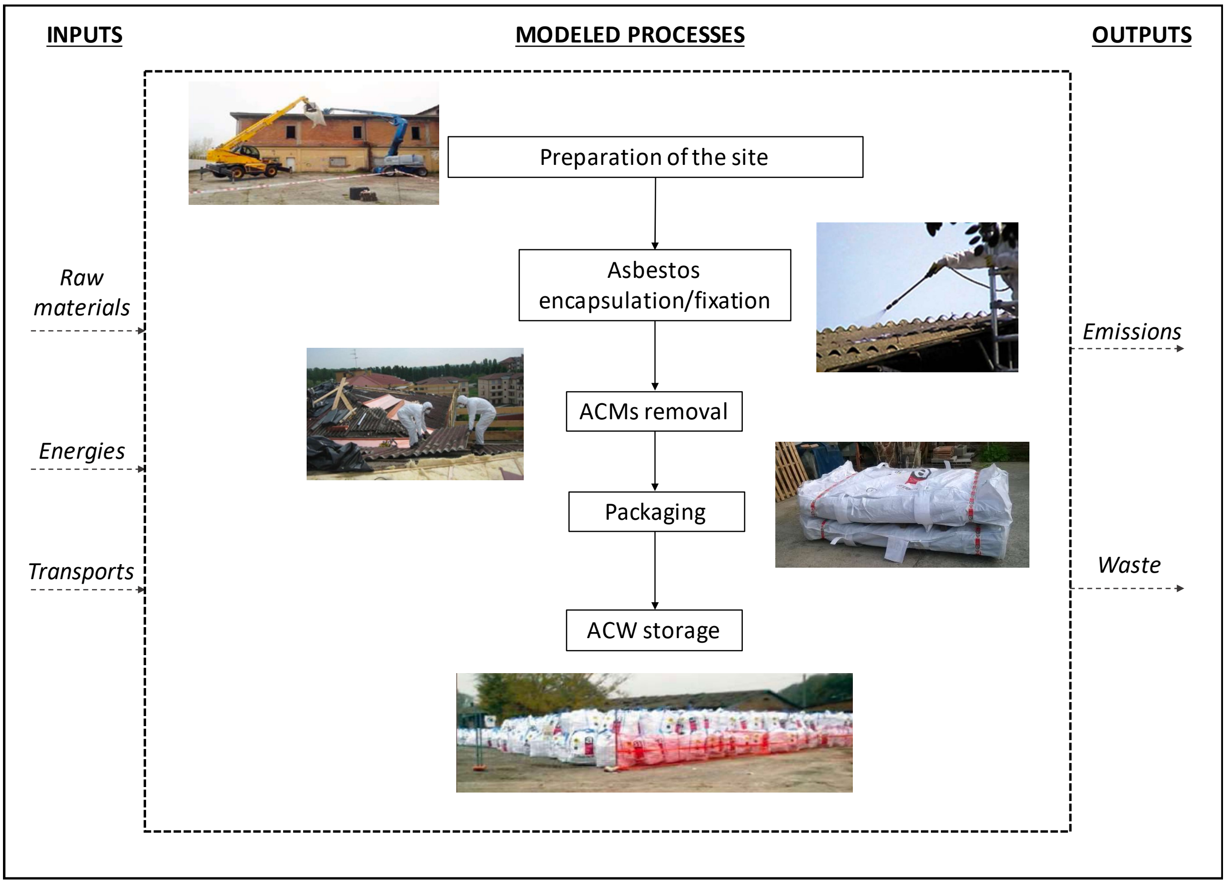


Figure 17-14: Flowchart showing the system boundaries considered in the LCA of the safe encapsulation, removal, packaging and preliminary storage of ACW before end of life.

Before performing the removal, the surfaces of the sheet (both upper and lower) were treated with a red colored encapsulation product for asbestos containing materials, a type "D" encapsulation product according to Italian Ministerial Decree 20/08/1999. The performance characteristics are shown in Figure 17-15.

Performance characteristics	
Color	red contrasting with the support
Dry film thickness	20 μm ± 0.5
Consumption	1 kg / 6 sqm (depending on the degradation of the substrate)
Drying time	40’ (depending on the environmental conditions)

Figure 17-15: Characteristics of the type D encapsulation product

An encapsulation product was used which, thanks to its special formulation - based on synthetic resins and additives in an aqueous emulsion - guarantees high-performance resistance to rain and sun. About 0.3 kg/sqm of this encapsulation material was applied and left to dry for about 3 hours. The resin was applied by spraying over the entire surface using an airless backpack pump with a low-pressure membrane (pressure of 14.1 liters/minute with a power of 0.34 kW and weight of 4.7 kg). In order to avoid the inhalation of asbestos dust by the operators, the following personal protective equipment (PPE) was provided:

- disposable one-piece overalls with chemical protection category 3a, type 5-6,
- half-face masks with P3 filter,
- washable gloves,
- safety shoes with non-slip sole,
- safety harness.

Fixings were removed both with hand tools (screwdrivers and pliers) and with portable equipment with low self-discharge batteries (power tool with 18 Ampere 500 W battery). The material was removed without breaking up and the pieces and/or scraps produced were treated with the encapsulation solution and placed in double sealed bags. The overlapping areas between the sheets were treated with the encapsulation product prior to removal. The dust deposited in the gutters was removed wet (drain closure, dampening of the material, removal with a trowel and placing into sealed bags). At the end of the work, the work area and access areas (roof, floor or ground below the roof, slab on which the roof was laid, balconies, terraces, internal stairs, lifts) were completely cleaned by removing any asbestos containing scrap material and vacuuming and/or washing of the surfaces. Below are the characteristics of the vacuum cleaner used (Table 17-21).

Performance characteristics		
Power	Kw	2
Depression	mmH_20	2,150
Air flow	Liter/min	5,400
Voltage	Volts	230/50/60
Filtering surface	Csqm	19,500
Union inlet	Ø	70
Waste container volume	Liters	38

Table 17-21: Performance specifications of the HEPA vacuum with absolute filters

The asbestos cement sheets were packaged in easy-to-handle sizes, not exceeding about 1 m^3, protected underneath by plastic material and sealed with transparent polyethylene. In addition to the labelling provided for by Italian Presidential Decree 215/88, the packages were also labelled according to the Resolution of the Interministerial Committee of 27 July 1984, consisting of a non-removable label or a label with a yellow background measuring 15 x 15 cm, showing the letter R in black, 10 cm high, 8 cm wide, and with a sign width of 1.5 cm (Figure 17-16).

Figure 17-16: Removal of asbestos cement sheets

The used PPE, treated with encapsulation solution, was placed in 200 μm sealed bags. These bags, together with the bags containing the pieces and scraps, were placed in one or more packages. The pallets, loaded on the roof, were lowered to the ground using a crane with harnesses (Figure 17-17).

Figure 17-17: Removal of asbestos cement sheets

The packages of asbestos containing waste, originating from the removal process, labelled according to the law, were loaded and taken to a temporary storage facility (Figure 17-18). A Daily-type vehicle with a fixed body and front-mounted crane was used for the transportation, with the following specifications:

- Engine capacity: 2,500 cm^3;
- Power: 85kW;
- Consumption: 7 km/liter;
- Weight: 2,700 kg;
- Maximum load: 800 kg;
- Overall mass: 3,500 kg;
- Body size: 4.5 m long, 2 m wide.

Figure 17-18: Transport of AC sheeting from the site to the storage facility

Table 17-22 below shows the extrapolation of the remediation process by removal. Tables 17-23 and 17-24 list the input parameters and the calculated parameters, respectively.

Removal of asbestos cement sheet rev1	Plastra	25.5	kg	Others\ ACM Treatment Considers a corrugated asbestos cement sheet of 1,5m length and 1m width Sheet area =1,5sqm Thickness=0,015-0,02=0,0175m Sheet weight:16-18kg/sqm=17kg/sqm F.U. 17*1,5=25,5kg Considers that the plate is fixed by 4 bolts that are cut during the activity and the bolt diameter is assumed to be 0,005mm. Assumes that the site is in the Municipality of Guastalla
Epoxy resin insulator, SiO2 {RoW}| production | APOS, U	Area*Spesprim*Densprim	0.00024	metric tons	Encapsulates both the upper and lower surfaces of the sheet. Thickness of the adhesive sprayed on the sheet: m
Epoxy resin insulator, SiO2 {RoW}| production | APOS, U	Areabul*Spesprim*Densprim*nbul	1.6E-6	metric tons	Thickness of the adhesive sprayed onto the surfaces surrounding the bolts: m
Polyethylene, linear low density, granulate {RER}| production | APOS, U	Ptelo/nlastre/0.997	0.00018	metric tons	LDPE film used to wrap the sheets: metric tons
Electricity/heat				
Electricity, low voltage {IT}| electricity voltage transformation from medium to low voltage | APOS, U	nbul*Potsvit*tsvit/60	0.05	kWh	Screwdriver power 500W Time required to unscrew 1 bolt: 1,5min
Mobile cable yarder, truck-mounted, incl. processor {GLO}| cable yarder production, truck-mounted | APOS, U	1/Tvitagru*Altcasa*2/Velsaldisc/3600/nlastre	2.381E-8	p	Lifting crane: 1/5E4*10*2/0,4667/3600/nlastre Crane lifetime: 50000h
Machine operation, diesel, >= 74.57 kW, generators {GLO}| machine operation, diesel, >= 74.57 kW, generators | APOS, U	Altcasa*2/Velsaldisc/0.74/nlastre	5.79	s	Time taken to move the removed asbestos sheets: 10m*2/0,4667m/sec/0,74 Height of building: 10m Ascent and descent speed: 0,4667m/sec performance: 0,74 Time taken to for the crane to ascend and descend (perhaps it is better to consider only the descent)
Blow moulding {RoW}| production |APOS, U	Ptelo/nlastre/0,997	0.0001837	metric tons	Film manufacture
Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO6 | APOS, U	(Area*Spesprim*Densprim+Plastra/1E3+Ptelo/nlastre)*22	0.5703	tkm	Transport of the sheets removed from the site in Guastalla (RE) to the storage facility that is assumed to be in Correggio (RE): 22km

Transport, freight, lorry 16-32 metric ton, EURO6 {RoW}| transport, freight, lorry 16-32 metric ton, EURO6 | Alloc Def, U (without lorry)	Pgru*1/Tvitagru*Altcasa*2/Velsaldisc/3600/nlastre*22	1.6237E-5	tkm	Transport of the crane by the removal company to the site: 22km Crane weight: 31t
^Steel recycling (from Ecoinvent 3) multi-output (Allocation 50%)	nbul*Pbul	0.00014	kg	Bolt recycling: m
Air emissions		**Amount**		**Comments**
Asbestos fiber	0.1*cemamasp*nbul*(1-frazlav)	1.98	g	It is assumed that for each cut, a mass of 5g of asbestos cement is removed The percentage of asbestos is 10% Total asbestos fibers that are assumed to enter the atmosphere: 0,1* 5
Asbestos fiber worker	0.1*cemamasp*nbul*frazlav	0.02	g	It is assumed that of the fibers removed 1% involves the worker
Particulates, < 2,5 um	0.9*cemamasp*nbul*(1-frazlav)	17.82	g	
Particulates, < 2,5um, indoor	0.9*cemamasp*nbul*frazlav	0.18	g	

Table 17-22: Extraction of the "Removal of asbestos cement sheet rev1" process

Input parameters	**Values**	**Comments**
ttagl	2	Cutting time: sec
cemamasp	5	Asbestos cement removed during a single bolt cut: g
nbul	4	Number of bolts per 1,5sqm of sheet
Lunglastra	1.5	Sheet length: m
Larglastra	1	Sheet width: m
Densprim	1.08	Primer density: t/m^3
frazlav	0.01	Portion of fiber inhaled by the worker
nlastre	10	Number of sheets in the package: n
stelo	0.0002	Film thickness: m
speslastra	0.0175	Sheet thickness: m thickness=0,015-0,02=0,0175m
Ronda	0,03	Sheet radius: m
densPE	0.925	PE density: 0,91-0,94 t/m^3
Areatetto	100	Roof area: sqm
Altcasa	10	Height of building: m
Velsaldisc	0.4667	Crane ascent and descent speed: m/sec

Potflex	850	Tool power: W
Pgru	31	Crane weight: t
denssupprim	160	Surface density of primer: g/sqm
Tvitagru	50000	Crane lifetime: h
Tsvit	1.5	Unscrewing time: min
Potsvit	0.5	Screwdriver power: kW
Dbul	0.01	Bolt diameter: m
Hbul	0.03	Bolt length: m
Dtestabul	0.02	Bolt head diameter: m
Spdadotesta	0.004	Head and nut thickness: m

Table 17-23: "Removal of asbestos cement sheet rev1" process input parameters

Calculated parameters	**Values**	**Comments**	
Area	Lunglastra*Larglastra	1.5	Sheet area: sqm
Areabul	0.05^2	0.0025	Area surrounding the bolt: sqm
Ptelo	densPE*2*((Lunglastra*larglastra)+(Lunglastra+10*(speslastra+Ronda))+(Larglastra+10*(speslastra+Ronda)))*stelo	0.018	Weight of film wrapping 10 sheets: t
Plastra	17*1*1,5	25.5	Sheet weight: kg sheet weight 16-18kg/sqm
Nlastretetto	Areatetto/1,5	66.66667	number of roof sheets
Npac	Nlastretetto/nlastre	6.66667	number of packages of sheets
Spesprim	denssupprim/(Densprim*1E)	0.00014	Primer thickness: m
Pbul	7.8*(pi*(Dbul/2)^2*Hbul)+Ptesta+Pdado	3.628E-5	Bolt weight: t
Latoesag	Dtestabul/2	0.01	Hexagon side: m
Apoesag	0.866*latoesag	0.00866	Hexagon apothem: m
Pdado1	7.8*(6*latoesag*apoesag)/2*Spdadotesta	8.105E-6	
Ptesta	7.8*pi*(Dtestabul/2)^2*Spdadotesta	9.8E-8	
Areaesag	3*3^(1/2)*(Dtestabul/2)^2/2	0.00025	
Pdado	7.8*Areaesag*Spdadotesta	8.105E-6	

Table 17-24: "Removal of asbestos cement sheet rev1" process calculated parameters

17.2.4. D15 and R13 authorised storage facility

The D15 and R13 authorised ACW storage facility was assumed to be in the Municipality of Correggio. Below is the extrapolation (Table 17-25) of the relative *"Storage facility rev1"* process, whose functional unit is the area of an asbestos cement sheet (1.5 sqm). Tables 17-26 and 17-27 list the input parameters and the calculated parameters, respectively.

Storage facility rev1	1.5	sqm	Removed sheet storage facility: A=1270,588 sqm Sheet area =1,5sqm Number of sheets in 1 package: 10 It is assumed that the packages are not stackable Total number of sheets contained in the warehouse: (1575/1,5)*10)
Inputs from nature	**Amount**	**Unit**	**Comments**
Occupation, industrial area, built up	1270,588*Tvitacap/(216000*365*50)*Plastra = 0.0004	sqma	It is assumed that the sheets are taken for inertisation after 5 days in the warehouse
Transformation, to industrial area, built up	1270,588*1/(216000*365*Tvitacap)*Plastra = 8.21917656E-6	sqm	
Transformation, from construction site	1270,588*1/(216000*365*Tvitacap)*Plastra = 8.21917656E-6	sqm	
Inputs from technosphere: electricity/heat	**Amount**	**Unit**	**Comments**
Transport, freight, lorry >32 metric ton, EURO6 {RER}| transport, freight, lorry >32 metric ton, EURO6 | APOS, U	Plastra*0.5 = 12.75	kgkm	Distance of the storage facility from the final destination: 50km For the transport of ACW from the storage facility to the final destination (landfill or inertisation plant), a curtain side semi-trailer with the following specifications was used: Engine capacity: 16000 cm^3 Power: 750 kW Consumption: 2,5 km/litre Weight: 20.000 kg Maximum load: 24.000 kg Curtainsider capacity: 70 m^3 Overall mass: 44 metric metric tons Curtainsider dimensions: length 13,6 m, width 2,4 m, height 2,4 m

CI_LCA Warehouse (2) (b)_correction of primary energy requirements in winter and summer	1/Acap*Acapstoc*1/(Tvitacap*365*216E3)*Plastra = 6.884118743E-9	p	Functional unit of the process: p Concrete consumption: 377m^3 Assumed height of 10m Warehouse area of the database process: Acap=Vcap/10=1193,93sqm Storage warehouse area =Acapstoc It is assumed that the warehouse is filled in 1 day and emptied on the same day: each day has the total calculated weight of sheets -Warehouse lifetime: 50 years
EAGLE LCA	1/TvitaLGV*(distorizLGV/vorizLGV+(distvertscLGV+distvertscLGV)/vvertLGV)/10/3600 = 1.965976662E-8	p	Use of EAGLE Assumes a lifetime of 43800h Total weight 1000kg EAGLE sold in Vietnam Power: 30kW Speed: 1,6667m/sec Distance to be travelled for unloading and loading a package of 10 sheets: 10m*4times=40m transport time: lungLGV/vLGV

Table 17-25: Extraction of the "Storage facility rev1" process

Input parameters	Value	Comments
Punitario	17	Unit weight of a sheet: kg/sqm
Arealastra	1.5	Sheet area: sqm
Areacap	500	Warehouse area: sqm
TvitaLGV	43800	LGV lifetime: h
VorizLGV	1.6667	LGV horizontal transfer speed: m/sec
distorizLGV	40	Journey that LGV takes to unload a package of 10 sheets and take it to the warehouse and then load it on the vehicle
VvertLGV	1	Fork handling speed: m/sec
nlastrecat	10	Number of stacked sheets
Tvitacap	50	Warehouse lifetime: years
Triemp	1	Warehouse filling time. It is assumed that the emptying occurs every 15 days.
hcap	10	Height of the warehouse of the database process: m
Vcalc	377	Warehouse concrete volume of the database process: m^3
spcap	0,1	Warehouse wall thickness of the database process: m^3

Table 17-26: "Storage facility rev1" process input parameters

Calculated parameters	Value	Comments
Plastra	Punitario*Arealastra = 25,5	Weight of one sheet: kg
distvertscLGV	1,5+1+0,5+0,5 = 3,5	Unloading from a Daily-type vehicle: Raise by 1,5m, lift the package from the first vehicle, lower by 1m, transfer the package from the unloading area to the warehouse, lower by 0,5m to deposit it, then raise the forks by 0,5m
distvertcarLGV	0,5+0,5+1,75+1,75 = 4,5	Loading on a semi-trailer: Lower by 0,5m, lift the package from the warehouse, raise by 0,5m, transfer the package from the warehouse to the unloading area, raise by 1,75m to deposit it on the trailer, then lower the forks by 0,5m
lcap	(-2*hcap+(4*hcap^2+4*Vcalc/(2*spcap))^0,5)/2 = 34,55333882	Area of the warehouse studied by the database process: sqm The area is calculated using the equation: Vp=2*l^2*sp+4*h*l*sp=377m^3 where 377m^3 is the volume of concrete l=34,553m A=l^2=1193,93
Acap	lcap^2 = 1193,933224	Warehouse area of the database process: sqm
Acapstoc	ACMinertgior*1E3*Arealastra/(nlastrecat*Plastra) = 1270,588235	It is assumed that the warehouse is filled in 1 day and emptied on the same day: each day has the total calculated weight of sheets.
ACMinertgior	ACMinertgior*1E3*Arealastra/(nlastrecat*Plastra)=1270,588	It is assumed that the warehouse is filled in 1 day and emptied on the same day: each day has the total calculated weight of sheets. Ac/Arealastra*nlastcat*Plastra=ACMinertgior

Table 17-27: "Storage facility rev1" process calculated parameters

17.2.5. ACM inertisation treatment plant: KRYAS

KRYAS technology (covered by Italian Patent Application MO2006A000205, "Industrial process for the thermal transformation of asbestos cement sheets using a continuous furnace" and related European Patent Application 07425495.4 – 1253 "Industrial process for the thermal transformation of asbestos cement sheets using a continuous furnace" of 31 July 2007) involves the direct thermal conversion of sealed packages containing asbestos cement sheets and other ACMs or harmful fibers generated from standard removal operations. The packaging is inertised by a direct thermal transformation process that takes place in a continuous industrial "tunnel" furnace similar to the types generally used for the production of bricks, refractories or sanitary ware. The methane-powered furnace is designed to ensure the complete insulation of the material being fired from the external environment. In order to minimize air emissions, the plant is equipped with a flue gas treatment system that includes sleeve filters, absolute filters, and afterburner capture system. The plant has a capacity of 216 metric tons/day based on 3 shifts, giving a total of 78,000 metric tons/year. The complete firing cycle is carried out in 38 h with an isotherm of 20 h at a temperature of 1250 °C. The flowchart relating to this process is shown in Figure 17-19.

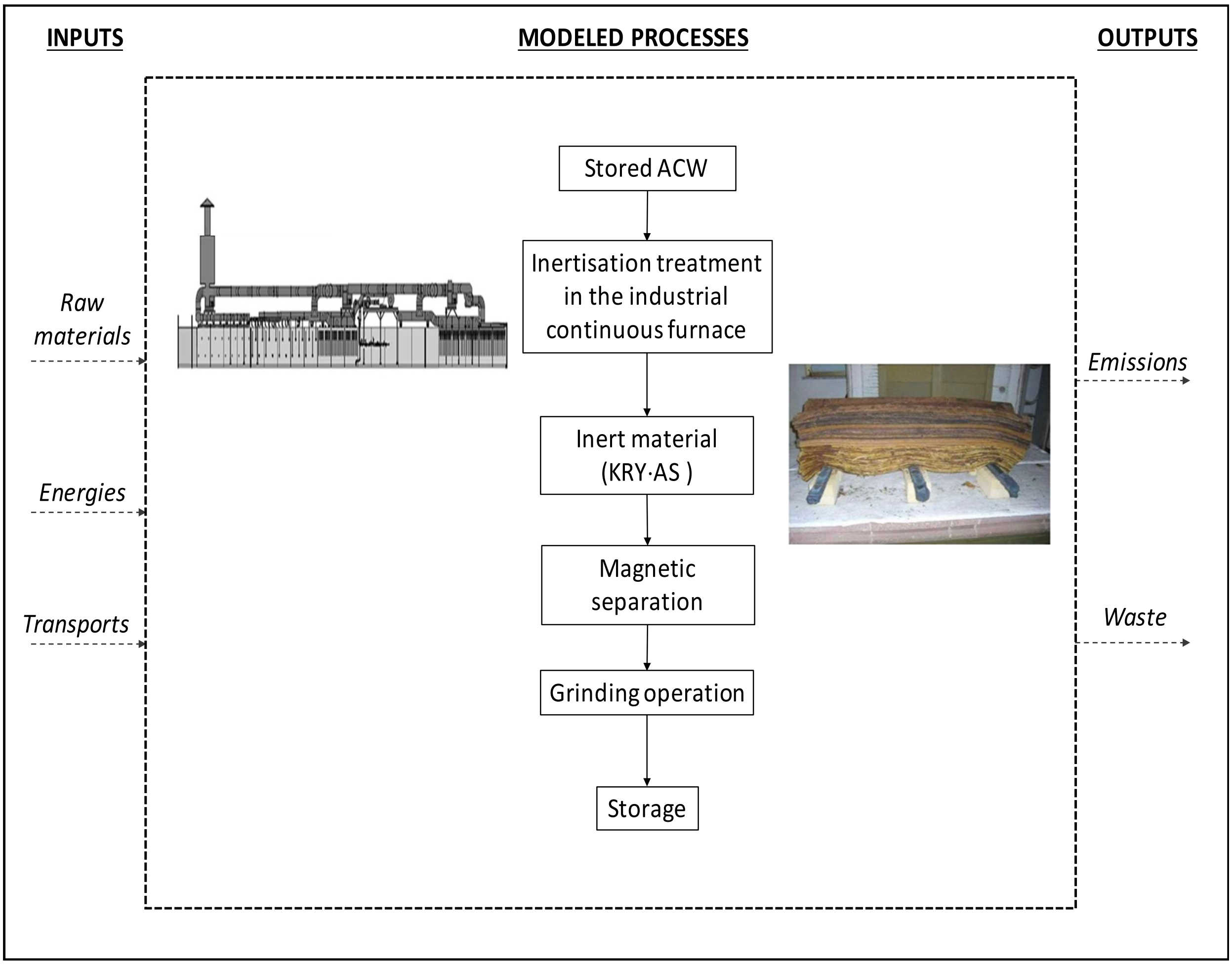


Figure 17-19: Flowchart showing the system boundaries considered in the LCA of the ACW thermal inertisation treatment by industrial continuous tunnel furnace.

Below is an outline of the process in the calculation code.

- *Products and co-products*

The functional unit of the "*ACM treatment by inertisation rev3*" process is the mass of asbestos containing materials inertised in a complete 38/hour cycle. Considering that 216 tons are treated in 24 hours (18 carts a day with an average weight of 12 metric tons each), the calculation for a complete treatment is as follows: *ACMinertg/24*Tinert: 216 tons/g/24h/g*38h=342 tons*

Avoided products

All flue gases produced are channelled to the pre-firing area where the flue gas treatment system is located, which has a maximum temperature of 160 °C in that area. In the cooling zone, there are two hot air extraction systems, a high-temperature system (R.A.T. with a flue gas temperature of 400 °C) and a low-temperature system (B.A.T. with a flue gas temperature of 105 °C). The R.A.T. system is coupled with a turbine that operates with a Rankine cycle (cogeneration system in the broad sense) for the production of electricity at 250 kW (Potenelprod) and hot water. The electricity produced allows the entire system to be self-powered while the hot water could be used in a district heating system for the supply of residential areas. It is assumed that the energy is produced in the entire 38-hour cycle (Tinert) and therefore not only during the firing but also during the pre-firing and cooling phases. The two types of energy being, as mentioned above, used to self-power the system itself and for district heating, were considered avoided products, which are specifically represented by the following processes:

- *Electricity, high voltage {IT}| heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical | APOS, U* with allocation Potenelprod*Tinert = 9,500 kWh;

- *Heat, district or industrial, natural gas {IT}| heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical | APOS, U* will allocation 0.907/0.093*Potenelprod*Tinert = 92,650.53763 kWh.

The ratio between electricity and thermal energy was obtained from Ecoinvent Report No. 6:
- ➢ Thermal energy CHP 6400 kW: 0.907 kWh;
- ➢ Electricity CHP 6400 kW: 0.093 kWh.

Inputs from nature

The plant covers a total area of 18,400 square meters, with an assumed occupation for 50 years of activity (years of plant life). The processes related to land occupation and transformation are as follows:

- *Transformation, to industrial area in ground,* with allocation: 18,400 sqm
- *Occupation, industrial area in ground,* with allocation: *18,400*50 = 920,000 sqma*
- *Transformation, from agriculture to ground,* with allocation: *18,400 sqm*

Materials/fuels

The materials used for NOx and CO_2 abatement (*Ammonia, liquid {RER}| market for | APOS, U* and *Sodium hydroxide, 50% in H2O, production mix, at plant/RER U*) were included in the secondary process *Abatement of oxidation and carbonisation emissions (with parameters) (with emissions)* inherent to the flue gas treatment through the afterburner. The water used (*Tap water {Europe without Switzerland}| tap water production, conventional treatment | APOS, U*) was considered within the process "*Fired ACM (Kryas) Grinding and Iron Removal"*.

Electricity/Heat

The plant shown in Figure 17-20, as mentioned above, covers a total area of 18,400 sqm, of which 10,000 sqm are uncovered impermeable surface, and 8,400 sqm are covered surface (inertisation and storage warehouse, laboratory, offices, changing rooms and toilets).

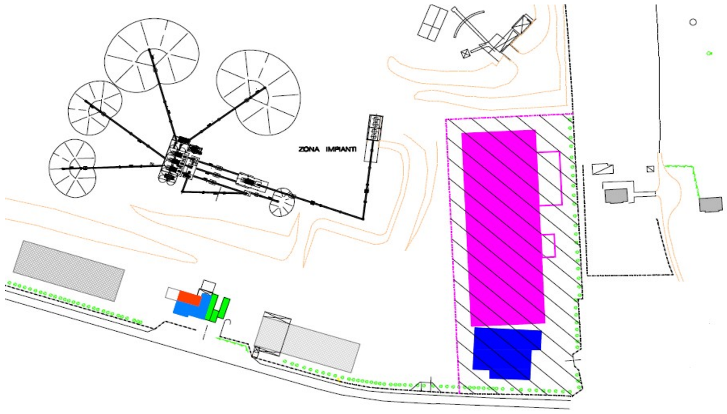


Figure 17-20: Map of asbestos cement inertisation treatment plant

- **Asbestos inertisation warehouse**
- **Weighing and control room**
- **Administrative office**
- **Changing rooms and toilets**

The *systems* of the entire ACM inertisation process are outlined below, stage by stage.

Material receipt - storage

The first stage of the process consists of receiving asbestos containing waste in dedicated distinct areas according to the type of ACW. The following EWC codes can be assigned:

- EWC code 170605* Construction materials containing asbestos.
- EWC code 170601* Insulating materials containing asbestos.
- EWC code 170603* Other insulation materials consisting of or containing hazardous substances.
- EWC code 150202* Absorbents, filter materials (including oil filters not otherwise specified), wiping cloths, protective clothing contaminated by hazardous substances.

Asbestos containing waste, namely packages with asbestos cement sheets, reaches the plant processed and packaged in accordance with the provisions of Italian Ministerial Decree 06/09/1994 and undergoes an x-ray check aimed at verifying the presence of unwanted components. The vehicles are weighed and stopped at the reception area to fill out the appropriate forms. Once the paperwork has been completed, the vehicles are sent to the unloading area inside the warehouse. Within this enclosed area, the packages are visually checked by the personnel receiving the material before unloading (personnel equipped with the appropriate PPE for control and handling operations). In addition, the entire enclosed storage area is under continuous extraction. The outlet air is channelled through a closed ducting system into the furnace cooling zone to be used as oxidizing air. This avoids releasing dust into the environment. Once the semi-trailers have been unloaded, the vehicle loading platform will be completely vaccumed according to standard procedures adopted in the storage areas. The clean vehicle can head towards the tyre washing area and then to the weighing area to measure the tare and to complete the exit procedures, which include the completion of the appropriate forms. The unopened packages are transported by electric forklift to the closed storage area, equipped with a suitable distribution structure, where the packages are placed on shelves with an iron framework that allows uniform load distribution. This precaution is necessary in order to avoid slipping, crushing or any situations that may affect the integrity of the packaging. If a damaged package is identified in the pre-storage area following a visual inspection, it will be promptly sealed using foam and taken to the self-contained reconditioning room, where personnel equipped with appropriate PPE will repackage it with polyethylene. The room is placed under extraction and the air that creates the negative pressure is passed through special HEPA filters with an efficiency greater than 99.97%. PPE (overalls, shoe covers and masks) and spent filters are bagged and heat-treated in the furnace during the inertisation of friable material or rock wool/glass. After the control process, the packages are temporarily moved using electric forklifts and stored inside the warehouse before being taken to the furnace. During all package receipt and storage activities, the packages containing asbestos sheeting are not opened under any circumstances. However, in order to further reduce the risks, an enclosed area maintained at a slightly lower air pressure is used for storage so that the air from the area can be channelled and treated using sleeve filters. Spent filters are then heat-treated in the inertisation cycle dedicated to packages of asbestos containing waste in a friable matrix.

Loading system

The sealed asbestos cement packages are loaded in the cart loading area using electric forklifts. The sealed packages can be classified as various types of ACW, but the dimensions must not exceed a height of 1,100 mm, a width of 1,300 mm and a length of 2,000 mm. The 7,000 x 4,500 mm carts consist of a fixed lower platform and five upper movable modules measuring 1,400 x 4,500 mm (fire brick frame). During loading/unloading operations, a single module is lifted by the electric forklifts and removed. The ACW packages are loaded onto the module until the available space runs out. The loading module is then transferred back onto the fixed platform of the cart. This operation is repeated for all modules (5 times). Once loaded, the carts move on tracks towards the furnace opening, measuring 7,000 x 1,100 mm, for subsequent thermal treatment operations.

Thermal treatment of asbestos cement sheets

The thermal treatment of asbestos containing sheeting takes place inside a furnace with walls made of refractory and semi-refractory bricks (depending on the zone) for the entire length and height in order to ensure an effective barrier even in case of long emergencies due to a power failure.

The bricks measure 220 * 110 * 76 mm and the wall has a thickness of 330 mm, while the furnace sides are lined with pre-coated plates.

In order to ensure the optimal treatment of the product, the following external equipment is used:

- ➢ flue gas extraction through large diameter outlets;
- ➢ high-flow pre-firing recycling;
- ➢ high-speed side burners both for pre-firing and firing;
- ➢ rapid cooling with high-speed inflow of external air and drawing of hot air from the furnace vault;
- ➢ low-temperature recovery with outlets in vault;
- ➢ counter-pressure achieved through the introduction of air through the vault, in many sections, to cool both the tiles and the plates that make up the support surface;
- ➢ control system for the under-cart area with subdivision into three zones, each treated separately, and suction or pressure ventilated as required.

The tunnel furnace has a standard cycle for the firing of asbestos cement sheet packages, where each cart has a capacity of 12 metric tons. The automatic opening of the furnace entrance gate, set according to the transit speed of the carts, allows the carts to enter the pre-firing chamber (length 5 m). After the carts enter, the main gate closes. Once the main gate is closed, the gate that leads the carts from the pre-firing chamber to the firing chamber opens (124 m long). The complete firing cycle is carried out in 38 h with an isotherm of 20 h at a temperature of 1250 °C. The maximum temperature that the furnace can reach is 1300 °C. The packages are burned in the firing zone, where they pass from room temperature to the isothermal temperature. In the cooling zone, the temperature progressively goes from 1250 to about 30-35 °C (Figure 17-21). On exiting the firing chamber, after the cooling phase, the automatic opening of a gate allows the carts to enter the post-firing chamber (length 5 m). After the carts enter the post-firing chamber, the entrance gate closes and the final gate that leads the carts out of the furnace opens.

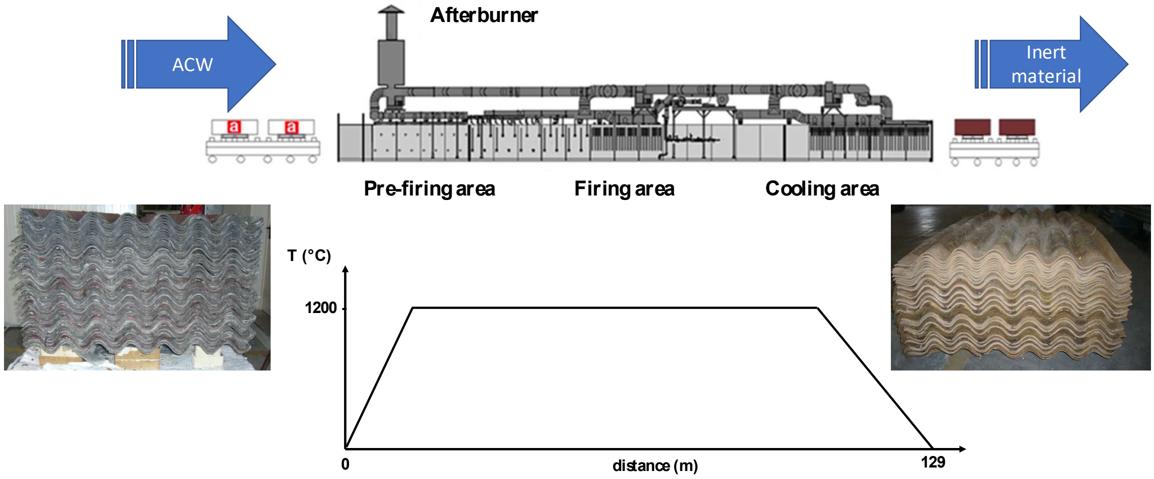


Figure 17-21: Summary of the thermal inertisation of ACW by industrial continuous tunnel furnace

The tunnel furnace works against the flow and is kept completely depressurised. It operates continuously 7 days a week and is fed on a shift basis, with 3 separate 8-h shifts every day from Monday to Friday. At the weekend, the shifts are suspended from 10 pm on Saturday to 10 pm on Sunday. The workforce can take a break because the system is equipped with an additional loading track where the necessary carts can be stored to feed the furnace during the three weekend downtime shifts.

Unloading system

The unloading system is very similar to the loading system but has been designed in such a way as to provide for the return to the firing (re-firing) zone of carts with packages which, only hypothetically, may not have undergone the thermal treatment necessary for the complete transformation of asbestos fibers. It should be said that this possibility is considered very remote since the automatic controls of the firing cycle in the furnace ensure the completion of the set heating cycle. In any case, with the return system and the option to repeat the firing cycle, any risk of partial thermal treatment of the material is avoided. On exiting the furnace, the transit of the carts to the unloading area is slow and allows sampling of the transformation product from each cart. The transit and sampling areas are located inside an enclosed low-pressure area with extractors with sleeve filters. Operators equipped with the appropriate PPE sample the material from each cart (about 500 grams per sample/cart) using an auger/corer, taking a sample from the core of the original package of sheets where the verification of the degree of inertisation is more critical and important. Any samples collected are cooled, sealed and labelled with a sequential reference number. 18 samples are collected each day for the 18 carts/day. All samples are delivered to the analytical laboratory each morning after sampling (consider 18 carts of technical stock, equivalent to one working day), where real-time control tests will be carried out.

The routine analyses performed on 6 samples are:

- •diffractometric analysis on a selected angular range and interpretation (average time of about 1 h); This analysis allows verification of the inertisation status of the sample.
- •FTIR analysis and interpretation (average time of about 30 minutes). This analysis makes it possible to verify the disappearance of the hydroxyl absorption bands of the asbestos phases;
- •analysis with polarized light optical microscopy (PLOM) (average time about 30 minutes);
- •calcimetry (average time about 30 minutes).

A selection of samples is sent to specialist laboratories for controls using scanning electron microscopy. At the end of the working day, at around 6 pm, the laboratory unblocks the carts carrying the inertised material for the unloading stage. Similar to the loading operations, during the unloading, a single module is lifted by the electric forklifts and removed. The forks hook onto the fire bricks so that they can be turned over and the inertised material can be discharged directly into the hopper. In practice, the unloading system exploits the movable fire bricks on the cart, which are gripped by the clamps on the overhead apparatus that enter the exhaust hoods and hook onto the fire bricks with toothing, lifting and tilting them, to allow them to be turned over inside a hopper. The unloading module is then placed back onto the fixed platform of the cart. This operation is repeated for all modules (5 times). Once all the modules have been unloaded, the carts move along the tracks, are completely cleaned using an extraction system, and proceed towards the loading area. The entire unloading area is enclosed and is equipped with an extraction system with sleeve filters. Spent filters are replaced and treated in the thermal cycle like the other waste. The cart designed for the plant has movable fire bricks to accommodate the flame of the side burner with the position of the fire bricks coinciding with the position of the burners. In the unlikely event of a sample where partial inertisation is suspected, the cart with the batch of sheets to be inertised passes once again through the unloading zone without being emptied and then proceeds towards the firing zone to be re-fired. The furnace is powered by methane gas with a calorific value lower than 8,200 kcal/Nmc (34,325 J/Nmc), working pressure 0.5 bar, voltage 380 V, frequency 50 Hz and auxiliary voltages of 220 V. Some process data relating to the energy consumed is shown in Table 17-28.

ACMinertg	216	216 metric tons per day inertised in the furnace
Pcalgas	34325	Lower calorific value of methane: 34325kJ/Nm^3
Tinert	38	Inertisation time: h
Consmetu	67,1	Specific consumption of methane: Nm^3/t
Ncarg	18	Number of carts per day
Carc	12	Weight transported by 1 cart: t
Enelconsu	26	Energy consumption per metric ton: kWh/t

Vgasinert	22948,2	Methane consumption during 38-hour inertisation cycle: Ncarg*Carc*Consmetu/24*Tinert Methane consumption in 24 hours: 18carts*12t/cart*67,1Nm^3/ton=14493m^3/g

Table 17-28: Input data for the "ACM treatment by inertisation rev3" process

The consumption of methane and electricity by the furnace and the plant is reported below

- *Heat, district or industrial, natural gas {RoW}| heat production, natural gas, at industrial furnace >100kW | APOS, U, with allocation: Vgasinert*Pcalgas*1E-3 = 787,696.965 MJ.*
- *Electricity, high voltage {IT}| heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical | APOS, U, with allocation: Enelconsu*ACMinertg/24*Tinert = 8,892 kWh.*
- *Electricity, high voltage {IT}| heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical | APOS, U, with allocation: Potenelprod*Tinert-Enelconsu*ACMinertg/24*Tinert = 608 kWh.*

Flue gas treatment line

Flue gases leaving the furnace are treated and purified using a specific treatment system comprising an afterburner. The flue gases leaving the vent of the pre-firing zone, with a flow rate of 60.000 m^3/h and an average inlet temperature of 160 °C, first pass through a dust filtration system (sleeve filter) and in sequence through an array of three absolute filters for total dust abatement. A fan is used to transport the gas at the end of the system to prevent particulate matter from damaging the fan itself. The entire system has been built in duplicate so that the process is not interrupted in the event of a malfunction or maintenance of a treatment line. Spent filters are bagged and thermally transformed inside the furnace during the thermal treatment cycle of friable products. From the absolute filters, the flue gases reach the afterburner, by means of a ventilation system, for the removal of organic substances, CO, IPA and dioxins, if present. They reach a temperature of 850 °C in the combustion chamber. For NOx abatement, a DenOX system has been installed. This is installed downstream of the sleeve filter, with the aim of reducing NOx emissions to values of the order of 50 mg/Nm^3 depending on the input value. The NOx reduction process is based on the injection of ammonia in 25% aqueous solution into the flue gases, after purification in the dry section. The NOx and ammonia combine on the surface of the catalyst (regenerable), based on metal oxide semiconductors (based on Ti, V and W oxides), forming an ammonium salt, which subsequently decomposes to form molecular nitrogen (N2) and water. The system can operate in a temperature range up to 300 °C. Spent filters from the sleeve and absolute filter system, which theoretically could contain asbestos fibers, are considered as waste to be treated inside the tunnel furnace in the normal inertisation cycle for asbestos containing waste. The nature of the waste produced by the scrubber depends on the additive used. In the case of Ca(OH)2, calcium sulphate, calcium fluoride and calcium chloride sludge is obtained, depending on the inorganic pollutants present. Similarly, in the case of NaOH, the relative sodium salts (sodium fluoride, chloride and sulphate) are obtained. The sludge is extracted from the bottom and sent to a press filter to be compacted. The inert solid can be recycled to dilute the secondary raw material. Table 17-29 reports the extrapolation of a summary of the processes of the inertisation plant flue gas abatement line, made up as follows:

Electric Fan + Extraction System, without secondary ducts (Q=60000 Nm^3/h, v=18m/sec) (multi-output)_revDEFINITIVA_3	1/Tvitaimpasp*Tinert = 0.00047	p	The fan, with a power of 5 kW, weighs 50 kg (Direct Industry). The pump is assumed to consist of the following materials: - 60% steel; - 20% copper; - 10% aluminium; - 10% PVC. The system weighs: Pcappa+Pcond+Pcam+Pvent = 1,3341t Running time: 7975h Extraction system lifetime: 7975h/y*10y = 79750h Pump lifetime: 9000h (5 years) Flow rate: 16.667 m^3/sec Allocation: 1/Tvitaimpasp*Tinert: 1/79750*38=0,0004764890282
Sleeve filter with parameters (Q=60000 m^3/h) (multi-output)_revDEFINITVA	2/Tvitafiltroman*Tinert = 0.007916	p	Double sleeve filter Number of sleeves: 432 sleeves with cage Sleeve lifetime: 9600h Hours of life: 240*8*5=9600h Volume: 2,2x6,48x3,25=46,332m^3 Dust filtration surface: 2,2x6,48=14,256sqm Pfiltroman=(Pman+Pcest+Pcil+Pan+Pcont+Psep+Psupantpost+Psuplaterali)=2,8921E5kg Allocation: 2/Tvitafiltroman*Tinert =2/9600*38: 0,007916666667
Absolute filter with parameters (Q=60000 m^3/h) (multi-output)_revDEFINITVA	3*2/Tvitafiltroman*Tinert = 0.02375	p	3 double absolute filters Number of sleeves: 432 sleeves with cage Sleeve lifetime: 9600h Hours of life: 240*8*5=9600h Volume: 2,2x6,48x3,25=46,332m^3 Dust filtration surface: 2,2x6,48=14,256sqm Pfiltroman=(Pman+Pcest+Pcil+Pan+Pcont+Psep+Psupantpost+Psuplaterali)=2,8921E5kg Allocation: 3*2/Tvitafiltroman*Tinert =3*2/9600*38: 0,02375
Abatement of oxidation and carbonisation emissions (with parameters) (with emissions) (Rev1)	Q*Tinert:2280000		Postcombusore Allocation: Q*Tinert: 60000*38:2280000

Table 17-29: Extraction of processes from the flue gas treatment line of the ACM inertisation plant

For completeness, the full afterburner process (Table 17-30) was extrapolated i.e. "*Abatement of oxidation and carbonisation emissions (with parameters) (with emissions) (Rev1)"*, whose functional unit is the volume of mixture in the combustion chamber for the production of 3.129 kg of fiber in one hour of use (Vpostcomb): 1,180,966.29 litres.

Inputs from technosphere: electricity/heat	**Amount**	**Unit**	**Comments**
Composite working factory/RER/I U (from Metal working factory/RER/I)	1/(8,5*294*80)*tproc*Aproc/Astab = 3.501E-7	p	Plant where afterburner production takes place
Natural gas, burned in industrial furnace >100kW/RER U (without NOx abatement filter) | Alloc	NmoliCH4*16*1E-3/(0,65444*200)/0,0272 = 2.6488	MJ	Burner for combustion of emissions

Extraction system downstream of the burner (with parameters)	1/20000*tproc = 5E-5	p	Extraction system downstream of the burner
Scrubber (flow rate 2547m^3/h) (with parameters) correct	1/20000*tproc = 5E-5	p	Abatement by scrubber
Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	(23+16+1)*(CO_2+CO_2comb)/(12+32) = 3152,656853	g	Abatement of CO_2 generated by the combustion process
Selective catalytic reactor (flow rate 2547m^3/h) (with parameters)	1/20000*tproc = 5E-5	p	NOx abatement
Ammonia, liquid {RER}| market for | APOS, U	2,6/76*34*NmoliCH4*16*1E-3 = 10ò969	g	NH3 necessary to reduce NOx as required
Electric fan (5kW)	1/20000*tproc = 5E-5	p	Extraction system electric fan
Electricity, low voltage {IT}| market for | APOS, U	(Paspbr/3600*hstot)/(102*0,6)*tproc = 2.1260	kWh	Electricity required for the ventilation system downstream of the burner
Transport, lorry 20-28t, fleet average/CH U	((7,8*3,1416*(Dcond+Ding)/2*((Hca+((Ding-Dcond)/2)^2)^0,5)*Sca+7,8*2*3,1416*Dcond/2*Lcond*Sc))*1/20000*tproc*100 = 0.0017	kgkm	Extraction system transport from the manufacturer: 100km
Transport, lorry 20-28t, fleet average/CH U	(4765,48*0,28E-8*(NmoliCH4*16*1E-3/(0,65444*200)/0,0272))*1/20000*tproc*100 = 1.7672E-7	kgkm	Burner transport from the manufacturer: 100km
Transport, lorry 20-28t, fleet average/CH U	(7,8*3,1416*Ss*((2*Dcs/2*Hcs+(Dcs/2)^2)+(Duas+Dcs)/2*((Htcus^2+((Dcs-Duas)/2)^2)^0,5)+(Dcond+Dics)/2*((Htcis^2+((Dcond-Dics)/2)^2)^0,5))+1*Vscrubber/100*20000*3600*1E-6)*1/20000*tproc*100 = 0-0056	kgkm	Scrubber transport from the manufacturer: 100km
Transport, lorry 20-28t, fleet average/CH U	((7,8*Acorporcs*Srcs+7,8*Asettoestfori*0.001*Nsetti+(Asettoestfori+Asettointfori)*3,9*65E-6*Nsetti))*1/20000*tproc*100 = 0.00065	kgkm	Reactor transport from the manufacturer: 100km
Transport, lorry 20-28t, fleet average/CH U	10*1/20000*tproc*100 = 0,05	kgkm	Electric fan transport from the manufacturer: 100km
Transport, lorry 20-28t, fleet average/CH U	((23+16+1)*(CO_2+CO_2comb)/(12+32)*1E-3+2,6/76*34*NmoliCH4*16*1E-3)*100 = 1412,169452	kgkm	Scrubber salt transport from the salt company: 100km

Table 17-30: Extraction of the process related to the flue gas treatment line afterburner of the ACM inertisation plant

Output material and raw material processing according to KRYAS

Downstream of the thermal treatment, the inert material obtained is processed by:

- magnetic separation of ferrous materials such as screws and bolts (1% of the input material);

- possible grinding to obtain materials with the desired size (for example, in the case where the inert material is used in the ceramics industry, grinding is not necessary since the material is delivered and then ground together with the other tile components).

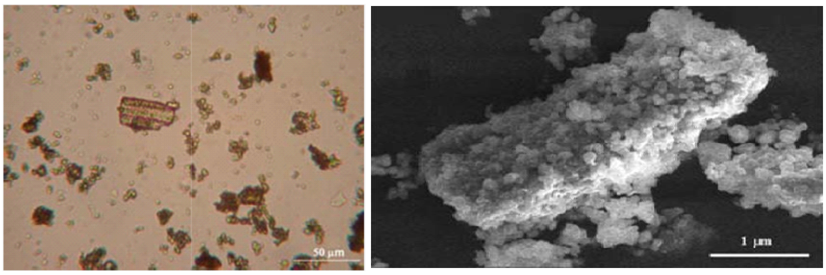
The secondary raw material (SRM) labelled as KRYAS (Figure 17-22) was added into the main *"ACM treatment with inertisation by firing"* process as a co-product. In fact, the output material shows a 25% reduction in mass, mainly linked to the loss of moisture, structural water, CO_2, and, to an almost negligible extent, to other atmospheric emissions associated with the inertisation process.

Figure 17-22: Left: package of asbestos cement sheets before thermal treatment; right: package of asbestos cement sheets after thermal treatment.

Below is the mass allocation for the functional unit of 150 metric tons of ACM (MACMsmalt) and 75% SRM exiting the inertisation process:

- *MACMsmalt/(MACMsmalt*(1+0.75))*100 = 150 metric tons*
- *0.75*MACMsmalt/(MACMsmalt*(1+0.75))*100 = 112.5 metric tons*

The SRM is transferred to the temporary storage area consisting of an enclosed room with air extraction system and misting system in order to limit dust emissions during material unloading operations. Periodically, the SRMs are loaded onto articulated lorries for transport to facilities where reuse is planned. The results of the quantitative diffractometric analysis carried out on a representative sample of original asbestos cement show that chrysotile (12%) and riebeckite (var. crocidolite) (0.2%) are present as the main asbestos phases in asbestos cement sheets that have not undergone thermal treatment. The results of the qualitative diffractometric analyses show that the phases that form after thermal treatment are predominantly silicates of Ca, Mg, Fe and Al (Figure 17-23).



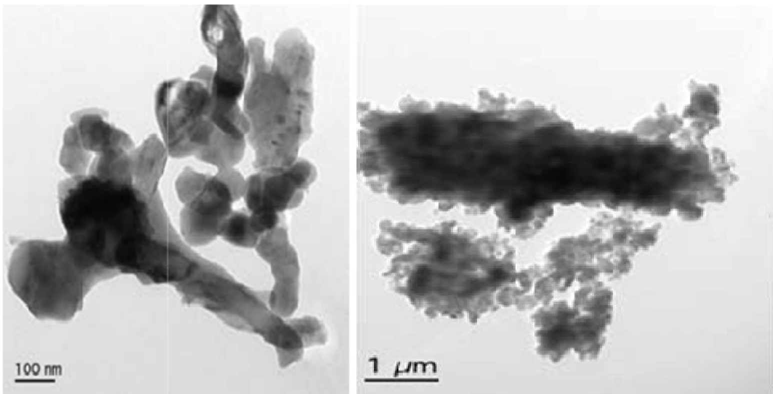


Figure 17-23: Examples of PLOM and SEM optical microscopy images of the inert product clearly showing complete inertisation of the original asbestos fibers following thermal treatment.

Therefore, based on the mineralogical associations and the microstructure of the minerals present in the asbestos cement powders subjected to thermal treatment, it was possible to conclude that the firing cycle used in this experiment enabled the complete inertisation of the package of asbestos cement sheets and therefore it is possible to recycle the material obtained into industrial products (Table 17-31).

Phase	Raw ACW (wt%)	KRY·AS (wt%)	Phase	Raw ACW (wt%)	KRY·AS (wt%)
Chrysotile	1.4-13.3	-	Mayenite	-	0-7.3
Amphibole asbestos	0-6.5	-	Lime	-	0-6.9
Calcium carbonates	0-68.8	-	Periclase	-	0-7.7
Quartz	0-1.9	0-9.4	Calcium sulphates	0-5.2	-
Cristobalite	-	0-0.6	Ternesite	-	0-11.3
Feldspars	0-2.9	-	Portlandite	0-10.9	0-1.5
Wollastonite	0-0.9	0-3.8	Yeelimite	-	0-8.3
Pseudo-wollastonite	-	0-9.9	Jarosite	0-1.8	-
Mica+illite	0-2.2	-	Ettringite	0-2.5	-

Belite-β	0-7.1	-	hydrogarnets	0-2.0	-
Alite-M_3/C_3S*	0-3.6	0-2.0	AFmc***	0-2.0	-
Larnite	-	4.8-71.0	Diopside	-	0-7.2
Ferrite/C4AF**	0-2.5	0-8.8	Forsterite	-	0-2.9
Aluminate	0-1.3	-	Enstatite	-	0-3.4
Rankinite	-	0-11.0	Magnetite	-	0-1.3
Akermanite	-	0-58.0	Hematite	-	0-0.7
Bredigite	-	0-31.6	Maghemite	-	0-3.2
Merwinite	-	0-19.2	Amorphous phase	9.5-66.6	3.4-19.2
Monticellite	-	0-1.6			

*C_3S = tricalcium silicate, Ca_3SiO_5; **C4AF = Tetracalcium aluminium ferrite, $4 \cdot CaO \cdot Al_2O_3 \cdot Fe_2O_3$; ***AFmc = calcium monocarboaluminate hydrate.

Table 17-31: Average phase composition for incoming ACW and thermally transformed product at 1200 °C (KRY·AS), as previously determined by X-ray fluorescence (XRF), X-ray powder diffraction and the Rietveld method.

In summary, the KRYAS product, and therefore the related thermal treatment process, complies with the requirements set by Italian legislation, which establishes that:

- Substitute materials must be asbestos free (pursuant to Italian Ministerial Decree 12/2/97);
- The SRM exiting the furnace does not contain in total concentration > 0.1% of substances listed in Annex 1 to Italian Ministerial Decree 16/2/93 and subsequent amendments that are classified as “carcinogenic category 1 or 2” and are labelled at least as toxic T with risk phrase R45 “May cause cancer” or with the risk phrase R49 “May cause cancer by inhalation”, or classified by the National Toxicological Advisory Commission (CCTN) as category 1 or category 2, or classified by the International Agency for Research on Cancer (IARC) as group 1 or group 2a;
- Fibrous materials (length/diameter > 3) must have an average geometric diameter > 3 mm and a fiber content with an average geometric diameter of less than 3 mm as a

percentage of the total fibers of less than 20%; they must not contain fibers which, regardless of their diameter, tend to fracture along lines parallel to the longitudinal axis.

Table 17-32 details the "*Fired ACM (Kryas) Grinding and Iron Removal*" process, and the related parameters are reported in Table 17-33 and Table 17-34, created for the grinding of and iron removal from SRM exiting the furnace. The KRYAS material, as mentioned above, represents 75% of the input asbestos containing waste, i.e. 150 metric tons (MACMsmalt).

Inputs from technosphere: materials/fuels	***Amount***	***Unit***	***Comments***
Grinding	MACMsmalt*0.75 = 112.5	metric tons	The KRYAS grinding plant is considered within this process, including the energy consumed
Iron removal plant	1/Tvitaimp*MACMsmalt*0,75/Capproddefer = 0.0002183787561	p	Iron removal plant.
Tap water {Europe without Switzerland}| tap water production, conventional treatment | APOS, U	MACMsmalt*0,75*0,001*1E6/100*1*effneb = 787.5	kg	Misting water: assumed 1l/100g of powders; assumed that the powders emitted are MACMsmalt*0,75*0,001-Emissaria/(1-efiltro)
Inputs from technosphere: electricity/heat	***Amount***	***Unit***	***Comments***
Electricity, low voltage {IT}| electricity voltage transformation from medium to low voltage | APOS, U	Potdefer*(MACMsmalt*0,75-emistrit)/Capproddefer = 32.7240566	kWh	Energy for the iron removal plant
Electricity, low voltage {IT}| electricity voltage transformation from medium to low voltage | APOS, U	Potnastro*(MACMsmalt*0,75-emistrit)/Capproddefer = 54.54009434	kWh	Energy for the belt; for each square metre of material with iron removed the belt must travel 10m
E13_Electric Fan + Extraction System, without secondary ducts (Q=33213 Nm^3/h, v=18m/sec) (multi-output)_revDEFINITIVA	1/tvitaimpasp*Scartocotto*10^3/prodmul = 0.007383495146	p	Electric fan and pipes. Primary data shows that the electric fan airflow capacity varies between 9000 and 40000 m^3/h; it is considered an intermediate system with an airflow capacity of 33000m3/h. Electricity consumption is included in the consumption of the mill. The extraction system (as well as the mill) is in the same grinding plant.
E13_Sleeve filter with parameters (Q=33213 m^3/h) (multi-output)_revDEFINITVA	1/tvitaimpfil*Scartocotto*10^3/prodmul = 0.01476699029	p	Sleeve filter.
Electricity, low voltage {IT}| electricity voltage transformation from medium to low voltage | APOS, U	Pneb*(MACMsmalt*0,75-emistrit)/Capproddefer = 32.7240566	kWh	Water mister energy: kWh

Air emissions	*Amount*	*Unit*	*Comments*
Particulates, > 10 um	emissatm*0.677*10^9 = 20594340	mg	Air emissions due to inertised ACM grinding and iron removal. For the distribution of dust in the three dimensions, refer to the appb-1 document (file path: Pubblica/Emissioni/EPA AP-42), pag 80, feldspar ball mill: - <2,5: 11.5% -2,5<x<10= (-11,5)%=20.8% - >10= (100-32.3)%=67.7%
Particulates, > 2.5 um, and < 10um	emissatm*0.208*10^9 = 6327360	mg	Air emissions.
Particulates, < 2.5 um	emissatm*0.115*10^9 = 3498300	mg	Air emissions.
Outputs to technosphere: Waste treatment	***Amount***	***Unit***	***Distribution***
Wastewater, average {Europe without Switzerland}| treatment of wastewater, average, capacity 1E9l/year | APOS, U	MACMsmalt*0.75*0,001*1E6/100*1*effneb = 787.5	l	Wastewater disposal from the misting system

Table 17-32: Extraction of the "Fired ACM (Kryas) Grinding and Iron Removal" process

Input parameters	**Value**	**Comments**
MACMsmalt	150	mass of ACM disposed of by the end of 2018: t
Potdefer	3	average power of iron removal plant: kW
Pdeferr	1.1	weight of iron removal plant: kg
Pottrit	110	grinder power: kW
Ptrit	10	Grinder weight
Caprodtrit	6.75	Grinder production capacity: t/h Iron removal plant productivity is assumed to be the same as the grinder productivity
vnastro	0.15	Belt speed: m/sec
largnastro	0.4	Belt width: m
spmat	0.09	Thickness of the material distributed on the belt: m
Potnastro	5	Belt power: kW
densmat	0.212	density of the material obtained after grinding: t/m^3
Tvitaimp	50000	Lifetime of iron removal plant: h
effiltro	0.99	Sleeve filter efficiency
Scartocotto	3042	Total fired waste due to firing, grinding and selection: t
prodmul	10300	Productivity of dry grinding mill: kg/h
frazemisstot	0.001	Portion of the treated mass assumed as total emissions due to grinding.

tvitaimpasp	40000	End of life of extraction system: h
tvitaimpfil	20000	End of life of extraction sleeve filter: h
lungnastro	2.5	Belt length: m belt inclination: 30° bag height: 1,25m belt length: 1,25/sen30=2,5m
Pneb	3	Misting system power: kW
effneb	0.7	Misting system efficiency

Table 17-33: "Fired ACM (Kryas) Grinding and Iron Removal" process input parameters

Calculated parameters	Expression
Capproddefer	lungnastro*largnastro*spmat*densmat*vnastro*3600 = 10,30
Emistrit	0,001*MACMsmalt*0,75 = 0,11
emisstot	Scartocotto*frazemisstot = 3,042
emissfilt	emisstot*effiltro = 3,01
emissatm	emisstot-emissfilt = 0,03
emissnocatneb	MACMsmalt*0,75*0,001*(1-effneb) = 0,03

Table 17-34: "Fired ACM (Kryas) Grinding and Iron Removal" process calculated parameters

Air emissions

With regard to air emissions, the following pollutant emissions were considered, produced during the different phases of the process in question. They were all allocated on the basis of the functional unit of the process, i.e. 342 metric tons of treated ACM.

1. ***Emissions of water vapour from dehydration (loss of moisture) and dehydroxylation of gypsum and portlandite in the furnace chamber at a temperature between 50 and 400 °C***. Considering that the asbestos cement sheets contain 0.21% of gypsum ($CaSO_4$ $2H_2O$) and 0.73% of portlandite ($Ca(OH)_2$), the expected water vapour released is:
    - *Gypsum dehydration CaSO4 2H2O =0.0021×78,000 = 164 metric tons of water vapour*

    *Mass allocation: 164/78,000*342=0.719 metric tons of water vapour*
    - *Dehydroxylation of portlandite $Ca(OH)_2$=0.0073×78,000=569 metric tons of water vapour*

    *Mass allocation: 569/78,000*342=2.495 metric tons of water vapour*
2. ***Emissions of CO_2, H_2O and water vapour from decarbonisation and dehydroxylation processes in the furnace chamber at 400 to 1100 °C***. Considering that 8% of the asbestos cement treated by the plant is serpentine-chrysotile and that there is an average of 20% calcite in the asbestos cement, the chemical reactions that release volatiles are as follows:
    - *Calcite decomposition: ($CaCO_3 \rightarrow CaO+CO_2$) = 0.2 × 78,000 = 15,600 metric tons of CO_2*

    *Mass allocation: 15,600/78,000*342=68.4 metric tons of CO_2*
    - *Chrysotile dehydroxylation:*
    *($Mg_3Si_2O_5(OH)_4 \rightarrow Mg_3Si_2O_7+2H_2O$) = 0.13×(8%*78,000) = 811 metric tons of H_20*

*Mass allocation: 811/78,000*342=3,556 metric tons of H_20*

- *Crocidolite dehydroxylation:*

$Na_2MgFe_2^{++}Fe_2^{+++}Si_8O_{22}(OH)_2 \rightarrow 2NaFe^{+++}Si_2O_6+ MgSiO_3+Fe_2O_3+3SiO_2+H_2O$=16 metric tons of water vapour

*Mass allocation: 0.0002 × 78,000 = 16/78,000*342=0.070 metric tons of water vapour*

3. ***CO_2 and water vapour emissions from the combustion of the polyethylene packaging in the furnace chamber at a temperature of 50 to 400 °C and subsequent decomposition in an oxidising environment up to 1200 °C***. Considering that the quantity of packaging burned in the plant is equal to 550 metric tons per year (asbestos cement package dimensions are 122×57×62 cm, the average density is 1.65 g/cm^3, the average mass of the package is 710 kg, the estimated mass of products making up the package is 5 kg, and the composition of the packaging is polyethylene (C_2H_4)), the emissions released are as follows:
   - *Combustion of LDPE packaging: $C_2H_4+3O_2 \rightarrow 2CO_2+2H_2O$:1728.5 metric tons of CO_2*

   *Mass allocation: 1.728.5/78,000*342=7,579 metric tons of CO_2.*
   - *Combustion of polyethylene packaging: $C_2H_4+3O_2 \rightarrow 2CO_2+2H_2O$: 707 metric tons of water vapour*

   *Mass allocation: 707/78,000*342=3,099 metric tons of water vapour.*
4. ***Emissions of other pollutants from the combustion of the components inside the packages containing asbestos sheeting such as polyethylene bags and pallets.*** Table 17-35 below shows the emissions per 78,000 metric tons of ACM treated by the plant in one year (1,200 m^3 of flue gases are produced in one year from the combustion of the packaging that wraps the asbestos cement sheets):

Particulates, < 2,5 um	12	g	calculated for burning of packaging
VOC, Volatile organic compounds as C	12	g	calculated for burning of packaging
NMVOC (non-methane volatile organic compounds)	12	g	calculated for burning of packaging
Hydrogen chloride	12	g	calculated for burning of packaging
Hydrogen fluoride and Hydrobromic acid	1.2	g	calculated for burning of packaging
Sulphur oxides	60	g	calculated for burning of packaging
Nitrogen oxides	60	g	calculated for burning of packaging
Nitrogen oxides	19.7	metric tons	general combustion process
Carbon monoxide, fossil	120	g	calculated for burning of packaging
Furans	120	Ng	calculated for burning of packaging
Dioxin, 2,3,7,8 Tetrachlorodibenzo	120	Ng	calculated for burning of packaging
Hydrocarbons, polycyclic	12	mg	calculated for burning of packaging

Table 17-35: Air emissions from the Kryas production plant for 78000 metric tons/year

Table 17-36 shows the reparameterised emissions based on the functional unit, i.e. 342 metric tons.

Particulates, < 2.5 um	52.62	mg	calculated for burning of packaging
VOC, Volatile organic compounds as C	52.62	mg	calculated for burning of packaging

NMVOC (non-methane volatile organic compounds)	52.62	mg	calculated for burning of packaging
Hydrogen chloride	52.62	mg	calculated for burning of packaging
Hydrogen fluoride and Hydrobromic acid	5.26	mg	calculated for burning of packaging
Sulphur oxides	263.1	mg	calculated for burning of packaging
Nitrogen oxides	263.1	mg	calculated for burning of packaging
Nitrogen oxides	0.086	metric tons	general combustion process
Carbon monoxide, fossil	526.2	mg	calculated for burning of packaging
Furans	0.526	Ng	calculated for burning of packaging
Dioxin, 2,3,7,8 Tetrachlorodibenzo	0.526	Ng	calculated for burning of packaging
Hydrocarbons, polycyclic	0.052	mg	calculated for burning of packaging

Table 17-36: Air emissions from the Kryas production plant for 342 metric tons

5. ***Dust emissions from the grinding of SRMs exiting the furnace*** were considered in the "*Fired ACM (Kryas) Grinding and Iron Removal" process.*

<u>*Treatment waste and emissions*</u>

Regarding the waste produced by the ACM treatment process, the ferrous waste resulting from the KRYAS iron removal (1% by weight of SRM exiting the furnace) was considered once it was ground (process considered "*Recycling steel and iron/RER U: (MACMsmalt*0.75)*0.01=(150*0.75)*0.01=1,125 metric tons")* and the disposal of rainwater, laboratory water and changing room water allocated according to the F.U. (process considered "*Treatment, sewage, to wastewater treatment, class 1/CH U: 500/78,000*342=2.1923 m^3).* The disposal of water from the misting system in the Kryas grinding and iron removal area was considered within the *"Fired ACM (Kryas) Grinding and Iron Removal"* process.

17.3. Analysis of results

17.3.1. Analysis of the asbestos containing material (ACM) treatment process with inertisation plant

The <u>ACM treatment process with inertisation by firing</u> can be found by following the path: SimaPro 8.5.2.2/LCA3_Database Unimore/Scarpellini/simone/ Waste treatment_Materiali Contenenti Amianto /Processing/others/Trattamento ACM. The method used is IMPACT 2002+010419indoor/locali_rif_IPCC+Amianto V2.12 / IMPACT 2002+. Below is the process network (Figure 17-24).

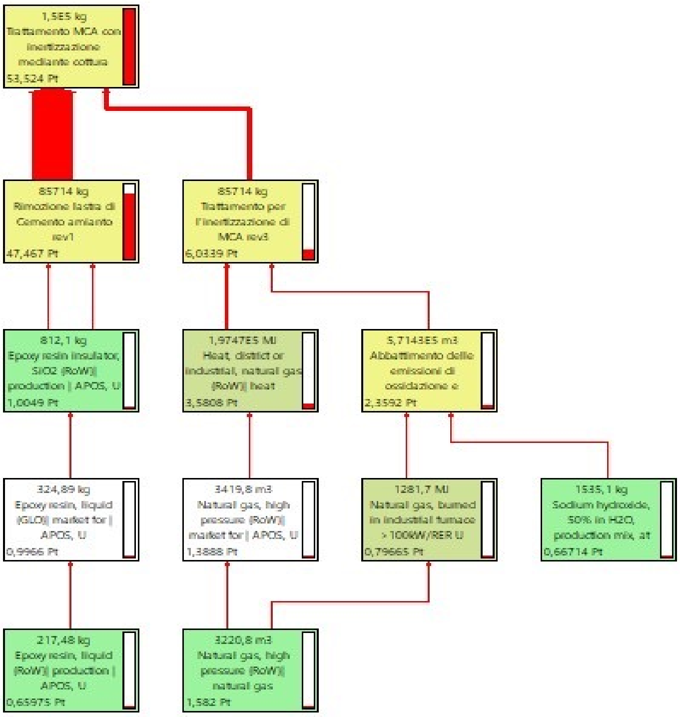


Figure 17-24: The single score process network with a cut-off of 1.23% of the ACM treatment with inertisation by firing process

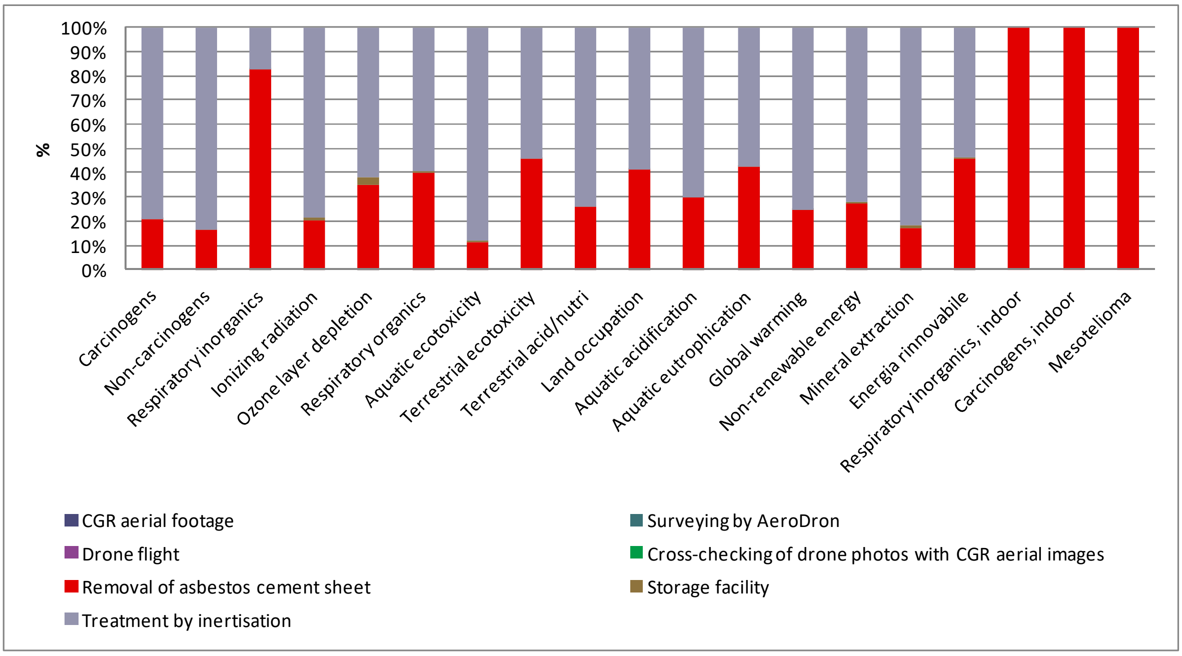


Figure 17-25: Diagram showing the characterisation of the ACM treatment with inertisation by firing process

From the analysis of the assessment results (Figure 17-25), it can be seen that:

- for **Carcinogens**, the damage is 1,865.5 kg C2H3Cl eq., with 77.23% due to 0.4073 kg of *Aromatic Hydrocarbons* in air (93.25% in ACM treatment by inertisation rev3 and, in particular, 99.32% in Natural gas, high pressure {RoW}| natural gas production|APOS, U with 59.47% used in the ACM firing and 40.63% in the afterburner), and 12.77% due to 68.208 kg of *Particulates*, *<2,5µm* in air (92.43% in Removal of asbestos cement sheet rev1 and, in particular, 95.01% in the process itself as a direct emission).

- for **Non-carcinogens**, the damage is 464.82 kg C_2H_3Cl eq., with 44.23% due to 0.0495 kg of *Arsenic* in water (88.91% in ACM treatment by inertisation rev3 and, in particular, 74.9% in Waste cement, hydrated {CH}| treatment of, residual landfill material | APOS, U representing the end of life of the soda used for the reduction of SO_2 and CO_2 emissions in the afterburner plant), and 22.22% due to 1,1877E-8 kg of *Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-* in air (90.89% in ACM treatment by inertisation rev3 and, in particular, 72.93% in Natural gas, high pressure {US}| market for | APOS, U, which represents the natural gas used for firing and the afterburner), 15.15% due to 1,52 kg of *Barium* in water (98.11% in ACM treatment by inertisation rev3 and, in particular, 99.3% in Natural gas, unprocessed, at extraction {GLO}| production | APOS, U used in the ACM firing and afterburner), and 10.14% due to 0,0038 kg of *Arsenic* in air (93.1% in ACM treatment by inertisation rev3 and, in particular, 26.03% in Copper {RAS}| production, primary | APOS, U used for the extraction system electric fan).
- for **Respiratory inorganics**, the damage is 82,529 kg PSQM,5 eq., with 82.65% due to 68,208 kg of *Particulates, <2,5µm* in air, 7.59% to 49,2 kg of *Nitrogen oxides* in air (60.46% in ACM treatment by inertisation rev3 and, in particular, 39.89% in Natural gas, burned in industrial furnace >100kW/RER U (without filter for NOx abatement) | Alloc, representing the natural gas used for firing and the afterburner).
- for **Ionizing radiation**, the damage is 1,797,800 Bq C-14 eq., with 60.42% due to 9,5046E8 Bq of *Radon-222* in air (91.34% in ACM treatment by inertisation rev3 and, in particular, 76.95% in Tailings, uranium milling/GLO U. This process considers the treatment of waste due to uranium extraction to produce the portion of electricity of nuclear origin in the Italian mix), and 35.41% due to 63,663 Bq of *Carbon-14* in air (79.05% in ACM treatment by inertisation rev3 and, in particular, 76.95% in Nuclear spent fuel, in reprocessing, at plant/RER U. The process represents the reprocessing of the fuel elements used to produce the nuclear power portion of the Italian mix).
- for **Ozone layer depletion**, the damage is 0.0014129kg CFC-11 eq., with 77.56% due to 9.132E-5 kg of *Methane, bromotrifluoro-, Halon 1301* in air (74.36% in ACM treatment by inertisation rev3 and, in particular, 48.53% in Natural gas, high pressure {RoW}| petroleum and gas production, on-shore | APOS, U. The process represents the thermal energy used for the firing of the sheets), with 11.4% due to 2,6853E-5 kg of *Methane, Bromochlorodiifluoro-, Halon-1211* in air (90.33% in ACM treatment by inertisation rev13 and, in particular, 73.14% in Transport, pipeline, long distance, natural gas {RU}| processing | APOS, U. The process considers the transport of the gas used to fire the sheets).
- for **Respiratory organics**, the damage is 8.19 kg C2H4 eq., with 79.63% due to 10.854 kg of *NMVOC, non-methane volatile organic compounds, unspecified origin* in air (98.11% in ACM treatment by inertisation rev3 and, in particular, 31.67% in Sweetening, natural gas {RoW}| processing | APOS, U. The process represents the purification of the natural gas used for firing).
- for **Aquatic ecotoxicity**, the damage is 3.8826E6 kg TEG water and 81.05% is due to 433.8 kg of *Aluminium* in water (98.11% in ACM treatment by inertisation rev3and, in particular, 78.93% in Filter dust from Al electrolysis {CH}| treatment of filter dust from Al

electrolysis, residual material landfill | APOS, U. The process considers the end of life of the Na_2CO_3 formed by the absorption of CO_2 by the scrubber).

- for **Terrestrial ecotoxicity**, the damage is 2.2145E5kg TEG soil and 22.09% is due to 0.0082753 kg of *Zinc* in soil (79.62% in Removal of asbestos cement sheets rev1 and, in particular, 55.33% in Tyre wear emissions, lorry {RoW}| treatment of | APOS, U. The process considers dust emissions due to the wear of lorry wheels), 21.68% due to 0.0633 kg of *Aluminium* in soil (7.85% in ACM treatment by inertisation rev3 and, in particular, 73.46% in Drilling waste {CH}| treatment of, landfarming | APOS, U. The process considers the landfarming treatment of waste resulting from drilling to extract methane), with 19.22% due to 0.336 kg of *Aluminium* in air (83.76% in ACM treatment by inertisation rev3 and, in particular, 46.12% in Blasting {RoW}| processing | APOS, U. The process considers the extraction of minerals used for the furnace using explosives), with 10.03% due to 0.019 kg of *Copper* in air (62.42% in ACM treatment by inertisation rev1 and, in particular, 21.46% in Copper {RAS}| production, primary | APOS, U).
- for **Terrestrial acid/nutri**, the damage is 334.07 kg SO_2 eq., with 80.83% due to *Nitrogen oxides*, 10.08% to *Sulphur dioxide*, and 9.09% to 33.668 kg of *Ammonia* (96.07% in ACM treatment by inertisation rev3 and, in particular, 81.59% in Abatement of oxidation and carbonisation emissions (with parameters) (with emissions) (Rev1). The process considers the afterburner).
- for **Land use**, the damage is 634.90 sqm, with 61.53% due to 644.57 sqma of *Occupation, forest, intensive* (60.31% in Removal of asbestos cement sheet rev1 and, in particular, 19.69% in Pulpwood, softwood, measured as solid wood under bark {RoW}| softwood forestry, pine, sustainable forest management | APOS, U. The process considers a cardboard component used for the moulding of the film) and 14.58% due to 91.628 sqma of *Occupation, traffic area, road network* (69.02% in ACM treatment by inertisation rev3 and, in particular, 36.07% in Residual material landfill {CH}| construction | APOS, U. The process considers the construction of the landfill for special waste).
- for **Aquatic acidification**, the damage is 73.086 kg SO_2 eq., with 47.12% due to 49.2 kg of *Nitrogen oxides* in air, and 46.07% to 33.668 kg of *Sulphur dioxide* in air
- for **Aquatic eutrophication**, the damage is 2.619 kg PO4 P-lim, with 74.3% due to 13.23 kg of *Phosphate* in water (85.09% in ACM treatment by inertisation rev3 and, in particular, 48.7% in Sulfidic tailing, off-site {GLO}| treatment of | APOS, U. The process considers the treatment of sulphur-containing substances used for the production of electricity), with 24.44% due to 801.69 kg of *COD, Chemical Oxygen Demand* in water (77.25% in Removal of asbestos cement sheet rev1 and, in particular, 49.32% in Epoxy resin, liquid {RoW}| production | APOS, U. The process considers the adhesive (primer)).
- for **Global warming**, the damage is 22,344,568 kg CO_2 eq., with 89.72% due to 20,047 kg of *Carbon dioxide, fossil* in air (73.99% in ACM treatment by inertisation rev3 and, in particular, 78.47% in Heat, district or industrial, natural gas {RoW}| heat production, natural gas, at industrial furnace >100kW | APOS, U. The process considers the furnace for the inertisation of sheets), and 9.36% due to 68.555 kg of *Methane, fossil* in air (64.93% in ACM treatment by inertisation rev3 and, in particular, 30.19% in Natural gas, unprocessed, at extraction {GLO}| production | APOS, U. The process considers the extraction of the natural gas used for the furnace).

- for **Non-renewable energy**, the damage is 429,764.16 MJ primary, with 70.61% due to 7,923.5 m^3 of *Gas, natural/m^3* (83.44% in ACM treatment by inertisation rev3 and, in particular, 26.12% in Natural gas, high pressure {RoW}| natural gas production | APOS, U. The process considers the natural gas used for the furnace), and 15.42% due to 1,447 kg of *Oil, crude* (82.78% in Removal of asbestos cement sheet rev1 and, in particular, 43.85% in Polyethylene, linear low density, granulated {RER}| production | APOS, U. The process considers the production of the material used for the film).
- for **Mineral extraction**, the damage is 25,483,735 MJ surplus, with 48.87% due to 12,421.739 m^3 of *Water, turbine use, unspecified natural origin* (97.81% in ACM treatment by inertisation rev3 and, in particular, 86.09% in Electricity, hydropower, at run-of-river power plant/RER U. The process considers the water used for hydroelectric electricity for the production of the sodium hydroxide used in the afterburner), 29.88% due to 7,596.238 m^3 of *Water, turbines use, unspecified natural origin, RoW* (70.8% in Removal of asbestos cement sheet rev1 and, in particular, 99.2% in Electricity, high voltage {RoW}| electricity production, hydro, run-of-river | APOS, U. The process considers the water used for hydroelectric electricity used for the production of the sodium hydroxide used in the afterburner), and 17.14% due to 4,357.752 m^3 of *Water, turbine use, unspecified natural origin, IT* (85.01% in ACM treatment by inertisation rev3 and, in particular, 96.7% in Electricity, high voltage {IT}| electricity production, hydro, run-of-river | APOS, U. The process considers the water used for hydroelectric electricity for the production of the sodium hydroxide used in the afterburner).
- The **Renewable energy** used is 12,364.662 MJ, with 47.45% due to 5,866.944 MJ of *Energy, potential (in hydropower reservoir), converted* (68.81% in ACM treatment by inertisation rev3 and, in particular, 21.82% in Electricity, hydropower, at run-of-river power plant/RER U. The process considers the hydroelectric electricity used for the production of the sodium hydroxide used in the afterburner), and 40.46% due to 5,003.32 MJ of *Energy, gross calorific value, in biomass* (59.34% in Removal of asbestos cement sheet rev1 and, in particular, 19.97% in Pulpwood, hardwood, measured as solid wood under bark {RoW}| hardwood forestry, birch, sustainable forest management | APOS, U. The process considers the wood used for the production of films).
- for **Respiratory inorganics, indoor**, the damage is 5.8040219 kg Psqm.5eq., with 100% due to 0.605kg of *Particulates, <2,5µm, indoor* (100% in Removal of asbestos cement sheet rev1)
- for **Carcinogens, indoor**, the damage is 20.27 kg C2H3Cl eq., with 100% due to 0.605 kg of *Particulates, <2,5µm, indoor* (100% in Removal of asbestos cement sheet rev1)
- for **Mesothelioma**, the damage is 0.009cases, with 100% due to 0.605 kg of *Particulates, <2,5µm, indoor* (100% Removal of asbestos cement sheet rev1).

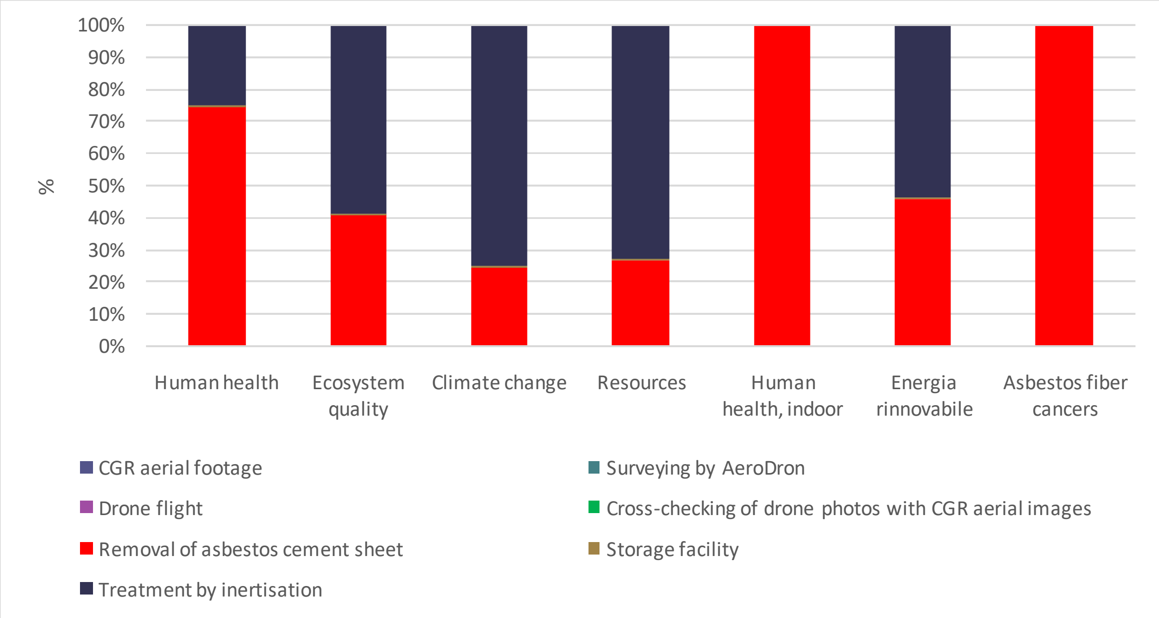


Figure 17-26: Diagram showing the damage assessment of the ACM treatment with inertisation by firing process

The following conclusions can be drawn from the results of the damage assessment (Figure 17-26):

- for **Human health**, the damage is 0.064 DALY, with 75.23% due to *Particulates, <2,5 µm*. The process that produces the maximum damage is Removal of asbestos cement sheet rev1 (0.05 DALY, 76.67%). The impact category that produces the maximum damage is **Respiratory inorganics** (0.06 DALY, 89.77%).
- for **Ecosystem quality**, the damage is 2,986.0858 PDF*sqm*yr, with 14.26% due to *Occupation, forest, intensive*, 13.09% to *Alumininium* in soil, 12.98% to *Zinc* in soil, and 11.55% to *Aluminium* in air. The process that produces the maximum damage is ACM treatment by inertisation rev3 (1,935 PDF*sqm*yr, 64.8%). The impact category that produces the maximum damage is **Terrestrial ecotoxicity** (1,751.71 PDF*sqm*yr, 58.66%).
- for **Climate change**, the damage is 22,344.57 kg CO_2 eq- with 89.72% due to *carbon dioxide, fossil*. The process that produces the maximum damage is ACM treatment by inertisation rev3 (14,832.86 kg CO_2 eq., 73.99%).
- for **Resources**, the damage is 455,247.89 MJ primary, with 66.66% due to *Gas, natural/m^3* and 14.09% to *Oil, crude*. The process that produces the maximum damage is ACM treatment by inertisation rev3 (325,090.34 MJ primary, 71.41%). The impact category that produces the maximum damage is **Non-renewable energy** (429,764.16 MJ primary, 94.4%).
- for **Human health, indoor**, the damage is 0.004 DALY, with 100% due to *Particulates, <2,5µm, indoor*. The process that produces the maximum damage is Removal of asbestos cement sheet rev1 (0.004 DALY, 100%).
- for **Asbestos fiber cancers**, the damage is 0,27 DALY, with 100% due to *Asbestos fiber* in air. The process that produces the maximum damage is Removal of asbestos cement sheet rev1 (0.27 DALY, 100%).
- The **renewable energy** used is 12,364.66 MJ, with 47.45% related to *Energy potential (in hydropower reservoir), converted* and 40.46% to *Energy, gross calorific value, in*

biomass. The process that produces the maximum damage is Removal of asbestos cement sheet rev1 (7,311.12 MJ, 59.13%).

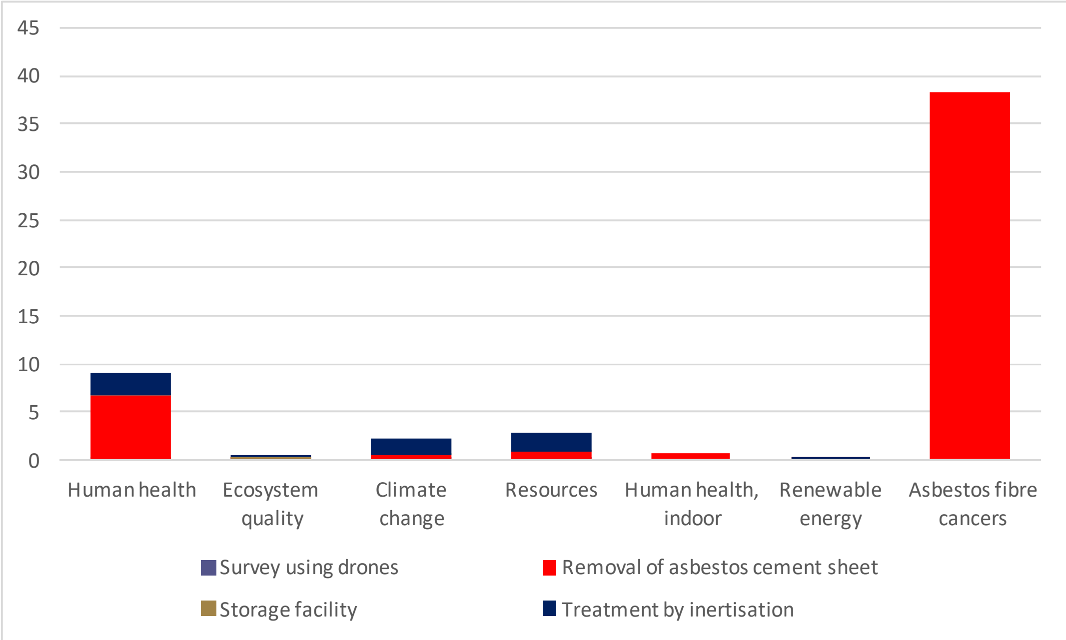


Figure 17-27: Diagram showing the normalisation of the ACM treatment with inertisation by firing process

From the analysis of the normalization results (Figure 17-27), it can be seen that:

- for **Human health**, the damage to the entire European population is 9.074 times that caused by human activities in Europe in a year, referring to the individual European citizen.
- for **Ecosystem quality**, the damage to European biodiversity is 0.22 times that caused by human activities in Europe in a year, referring to the individual European citizen.
- for **Climate change**, the damage to the entire planet is 2.26 times that caused by climate change due to human activities in Europe in a year, referring to the individual European citizen.
- for **Resources**, the damage to the entire planet is 2.99 times that caused by depletion of resources by human activities in Europe in a year, referring to the individual European citizen.
- for **Human health, indoor**, the damage to workers is 0.58 times that caused by human activities in Europe in a year, referring to the individual European citizen.
- for **Asbestos fiber cancers**, the damage to Italian citizens is 38.4 times that caused by human activities in Europe in a year, referring to the individual European citizen.
- The **Renewable energy** used is 0.11 times the energy consumed by a single European citizen in 1 year.

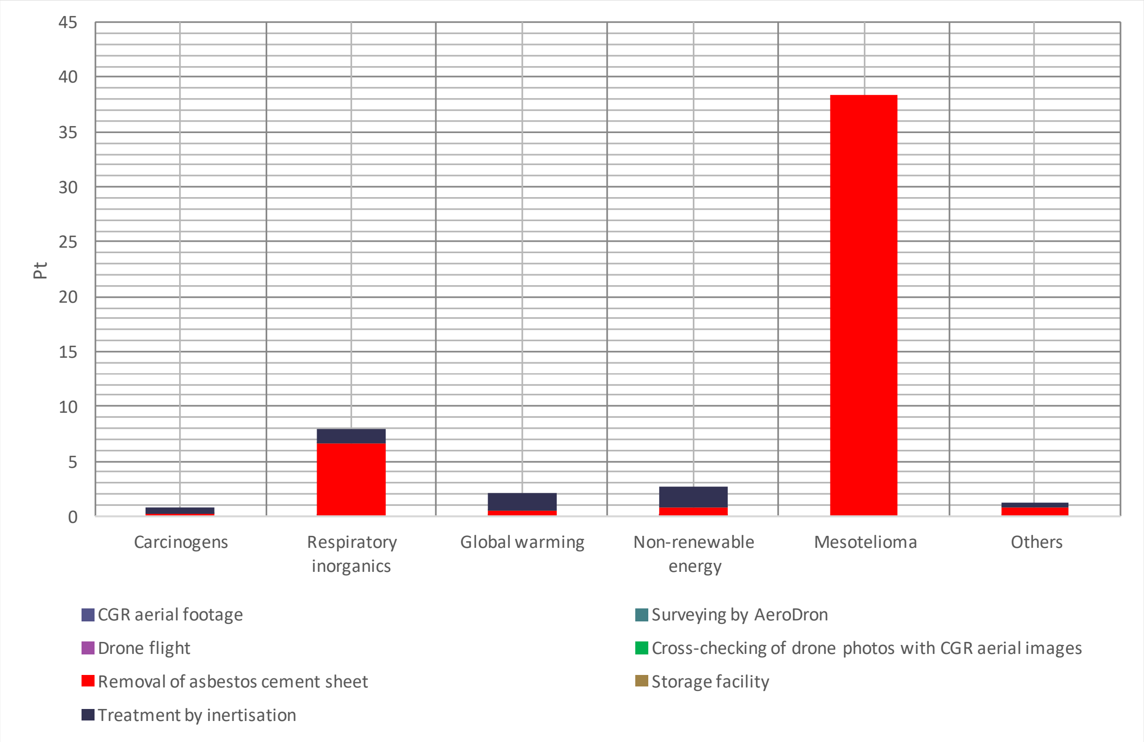


Figure 17-28: Diagram showing the assessment by impact category of the <u>ACM treatment with inertisation by firing</u> process

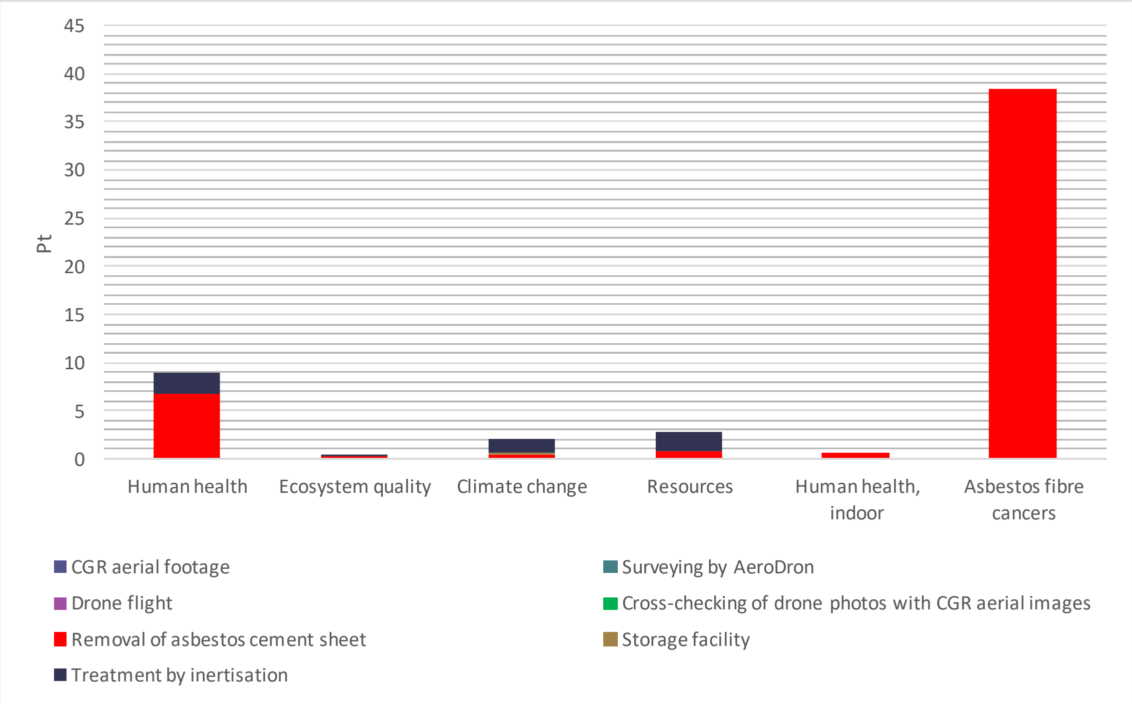


Figure 17-29: Diagram showing the assessment by damage category of the <u>ACM treatment with inertisation by firing</u> process

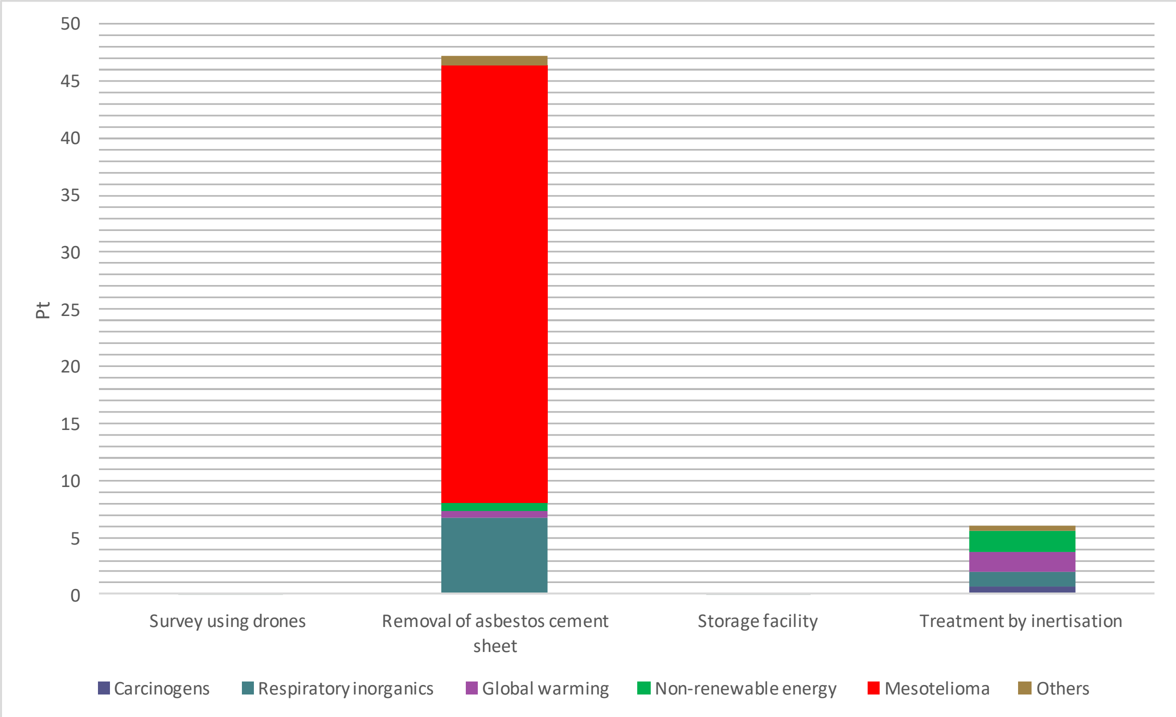


Figure 17-30: Diagram showing the single score assessment by impact category of the ACM treatment with inertisation by firing process

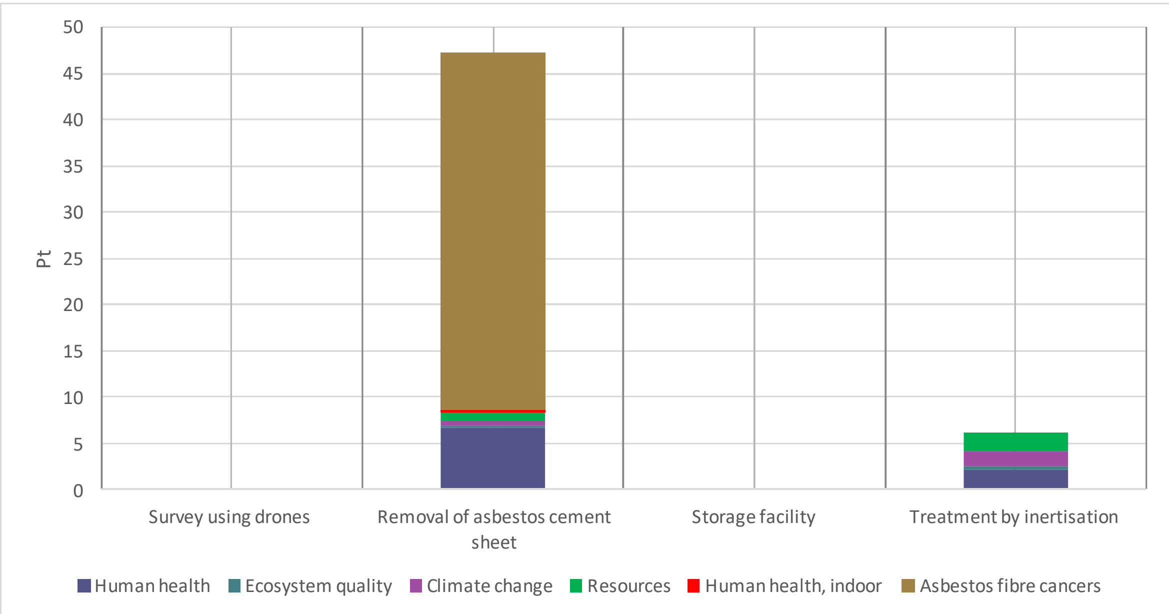


Figure 17-31: Diagram showing the single score assessment by damage category of the ACM treatment with inertisation by firing process

From the analysis of the results, it is noted that the total damage is 53.53 Pt, with 0% due to ACM Treatment by inertisation with firing, 4.27E-5% to CGR aerial footage, 3.58E-6% to Surveying by AeroDron, 2.05E-5% to Drone flight for the 8 municipalities of theLower Reggiana area, 0.0001% to Cross-checking of drone photos with CGR aerial images, 88.68% to Removal of asbestos cement sheet rev1, 0.043% to Storage facility rev2, and 11.27% to ACM treatment by inertisation rev3 (Figure 17-28, Figure 17-29). As for the damage categories, 16.95% of the damage relates to **Human Health** (the effects of asbestos are not considered in this category), 0.41% to **Ecosystem**

Quality, 4.22% to **Climate Change**, 5.6% to **Resources**, 1.08% to **Human Health, indoor**, and 71.74% to **Asbestos Fiber Tumours (**Figure 17-30, Figure 17-31).

17.4. Sensitivity analysis

17.4.1. ACM management process with inertisation plant without fibers inhaled by the worker with Ecoinvent 3.6

The process designed for 150 metric tons is *ACM treatment with inertisation by firing (without asbestos fibers inhaled by the worker) with the IMPACT 2002+010419indoor/locali_rif_IPCC+Amianto V2.12 method.

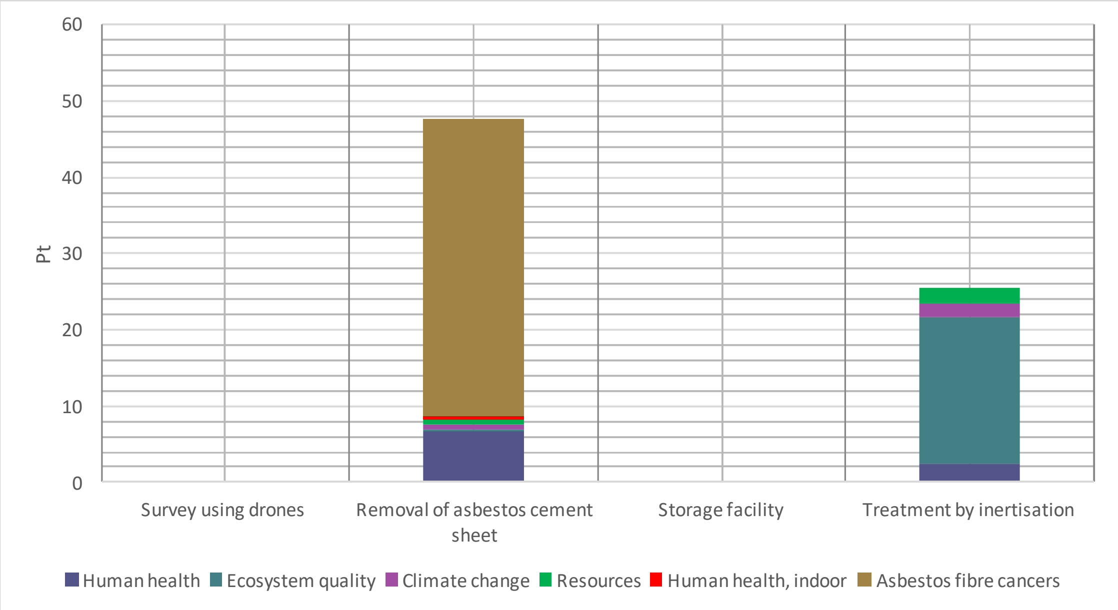


Figure 17-32: Diagram showing the damage due to the *ACM treatment with inertisation by firing (without asbestos fibers inhaled by the worker) process

From the results obtained with version 3.6 of Ecoinvent 3.6 (Figure 17-32), it is noted that the damage due to the treatment of ACM with inertisation is 53.84 Pt and 72.05% is due to *Asbestos fiber tumours.* Compared to the previously analysed process with Ecoinvent 3.5 (where the damage was 53.52 Pt), the difference is 0.32 Pt (+0.59%) due to the updating of the Ecoinvent database.

17.4.1. Comparison of the ACM management process with landfill facility and the ACM management process with inertisation plant without co-product

It is assumed that the ACW inertisation process does not produce an SRM that can be used as cement material but only an inert waste to be landfilled. An inertisation process has been created in which crystallised asbestos cement is sent to a landfill for inert waste without undergoing the grinding and iron removal process. The new process is as follows: ACM treatment by inertisation rev3 with end of life in landfill (KRYAS). The calculation was made for 150 metric tons using the IMPACT 2002+010419indoor/locali_rif_IPCC+Amtot V2.12 method.

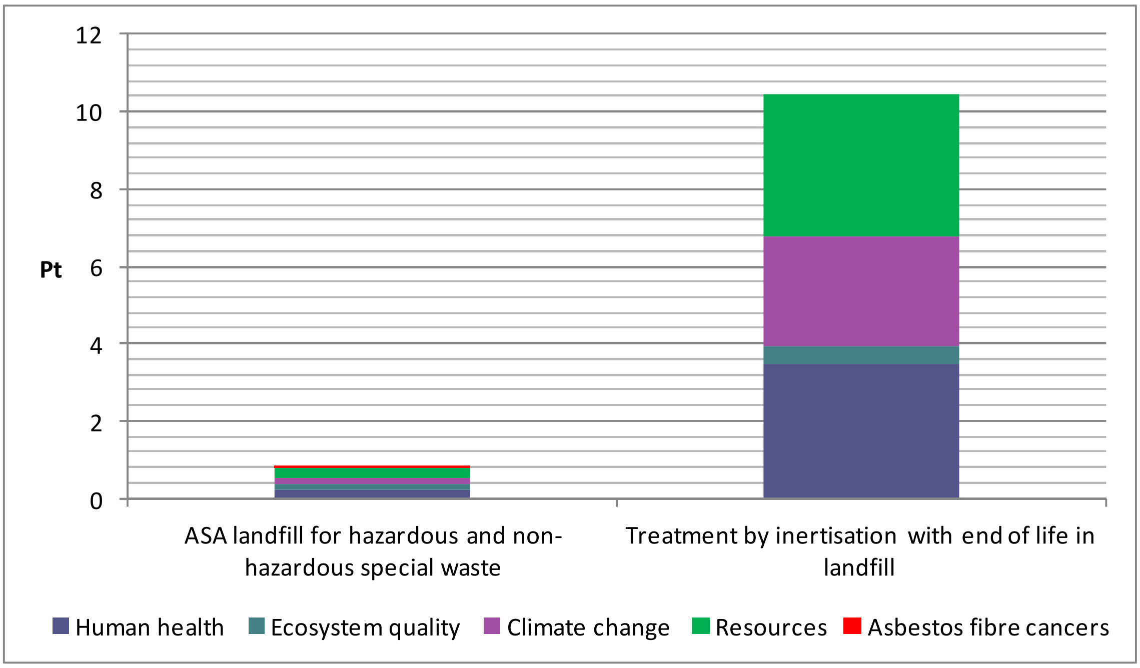


Figure 17-33: Diagram comparing the processes ASA landfill for hazardous and non-hazardous special waste (with CPT) (Multi-output) (Final)_rev and ACM treatment by inertisation rev3 with end of life in landfill (Kryas)

From the comparison (Figure 17-33), it can be seen that the process of inertisation without recovery of the KRYAS (SRM) produces an impact more than 10 times higher (10,45 Pt vs. 0,83 Pt) than the damage produced by the landfill for special hazardous and non-hazardous waste.

17.4.2. Changes to the analytical method

The methods used for sensitivity analyses below are the "*IMPACT 2002+010419indoor/locali_rifIPCCAmlavCest V2.12 / IMPACT 2002+*" and "*USEtox 2 (recommended + interim)+Asbestos V1.00*" methods. Unlike the method used for the environmental damage assessment, "*IMPACT 2002+010419indoor/locali_rif_IPCC+Amianto V2.12 / IMPACT 2002+*", the methods mentioned above take into account the damage due to asbestos fibers inhaled by an operator during the removal of an asbestos cement sheet.

17.4.2.1. The characterisation coefficient of the asbestos fiber that is inhaled by an operator during remediation by removal of an asbestos cement sheet

17.4.2.1.1. Modified IMPACT 2002+ method

The *IMPACT 2002+010419indoor/locali_rifIPCCAmlavCest V2.12 / IMPACT 2002+* method has been modified to consider damage from asbestos fiber emissions inhaled by an operator when removing a sheet. The substance considered is "*Asbestos fiber inhaled by the worker*", while the impact category is "*Malignant mesothelioma*". The parameters used for the calculation of the asbestos fiber characterisation coefficient are shown below (Table 17-37). The data used is primary, and if absent, assumptions or estimates were made.

Pesofibram	3.33e-11	The average weight of a fiber in PCOM (Standard techniques available nationally and internationally for the detection of asbestos containing materials by laboratory analysis INAL seminar 2019): g
nbul	4	Number of bolts cut during the removal operation: n
Volfiberam	1	Volume of air surrounding the worker's head: m^3

cemamasp	5	Weight of asbestos cement removed for each bolt cut: g
Plastra	25.5	Weight of 1,5 sqm of asbestos cement sheet: kg
Volariainspgiorno	19	Volume of air inhaled by a human in a working day: m^3/day
Tsvit	0.5	Time needed to cut a bolt: min
efiltro	0.99	HEPA absolute filter efficiency
frazlav	0.002	Portion of fibers involving the worker: %
Percamianto	0.1	Mass of asbestos fibers contained in a sheet: %
ProbMM	0.2	Probability of contracting malignant mesothelioma (MM): %
Percfiblav	0.001	Mass of fibers removed involving the worker: %

Table 17-37: Process Change Parameters: IMPACT 2002+010419indoor/locali_rifIPCCAmAmlavCest V2.12

The substance inhaled by a worker (*Asbestos fiber inhaled by the worker)* who removes an asbestos cement sheet (*Merler E.,2006; Albin M., 1990;Anderson,1991;Berry G.,1999; Hisanga N.,1988; Kauppinen T. ,2000;Mirabelli D.,2005;Mirabelli D.,2008; Gylseth B.,1981; Magnani. C.,1998*) is calculated below:
Percamianto*cemamasp*nbul*frazlav/Pesofibram/Volfiberam*Volariainspgiorno/24*nbul*Tsvit/60*(1-efiltro)= 0.1*5 g*4*0.002/3.33e-11 g/1 m^3*19 m^3/day/24*4*0.5 min/60*(1-0.99)
Subsequently, the mass of asbestos cement that the worker must reach when removing a sheet to ensure that a fiber is inhaled was calculated as:
Emissfibrammesot=cemamasp/Percfiblav/(1/Volfiberam*Volariainspgiorno/24*nbul*Tsvit/60)*(1-efiltro):5 g/0.002/(1/1 m^3*19 m^3/day/24*4*0.5 min/60)*(1-0.99)= 189.47 grams (0.18947 kg) of asbestos cement that a worker must reach to inhale an asbestos fiber.
If it is assumed that there is a 20% probability that this mass will produce a tumour (*Merler E., 2009; Barbieri P.G,2008*; *V and VI Renam Report*), the cases of malignant mesothelioma (M.M.), i.e. the characterisation factor, are ProbMM /189.47 = 0.0010556 cases/g = 1.0556 cases/kg.

Considering the functional unit of the process, i.e. the 150 metric tons of asbestos cement sheets removed, 150,000 kg/ Plastra*(cemamasp*nbul)/1,000) =117.647 kg of asbestos cement are released inhaled by the worker.

17.4.3. LCA of the ACM treatment process with inertisation plant with asbestos fibers inhaled by the worker during the removal phase

The process designed for 150 metric tons is ACM treatment by inertisation by firing (with asbestos fibers inhaled by the worker). The method used for damage calculation is IMPACT 2002+010419indoor/locali_rifIPCCAmAmlavCest V2.12.

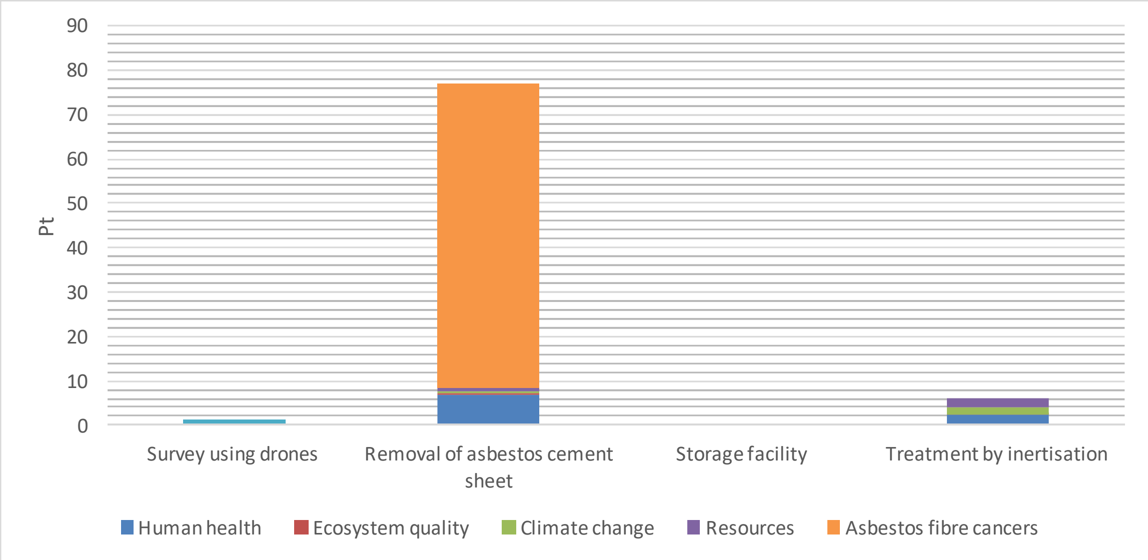


Figure 17-34: Diagram showing the single score assessment and damage category of the ACM treatment with inertisation by firing (with asbestos fibers inhaled by the worker) process

The process produces damage of 83.352 Pt, with 82.5% due to Asbestos fiber tumours (68.767 Pt, Figure 17-34). Comparing the results obtained using the IMPACT 2002+ damage assessment method set out in the previous section 17.3.1 shows that the damage due to *Asbestos fiber tumours* goes from 38.788 Pt to 68.77 Pt if we also take into account the fiber emissions inhaled by the worker during the remediation by removal.

17.4.4. Calculation using the USEtox method of ACM management through an inertisation plant

17.4.4.1. Calculation of the indicator using the USEtox method

The environmental impacts were calculated (LCIA phase) using the USEtox evaluation method (*P.Fantke, M.Bijster,2017*), in order to determine the environmental impacts related to the emissions released and the resources consumed in the system under study. USEtox is a midpoint LCIA method that quantifies the human toxicity (for both carcinogenic and non-carcinogenic substances) and fresh water ecotoxicity, associated with a given process. More specifically, the USEtox method is a scientific consensus LCIA model, which has been developed since 2003 under the auspices of the United Nations Environment Programme–Society of Environmental Toxicology and Chemistry Life Cycle Initiative as a harmonised approach for characterising human and freshwater toxicity in life cycle assessment and other comparative assessment frameworks (*E.Saouter, K.Aschberger,2017*). Therefore, the USEtox model has been adopted to identify the characterisation factors for assessing the potential effects on human health caused by asbestos emissions in both indoor (occupational settings) and outdoor environments. In detail, USEtox defines the characterisation factor (CF) of a particular substance as a quantitative representation of how hazardous that substance is or the potential impacts, in relation to the emission of a unit mass of a pollutant (*A.D.Henderson,2011*). Specifically, for each substance, its CF is calculated as reported below in eq. 1. The equation considers the fate factor (FF), the exposure factor (XF) and the effect factor (EF) of the emitted substance (*Rosenbaum,2008,R.K. Huijbregts,2011*), together with its severity factor (SF), in order to obtain the endpoint characterisation factor (*L.J.A.Rombouts,2005; J.Struijs,2005*).

$$CF = FF * XF * EF * SF$$

Since asbestos does not accumulate in the food chain and no biomagnification process occurs (*G.D. Hanley,2011*), this study focuses only on direct exposure by inhalation (human toxicity). During the procedure for creating a new substance in the USEtox model file worksheets, some substance-specific data, i.e. physical-chemical properties, environmental degradation and human toxicity, must be included. Current research suggests that asbestos fibers can physically resemble carbon nanotubes (*K.Donaldson,2013*), showing similar properties. Therefore, in this work, the physical-chemical properties and degradation rates of carbon nanotubes proposed by Rodriguez-Garcia et al. *(G. Rodriguez-Garcia, 2014*) were used and implemented in the USEtox worksheets to model the fate factor of asbestos fibers. Finally, human toxicity value $ED50_{inh,\ can}$ (human equivalent lifetime dose that would cause a cancer probability of 50% after inhalation [kg*lifetime^{-1}]) needs to be entered in the USEtox workbook to assess the effect factor. For carcinogenic effects, the ED50 has been estimated from the *carcinogenic, low-dose, slope factor* q* by the 1/q*-to-ED50 extrapolation factor, which is equal to 0,8 (*G. D.Hanley, 2011*) as recommended by the USEtox method. A slope factor q* equal to 1.2E+01 (mg/kg-day)$^{-1}$ has been taken here into account (*OEHHA, 2009*). Therefore, the result $ED50_{inh,\ can}$ is 6.5E-3 [kg*lifetime^{-1}]. Consequently, the CFs obtained for asbestos fibers are reported in Table 17-38, for both indoor and outdoor environments. Hence, the USEtox method has been modified in this study in order to consider the calculated human health CFs for asbestos fibers and describes the analysed system in a more representative way.

Indoor air (occupational setting) [cases/$kg_{emitted}$]	*Outdoor environment* [cases/$kg_{emitted}$]
1,07E-02	1,63E-04

Table 17-38: Human health characterisation factors for asbestos fibers related to carcinogenic effects.

17.4.4.2. Calculation using USEtox of the asbestos cement sheet removal process

The *Removal of asbestos cement sheet rev2 (with asbestos fibers_USEtox) process for 150 metric tons was analysed using the USEtox 2 (recommended + interim)+Asbestos V1.00 method.

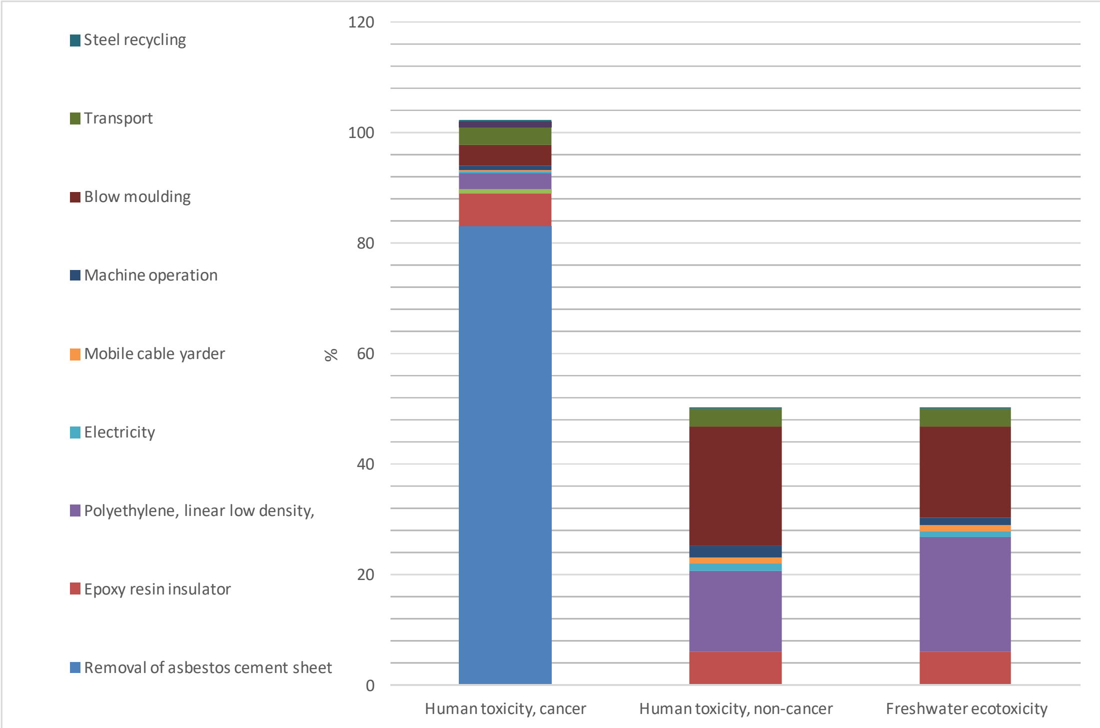


Figure 17-35: Diagram of the characterisation calculated using USEtox of the <u>*Removal of asbestos cement sheet rev2 (with asbestos fibers_USEtox)</u> process

Analysis of the impact assessment results shows that in **Human toxicity, cancer**, damage consists of 0.002 cases, with 83.12% due to *Asbestos fiber* (Figure 17-35).

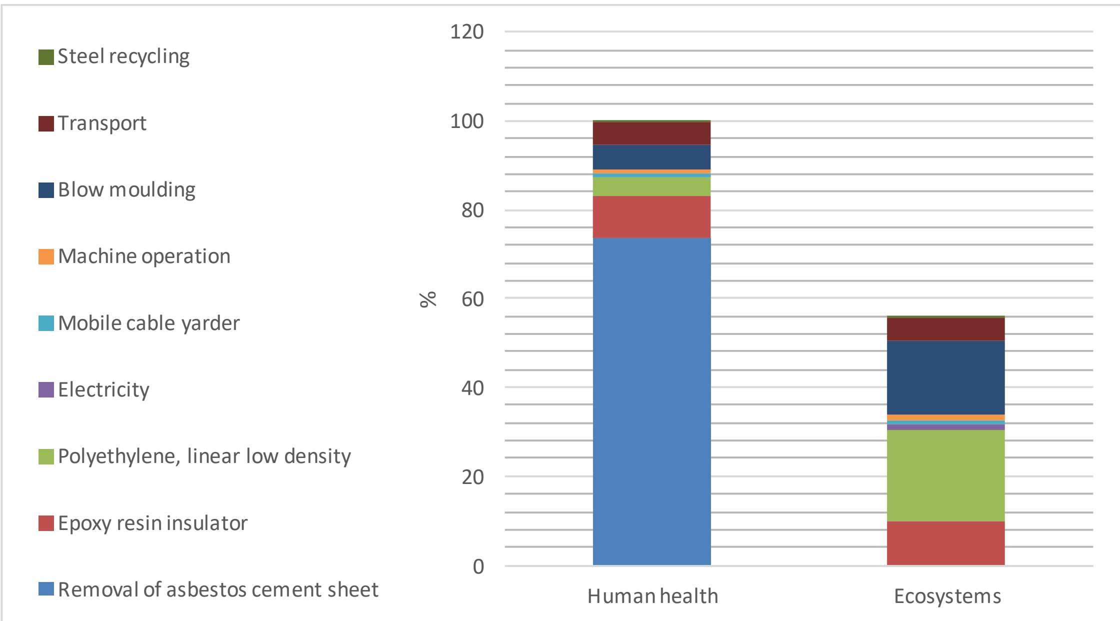


Figure 17-36: Diagram of the damage assessment calculated using USEtox of the <u>* ACM treatment with inertisation by firing (asbestos fibers inhaled by the worker) USEtox</u> process

From the analysis of the damage assessment results (Figure 17-36) it can be seen that:

- for **Human health**, the damage is 0.029DALY, with 73.52% due to *Asbestos fiber* as a direct emission of the removal process, and 13.26% to *Chromium VI*, with 32.5% in the <u>Epoxy resin insulator, SiO2{RoW}| production | APOS, U</u> process;

- for **Ecosystems**, the damage is 5.2996E7 PDF.m3.day, with 81.75% due to *Aluminium* in water, with 46.73% in the Epoxy resin insulator, SiO2{RoW}| production | APOS, U process.

17.4.5. Comparison of the remediation processes through removal with and without inhalation of asbestos fibers by the worker

In this sensitivity analysis, the processes of Removal of asbestos cement sheet rev1 and Removal of asbestos cement sheet rev1 without fibers inhaled by the worker were compared. Unlike the second process, the first process contains an emission of *Asbestos fibers inhaled by the worker* equal to 2% of the total. The latter represent the asbestos fibers released into the air and potentially inhalable by the worker during the removal phase, which are added to the airborne fibers dispersed in the air. The calculation was made for 150 metric tons using the *IMPACT 2002+010419indoor/locali_rif_IPCC+Amianto* method.

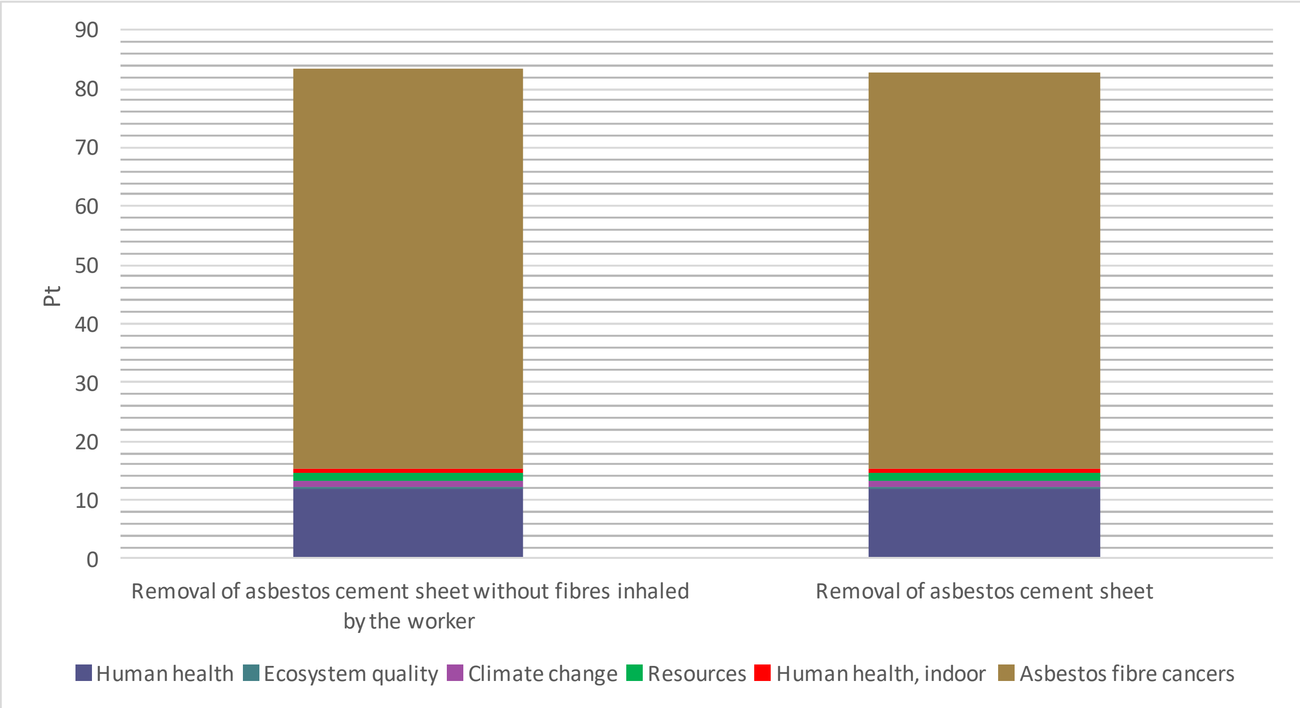


Figure 17-37: Diagram assessing the comparison between the Removal of asbestos cement sheet rev1 and Removal of asbestos cement sheet rev1 without fibers inhaled by the worker processes

The comparison of the two removal processes mentioned above shows that, for the process where the asbestos fibers inhaled by the worker have not been considered, the damage is 82.665174 Pt, 0.81% less than the process which considers the damage of fibers inhaled by the worker (83.343965 Pt, Figure 17-37).

17.5. Conclusions

- The damage of ACM treatment using inertisation, if the fibers potentially inhalable by the worker during the removal phase are considered, is 83.35 Pt, with 82.5% related to Asbestos fiber tumours. If the fibers inhaled by the worker are not taken into account, the damage is 53.84 Pt, with 72.05% related to *Asbestos fiber tumours.* Comparing the results in the previous section 17.3.1, it can be seen that the damage due to *Asbestos* *fiber tumours* goes from 38.79 Pt to 68.77 Pt (+56.4%), if the fiber emissions inhaled by the worker are also taken into account.

- The ACM treatment with landfill process, if the asbestos fibers inhaled by the worker during the removal are considered, produces a damage of 135.6 Pt, with 99.36% due to the removal of the sheet.
- In the individual removal process, failure to consider the 2% of asbestos fiber emissions during removal produces a downward error of 0.81%.
- The comparison shows that the process of inertisation without recovery of the Kryas material has an impact that is more than 10 times greater than the damage caused by the special waste landfill process.
- In the removal process studied using USEtox, it is found that in **Human toxicity, cancer**, the damage is 0.03 DALY, with 73.52% related to *Asbestos fiber* as a direct emission of the removal process.

17.6. Comparison with different types of ACW treatment

17.6.1. Disposal in landfill for hazardous and non-hazardous special waste

17.6.1.1. Objectives and field of application

17.6.1.1.1. Objectives

The aim of the study is the environmental assessment of the damage due to the management of the ASA spa landfill in Castel Maggiore (BO) and in particular sector III (S. Alessandro area) from the year of construction of this sector (2004) to the year of closure (2019). Field of application

17.6.1.1.2. System purpose

The purpose of the system is the transfer of non-putrescible hazardous and non-hazardous special waste.

17.6.1.1.3. The analysed system

The system analysed is the ASA spa facility in Via Saliceto, 43, 40013 Castel Maggiore BO. The facility consists of two separate landfill areas, where the first one, known as the “old landfill” (Casallona), has reached capacity and is in the post-operation phase, and the second, called “S. Alessandro” (sector III), is currently in operation. Therefore, the latter area will be analysed here.

17.6.1.1.4. Functional unit

The Functional Unit corresponds to the amount of waste treated from the year of construction (2004) to the year of end of operation (2019): 936,000 m^3*1.75 metric tons/m^3 (amount of waste transferred up to 2013) + 150,126.976 metric tons (amount transferred in 2014) + 140,809.58 metric tons (amount transferred in 2015) + 149,996.03 metric tons (amount transferred in 2016) + 150,000 metric tons (maximum annual amount transferred in 2017) + 150,000 metric tons (maximum annual amount transferred in 2018) + 88,723 metric tons (maximum annual amount transferred in 2019)= 2,467,655.586 metric tons.

17.6.1.1.5. System boundaries

The system boundaries range “from cradle to grave”, i.e. from the construction of the landfill, considering all the materials necessary for implementation, to the assessment of all the plant

necessary for its management, to the transport of the vehicles serving the facility, to the consumption of electricity and thermal energy, to the assessment of the trend of emissions of landfill gases and leachate during the years of operation of sector III, and to the end-of-life treatment of leachate (chemical-physical treatment).
Within the system boundaries, all emissions and leachate to be disposed of have been assessed starting from the year of activity of sector 3 (2004) to the end of the year of the post-mortem period of the sector:

- Years required for construction: 5
- Start year of activity and waste transfer: 2004
- Years of activity: 15
- Post-operation years: 30

The process flowchart is shown below (Figure 17-38).

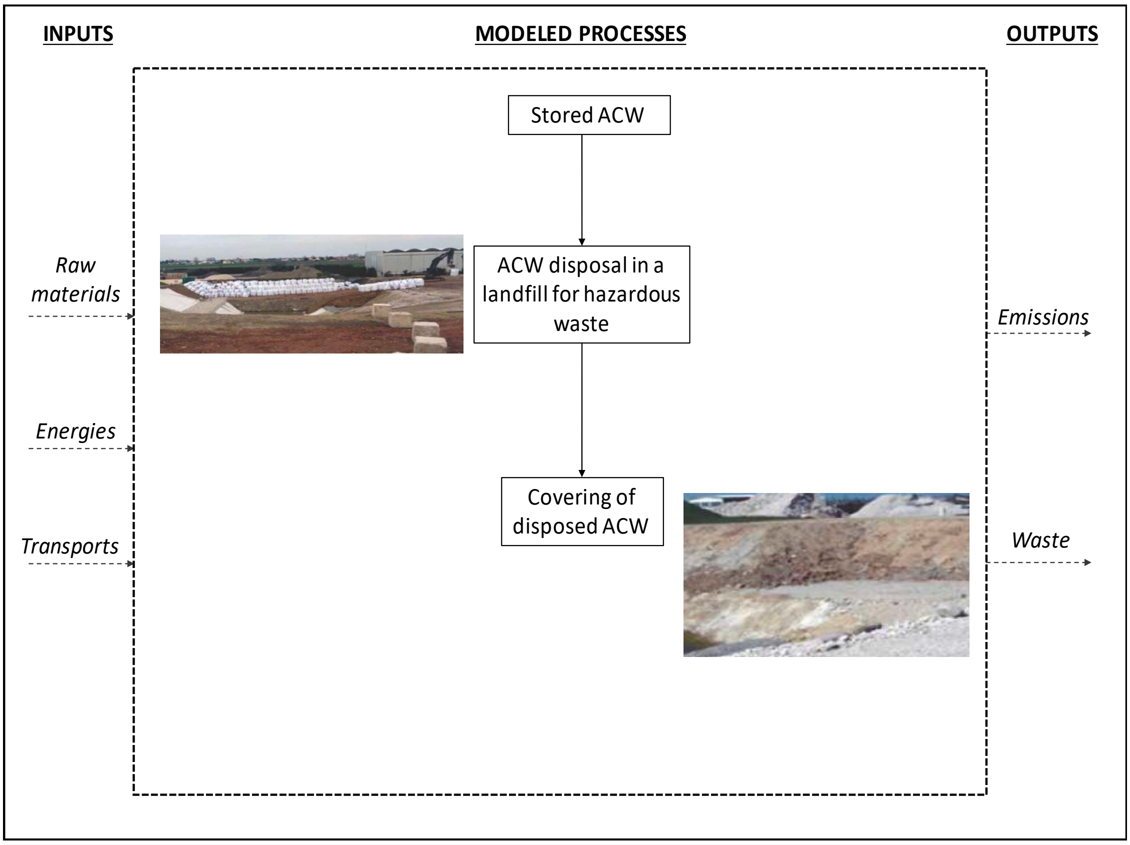


Figure 17-38: Flowchart showing the system boundaries considered in the LCA of ACW disposal in a dedicated landfill for hazardous wastes.

17.6.1.1.6. Data quality

Primary data provided directly by ASA spa personnel was used and partly obtained from the following documents:

- "Control and monitoring results", A.S.A. landfill - Azienda Servizi Ambientali, Castel Maggiore (BO), management year 2015, by: Manuela Aloisi, Emanuela Lischi, Roberto Riberti, Massimo Vezzali - Servizio Territoriale di Bologna
- "Control and monitoring results", A.S.A. landfill - Azienda Servizi Ambientali, Castel Maggiore (BO), management year 2013
- Integrated Environmental Authorisation - IEA, 2017

- Technical Report, 2016

Where primary data was missing, ad hoc processes were created. The method for calculating the damage is IMPACT 2002+ (*Jolliet et al.,2003*) modified by the study group (*Pini et al.,2014; Ferrari et al.,2019*). This method assesses the continental (European) dispersion of emissions generated by the system. The code used is SimaPro 8.5.2 (*Prè,2017*). The reference database is Ecoinvent v 3.4 (*Ecoinvent Centre,2014*).

17.6.1.2. Inventory analysis of the ASA spa landfill in Castel Maggiore (BO)

The landfill is authorised to carry out the following waste management operations:

- disposal of non-hazardous waste (D1);
- recovery of waste with adequate particle size characteristics for the construction of the base layer of the multilayer gaseous system for the drainage of gaseous emissions (R5).

The “S. Alessandro” area (sector III) is currently operational, authorised with superelevation by Regional Government Resolution no. 181 of 26 April 2011, which establishes the maximum annual quantities that can be transferred until 2017 (expected year that landfill capacity will be reached); any lower annual contributions compared to the maximum quantity indicated can be offset in subsequent years with an increase in the maximum annual amount of waste that can be transferred, in proportion to the lower contributions in the previous years. The landfill layout is shown below. The total area of the facility, comprising the “Casallona” area made up of sectors I and II and the “S. Alessandro” area comprising sector III, is 216,000 sqm, with approximately 80% intended for landfill activities. The remaining area is for technical installations (leachate storage, wheel washing system), vehicle turning areas, and office buildings in keeping with the type of rural buildings in the area. The main figures relating to the layout are as follows (Figure 17-39):

- Upper area of basins 1 and 2: 70,000 sqm
- Upper area of basin 3: 100,000 sqm

2016 data:

- ➢ Hazardous waste: 84,423 metric tons or 56.28% of the total, broken down as follows:
  - 48.90% inertised 56.28% in 2015
  - 2.80% Eternit 0.80% in 2015
  - 4.50% other 4.84% in 2015
- ➢ Non-hazardous waste: 65,573 metric tons or 43.72% broken down as follows:
  - 29.3% slag 26.30% in 2015
  - 15.50% other 6.60% in 2015

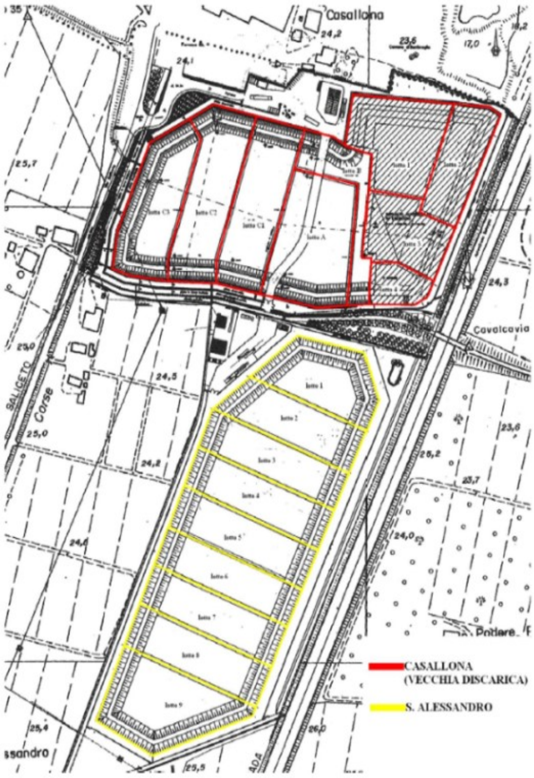


Figure 17-39: ASA Castel Maggiore (BO) Landfill Layout

17.6.1.2.1. Air emissions

The ASA landfill does not produce biogas since putrescible (biodegradable) waste is not disposed of and therefore does not require a gas capture and extraction plant for energy purposes. The air emissions from the facility are *point emissions*, relating to vents, the leachate odor abatement plant and civil heating system, and *diffuse emissions* from the body of the landfill.

17.6.1.2.1.1. Point emissions

The emission points concerned, identified as E1 and E2, come from the vapour extraction systems originating from the leachate tanks, specifically:

- E1 – recirculation tank for leachate produced in sector III of the landfill;
- E2 – final storage tank for leachate originating from the recirculation tank and the leachate produced in sectors I and II of the landfill.

Both emission points are equipped with an abatement system (Figure 17-40):

- the vapours from the recirculation tank are treated by a chemical absorption system (drum), consisting of two units in series which, through contact with a chemically active porous material, treat hydrogen sulphide/sulphur compounds and ammonia, respectively;
- the vapours in the storage tank are treated using a chemical-physical treatment system (scrubber), which uses sulphuric acid to treat ammonia, and soda and sodium hypochlorite for sulphur-based substances.

Figure 17-40: Drum and Scrubber

For air emissions, the reported measurements obtained from emission points E1 (Drum emissions, Table 17-40) and E2 (Scrubber emissions, Table 17-39) were considered.

E2 - Leachate recirculation tank scrubber - both sectors I and II and sector III				
Parameter	CAS No.	unit of measurement	authorisation limits	recorded data (annual)
Flow rate		Nm^3/h	2000	1742
Ammonia		mg/Nm^3	300	5
Hydrochloric_acid		mg/Nm^3	20	<1
VOCs				
Benzene		mg/Nm^3	null	<0,2
Dichlorodifluoromethane		mg/Nm^3	null	<0,2
Dichloromethane		mg/Nm^3	null	<0,2
1,1,2-trichloro-2,2,1-trifluoroethane	76-13-1	mg/Nm^3	null	<0,2
trichloromethane		mg/Nm^3	null	<0,2
1,1,1-trichloroethane		mg/Nm^3	null	<0,2
Carbon_tetrachloride		mg/Nm^3	null	<0,2
1,2-dichloropropane	78-87-5	mg/Nm^3	null	<0,2
Trichloroethylene		mg/Nm^3	null	<0,2
Toluene		mg/Nm^3	null	<0,2
Tetrachloroethylene		mg/Nm^3	null	<0,2
Ethylbenzene		mg/Nm^3	null	<0,2
m+p-Xylene		mg/Nm^3	null	<0,2
Styrene		mg/Nm^3	null	<0,2
o-Xylene		mg/Nm^3	null	<0,2
1,3,5-trimethylbenzene	108-67-8	mg/Nm^3	null	<0,2
1,2,4-trimethylbenzene	95-63-6	mg/Nm^3	null	<0,2
Hexachlorobutadiene		mg/Nm^3	null	<0,2
Vinyl_Chloride_CVM		mg/Nm^3	null	<0,2

Table 17-39: E2 abatement system operating data

E1 – Drum		
Parameter	**Unit of measurement**	**Wet gas emission flow rate**
Flow rate	Nm^3/h	411
Ammonia	mg/Nm^3	145

Table 17-40: E1 abatement system operating data

17.6.1.2.1.2. Diffuse Emissions and Air Quality

The monitoring of air quality is carried out at 4 points, along the perimeter of the landfill and outside the basin, positioned in consideration of the prevailing wind directions and the fact that part of the plant is already closed (Casallona area): 1 point at the area of the exhausted landfill and 3 points at the operational landfill, as outlined in Figure 17-41.

Figure 17-41: ASA landfill air emission monitoring points

The sampling point in the completed landfill area (POS3) can be considered as a "*blank*" for comparison, as it is not affected by the current landfill activities, but has similar boundary characteristics to those monitored. The air quality assessment is carried out through the analytical determination, on an annual basis by the operator, of numerous compounds belonging to the classes of sulphur organic compounds and volatile organic compounds, as well as ammonia, hydrogen sulphide and asbestos fibers. Table 17-41 below shows the emission measurements at the 4 points.

Position		POS 1	POS 1	POS 1	POS 1	POS 2	POS 2	POS 2	POS 2	POS 3	POS 3	POS 3	POS 3	POS 4	POS 4	POS 4	POS 4
VOCs and sulphur-containing	Sampling date	26/09/2016	27/09/2016	28/09/2016	29/09/2016	26/09/2016	27/09/2016	28/09/2016	29/09/2016	26/09/2016	27/09/2016	28/09/2016	29/09/2016	26/09/2016	27/09/2016	28/09/2016	29/09/2016
	Diffuse emission alert levels	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3
Benzene	0,017	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
Dichlorodifluoromethane		<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
Dichloromethane		<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
1,1,2-trichloro-2,2,1-trifluoroethane		<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
trichloromethane		<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
1,1,1-trichloroethane		<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
Tetrachloromethane		<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
1,2-dichloropropane		<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
Trichloroethylene		<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
Toluene	2,06	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
Tetrachloroethylene		<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
Ethylbenzene		<0,015	<0,015	0,02	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	0,02	<0,015	<0,015
m+p-Xylene	0,47	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
Styrene	0,93	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
o-Xylene	0,47	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
1,3,5-trimethylbenzene		<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
1,2,4-trimethylbenzene		<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
Vinyl Chloride (CVM)	0,028	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
Hexachlorobutadiene		<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015	<0,015
Ethyl Mercaptan		<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015
n-Propyl Mercaptan		<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015
n-Butyl Mercaptan		<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015	<0,0015
Ammonia	0,19	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
Hydrochloric acid		<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
Airborne fibers	200*	1,18	0,87	1,24	1,15	1,76	0,91	0,91	0,95	1,33	1,21	0,99	0,54	1,63	1,24	1,41	1,19

Table 17-41: Measurement of emissions at the 4 sampling points at the ASA landfill

17.6.1.2.1.3. Leachate

The quantities of leachate (in m^3) relating to sector III from 1997 to 2018 are reported below (Table 17-42 and Figure 17-42):

Year	Total m^3
1997	-
1998	-
1999	-
2000	-
2001	-
2002	-
2003	-
2004	1,600
2005	12,442
2006	9,117
2007	14,720
2008	26,015
2009	25,511
2010	30,663
2011	22,897
2012	18,097
2013	24,649
2014	22,892
2015	27,058
2016	27,912
2017	22,510
2018	5,203
TOTAL	291,285

Table 17-42: Quantities of leachate broken down by year for sector III of the ASA landfill

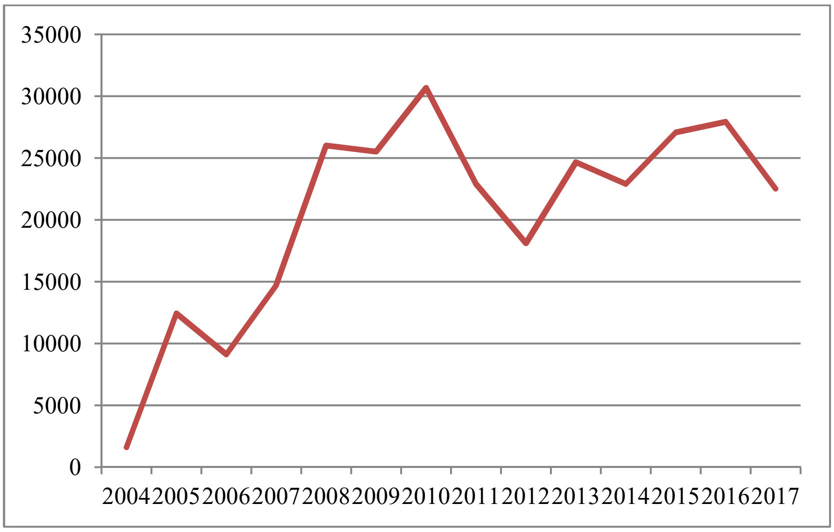


Figure 17-42: Trend in leachate production (in m^3) in Sector III from 2004 to 2017

Since the system boundaries go from the year of construction to the year of end of operation (2049), the leachate trend in these years had to be evaluated. The trend was considered constant from 2008 to 2019. Analysing the data provided for Sectors 1-2, it was noted that since the year of closure of

Sectors 1-2 (2005), the amount of leachate decreased rapidly in the subsequent three years. The same trend was therefore assumed for Sector 3 after its closure. The inventory table 17-44 shows the calculations for assessing the total quantity of leachate from 2004 to 2049. Table 17-43 and Figure 17-42 show the leachate production (in m^3) for sectors I and II from 2005 to 2016.

Year	Production m^3
2005	9,227
2006	4,767
2007	1,450
2008	1,065
2009	1,325
2010	1,345
2011	995
2012	627
2013	1,865
2014	1,426
2015	1,424
2016	1,072

Table 17-43: Production of leachate for sectors I and II from 2005 to 2016

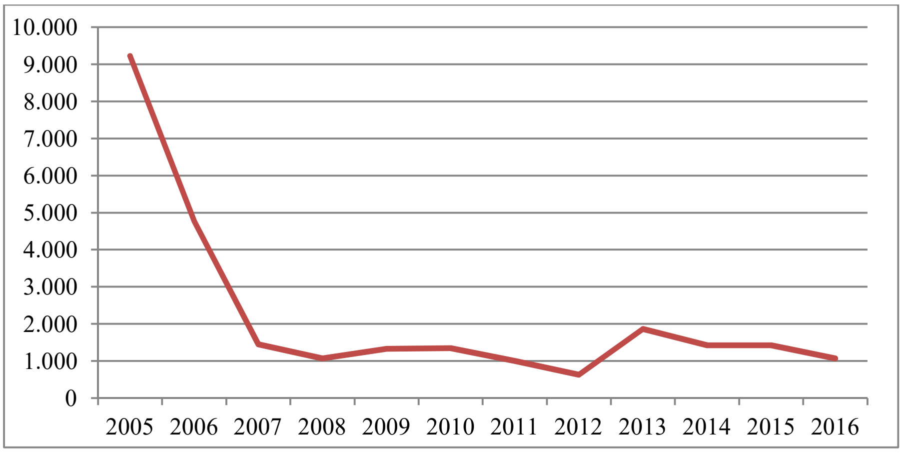


Figure 17-43: Trends in leachate in sectors I and II since closure in 2004 to 2016

17.6.1.2.1.4. Inventory data tables

The trend of leachate produced by sectors 1-2 for 2004-2035 (end of post-mortem period) were analysed, considering 30 years as the end of operations. Below is the inventory table (Table 17-48) for the "ASA landfill for hazardous and non-hazardous special waste (with CPT) (Multi-output) (Final)" process modelled with the LCI (Life Cycle Inventory) model with Simapro 8.5.2 software. The transfer of waste, the processes carried out, the resources and energy consumed, and related emissions were considered for this process. The process was also modelled using a system expansion approach, but since for this type of context the environmental results do not change substantially, the inventory and related analysis from one modelling are reported.

Products	Amount	Unit	Comments
ASA landfill for hazardous and non-hazardous special waste (with CPT) (Multi-output) (Final)	Riftot= 2467655.586	metric tons	ASA landfill for hazardous and non-hazardous special waste Year of start of construction: 2004, estimated year of closure: 2019 Waste transfer time = Tconfrif: 2019-2004= 15years It is assumed that: -the landfill will close after 15 years -trees will be grown on the landfill for 5 years -the landfill will remain active for up to 15 years+30 years= 45 years after construction during which air emissions and leachate production will continue. -for air emissions released after the closure of sector III, those available for sectors I and II and allocated to the mass of waste transferred to sector III are assumed. -the scrubber will be used during the period when the landfill remains active and in the post-mortem period, while the drum will be used for 15 years -the scrubber will treat emissions from leachate from both sectors I and II and sector III.
Avoided products	**Amount**	**Unit**	**Comments**
Sand {RoW}| gravel and quarry operation | Alloc Def, U	Scincrec= 2969.32	metric tons	Incinerator slag recovered and used for final landfill cover (R5). EWC code: 190112.
Resources	**Amount**	**Unit**	**Comments**
Occupation, construction site	Areaset3*5= 500000	sqma	(2,3,5,1,1,na) Occupation of Landfill Area sector 3 to be built (5 years)
Transformation, from shrub land, sclerophyllous	Areaset3= 100000	sqm	(2,3,5,1,1,na) Transformation from sclerophyll vegetation
Transformation, to shrub land, sclerophyllous	Areaset3= 100000	sqm	(2,3,5,1,1,na) Transformation to sclerophyll vegetation
Transformation, to dump site, residual material landfill	Areaset3= 100000	sqm	(2,3,5,1,1,na) Transformation to landfill site
Occupation, dump site	Areaset3*15= 150000	sqma	(2,3,5,1,1,na) Occupation of Landfill Area sector 3 for its activities (15 years)
Transformation, from dump site, residual landfill material	Areaset3= 100000	sqm	(2,3,5,1,1,na) Transformation from landfill site
Transformation, from pasture, man made	Areaset3= 100000	sqm	(2,3,5,1,1,na) Transformation from pasture site
Transformation, to construction site	Areaset3= 100000	sqm	(2,3,5,1,1,na) Transformation to construction site
Occupation, shrub land, sclerophyllous	Areaset3*30	sqma	(2,3,5,1,1,na) Occupation during the 30 years after the 15, during which the landfill is still considered to be active.
Transformation, to traffic	1800	sqm	Yard: sqm

area			
Occupation, traffic area	1800*50= 90000	sqma	Land use: 5+15+30=60 years
Materials/fuels	**Amount**	**Unit**	**Comments**
Sodium hypochlorite, without water, in 15% solution state {RoW}| sodium hypochlorite production, product in 15% solution state | Alloc Def, U	NaClO*(1-frazemisset12)/Percset3*Perctot= 18.38	metric tons	Material for vapour-scrubber treatment Sodium hypochlorite 15% t/year NaClO*(1-frazemisset12)*Tconfrif
Sulfuric acid {RoW}| production | Alloc Def, U	H2SO4*(1-frazemisset12)/Percset3*Perctot= 66.13	metric tons	Material for vapour-scrubber treatment Sulphuric acid 50% t/year
Sodium tripolyphosphate {RER}| production | Alloc Def, U	Anticalc*(1-frazemisset12)/Percset3*Perctot= 1.57	metric tons	Material for vapour-scrubber treatment Anti-limescale salt (polyphosphates) Sodium tripolyphosphate is assumed instead of polyphosphate Anticalc*(1-frazemisset12)/Percset3*Perctot
Ammonium carbonate {RER}| production | Alloc Def, U	AmACMrb*Tconfrif= 5.4	metric tons	Material for vapour treatment- Drum Ammonium Carbonate t/year AmACMrb*Tconfrif
Expanded clay {RoW}| production | Alloc Def, U	Argillaesp*Tconfrif= 1005	metric tons	LEKA -LATERLITE: extension of leachate wells during the landfill filling and superelevation phase Argillaesp*Tconfrif
Construction of sector 3 of the Castelmaggiore ASA landfill (from Residual material landfill {CH}| construction | Alloc Def, U)	1	p	(1,1,5,1,1,na) demands per kilogram waste. uncertainty is heeded in the module (2,0833E-9p)
Sand {RoW}| gravel and quarry operation | Alloc Def, U	Psabbiacop= 22500	metric tons	FINAL LANDFILL COVER layering includes: 1- first layer of sand(15cm)+clay(35cm) 2- bentonite geocomposite (2 layers of PP and a layer of bentonite) with a thickness of at least 6 mm 3-HDPE geomembrane, with a thickness of 1 mm 4- draining geocomposite → two non-woven geotextiles (tot 2mm) 5- one clay-matrix soil layer Sand cover: t Psabbiacop
Clay {RoW}| clay pit operation | Alloc Def, U (no loop) (machine life 50 years)	Pargcop= 63000	metric tons	Clay cover: t Pargcop
Polypropylene, granulate {RER}| production | Alloc Def, U	Ppcop= 189.2	metric tons	the two layers of PP of the bentonite compound: t Ppcop

Bentonite {RoW}| quarry operation | Alloc Def, U	Bentcop= 860	metric tons	the two layers of PP of the bentonite compound: t Ppcop
Spinning, bast fiber {RoW}| processing | Alloc Def, U	PPcop= 189.2	metric tons	PP spinning: t Ppcop
Weaving, bast fiber {RoW}| processing | Alloc Def, U	PPcop= 189.2	metric tons	PP weaving: t Ppcop
Polypropylene, granulate {RER}| production | Alloc Def, U	PPcop= 189.2	metric tons	drained geotextile layer equal to the two geotextile layers of bentonite composite: t Ppcop
Polyethylene, high density, granulate {RoW}| production | Alloc Def, U	PHDPEcop= 96	metric tons	drained geotextile layer equal to the two geotextile layers of bentonite composite: t Ppcop
Spinning, bast fiber {RoW}| processing | Alloc Def, U	PPcop= 189.2	metric tons	PP spinning: t Ppcop
Weaving, bast fiber {RoW}| processing | Alloc Def, U	PPcop= 189.2	metric tons	PP weaving: t Ppcop
Transport, freight, lorry 16-32 metric ton, EURO6 {RoW}| transport, freight, lorry 16-32 metric ton, EURO6 | Alloc Def, U	(Psabbiacop+Pargcop+PHDPEcop+PPcop+PPcop+Bentcop)*100= 8683440	tkm	Transport of sheeting materials: 100km (Psabbiacop+Pargcop+PHDPEcop+PPcop+PPcop+Bentcop)*100
Electricity/heat	**Amount**	**Unit**	**Comments**
Transport, passenger car, medium size, petrol, EURO 5 {RoW}| transport, passenger car, medium size, petrol, EURO 5 | Alloc Def, U (kg)	benz/dbenz*(Vset3/Vtot)*(Tconfrif+Taftercare)= 6820.54	kg	Vehicles serving the plant, petrol transport: kg/dm^3
Transport, passenger car, medium size, diesel, EURO 5 {RoW}| transport, passenger car, medium size, diesel, EURO 5 | Alloc Def, U (kg)	Gasolio*dgasolio*(Vset3/Vtot)*(Tconfrif+Taftercare)= 7971.44	kg	Landfill sweeper consumption: kg/dm^3
Transport, passenger car, medium size, liquefied petroleum gas, EURO 5 {GLO}| transport, passenger car, medium size, liquefied petroleum gas (LPG), EURO 5 | Alloc Def, U (kg)	GPL*DGPL*(Vset3/Vtot)*(Tconfrif+Taftercare)=71092.03	kg	Office heating system consumption: kg/dm^3

Electricity, low voltage {IT}| electricity voltage transformation from medium to low voltage | Alloc Def, U	Enel*(Vset3/Vtot)*(Tconfrif+Taftercare)= 2417802.074	kWh	Electricity consumed in 2016
Heat, central or small-scale, natural gas {GLO}| propane extraction, from liquefied petroleum gas | Alloc Def, U (kg GPL)	GPL*DGPL*(Vset3/Vtot)*(Tconfrif+Taftercare)= 71092.03	kg	Thermal energy for office heating
Electric Fan + Extraction System (Q=1742Nm^3/h, 9m/sec)	1/tvitaimpasp*tscrub*(Tconfrif+Taftercare)= 1.125	p	The fan, with a power of 5 kW, weighs 50 kg (Direct Industry). The pump is assumed to consist of the following materials: - 60% steel; - 20% copper; - 10% aluminium; - 10% PVC. The system consists of a hood, and a pipe from the chimney and the vent Pcappa+Pcond+Pcam+Pvent = 0,19455t Operating time: 87600h (10 for an annual use of 8760h) Pump lifetime: 26280h (3 years) (number of pumps 87600/26280=3,3333) Flow rate: 2,5/5,1665=0,483889m^3/sec=1742 m^3/h The weights of some electric fan ranges are defined as follows: -50kg from 80000 to 50000Nm^3/h -40kg from 50000 to 30000 -30kg from 30000 to 20000 -20kg from 20000 to 10000 -10kg from 10000 to 250 and the linear interpolation formula is used: 10+ (50-10)/(80000-250)*(Q*3600-250) extraction speed: 9m/sec
Scrubber (flow rate 1742m^3/h) (Alloc, Def)	1/Tvitafiltro*tscrub*(Tconfrif+Taftercare)= 1.971	p	The air sucked into the scrubber is retained there for 2 sec Scrubber volume: 1742/3600*2=0,96778m^3 (Vscrubber) The height is set at: Hcs=Dcs/0,8m 3,1416*(Dcs/2)^2=V/Hcs Dcs=(4*0,8*V1/3,1416)^0,333m Scrubber plant lifetime: 50000h Scrubber weight:(7,8*3,1416*Ss*((2*Dcs/2*Hcs+(Dcs/2)^2)+(Duas+Dcs)/2*((Htcus^2+((Dcs-Duas)/2)^2)^0,5)+(Dcond+Dics)/2*((Htcis^2+((Dcond-Dics)/2)^2)^0,5)))=0,089833t

Electric Fan + Extraction System (Q=411Nm^3/h, 9m/sec) Alloc, Def	1/tvitaimpasp*Tdrum*Tconfrif= 0.375	p	Drum emission point (E1) located above the small leachate pumping tank where it rests temporarily. Chemisorption plant The fan, with a power of 5 kW, weighs 50 kg (Direct Industry). The pump is assumed to consist of the following materials: - 60% steel; - 20% copper; - 10% aluminium; - 10% PVC. The system consists of a hood, and a pipe from the chimney and the vent Pcappa+Pcond+Pcam+Pvent = 0,14785186t Operating time: 87600h (10 for an annual use of 8760h) Pump lifetime: 26280h (3 years) (number of pumps 87600/26280=3,3333) Flow rate: 2,5/21,897804=0,1141667m^{3}sec=411 m^3/h: extraction speed: 9m/sec
Activated carbon filter (Q=411Nm^3/h) (Pca=28,617786kg) (activated carbon with regen.) (multi-output)	1/Tvitafiltro*Tdrum*Tconfrif= 0.657	p	Drum Filter Functional Unit: Activated carbon filter. A filtration speed of vf=1,5m/sec was considered. From here, we calculated the area of the circular section of the filter considering the flow rate in the pipe and matching it to that through the filter (Q= Vi/tric): Af=Q/vf Vi: volume of the system and therefore of the air to be sucked= 2,5m^3 System air exchange time: tric=21,897804sec Filter diameter: Df=2* (Af/3,1416)^0,5 Total filter weight: (Pca/1000/tvitaca*Tvitafiltro+7,8*(2*3,1416*(Df/2)^2+2*3,1416*Df/2*hcf)*scf)=28,617786t activated carbon lifetime: 2400h Filter lifetime: 20000h
Leachate collection tank (ASA landfill) (700m^3)	1/Tvitavasca*(Tconfrif+Taftercare)/(Perctot+Perctot12)*Perctot= 0.594	p	Leachate collection tank for sector 1-2 and 3 Capacity 700m^3 Scrubber
Leachate collection tank (ASA landfill) (700m^3)	1/700*150/Tvitavasca*(Tconfrif+Taftercare)= 0.138	p	Leachate recirculation tank for sector 3 only Capacity 150m^3 Drum
Leachate collection tank (ASA landfill) (700m^3)	1/700*18/Tvitavasca*(Tconfrif+Taftercare)*Vset3/Vtot= 0.0115	p	First rainwater leachate collection tank for sector 1-2 and 3 Capacity 18m^3 Rainfall 2016: 835mm the first rainwater refers to the first 5 minutes of rain, it is assumed that the duration of the rain is 1h yard area: 1800m the first rainwater is: 835E-3*1800/60*5

Leachate collection tank (ASA landfill) ($700m^3$)	1/700*100/Tvitavasca*(Tconfrif+Taftercare)*Vset3/Vtot= 0.064	p	Second rainwater leachate collection tank for sector 1-2 and 3 Capacity $100m^3$ the second rainwater is: 835E-3*1800/60*55 the duration of the rain is 60min, of which 5min are first rain and 55 second rain
Slag sieving	Scincrec= 2969.32	metric tons	Incinerator slag sieving From the 2016 ASA technical report there is: 65573t of non-hazardous waste equal to 43.72% of incoming waste, divided as follows: 29.3% of slag and 15.5% of other 65573/0,4372*0,293=43945,309t 2969,320t exit the vibrosifter used to cover the landfill It is assumed that all slag is sieved. The portion of slag retained by the sieve is equivalent to: 1-(2969,320/43945,309)=93.243%
Revised Chemical-Physical Treatment (CPT)_rev (for hazardous wastewater) (with dehydrated sludge sent to landfill) (multi-output)	(Perctot+835E-3*1800/60*5*(Tconfrif+Taftercare))*1,29= 594592.92	metric tons	Treatment of leachate from sector 3 and first rainwater Wastewater density =1,29t/m^3
Air emissions	**Amount**	**Unit**	**Comments**
Ammonia	CNH3scrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)= 1.5843E10	mg	Scrubber emissions (E2) due to sector 3 and sectors 1-2.
Hydrogen sulphide	CH2Sscrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)= 52811445.16	mg	Scrubber emissions (E2)
Benzene	C6H6scrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289.03	mg	Scrubber emissions (E2)
Methane, dichlorodifluoro-, CFC-12	CCl2F2scrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289.03	mg	Scrubber emissions (E2)
Methane, dichloro-, HCC-30	CH2Cl2scrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289.03	mg	Scrubber emissions (E2)
1,1,2-Trichloro-2-fluoroethane	CFC113scrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289.03	mg	Scrubber emissions (E2)

Chloroform	CHCl3scrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289.03	mg	Scrubber emissions (E2)
Ethane, 1,1,1-trichloro-, HCFC-140	C2H3Cl3scrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289.03	mg	Scrubber emissions (E2)
Methane, tetrachloro-, CFC-10	CCl4scrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289.03	mg	Scrubber emissions (E2)
Propane, 1,2-dichloro-	C3H6Cl2scrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289.03	mg	Scrubber emissions (E2)
Ethene, trichloro-	C2HCl3scrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289.03	mg	Scrubber emissions (E2)
Toluene	Toluenescrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289.03	mg	Scrubber emissions (E2)
Ethene, tetrachloro-	Cl2CCCl2scrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289.03	mg	Scrubber emissions (E2)
Benzene, ethyl-	C8H10scrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289.03	mg	Scrubber emissions (E2)
m-Xylene	mXylenescrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289.03	mg	Scrubber emissions (E2)
Styrene	C8H8scrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289.03	mg	Scrubber emissions (E2)

o-Xylene	oXylenescrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289,03	mg	Scrubber emissions (E2)
Benzene, 1,3,5-trimethyl-	C9H12ascrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289,03	mg	Scrubber emissions (E2)
Benzene, 1,2,4-trimethyl-	C9H12bscrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289,03	mg	Scrubber emissions (E2)
Butadiene, hexachloro-1,3-	C4Cl6scrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289,03	mg	Scrubber emissions (E2)
Ethene, chloro-	C2H3Clscrub*Q*tscrub*(distrconcgasdiscap+distrconcgasdisc45)*(1-frazemisset12)=10562289,03	mg	Scrubber emissions (E2)
Ammonia	CNH3drum*Qdrum*tdrum*distrconcgasdiscap=1223559844	mg	Drum emissions (E1) due to sector 3 only
Hydrogen sulphide	CH2Sdrum*Qdrum*tdrum*distrconcgasdiscap=1518901.875	mg	Drum emissions (E1)
Benzene	C6H6drum*Qdrum*tdrum*distrconcgasdiscap=1518901.875	mg	Drum emissions (E1)
Methane, dichlorodifluoro-, CFC-12	CCl2F2drum*Qdrum*tdrum*distrconcgasdiscap=1518901.875	mg	Drum emissions (E1)
Methane, dichloro-, HCC-30	CH2Cl2drum*Qdrum*tdrum*distrconcgasdiscap=1518901.875	mg	Drum emissions (E1)
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	CFC113drum*Qdrum*tdrum*distrconcgasdiscap=1518901.875	mg	Drum emissions (E1)
Chloroform	CHCl3drum*Qdrum*tdrum*distrconcgasdiscap=1518901.875	mg	Drum emissions (E1)
Ethane, 1,1,1-trichloro-, HCFC-140	C2H3Cl3drum*Qdrum*tdrum*distrconcgasdiscap=1518901.875	mg	Drum emissions (E1)

Methane, tetrachloro-, CFC-10	CCl4drum*Qdrum*tdrum*distrconcgasdiscap=1518901.875	mg	Drum emissions (E1)
Propane, 1,2-dichloro-	C3H6Cl2drum*Qdrum*tdrum*distrconcgasdiscap=1518901.875	mg	Drum emissions (E1)
Ethene, trichloro-	C2HCl3drum*Qdrum*tdrum*distrconcgasdiscap=1518901.875	mg	Drum emissions (E1)
Toluene	Toluenedrum*Qdrum*tdrum*distrconcgasdiscap=1518901,875	mg	Drum emissions (E1)
Ethene, tetrachloro-	Cl2CCCl2drum*Qdrum*tdrum*distrconcgasdiscap=1518901.875	mg	Drum emissions (E1)
Benzene, ethyl-	C8H10drum*Qdrum*tdrum*distrconcgasdiscap=1518901.875	mg	Drum emissions (E1)
m-Xylene	mXylenedrum*Qdrum*tdrum*distrconcgasdiscap=1518901,875	mg	Drum emissions (E1)
Styrene	C8H8drum*Qdrum*tdrum*distrconcgasdiscap=1518901.875	mg	Drum emissions (E1)
o-Xylene	oXylenedrum*Qdrum*tdrum*distrconcgasdiscap=1518901,875	mg	Drum emissions (E1)
Benzene, 1,3,5-trimethyl-	C9H12adrum*Qdrum*tdrum*distrconcgasdiscap=1518901.875	mg	Drum emissions (E1)
Benzene, 1,2,4-trimethyl-	C9H12bdrum*Qdrum*tdrum*distrconcgasdiscap=1518901.875	mg	Drum emissions (E1)
Butadiene, hexachloro-1,3-	C4Cl6drum*Qdrum*tdrum*distrconcgasdiscap	mg	Drum emissions (E1)
Ethene, chloro-	C2H3Cldrum*Qdrum*tdrum*distrconcgasdiscap=1518901.875	mg	Drum emissions (E1)
Ammonia	NH3*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)= 5659226.654	mg	Air emissions of interstitial landfill gases from sector 3. Emission lasts 45 years. Gases come out of the landfill throughout the lifetime of the landfill. This time is divided into the time when the landfill is open (15 years) and the time when it is closed (30 years). The emission curve is constructed by points and contained in the parameters (distrconcgasdiscap+distrconcgasdisc45).

Benzene	benzene*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)= 848883.9982	mg	Benzene
Methane, dichlorodifluoro-, CFC-12	Dicdifmet*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883.9982	mg	Dichlorodifluoromethane
Methane, dichloro-, HCC-30	Dicmet*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883.9982	mg	Dichloromethane
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	trictrifloet*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883.9982	mg	1,1,2-trichloro-2,2,1-trifluoroethane
Chloroform	Tricmet*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883.9982	mg	Chloroform or Trichloromethane
Ethane, 1,1,1-trichloro-, HCFC-140	tricetano*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883.9982	mg	1,1,1-Trichloroethane
Methane, tetrachloro-, CFC-10	Tetraclmet*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883.9982	mg	Tetrachloromethane
Propane, 1,2-dichloro-	Diclprop*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883.9982	mg	1,2-Dichloropropane
Ethene, trichloro-	Tricleti*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883.9982	mg	Trichloroethylene
Toluene	Toluene*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883.9982	mg	Toluene
Ethene, tetrachloro-	Tetetracletil*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883.9982	mg	Tetrachloroethylene
Benzene, ethyl-	Etibenz*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883.9982	mg	Ethylbenzene
m-Xylene	mpxilene*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883.9982	mg	m+p-xylene

Styrene	stirene*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883.9982	mg	styrene
o-Xylene	oxilene*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883,9982	mg	o-xylene
Benzene, 1,3,5-trimethyl-	Atrimetbenz*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883,9982	mg	1,3,5-trimethylbenzene
Benzene, 1,2,4-trimethyl-	Btrimetbenz*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883,9982	mg	1,2,4-trimethylbenzene
Butadiene, hexachloro-	Esaclbut*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883,9982	mg	hexachlorobutadiene
Ethene, chloro-	CVM*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883,9982	mg	vinyl chloride
Ethane thiol	Etilmarcap*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883,9982	mg	ethylmercaptan
Mercaptans, unspecified	npropmercap*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883,9982	mg	n-propyl mercaptan
Mercaptans, unspecified	nbutmercap*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=848883,9982	mg	n-butyl mercaptan
Hydrogen sulphide	H2S*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)=5659226,654	mg	hydrogen sulphide
Asbestos fiber	nfiberam*amianto*1E3*Qdiff*tesal*(distrconcgasdiscap+distrconcgasdisc45)= 65470178,36	mg	Asbestos fibers
Water emissions	**Amount**	**Unit**	**Comments**

Ammonia	NH3acqsup*Vset3/Vtot*1E3*835E-3*1800/60*55*(Tconfrif+Taftercare)= 86057798,76	mg	Emissions into water of the substances contained in the SECOND RAINWATER Average of the MAS1, MAS2 and MAS3 measurements made in 2016: 1,9955556mg/l it is assumed that these measurements relate to the entire landfill and therefore the emissions are allocated according to the ratio of the volume of sector 3 to the total volume of waste total SECOND RAINWATER: the duration of the rain is 60min, of which 5min are first rain and 55 second rain. Annual rainfall (2016): 835 mm 835E-3*1800/60*55*(Tconfrif+Taftercare) m^3 The second rainwater is discharged into the Carsè canal (surface water).
Treatment waste	**Amount**	**Unit**	**Comments**
Long-term groundwater emissions (from Redmud from bauxite digestion {RoW}| treatment of, residual material landfill | Alloc Def, U)	Riftot= 2467655.586	metric tons	Long-term groundwater emissions (>100a) Long-term groundwater emissions from the Ecoinvent database process were considered.
Input parameters	**Amount**	**Unit**	**Comments**
Rif	149996.03	t	Waste treated in 2016: t
Vtot	2119400	m^3	Total volume of waste disposed of in the ASA landfill: m^3
Vset12	768000	m^3	Total volume of waste disposed of in Sectors I and II: m^3
Vset3	1474200	m^3	Total volume of waste disposed of in Sector III: m^3
Areatot	216000	sqm	Total landfill area: sqm
Vrif2016	80463	m^3	Volume occupied by waste 2016: m^3
Areaset12	70000	sqm	Upper area of basins 1 and 2: sqm
Areaset3	100000	sqm	Upper area of basin 3: sqm
Enel	77244	kWh	Electricity used in 2016: kWh
Perc	28983.94	m^3	Leachate produced in 2016 from both sector 3 and sectors 1-2: m^3
Benz	156.89	l	Unleaded petrol consumption: l
Gasolio	296.13	l	Diesel consumption: l
GPL	3950	l	LPG consumption: l
Dbenz	0.72	kg/dm^3	petrol density: 0,720kg/dm^3
Q	1742	Nm^3/h	flow rate of the extraction system on the leachate in the storage tank: Nm^3/h
Dgasolio	0.86	kg/dm^3	diesel density: 0,860kg/dm^3

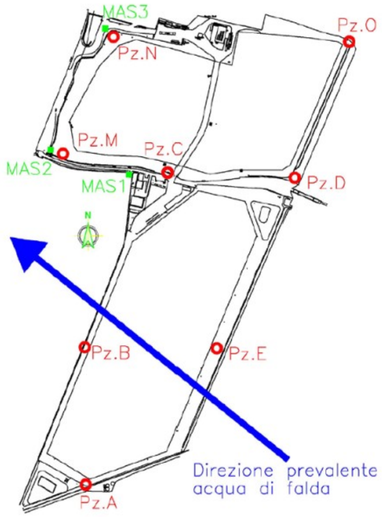
DGPL	0.575	kg/dm3	LPG density: 0,575kg/dm^3
Tvitafiltro	50000	h	filter lifetime: h
tstoc	8760	h/year	leachate storage time: h/year 24h/day for 365 g/year
Tvitaimpasp	87600	h	extraction system lifetime: h
CH2Sscrub	1	mg/Nm3	Scrubber (E2). H2S concentration: mg/Nm^3
C6H6scrub	0.2	mg/Nm3	Scrubber (E2). Benzene concentration: mg/Nm^3
CCl2F2scrub	0.2	mg/Nm3	Scrubber (E2). Dichlorodifluoromethane: mg/Nm^3
CH2Cl2scrub	0.2	mg/Nm3	Scrubber (E2). Dichloromethane: mg/Nm^3
CFC113scrub	0.2	mg/Nm3	Scrubber (E2). 1,1,2-trichloro-2,2,1-trifluoroethane: mg/Nm^3
CHCl3scrub	0.2	mg/Nm3	Scrubber (E2). trichloromethane: mg/Nm^3
C2H3Cl3scrub	0.2	mg/Nm3	Scrubber (E2). 1,1,1-trichloroethane: mg/Nm^3
CCl4scrub	0.2	mg/Nm3	Scrubber (E2). Carbon tetrachloride: mg/Nm^3
C3H6Cl2scrub	0.2	mg/Nm3	Scrubber (E2). 1,2-Dichloropropane: mg/Nm^3
C2HCl3scrub	0.2	mg/Nm3	Scrubber (E2). Trichloroethylene: mg/Nm^3
Toluenescrub	0.2	mg/Nm3	Scrubber (E2). Toluene: mg/Nm^3
Cl2CCCl2scrub	0.2	mg/Nm3	Scrubber (E2). Tetrachloroethylene: mg/Nm^3
C8H10scrub	0.2	mg/Nm3	Scrubber (E2). Ethylbenzene: mg/Nm^3
mXylenescrub	0.2	mg/Nm3	Scrubber (E2). m+p Xylene: mg/Nm^3
C8H8scrub	0.2	mg/Nm3	Scrubber (E2). Styrene: mg/Nm^3
oXylenescrub	0.2	mg/Nm3	Scrubber (E2). o-Xylene: mg/Nm^3
C9H12ascrub	0.2	mg/Nm3	Scrubber (E2). 1,3,5-trimethylbenzene: mg/Nm^3
C9H12bscrub	0.2	mg/Nm3	Scrubber (E2). 1,2,4-trimethylbenzene: mg/Nm^3
C4Cl6scrub	0.2	mg/Nm3	Scrubber (E2). Hexachlorobutadiene: mg/Nm^3

C2H3Clscrub	0.2	mg/Nm^3	Scrubber (E2). Vinyl_Chloride_CVM: mg/Nm^3
H2SO4	4.21	t/year	Consumption of 50% sulphuric acid for scrubber vapour treatment: t/year
NaClO	1.17	t/year	Consumption of sodium hypochlorite for scrubber vapour treatment: t/year
Anticalc	0.1	t/year	Consumption of anti-limescale salt for scrubber vapour treatment: t/year
AmACMrb	0.36	t/year	Consumption of ammonium carbonate for drum-vapour treatment: t/year
Argillaesp	67	t/year	Leachate well filling / raising: t/year
CNH3drum	145	mg/Nm^3	Drum (E1). Ammonia concentration: mg/Nm^3
CH2Sdrum	10	mg/Nm^3	Drum (E1). H2S concentration: mg/Nm^3
C6H6drum	0.18	mg/Nm^3	Drum (E1). Benzene concentration: mg/Nm^3
CCl2F2drum	0.18	mg/Nm^3	Drum (E1). Dichlorodifluoromethane: mg/Nm^3
CH2Cl2drum	0.18	mg/Nm^3	Drum (E1). Dichloromethane: mg/Nm
CFC113drum	0.18	mg/Nm^3	Drum (E1). 1,1,2-trichloro-2,2,1-trifluoroethane: mg/Nm^3
CHCl3drum	0.18	mg/Nm^3	Drum (E1). trichloromethane: mg/Nm^3
C2H3Cl3drum	0.18	mg/Nm^3	Drum (E1). 1,1,1-trichloroethane: mg/Nm^3
CCl4drum	0.18	mg/Nm^3	Drum (E1). Carbon tetrachloride: mg/Nm^3
C3H6Cl2drum	0.18	mg/Nm^3	Drum (E1). 1,2-Dichloropropane: mg/Nm^3
C2HCl3drum	0.18	mg/Nm^3	Drum (E1). Trichloroethylene: mg/Nm^3
Toluenedrum	0.18	mg/Nm^3	Drum (E1). Toluene: mg/Nm^3
Cl2CCCl2drum	0.18	mg/Nm^3	Drum (E1). Tetrachloroethylene: mg/Nm^3
C8H10drum	0.18	mg/Nm^3	Drum (E1). Ethylbenzene: mg/Nm^3
mXylenedrum	0.18	mg/Nm^3	Drum (E1). m+p Xylene: mg/Nm^3
C8H8drum	0.18	mg/Nm^3	Drum (E1). Styrene: mg/Nm^3
oXylenedrum	0.18	mg/Nm^3	Drum (E1). o-Xylene: mg/Nm^3

C9H12adrum	0.18	mg/Nm^3	Drum (E1). 1,3,5-trimethylbenzene: mg/Nm^3
C9H12bdrum	0.18	mg/Nm^3	Drum (E1). 1,2,4-trimethylbenzene: mg/Nm^3
C4Cl6drum	0.18	mg/Nm^3	Drum (E1). Hexachlorobutadiene: mg/Nm^3
C2H3Cldrum	0.18	mg/Nm^3	Drum (E1). Vinyl_Chloride_CVM: mg/Nm^3
Qdrum	411	Nm^3/h	flow rate of the extraction system (drum) on the leachate in the holding tank before the storage tank: Nm^3/h
Taftercare	30	years	landfill activity time after closure: years
Qdiff	112.35312	Nm^3/h	Intake flow rate of interstitial landfill gases: m3/h Q=v*A= 0,0312092m3/sec (see comments)
CNH3scrub	300	mg/Nm^3	NH_3 concentration from the scrubber: mg/Nm^3
Tvitavasca	70	years	Tank lifetime: years
Percset3	27911.64	t/year	Leachate produced in 2016 from sector 3: t/year
Scincrec	296932	t	Recovered incinerator slag used as landfill cover: t
Spstrsabbia	0.15	m	Thickness of sand layer used as cover: m
denssabbia	1.5	t/m3	Density of dry sand cover: t/m^3
spargcop	0.35	m	Clay cover thickness: m
densarg	1.8	t/m^3	Clay cover density: t/m^3
spHDPEcop	0.001	m	HDPE cover thickness: m
densHDPE	0.96	t/m^3	HDPE cover density: t/m^3
spPPcop	0.001	m	PP cover thickness: m
densPP	0.946	t/m^3	PP cover density: t/m^3
spcompbentcop	0.006	m	Thickness of the bentonite composite cover: m
densbent	2.15	t/m^3	Bentonite cover density: t/m^3
Calculated parameters	**Amount**	**Unit**	**Comments**
drif	1.75	t/m^3	Waste density: t/m^3
tfunz	24*365= 8760	h/year	Operating time: h/year
tscrub	24/2*0,5*365=2190	h/year	Scrubber operating time: h/y 30 min (0,5h) every 1,5 h--> Seven days out of seven. So in one day the Scrubber operates: 24/2h*0,5h=6 h
tdrum	6*365=2190	h/year	Drum operating time of 6h/g: h/y
Tconfrif	2019-2004=15	years	Landfill activity time. Time required for the transfer of waste to sector 3: years

Areaimp	Areatot-Areaset3-Areaset12=46000	sqm	Area relating to landfill facilities, offices and roads: sqm
Areaimpset3	Areaimp/(Vtot*drif)*Vset12*drif=16668.87	sqm	Area relating to landfill facilities, offices and roads associated with the sector 3 landfill: sqm
frazemisset12	(Perc-Percset3)/Perc=0.037		portion of waste treated in sectors 1-2 in relation to the total
Qgasdisc	(2*9,81*0,6E-4/1,2)^0,5*A=0.03132	m^3/sec	Landfill gas emission flow rate: m^3/sec
A	1	sqm	Release area: m^2
Riftot	936000*drif+150126.976+140809.58+149996.030+150000+150000+88723= 2467655.586	t	Total mass of waste: t
distrconcgasdiscap	(1/2*12+3+(15/12-1)/2*3)=9.375		Time distribution of landfill gas concentration with landfill open therefore the trend from 0 to 15 years (2016 was the 12th year of activity of the landfill, current situation): maximum emission fraction*number of years. Trend between 0 and 12: C_{0-12}=C/2*12 years Trend between 12 and 15 years: C_{12-15}=C*3years+(C_{max}-C)/2*3years **Total trend between 0 and 15 years** [with C_{max}=C-(15/12)]: C_{0-12}+ C_{12-15}= C* (1/2*12+3+(15/12-1)*1/2)*3=C*9,375
distrconcgasdisc45	15/12*((0.9/2+0,1)*5+0.1/2*25)=5		Time distribution of the landfill gas concentration with landfill closed for 30 years calculated from the maximum concentration in the 15th year: fraction*year - Concentration at 15 years: C_{15}=C_{max}= C-(15/12) - Concentration at 20 years: C_{20}=C_{max}/10 (it is assumed that at 20 years the concentration will decrease to 1/10) - Trend of the concentration between 15 and 20 years: C_{15-20}= (C_{max}-C_{20})/2*(20-15)=9/20*C_{max}*5years - Trend of the concentration at 45 years: C_{45}= C_{20}/2*(45-20) Trend between 15 and 45 years: C_{15}+C_{20}+ C_{15-20}+ C_{45}= C*(15/12*((0,9/2+0,1)*5+0,1/2*25))= C*5
tesal	24*365=8760	h	Duration of landfill gas emissions: h
NH3	0.1+0.1+0.1+0.1=0.4	mg/Nm^3	interstitial gas concentrations at the 4 sampling points in sector 3 (diffuse emissions measured in 2016): mg/m3
Benzene	0.015*4=0.06	mg/m^3	Landfill gas emission: benzene: mg/Nm^3
Dicdifmet	0.015*4=0.06	mg/m^3	Landfill gas emission: Dichlorodifluoromethane: mg/Nm^3
Dicmet	0.015*4=0.06	mg/m^3	Landfill gas emission: Dichloromethane: mg/Nm^3

trictrifloet	0.015*4=0.06	mg/m^3	Landfill gas emission: 1,1,2-trichloro-2,2,1-trifluoroethane: mg/Nm^3
Tricmet	0.015*4=0.06	mg/m^3	Landfill gas emission: Trichloromethane: mg/Nm^3
tricetano	0.015*4=0.06	mg/m^3	Landfill gas emission: 1,1,1-Trichloroethane: mg/Nm^3
Tetraclmet	0.015*4=0.06	mg/m^3	Landfill gas emission: Tetrachloromethane: mg/Nm^3
Diclprop	0.015*4=0.06	mg/m^3	Landfill gas emission: 1,2-Dichloropropane: mg/Nm^3
Tricleti	0.015*4=0.06	mg/m^3	Landfill gas emission: Tricolouroethylene: mg/Nm^3
Toluene	0.015*4=0.06	mg/m^3	Landfill gas emission: Toluene: mg/Nm^3
Tetetracletil	0.015*4=0.06	mg/m^3	Landfill gas emission: Tetrachloroethylene: mg/Nm^3
Etibenz	0.015*4=0.06	mg/m^3	Landfill gas emission: Ethylbenzene: mg/Nm^3
mpxilene	0.015*4=0.06	mg/m^3	Landfill gas emission: m+p-xylene: mg/Nm^3
styrene	0,015*4=0.06	mg/m^3	Landfill gas emission: styrene: mg/Nm^3
oxilene	0.015*4=0.06	mg/m^3	Landfill gas emission: o-xylene: mg/Nm^3
Atrimetbenz	0.015*4=0.06	mg/m^3	Landfill gas emission: 1,3,5-trimethylbenzene: mg/Nm^3
Btrimetbenz	0.015*4=0.06	mg/m^3	Landfill gas emission: 1,2,4-trimethylbenzene: mg/Nm^3
Esaclbut	0.015*4=0.06	mg/m^3	Landfill gas emission: hexachlorobutadiene: mg/Nm^3
CVM	0.015*4=0.06	mg/m^3	Landfill gas emission: vinyl chloride: mg/Nm^3
Etilmarcap	0.0015*4=0.006	mg/m^3	Landfill gas emission: ethylmercaptan: mg/Nm^3
npropmercap	0.0015*4=0.006	mg/m^3	Landfill gas emission: n-propyl mercaptan: mg/Nm^3
nbutmercap	0.0015*4=0.006	mg/m^3	Landfill gas emission: n-nbutyl mercaptan: mg/Nm^3
H2S	0.1*4=0,4	mg/m^3	Landfill gas emission: hydrogen sulphide: mg/Nm^3
nfiberam	4.6275	f/l	Landfill gas emission: asbestos fibers: f/l
Asbestos	0.001	mg	Average weight of asbestos fiber: mg

NH3acqsup	(1,1+3,2+0,21+0,41+0,1++2,2+3,4+1,3+5,8+3,7+0,1+0,21+2,3+0,84+0,45+3,4+0,1+7,1)/18=1,9956	mg/l	Concentrations measured twice a year from 2014 to 2016 at points MAS1, MAS2 and MAS3. Source: *Technical Report 2016*, page 7 table 3 “**Surface water monitoring**”.  Chlorides and sulphates were also measured. LCA calculation methods do not consider chlorides or sulphates in the categories of human health and water ecotoxicity.
Aldiscset3	Vset3/Areaset3=14, 742	m	Waste height in sector 3: m
Psabbiacop	Areaset3*Spstrsabbia*denssabbia=22500	t	The sand cover has a thickness of 0,15m: t
Pargcop	Areaset3*Spargcop*densarg=63000	t	The clay cover has a thickness of 0,35m: t
PHDPEcop	Areaset3*SpHDPEcop*densHDPE=96	t	The HDPE cover has a thickness of 0,001m: t
PPcop	2*Areaset3*SpPPcop*densPP=189,2	t	2 PP textiles for the bentonite geocomposite cover: a thickness of 0,001m is assumed for each: t
Bentcop	Areaset3*(spcompbentcop-2*SpPPcop)*densbent=860	t	Bentonite for bentonite geocomposite cover: t
A0	(2004-2003)*1600/2=800	m^3/year	Data provided directly by ASA spa. Sector 3 leachate produced in 2004 Area A0=(2004-2003)*1600/2=800
A1	(2008-2004)*(26015-1600)/2=48830	m^3/year	Sector 3 leachate produced in 2004-2008 Area A1=(2008-2004)*(26015-1600)/2=48830
A1,1	(2008-2004)*1600=6400	m^3/year	Sector 3 leachate produced in 2004-2008 Area A1,1= (2008-2004)*1600=6400
A2	(2019-2008)*26015=286165	m^3/year	Sector 3 leachate produced in 2008-2019 Area A2=(2019-2008)*26015=286165
A3	(2021-2019)*(26015-26015*1065/9227)/2=23012,2932	m^3/year	Sector 3 leachate produced in 2019-2021 Area A3=(2021-2019)*(26015-26015*1065/9227)/2=23012,2932
A4	(2021-2019)*(26015*1065/9227)=6005,4135	m^3/year	Sector 3 leachate produced in 2019-2021 Area A4=(2021-2019)*(26015*1065/9227)=6005,4135

A5	(2031-2021)*(26015*1065/9227) =30027.067	m^3/year	Sector 3 leachate produced in 2021-2031 Area A5=(2031-2021)*(26015*1065/9227)=30027,067
A6	(2049-2031)*(26015*1065/9227) =54048.721	m^3/year	Sector 3 leachate produced in 2031-2049 Area A6=(2049-2031)*(26015*1065/9227)=54048,721
Perctot	A0+A1+A11+A2+A3+A4+ A5+A6=455288.4952	m^3/year	Total leachate produced in sector 3
B3	(2007-2005)*(9227-1450)/2=7777	m^3/year	Sector 1-2 leachate produced in 2005-2007 Area B3=(2007-2005)*(9227-1450)/2=7777
B4	(2007-2005)*1450=2900	m^3/year	Sector 1-2 leachate produced in 2005-2007 Area B4=(2007-2005)*1450=2900
B5	(2016-2007)*1450=13050	m^3/year	Sector 1-2 leachate produced in 2007-2016 Area B5=(2016-2007)*1450=13050
B6	(2035-2016)*1450/2=13775	m^3/year	Sector 1-2 leachate produced in 2016-2035 Area B6=(2035-2016)*1450/2=13775
Perctot12	B3+B4+B5+B6=37502	m^3/year	Total leachate produced in sector 1-2

Table 17-44: Inventory table "ASA landfill for hazardous and non-hazardous special waste (with CPT) (Multi-output) (Final)"

The landfill construction inventory table (Table 17-48) is shown below, which was drawn up from a special waste landfill process of the Ecoinvent v3 Database (*Residual material landfill {CH}| construction | Alloc Def, U*).

Products	**Amount**	**Unit**	**Comments**
Construction of sector 3 of the Castelmaggiore ASA landfill (from Residual material landfill {CH}| construction | Alloc Def, U)	1	p	Construction phase is 5 years; use phase is 30 years; aftercare phase is 40 years.
Resources	**Amount**	**Unit**	**Comments**
Occupation, traffic area, road network	Areaimpset3*75= 2399731.056	sqma	
Transformation, from pasture, man made	Areaimpset3=31996.414	sqm	
Transformation, to traffic area, road network	Areaimpset3=31996.414	sqm	
Materials/fuels	**Amount**	**Unit**	**Comments**
Excavation, skid-steer loader {GLO}| market for | Alloc Def, U	158000/VdiscEcoinvent*Vset3=77.6412	m^3	
Concrete, sole plate and foundation {CH}| market for | Alloc Def, U	10,8/VdiscEcoinvent*Vset3 =53.0712	m^3	
Polyethylene, high density, granulate {GLO}| market for | Alloc Def, U	118000/VdiscEcoinvent*Vset3=57.9852	kg	

Extrusion, plastic film {GLO}| market for | Alloc Def, U	29000/VdiscEcoinvent*Vset3=142506	kg	
Gravel, round {CH}| market for gravel, round | Alloc Def, U	95000000/VdiscEcoinvent*Vset3=466830000	kg	
Excavation, hydraulic digger {GLO}| market for | Alloc Def, U	158000/VdiscEcoinvent*Vset3=776412	m^3	
Pitch {CH}| market for pitch | Alloc Def, U	1640000/VdiscEcoinvent*Vset3=8058960	kg	
Electricity/heat	**Amount**	**Unit**	**Comments**
Diesel, burned in building machine {GLO}| market for | Alloc Def, U	858000/VdiscEcoinvent*Vset3=4216212	MJ	
Input parameters	**Amount**	**Unit**	**Comments**
Rif2016	149996,03	metric tons	Waste treated in 2016: t
Vtot	2119400	m^3	Total volume of waste disposed of at Castelmaggiore landfill: m^3
Vset3	1474200	m^3	Total volume of waste disposed of at Castelmaggiore landfill for sector 3: m^3
Areatot	216000	sqm	Total landfill area: sqm
Areaset12	70000	sqm	Upper area of basins 1 and 2: sqm
Areaset3	100000	sqm	Upper area of basin 3: sqm
VdiscEcoinvent	300000	m^3	Landfill volume from Residual material landfill {CH}| construction | Alloc Def, U of the Ecoinvent database: m^3
Calculated parameters	**Amount**	**Unit**	**Comments**
Areaimp	Areatot-Areaset3-Areaset12=46000	sqm	Area relating to landfill facilities, offices and roads: sqm
Areaimpset3	Areaimp/(Vtot*drif)*Vset3*drif=31996,414	sqm	Area relating to landfill facilities, offices and roads associated with the sector 3 landfill: sqm
drif	1,75	t/m^3	Waste density
Tconf	2019-2004= 15	years	years of waste disposal (years landfill is open)
Riftot	936000*drif+150126,976+140809,58+149996,030+150000+150000+88723=2467655,586	m^3	Total mass of waste: t

Table 17-45: Inventory table for "Residual material landfill {CH}| construction | Alloc Def, U" process

17.6.1.3. Environmental damage analysis of the ASA spa landfill site in Castel Maggiore (BO)

17.6.1.3.1. Damage assessment

The process analysed is ASA landfill for hazardous and non-hazardous special waste (with CPT) (Multi-output) (Final) for 1 kg. This process follows the LCI multi-output modelling. The process is found in the Simapro software v8.5.2e and in the Database: LCA2_DatabaseUNIMORE: Waste scenario_PRGR E-R processi regionali/neri/paolo/waste treatment/Incinerition/Municipal incenerition/transformation. The calculation was performed using the IMPACT 2002+260218indoor/ locali_riferimento_Finale V2.12 / IMPACT 2002+ method. Below is the damage assessment diagram by impact category of the process considered (Figure 17-44).

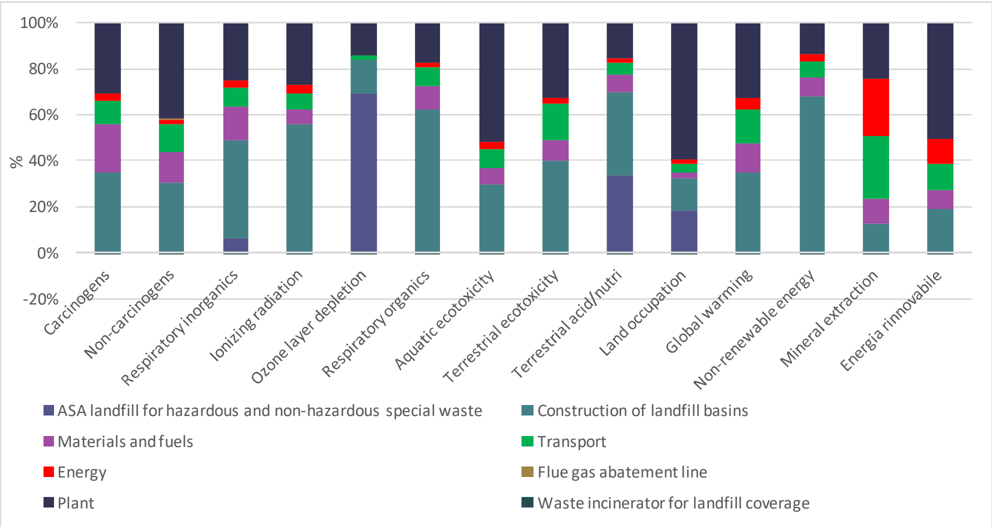


Figure 17-44: Diagram showing the damage assessment by impact category of the ASA landfill for hazardous and non-hazardous special waste (with CPT) (Multi-output) (Final) process

From the damage assessment it is noted that:

- for **Human health**, the damage is 1.0422-8DALY, with 30.23% related to *Particulates, <2,5 μm* and 22.9% to *Nitrogen oxides*, 13.9% and 25.17% of which is due to Diesel, burned in building machine {GLO}| market for | Alloc Def, U (diesel consumption for landfill construction), respectively, and 13.26% related to *Sulphur dioxide*, 26.85% to Waste natural gas, sour {GLO}| treatment of, burned in production flare | Alloc Def, U, the end of life process of acid natural gas waste used for the production of bitumen for landfill construction.
- The impact category that produces the maximum damage is **Respiratory inorganics** (0.8985E-8 DALY, 86.21%).

The contribution of emissions to the Human Health category is shown below (Figure 17-45).

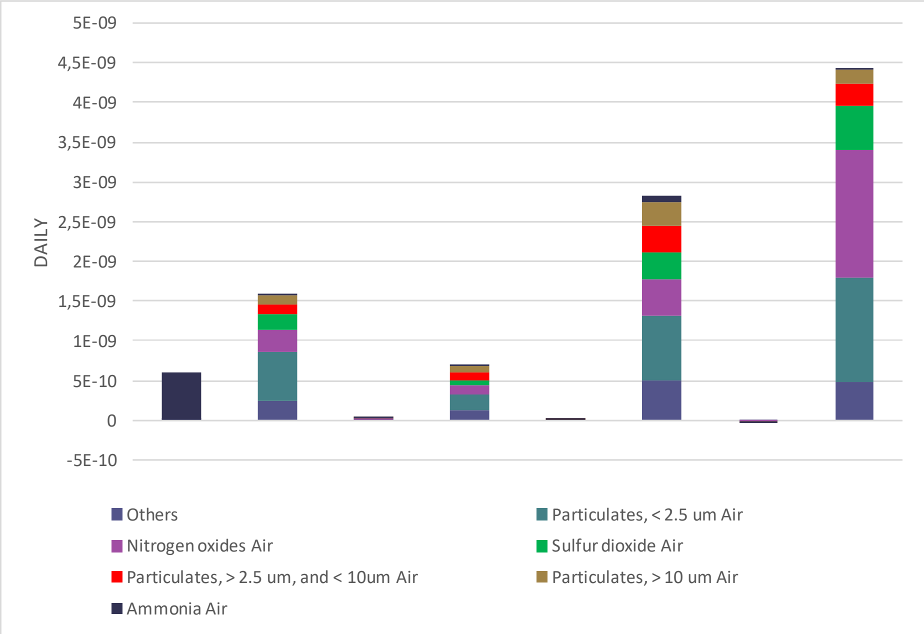


Figure 17-45: Table of the contribution of emissions to the Human Health damage category

- for **Ecosystem quality**, the damage is 0.00731 PDF*sqm*yr, with 18.74% related to *Occupation, dump site* (land occupation of the landfill (15 years)), 14.85% to *Occupation, shrub land, sclerophylous* (land occupation for the post-mortem phase for vegetation regrowth (40 years)), and 16.29% to *Occupation, traffic area, road network* related to land occupation for the landfill construction phase. The impact category that produces the maximum damage is **Land occupation** (0.004554 PDF*sqm*yr, 62.29%).

The contribution of emissions to the Ecosystem Quality category is shown below (Figure 17-46).

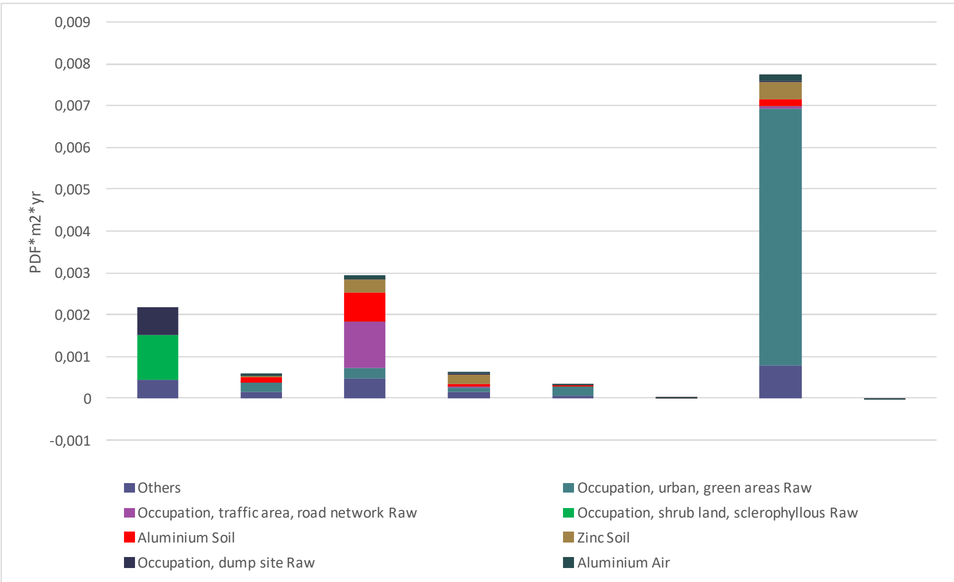


Figure 17-46: Table of the contribution of emissions to the Ecosystem Quality damage category

- for **Climate change**, the damage is 0.0082 kg CO_2eq., with 94.02% due to *Carbon dioxide, fossil* in air and, in particular, to the process of incineration of hazardous sludge in the chemical-physical treatment of leachate.

The contribution of emissions to the Climate Change category is shown below (Figure 17-47).

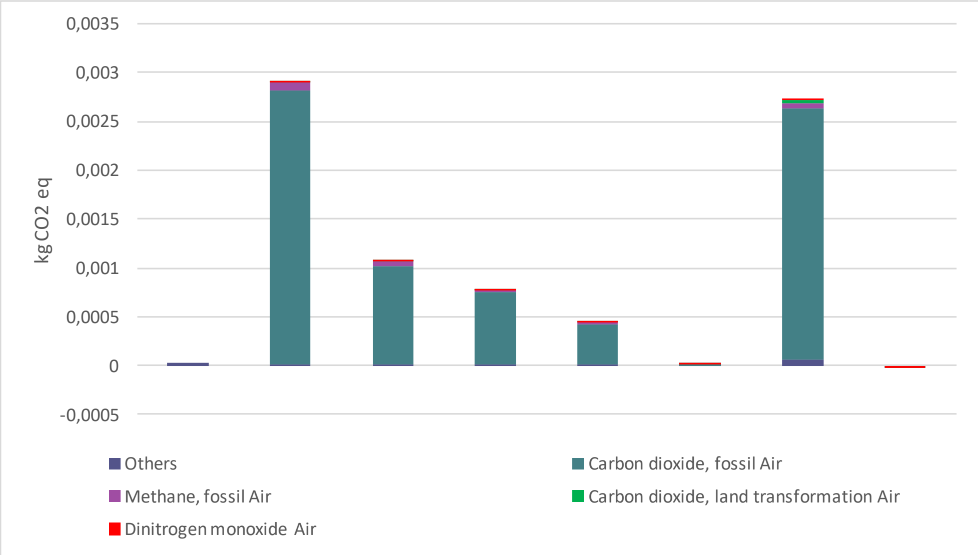


Figure 17-47: Table of the contribution of emissions to the <u>Climate Change</u> damage category

- for **Resources**, the damage is 0.305 MJ, with 73.4% due to *Oil, crude* and, in particular 27.6% to <u>Petroleum {RoW}| petroleum and gas production, on-shore | Alloc Def, U</u>, petroleum used in the production of the impermeable landfill layer (pitch), and 10.72% to Gas, natural/m^3, in particular, 17.25% to the use of HDPE for the production of the geotextile layer of the final landfill cover. The impact category that produces the maximum damage is **Non-renewable energy** (0.298MJ surplus, 97.7%).

The contribution of emissions to the Resources category is shown below (Figure 17-48).

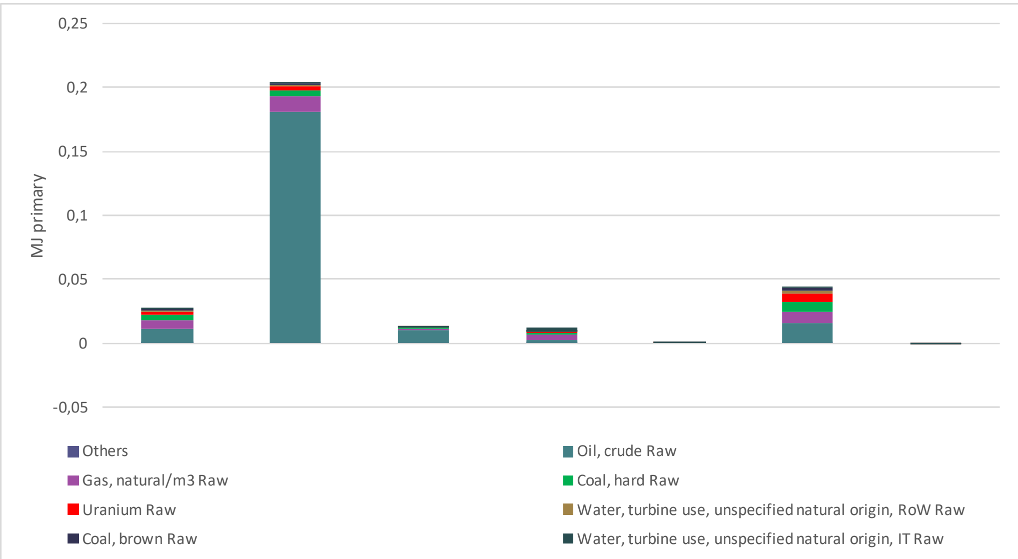


Figure 17-48: Table of the contribution of emissions to the <u>Resources</u> damage category

17.6.1.3.2. Single score assessment

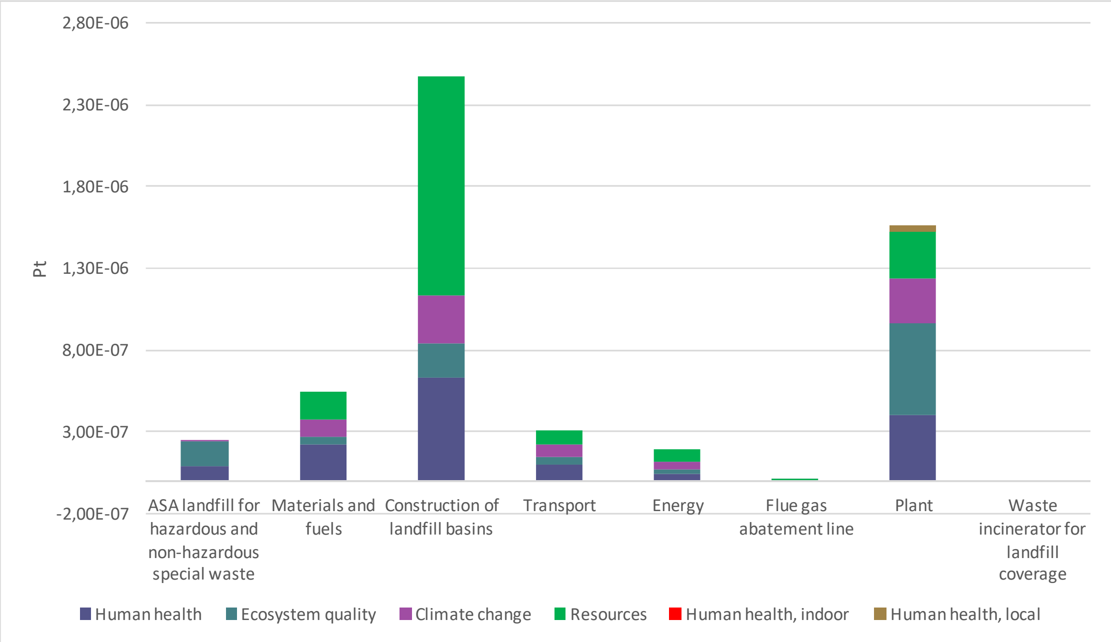


Figure 17-49: Diagram showing the single score damage assessment for the <u>ASA landfill for hazardous and non-hazardous special waste (with CPT) (Multi-output) (Final)</u> process

From the analysis of the assessment results (Figure 17-49), it can be seen that the total damage is 4.8733E-6 Pt, with 50.76% due to the construction of sector 3 of the landfill, 21.37% to the chemical-physical treatment of leachate and rainwater, 6.11% to direct emissions from the landfill, 4.53% to the consumption of LPG for office heating, and 3.71% to the annual consumption of electricity. In addition, 30.15% of the damage is related to **Human health**, 10.95% to **Ecosystem quality**, 17.02% to **Climate change**, and 41.21% to **Resources** (Table 17-46).

Impact category	%	Damage category	%
Carcinogens	2.93	Human Health	30.15
Non-carcinogens	1.03		
Respiratory inorganics	26		
Ionizing radiation	0.11		
Ozone layer depletion	0.047		
Respiratory organics	0.039		
Aquatic ecotoxicity	0.113	Ecosystem Quality	10.95
Terrestrial ecotoxicity	3.56		
Terrestrial acid/nutri	0.452		
Land occupation	6.82		
Aquatic acidification	0		
Aquatic eutrophication	0		
Global warming	17.02	Climate Change	17.02
Non-renewable energy	40.28	Resources	41.21
Mineral extraction	0.933		

Table 17-46: Summary table of single score results as % of total damage

Analysis of the results with system expansion showed that the total damage is 4.5968E-6 Pt, with a 5.67% decrease compared to the multi-output model. In addition, 58.36% of the total damage is due to the construction of sector 3 of the landfill, 8.99% to the chemical-physical treatment of leachate and rainwater, 6.48% to direct emissions from the landfill, 5.85% to the consumption of LPG for office heating, and 2.79% to the annual consumption of electricity. In addition, 31.63% of the damage is related to **Human health**, 14.25% to **Ecosystem quality**, 16.95% to **Climate change**, and 36.46% to **Resources**. As can be seen, the trend of the results for this type of waste treatment does not change with the use of different LCI models, and so only the detailed environmental results obtained using the multi-output approach are reported.

17.6.1.3.3. Analysis of the single score results for the process that causes the greatest damage (landfill construction)

The calculation was carried out for 1 p of the Construction of sector 3 of the Castelmaggiore ASA landfill (from Residual material landfill {CH}| construction | Alloc Def, U) process.

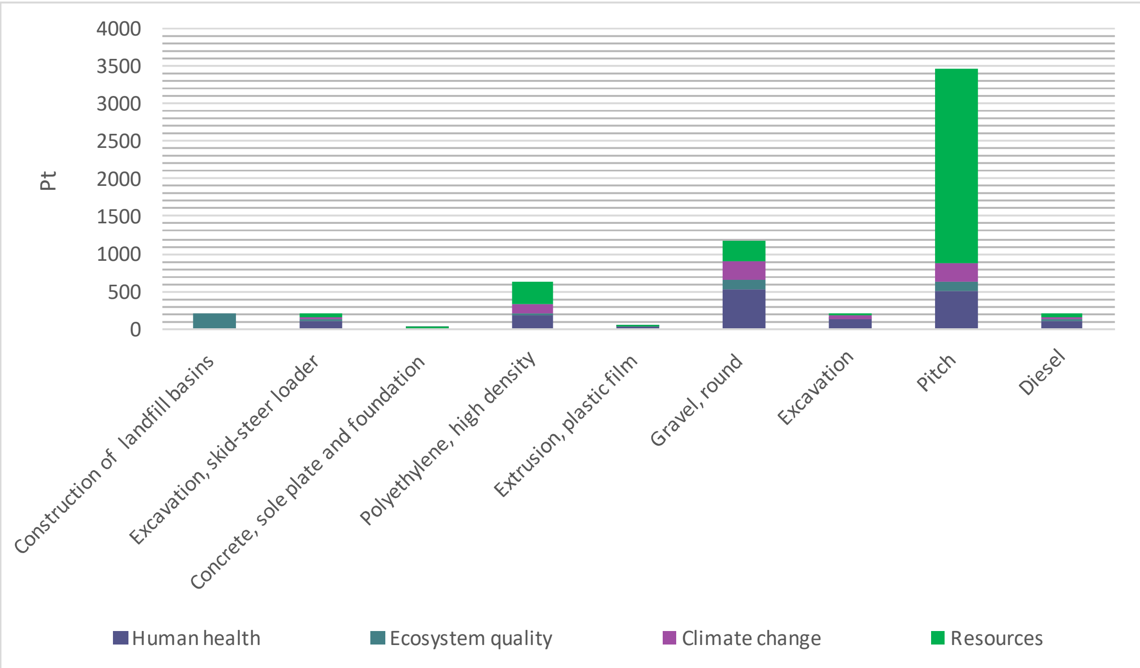


Figure 17-50: Table of the single score assessment by 1 p impact category the Construction of sector 3 of the Castelmaggiore ASA landfill (from Residual material landfill {CH}| construction | Alloc Def, U) process

From the analysis of the 1 p damage assessment (Figure 17-50) of the process, it is noted that:

- for **Human health**, the damage is 10.94 DALY/p, with 34.08% due to *Nitrogen oxides* and 30.33% to *Particulates, <2,5 µm*, in particular, 29.68% and 24.32% related to Diesel, burned in building machine {GLO}| market for | Alloc Def, U, respectively.
- for **Ecosystem quality**, the damage is 6,187,411.72/p PDF*n^2*yr, with 44.37% related to *Occupation, traffic area, road network* due to land occupation for the landfill construction phase, and 24.12% to *Aluminium* in soil, and, in particular, 98.07% related to the Drilling waste {CH} | treatment of, landfarming | Alloc Def, U process, end of life of waste from drilling to obtain petroleum to produce the impermeable landfill material (pitch).
- for **Climate change**, the damage is 7,186,041.654 kg CO_2eq/p,$_2$eq/p, with 95.24% due to*Carbon dioxide*, *fossil* in air and, in particular, 12.86% from the Diesel, burned in building machine {GLO}| market for | Alloc Def, U process, consumption of diesel used for landfill construction.

- for **Resources**, the damage is 514,221,475.3 MJ primary/p, with 87.72% due to *Crude Oil* and, in particular, 28.73% to Petroleum {RoW}| petroleum and gas production, on-shore | Alloc Def, U, petroleum used for the production of the impermeable landfill layer (pitch).

Considering 1 p of landfill construction and that the total special waste treated is 2,467,655,586 kg, the share of landfill construction per 1 kg of waste is 1p/2.467.655.586 kg=4,0524E-10 p/kg. From the analysis of the 1 p landfill construction assessment results, it can be seen that the total damage is 6,103.708 Pt/p (6,103.708 Pt/p*4.0524E-10 p/kg= 2.473E-6 Pt/kg of special waste), with 57.85% due to the production of waterproofing material (Pitch {CH}| market for pitch | Alloc Def, U), 19.26% to Gravel, round {CH}| market for gravel, round | Alloc Def, U (gravel, material used for the construction of the landfill site), and 9.01% to Polyethylene, high density, granulate {GLO}| market for | Alloc Def, U (HDPE, material used for the construction of the landfill site). In addition, 25.27% of the damage is related to **Human health**, 7.4% to **Ecosystem quality**, 11.89% to **Climate change**, and 55.43% to **Resources**.

17.6.1.4. Conclusions

The environmental impact analysis of 1 kg of special waste transferred to the ASA spa landfill in Castel Maggiore (BO) showed that the total damage is 4.8733E-6 Pt , with 50.76% due to the construction of the site of sector 3 of the landfill (mainly due to the production of waterproofing material), 21.37% to the chemical-physical treatment of leachate and rainwater, 6.11% to direct emissions from the landfill, 4.53% to the consumption of LPG for office heating, and 3.71% to the annual consumption of electricity. In addition, 41.21% of the damage is related to **Resources** (mainly for the substance *Oil, crude* and, in particular, *Petroleum {RoW}| petroleum and gas production, on-shore | Alloc Def, U*, petroleum used for the production of the impermeable landfill layer), 30.15% to **Human health** (the damage is mainly due to *Particulates, <2,5⌠m* in air due to the consumption of diesel for landfill construction), 17.02% to **Climate change**, and 10.95% to **Ecosystem quality**.

17.6.1.5. Sensitivity analysis

17.6.1.5.1. ACM management with transfer to landfill and asbestos fibers inhaled by the worker during the removal phase

The process designed for 150 metric tons is ACM treatment by landfill (with asbestos fibers inhaled by the worker) The method used for damage calculation is IMPACT 2002+010419indoor/locali_rifIPCCAmAmlavCest V2.12.

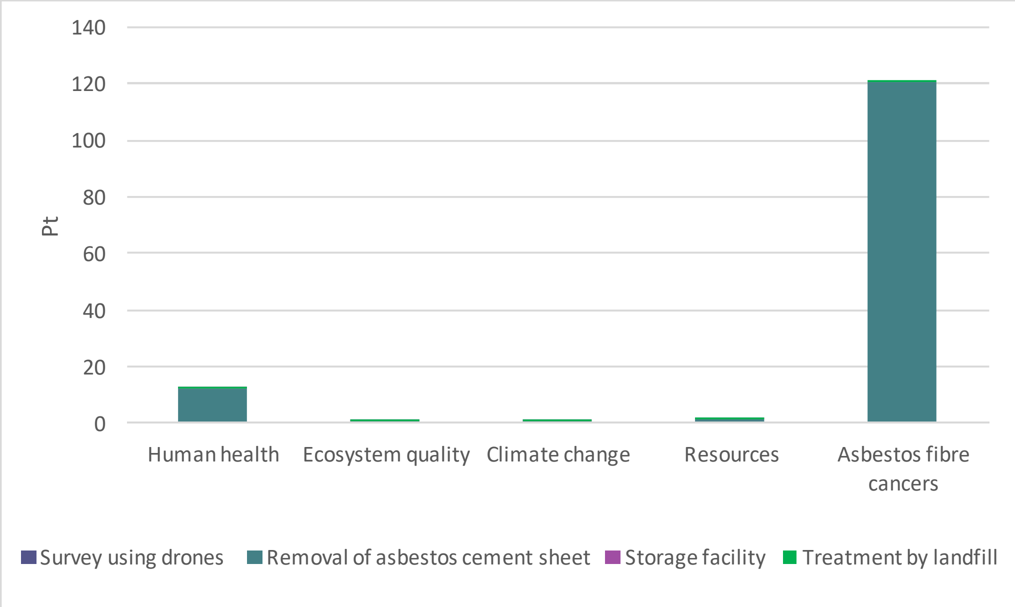


Figure 17-51: Diagram showing the single score assessment and damage category of the ACM treatment by landfill (with asbestos fibers inhaled by the worker) process

The ACM management with end of life in landfill process, with asbestos fibers inhaled by the worker during the removal, produces a damage of 135.85918 Pt, with 99.36% due to the removal of the sheet (Figure 17-51). Landfill affects the total score by 0.61%.

17.6.1.5.2. Comparison of landfill for hazardous and non-hazardous special waste located in Italy and landfill (of the same type) located in Germany

The following processes were compared:

- "ASA landfill for hazardous and non-hazardous special waste (with CPT) (Multi-output) (Final)_rev Internal costs": in this process, it was assumed that ACW is transported to a landfill site in Italy (100 km);
- "ASA landfill for hazardous and non-hazardous special waste (with CPT) (Multi-output) (Final)_rev Internal costs (with transport of sheeting to Germany 700 km instead of 100 km)": in this process, it was assumed that ACW is transported to a landfill site in Germany (700 km).

The calculation was made for 150 metric tons using the IMPACT 2002+010419indoor/locali_rif_IPCC+Amtot V2.12 / IMPACT 2002+ method.

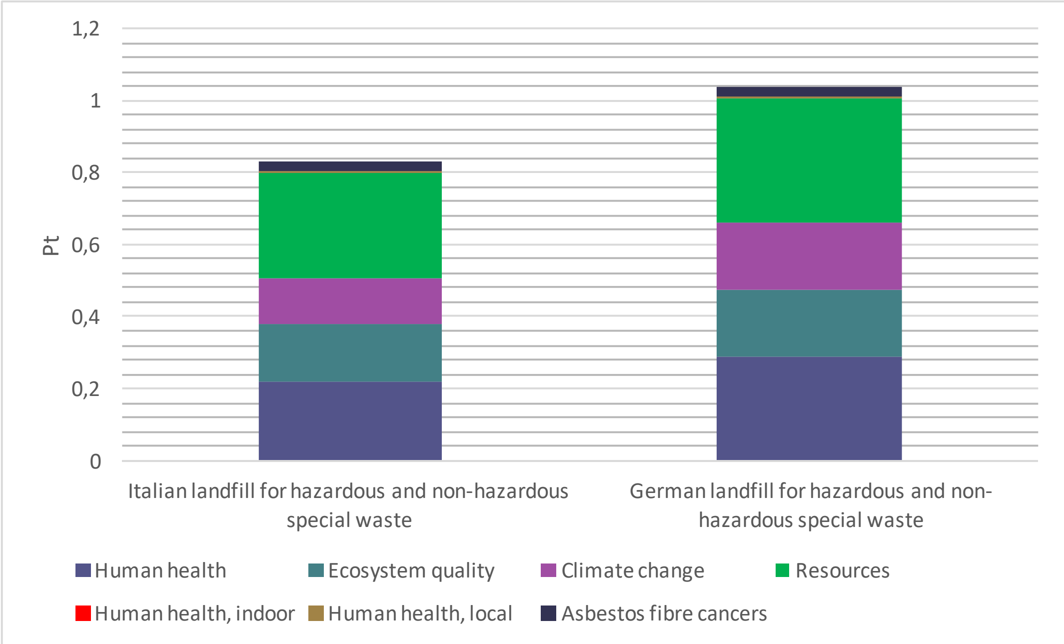


Figure 17-52: Diagram showing the assessment of the comparison of the damage caused by the transferring ACM sheets to a landfill in Italy or to a landfill in Germany

From the comparison (Figure 17-52), it can be seen that the transfer to a hazardous and non-hazardous special waste landfill in Germany produces damage of 1.0369 Pt, while the transfer to a landfill of the same type located in Italy produces damage of 0.829 Pt (-25.08%). Compared to the scenario which ends in Italy, the category with the highest increase is **Climate change**, with 41.84% due to an increase in the emission of *Carbon dioxide, fossil* due to transport. This is followed by an increase in **Human Health** of 29.75% due to an increase in *Particulates emission, <2,5⌈m*, and an increase in the **Ecosystem quality** category with 20% mainly due to a higher emission of *Zinc* in soil. Finally, there is a 19.27% increase in the **Resources** category due to an increase in the use of *Crude oil.*

17.6.1.5.3. Changes to the ACM management with landfill treatment of ACW process

The following changes were made to the landfill process described in section 17.6.1.3:

- Occupation of the land by landfill (dump site): 1,000 years instead of 15 because the land cannot be used except for the planting of small vegetation. Indeed, the landfill cover limits the length of the roots. The occupation was maintained as a landfill (dump site). It can be assumed that the damage to biodiversity remains the same as that of a landfill site for 1,000 years.
- Discharge time for all emissions: tesal=100 years. In particular, emissions of asbestos fibers were considered for 100 years instead of 24 years. This could be due to the following possible sequence of events:
    1. Breakage of the reinforced concrete shell after 70 years.
    2. Breakage of the HDPE sheet isolating the landfill from the ground below after 50 years of sealing.
    3. Leakage of asbestos fibers into the groundwater.
    4. Leakage of asbestos fibers that are captured by the air and water pores which together with organic matter and inorganic substance, make up the structure of the soil.

5. The fibers can reach the ground surface and go into the atmosphere.
- The carcinogenic effect of asbestos fibers in water has not been considered because it has not yet been proven, as discussed in Section 16.2.

The details of landifills' risks described above were discussed in chapter 15.1 "*Landfill disposal*".

17.6.1.5.4. Comparison between different landfill treatment processes

The processes ASA landfill for hazardous and non-hazardous special waste (with CPT) (Multi-output) (Final)_rev and ASA landfill for hazardous and non-hazardous special waste (with CPT) (Multi-output) (Final)_rev1 (with 1000y occupation and discharge time of emissions of 100 years) were compared for 150 metric tons. The following method was used for the calculation: IMPACT 2002+010419indoor/locali_rif_IPCC+Am+Amlav V2.12 / IMPACT 2002+.

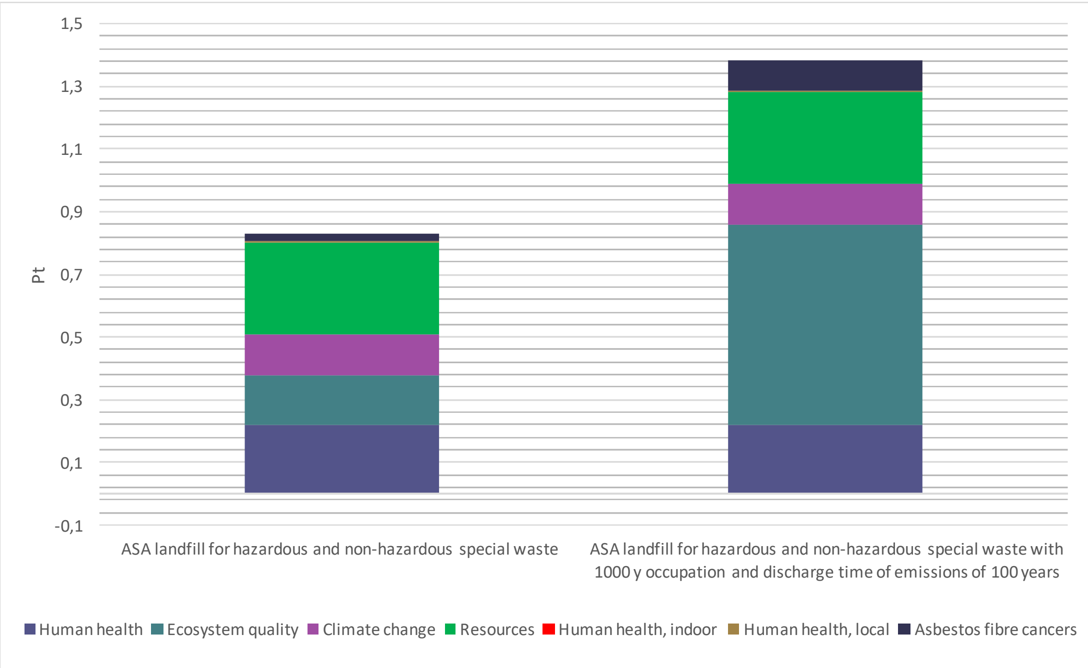


Figure 17-53: Diagram showing the damage assessment for the comparison between the processes ASA landfill for hazardous and non-hazardous special waste (with CPT) (Multi-output) (Final)_rev and ASA landfill for hazardous and non-hazardous special waste (with CPT) (Multi-output) (Final)_rev1 (with 1000y occupation and discharge time of emissions of 100 years)

The damage of the landfill from the database is 0.829 Pt, while that of the landfill with 1,000 years of occupation and 100 years of emissions is 1.383 Pt (Figure 17-53). The damage category that increases the most is Tumors from asbestos fibers (+312.4%) followed by an increase of 305.55% in Ecosystem quality, especially relating to *Occupation, dump site*. The other damage categories show an increase of less than 1%.

17.6.2. Chemical-physical treatment

17.6.2.1. Objectives and field of application

17.6.2.1.1. Objectives

The aim of the study is the environmental assessment of the damage due to the transfer of asbestos containing waste (ACW) to a chemical-physical treatment plant.

17.6.2.2. Field of application

17.6.2.2.1. System purpose

The function of the system is to transfer ACW.

17.6.2.2.2. The analysed system

The plant described below, patented by Chemical Center S.r.l. (Application number: MI2010A001443), is designed to chemically break down asbestos fibers (mainly chrysotile), contained within asbestos cement products. The plant has the capacity to process a total daily quantity of 60 metric tons of asbestos cement products, corresponding to a quantity of 15,000 metric tons for 250 days of activity.

17.6.2.2.3. Functional unit

The function of the system is the mass of asbestos containing materials treated by the plant in 15 days of operation.

17.6.2.2.4. System boundaries

The system boundaries range "*from cradle to grave*", i.e. from the construction of the plant, considering all the materials necessary for implementation, to the assessment of all the plant necessary for its management, to the transport of the vehicles serving the plant, to the consumption of electricity and thermal energy, and to the assessment of the emissions and end-of-life treatment.
The process flowchart is shown below (Figure 17-54).

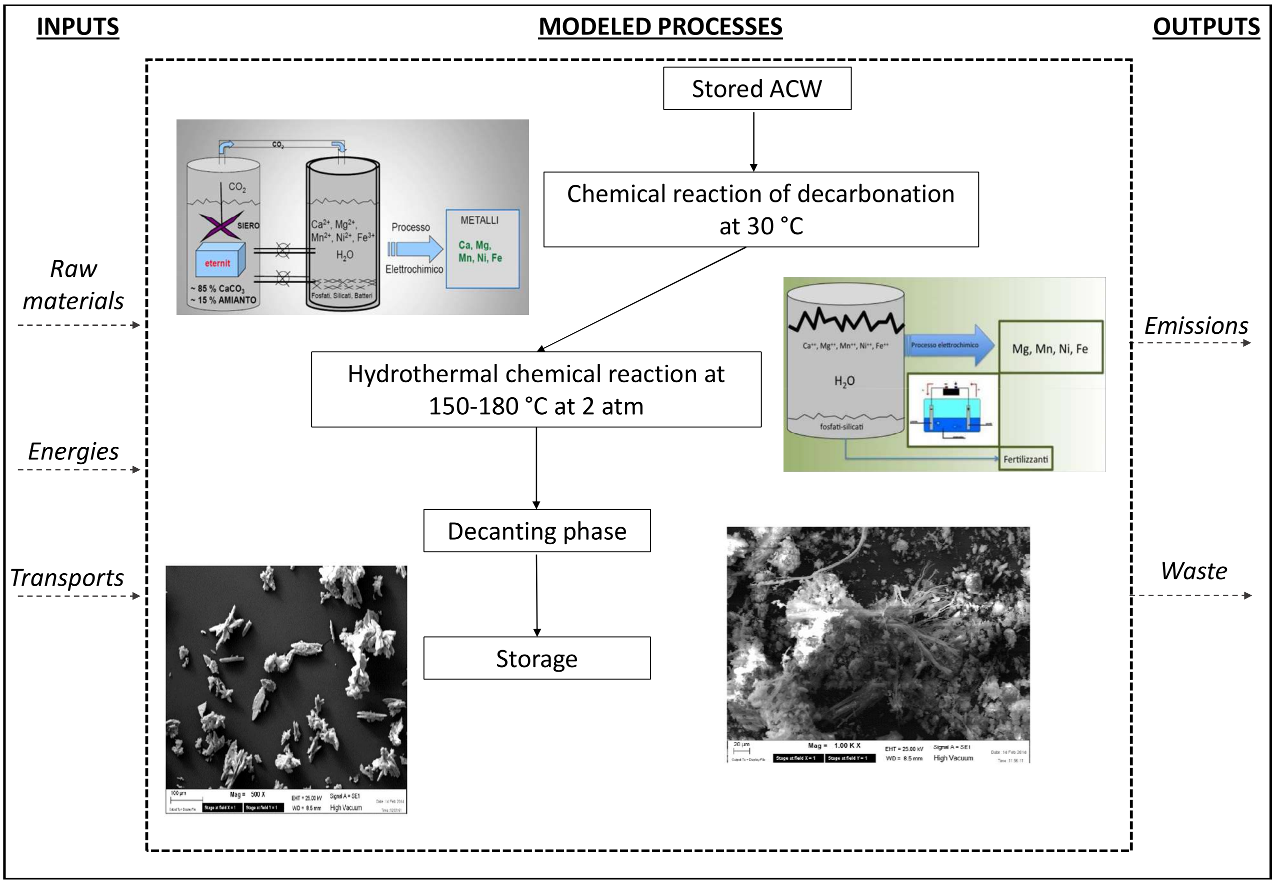


Figure 17-54: Flowchart of the "ACM chemical-physical treatment with mass allocation (emissions with extraction)" process

17.6.2.2.5. Data quality

Primary data was used where present. Where primary data was missing, ad hoc processes were created or database processes were used. The method used for the damage calculation is IMPACT 2002+010419indoor/locali_rif_IPCC+Amianto V2.12 / IMPACT 2002+. The code used is SimaPro 9.0.0.49.

17.6.2.3. Inventory analysis of chemical-physical treatment process

17.6.2.3.1. Phases of the treatment process

The process consists of two main steps. The first step consists of the decomposition at room temperature of the cement matrix of the product (about 85% by mass) with the resulting release of asbestos fibers contained in it (asbestos fibers represent an average of 15% by mass) through the use of substantial quantities of spent whey with an acid pH (about pH 3 at a temperature of around 30 °C). In the second step, the fibers are decomposed using further quantities of spent whey in a closed hydrothermal process at 150-180 °C and 2 atm of pressure, forming Magnesium, Calcium, Manganese, Nickel, and Iron ions, as well as silicates and phosphates. At no stage of the process are asbestos fibers released into the air, since the two treatment steps always take place inside spent whey, and an air treatment line has been installed on the plant.

17.6.2.3.1.1. Products

The functional unit of the process is the mass of asbestos containing materials treated by the plant in 15 working days:

ACM chemical-physical treatment with mass allocation (emissions with extraction): 969.949 metric tons

Mass allocation:

ACM/(ACM+Idropittura+Intermfertvasca5+Grassisapon+Biopolimeri+Metallivasca4)*100=969.949/(969.949+315.682+793.098+84.044+500+300)*100=32.74%

17.6.2.3.1.2. Co-products

The co-products of the treated ACMs are as follows:

- *Intermediate water paint (Reactor 1-Tank 3) (emissions with extraction)* = 315.682 metric tons
  - ✓ Mass allocation:
  Idropittura/(ACM+Idropittura+Intermfertvasca5+Grassisapon+Biopolimeri+Metallivasca4)*100 = 10.65%
- *Intermediate fertiliser (Reactor 2-Tank 5)* (emissions with extraction) = 793.098 metric tons
  - ✓ Mass allocation:
  Intermfertvasca5/(ACM+Idropittura+Intermfertvasca5+Grassisapon+Biopolimeri+Metallivasca4)*100 = 26.77%
- *Intermediate saponified fats (Reactor 1-Tank 3) (emissions with extraction)* = 84.044 metric tons
  - ✓ Mass allocation:
  Grassisapon/(ACM+Idropittura+Intermfertvasca5+Grassisapon+Biopolimeri+Metallivasca4)*100 = 2.84%
- *Biopolymers (Reactor 1-Tank2) (emissions with extraction)*= 500 metric tons

- ✓ Mass allocation: Biopolimeri/(ACM+Idropittura+Intermfertvasca5+Grassisapon+Biopolimeri+Metallivasca)*100 = 16.88%

- *Metals (Reactor 2-Tank 4) with mass allocation* (emissions with extraction)= 300 metric tons
  - ✓ Mass allocation: Metallivasca4/(ACM+Idropittura+Intermfertvasca5+Grassisapon+Biopolimeri+Metallivasca4)*100 = 10.13%

17.6.2.3.1.3. Inputs from nature

The plant covers a total area of 1300 sqm, which were assumed to be occupied for 50 years of activity (years of plant life). The following are the related land occupation and transformation items:

- *Transformation, to industrial area in ground: 13,000 sqm*
- *Occupation, industrial area in ground: 13,000*50 = 650,000 sqma*
- *Transformation, from agriculture to ground: 13,000 sqm*

17.6.2.3.1.4. Materials/fuel

During both stages, the following materials are used for the treatment:

1. *Spent whey (ElisaG_Siero (with co-products) (correct))*: 10,835 metric tons
   - Spent whey used in the grinding process and both chemical reactions: 10,835 metric tons
2. *Phosphoric acid, industrial grade, without water, in 85% solution state {RER}| purification of wet-process phosphoric acid to industrial grade, product in 85% solution state | APOS, U*: 86.68 metric tons
   - Phosphoric acid used as a reagent in both chemical reactions: 86.68 metric tons
3. *Soda ash, light, crystalline, heptahydrate {RER}| soda production, solvay process | APOS, U*: 466.528 metric tons
   - Soda used for the production of saponifiable fatty acids and calcium hydroxide or water paint: 466.528 metric tons
4. *Aluminium, cast alloy {RER}| treatment of aluminium scrap, new, at refiner | APOS, U*: 43,34 metric tons
   - Aluminium used as a reagent in both chemical reactions: 43,34 metric tons
5. *Nitrogen, liquid {RER}| air separation, cryogenic | APOS, U*: 2.344 metric tons
   - Nitrogen used in the hydrothermal chemical reaction in order to reach temperatures of 150-180 °C: 2.344 metric tons
6. *Tap water {Europe without Switzerland}| tap water production, underground water without treatment | APOS, U*: 300 metric tons
   - Water consumption due to the fire protection system and the irrigation system for the green areas: 300 metric tons
7. *Compressed air, 600 kPa gauge {RER}| compressed air production, 600 kPa gauge, >30kW, average generation | APOS, U (200 kPa):*Pariacomp*1E3/densaria2atm = 1,125*1E3/3,244: 346,800.9337 m^3

- Compressed air used in the hydrothermal reaction to reach 2 atm pressure: 346,800.9337 m^3

17.6.2.3.1.5. Electricity/Heat

The processes related to the warehouse, the systems and the flue gas treatment line of the entire ACM chemical-physical treatment process is described below, then extrapolated. The plant, as mentioned above, covers a total area of 13,000 sqm, of which 8,000 are uncovered impermeable surface, and 5,000 sqm are covered surface (inertisation and storage warehouse, laboratory, offices, changing rooms and toilets). Below is the related ad hoc created process "*Warehouse for chemical-physical treatment: 1 p*".

17.6.2.3.1.5.1. Material receipt - storage

The first stage of the process consists of the receipt of asbestos containing waste duly wrapped and packaged in accordance with current regulations. It has been assumed that the plant can only receive *EWC code 170605* "Construction materials containing asbestos"* in the case of asbestos cement sheets in a compact matrix. The vehicles, once weighed, are sent to an authorised R13 storage area.

17.6.2.3.1.5.2. Loading and grinding

The pallets, once transported inside the main warehouse, are loaded, through a conveyor belt, into a grinder with sieve. The optimal size for the process in question is 1 mm, while any larger material will return to the head of the grinder to obtain the optimal size, thus reducing the time necessary for its subsequent transformation during the chemical phase. This grinding process takes place in a sealed enclosed environment, with an appropriate air treatment system and with the spraying of whey from above (ca. 1,000 litres of lactic acid). The ground material is transferred into 4 storage silos of 30 m^3 each by means of a closed screw conveyor (made entirely of stainless steel). The dimensions of the auger (section of 300 mm, with 200 mm pitch) and the flow rate (about 5 m^3/h) were calculated on the basis of the quantity of ground products and whey to be transported into the reactor.

17.6.2.3.1.5.3. Decarbonation chemical reaction at 30 °C

The transfer of asbestos, via the screw conveyor, starts the whey feed pump into the first reactor. The ratio of asbestos to whey within the reactor is 1:7. The control of whey flow and the measurement of the total weight reached by the materials (including loaded reagents) in the reactor allow the grinding cycle to be stopped when the set quantity of material to be treated is reached. In the first phase of the chemical decarbonation reaction, the carbonate ($CaCO_3$) contained in the cement is completely transformed into gaseous CO_2 and Calcium ions, which remain in solution. Asbestos fibers and the non-carbonate minerals used (quartz and silicates) together with cement and asbestos in the asbestos cement manufacturing stage (Eternit) accumulate at the bottom of the vessel. The released CO_2 is channelled, through a ducting system, to a gas holder to avoid release into the air, pending withdrawal for various uses. From the gas holder, the CO_2 is compressed in different tanks where, based on production needs and the addition of soda, intermediate products such as water paint and saponified fats will be created. An aqueous solution is formed during the transformation of the cement, which is rich in the bacteria that captured the Ca^+ ions, with a pH that has gone from acidic to neutral-basic. This solution, removed by means of a special pump equipped with an appropriate HEPA filter, is transferred to a tank for subsequent settling.

17.6.2.3.1.5.4. Hydrothermal chemical reaction at 150-180 °C at 2 atm

The asbestos fibers, suitably filtered, and the minerals resulting from the first chemical reaction accumulated at the bottom of the reactor, are transferred using a hydraulic pump to a second reactor where the hydrothermal chemical reaction takes place. New spent whey is added to the reactor (about 3/5,000 liters per 150 kg of deposited material, corresponding to the quantity of fiber obtained from 1,000 kg of asbestos cement) as well as reagents. Once the required fill level is reached, the reactor closes and the hydrothermal process begins at 150-180 °C at 2 atm, resulting in the breakdown of the asbestos fibers into ions of Mg (metal representing about 50% of the chrysotile fiber), Ni, Mn, Fe, and Cr, as well as silicates. From this reaction, an aqueous solution rich in these metals will be obtained, while phosphates, silicates and dead bacteria due to firing will be deposited at the bottom. In order to achieve the complete breakdown (not inertisation) of the fibers and the complete separation of the iron present in the asbestos fibers of amphibole structure, after the hydrothermal reaction, two additional reagents are added. Below are the scanning electron microscope (SEM) images of the residue after denaturation treatment with whey (Figure 17-55), where it is no longer possible to see the asbestos fibers, which have been completely destroyed.

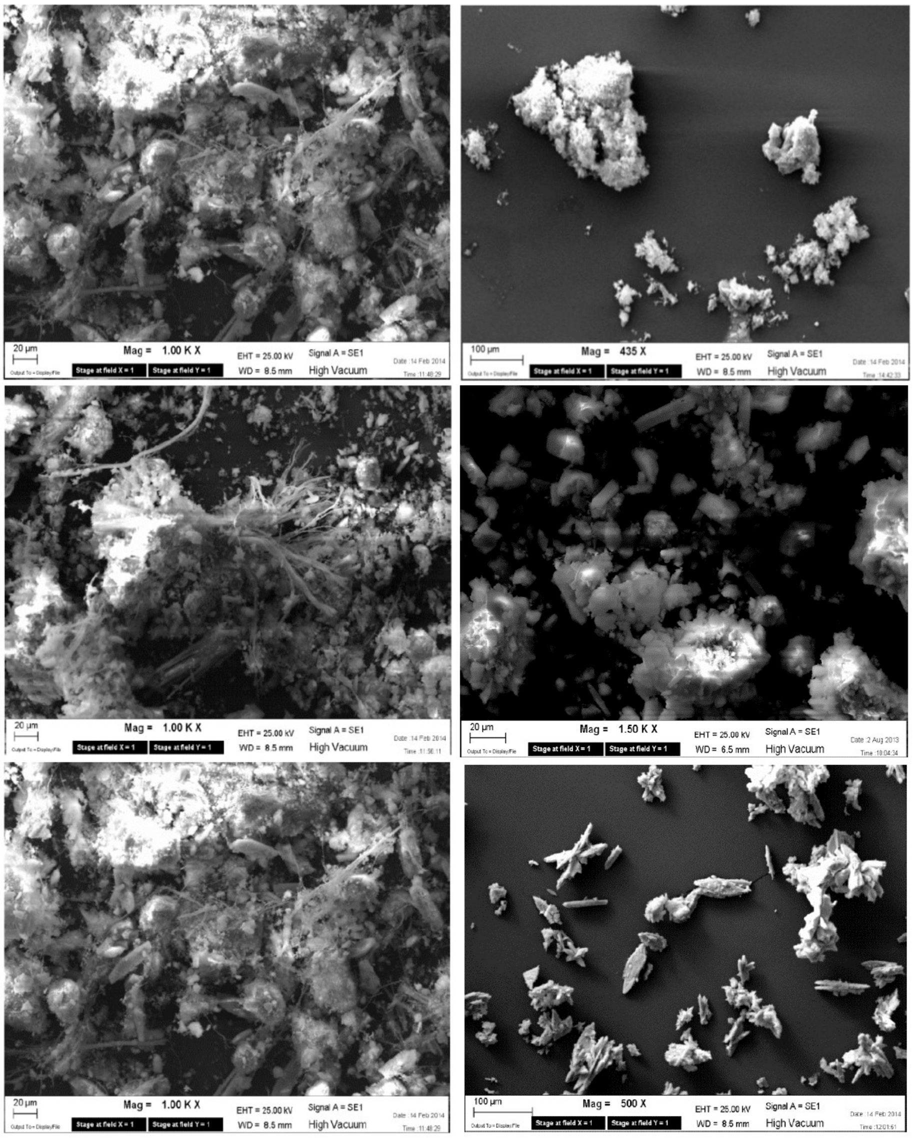


Figure 17-55: Scanning Electron Microscope (SEM) images of the residue following denaturation with whey

17.6.2.3.1.5.5. Settling and extraction of the resulting products

Once the complete cycle has been performed, the reactor is emptied and its contents sent via screw conveyors to 4 settling tanks (each with a capacity of 150 m^3), where the material will stay for about one day to allow sedimentation of the solid part at the bottom. After settling, the following products will be obtained:

- The sediment, which is emptied from the bottom of the tank to be treated and marketed as fertiliser containing silicates, phosphates and boiled bacteria.
- The supernatant which given that it is particularly rich in metal ions, is transferred to a tank and then treated with an electrochemical process to separate out the metals. Following this process, the wastewater from the process is transferred to a sewage treatment plant (it can be assumed that it is reused in agriculture).

Various by-products can be obtained from the sludge from the sedimentation tanks, allowing the gaseous CO_2 accumulated during the first phase of the process to flow into it. The pH of the solution varies depending on the amount of CO_2 introduced into the tanks, resulting in several by-products:

- saponifiable fatty acids are obtained through the addition of soda, stratifying on the surface, while in the solution below a calcium hydroxide or a water paint will be formed
- the CO_2 can be used to produce biomass through algae growth or can be compressed and then sold.

For the present study, it has been assumed that all CO_2 generated by the process is used for the production of saponifiable fatty acids and calcium hydroxide. Underground tanks have been built to store each of the recovered materials.

17.6.2.3.1.6. Air emissions

Regarding emissions, the following flows of pollutants produced during the hydrothermal reaction were considered once they have passed through the flue gas treatment line.

1. *Nitrogen oxides*: (PN_2*1E6/28*64+PN_2*1E6)*(1-efiltro) = 77,017.14 g
   - NOx: it is assumed that all the nitrogen introduced into reactor 2 reacts with the oxygen in the compressed air;
   - $N_2+2O_2=2NO_2$;
   - Atomic weight of nitrogen: N=14 g;
   - N_2=28g;
   - PN_2=2.344E6 g;
   - $NmolN_2$=2.344E6/28;
   - $2O_2$=64g;
   - $P_2O_2=NmolN_2*2O_2$;
   - Filter efficiency: Efiltro: 0.99%.
2. *Ammonia*: (Sgasi*1E6-(PN2*1E6/28*64+PN2*1E6))/8*(1-Efiltro) = 438,705.36 g
   - NH_4: ammonia from nitrogen in air and hydrogen contained in spent whey;
   - It is assumed that emissions occur only during the hydrothermal reaction: Sgasi: 358.67 metric tons;
   - Filter efficiency: Efiltro: 0.99%.

3. *Nitrogen oxides*:(Sgasi*1E6-(PN2*1E6/28*64+PN2*1E6))/8*(1-Efiltro) = 438,705.36 g
    - NOx: oxides from heating of air;
    - It is assumed that emissions occur only during the hydrothermal reaction: Sgasi: 358,666 metric tons;
    - Filter efficiency: Efiltro: 0.99%.
4. *Carbon dioxide, biogenic*:(Sgasi*1E6-(PN2*1E6/28*64+PN2*1E6))/2 = 175,482,142.9 g
    - CO_2: methane from the reaction of C from the lactose with oxygen from the air;
    - It is assumed that emissions occur only during the hydrothermal reaction: Sgasi: 358,666 metric tons;
    - Filter efficiency: Efiltro: 0.99%.
5. *Methane, biogenic*: (Sgasi*1E6-(PN2*1E6/28*64+PN2*1E6))/4 = 87,741,071.43 g
    - CH_4: methane from the reaction of C from the lactose with H from the lactose;
    - It is assumed that emissions occur only during the hydrothermal reaction: Sgasi: 358.67 metric tons;
    - Filter efficiency: Efiltro: 0.99%.

The dusts generated during the ACM grinding process, treated with a sleeve filtration system, were calculated within the process "*Grinding (2017 - 21 Grinding fired waste_rev1)*".

17.6.2.3.1.7. Treatment waste and emissions

In the ACM chemical-physical transformation process, at the end of the hydrothermal reaction and the metal electrolysis process, 13,626.63 m^3 of water are produced, which must be treated in a purifier.
The process is "*Wastewater from maize starch production {RoW}| treatment of, capacity 1.1E10l/year | APOS, U*": H2Ouscitavasca1+H2Ouscitareatt2 =8,283.646+5,342.98= 13,626.6 m^3

- Water output from tank 1: H2Ouscitavasca1= Entratavasca1-Uscitavasca1 = 8,283.646 m^3
- Water output from reactor 2: H2Ouscitareatt2= Entratreatt2-Uscitareatt2 = 5,342.98 m^3

17.6.2.3.2. Inventory data tables

Below is the extrapolation of all the previously described processes (Table 17-47) with related parameters (Table 17-48 and Table 17-49).

Grinding	ACM+PsierotritACM = 1969,949	metric tons	Grinding of asbestos cement materials and whey used to prevent dust: t This process includes the grinder and the air treatment system with sleeve filter with related energy and transport
Generic ACM plant (3.5t)	1/3,5*Preat1/Tvitareat*Tusoreath*Impegnoimp = 0.148	p	Reactor 1 where the decarbonation reaction takes place at 30 °C
Tank	2/Tvitavascah*Tusovascah*Impegnoimp = 0.0346	p	Tank 1 for the production of water paint: tank 1 has double the capacity of tanks 2 and 3

Tank	1/Tvitavascah*Tusovascah*Impegnoimp = 0.0173	p	Tank 2 for biopolymer storage
Tank	1/Tvitavascah*Tusovascah*Impegnoimp = 0.0173	p	Tank 3 for saponified fat storage
Generic ACM plant (3.5t)	1/3,5*Preat2/Tvitareat*Tusoreath*Impegnoimp = 0.049	p	Reactor 2 where the hydrothermal reaction takes place
Heat, district or industrial, natural gas {Europe without Switzerland}| heat production, natural gas, at industrial furnace >100kW | APOS, U	(ACMdopocarbonat*CpACM+Psiereat2*Cpsiero+Palluminio*CpAl+Pacfosfor/2*Cpacfosfor+PN2*CpN2+Pariacomp*Cparia)*DT = 3479127,44	MJ	Heating at (150+180)/2=165 °C of materials contained in reactor 2
Tank	1/Tvitavascah*Tusovascah*Impegnoimp = 0,01733333333	p	Tank 4 for metal storage
Tank	1/Tvitavascah*Tusovascah*Impegnoimp = 0,01733333333	p	Tank 5 for fertiliser storage
Whey tank	1/Nriempserbvita*Nriempusoserb = 0,1	p	Whey tank Capacity: 50m3 Weight: 7.5827t
Pipe	Lungtubo/Tvitatubo*Tusotubo*24*Impegnoimp = 10,96256256	m	Connecting pipe between the different systems: m
Generic ACM plant (3.5t)	1/3,5*Ppompa/Tvitapompa*Tusopompa*24*Impegnoimp = 0,003714285714	p	Circulation pump
Electricity, low voltage {IT}| electricity voltage transformation from medium to low voltage | APOS, U	Potenzaelpompa/1E3*Tusopompa*24*Impegnoimp = 521,8743567	kWh	Energy to move fluids in the pipes: kWh It is asssumed that it is water
Transport, freight, lorry 16-32 metric ton, EURO6 {RER}| transport, freight, lorry 16-32 metric ton, EURO6 | APOS, U	((Preat1+Preat2)/Tvitareat*Tusoreath*Impegnoimp+Pserbatoio/Nriempserbvita*Nriempusoserb+(Ptubo/Tvitatubo*Tusotubo+Ppompa/Tvitapompa*Tusopompa)*24*Impegnoim)*100 = 162,5785891	tkm	Plant transport: tkm
Transport, freight, lorry 16-32 metric ton, EURO6 {RER}| transport, freight, lorry 16-32 metric ton, EURO6 | APOS, U	(ACM+Psierotot+Soda+PAlluminio+Pacfosfor+PN2)*100 = 1240384,1	tkm	Material transport: tkm

Electric Fan + Extraction System ($Q=20000\ Nm^3/h$, v=18m/sec) (multi-output)	1/Tvitaimpasp*Ttratth = 0,1	p	The electric fan consists of the following materials: 70% steel; 10% copper; 10% aluminium; 10% PVC. Air recycling time:1s $Q=5.556m^3/s(20000Nm^3/h)$ Ptot=Pcond+Pcam+Pvent+Psec *nCondsec= 0,375659 t Lifetime of extraction system: 40000h Lifetime: 9000h Load losses:137,279 kg/sqm
Biofilter ($Q=20000Nm^3/h$) (multi-output)(New recycling)	1/Tvitabiofiltroh*Ttratth = 0,01369863014	p	Biofilter $Vfil=1400m^3$ Filter bed height: 1.5m Filter area: Afiltro=1400/1,5=933,33sqm Flow rate: $185500/3600=51{,}528m^3/sec$ Filtration speed: vf=Q/Afiltro=0,05521m/sec Moist chip density 35%: $0{,}245kg/dm^3$ Pcippatosecco=dcipumido*(1-0.35)=245*Afiltro*hlf*(1-0,35) Tank life: 50 years Chip life: 3 years Number of chip beds in 50 years: 50/3=16,667 Biofilter lifetime: 50 years Pbiofiltro=3987,824t
Scrubber ($Q=20000\ m^3/h$, v=18m/sec)	1/Tvitascrub*Ttratth = 0,3	p	Scrubber Flow rate: $5.5556\ m^3/s=20000\ m^3/h$ Scrubber lifetime: 20000h Scrubber weight =0,3028 t
Sleeve filter with parameters ($Q=20000\ m^3/h$) (multi-output)_revDEFINITVA	1/Tvitafiltrman*Ttratth = 0,3	p	Sleeve filter with parameters. Hours of lifetime: 20000h Filter weight =945,7889099kg
Selective catalytic reactor (flow rate $20000m^3/h$) (with parameters)	1/Tvitareatcatsel*Ttratth = 0,15	p	Selective catalytic reactor Flow rate $20000m^3/h$ at 200 °C Lifetime: 20000h Gas retention time: 1sec Reactor volume: $20000m^3/h*1/3600=5{,}5556m^3$ Weight=0,7554144668 t
Electricity, low voltage {IT}| market for | APOS, U	Q*Pctotimpasp/(102*0,6)*ttratth = 74771,29533	kWh	Electrical power of extraction system: P=Q*Pctotimpasp/(102*0,6) where: $Q=20000m^3/h=5{,}556m^3/sec$ Pressure drops PctotrealeE8=137.279kg/sqm

Transport, freight, lorry 16-32 metric ton, EURO6 {RoW}| transport, freight, lorry 16-32 metric ton, EURO6 | APOS, U	(Pimpasp/Tvitaimpasp+Pbiofiltro/Tvitabiofiltroh+Pscrub/Tvitascrub+Pfiltrman/Tvitafiltrman+Preatcatsel/Tvitareatcatsel)*ttratth*100 = 5513,115261	tkm	Transport of the extraction system, biofilter, scrubber, sleeve filter, and selective catalytic reactor

Table 17-47: Extraction of the "ACM chemical-physical treatment with mass allocation (emissions with extraction)" process

Input parameters	Expression	Comments
densaria1atm	1,225	1,225 kg/m³
Cpsierocal	0,92	whey specific heat: cal/g
Psierotot	10835	whey weight: t Contains lactose (50-75% of the dry fraction), proteins (about 8-14% of the dry fraction) mineral salts (6-8%) and traces of lipids, in addition to lactose degradation products (lactic acid, glucose, galactose) in varying proportions depending on the cheesemaking process. Empirical or molecular formula of lactose: C12H22O11 12*12+22*1+11*16=342g It is assumed that it converts to H2O and C C12H22O11=11H2O+12C It is assumed that 90% of the C combines with the Eternit Water weight in a mole of lactose: 11*(2*1+1*16)=198g Number of lactose molecules: 0,75*10835*1E6/342=23760964,91 Water weight: 23760964,91*198=4704671053g
denssiero	1,028	whey density: g/ml=kg/l=t/m^3
ACM	969,949	Eternit weight: t
CpACMKcal	0,186	specific heat of Eternit: that of Portland cement taken: kcal/kgK
PAlluminio	43,34	aluminium weight. t
CpAlkcal	0,222	specific heat of aluminium at 100 °C: kcal/kgK
Pariapress	1125	compressed air weight: t
Pacfosfor	86,68	weight of phosphoric acid: t
CpacfosforKcal	0,42	specific heat of phosphoric acid: kcal/kgK
Cpsodiumhydroxidemol	0,56	specific heat of soda: J/molK
Pmolsodiumhydroxide	39,9971	molecular weight: g/mol
PNaOH	466,528	soda weight: t
PH2O	300	water weight: t
CpHOKcal	1,09	specific heat of water at 100°C: Kcal/kgK
PN2	2,344	Nitrogen weight: t
Pariacomp	1125	Compressed air weight: t
Cparia	1,005	specific heat of compressed air: J/gK
PsierotritACM	1000	Whey weight used for grinding ACM: t
Preat1	6	Reactor 1 weight: t

Preat2	2	Reactor 2 weight: t
Tvitareat	60000	Reactor lifetime: h
Tusoreatg	250	Reactor usage time: g
Biopolimeri	500	Biopolymers: metric tons
Idropittura	315,682	Water paint: metric tons
Grassisapon	84,044	Saponified fats: metric tons
CO_2prod	108,741	CO_2:metric tons
Soda	466,528	Soda: metric tons
Tvitavasca	50	Lifetime: years
Tusovasca	250	tank usage time: g
Intermfertvasca5	793,098	Fertiliser collected from tank 5
Metallivasca4	300	Metals collected from tank 4
Liquidoreat1	8608,103	
Tvitatubo	60000	Pipe lifetime: h
Tusotubo	250	Pipe usage time: g
Tvitaserb	60000	Whey tank lifetime
Volserb	50	Volume of whey tank, assumed cylindrical: m^3
Tusoserb	250	Whey tank usage time: g
Pserbatoio	7,5827	Whey tank weight: t
Ptubounit	0,014703	Weight of 1m of pipe: t
Portpompa	6	Flow rate of circulation pump: m^3/h
Prevalpompa	3,5	Circulation pump discharge head: mH2O
Rendpompa	0,57	Circulation pump performance
Tusopompa	250	Pump usage time: g
Ppompa	0,05	Pump weight: t
Tvitapompa	20000	Circulation pump lifetime: h
Qasp	10000	Extraction flow rate: Nm^3/h
Ttrattg	250	Treatment time and therefore extraction time, assumed continuous: g
Tvitaimpasp	60000	Extraction system lifetime: h
Tvitareatcatsel	40000	Extraction system lifetime: h
Qh	20000	Extraction system flow rate
Q	5,5556	Extraction system flow rate E8: Nm^3/sec
Tvitafiltrman	20000	Sleeve filter lifetime: h
Pimpasp	0,1553774278	Weight of extraction system E8: t

Preatcatsel	0,7554144668	Weight of selective catalytic reactor plant: t
PctotE8	223,9394699	E8 load losses: kg/sqm
Pfiltrman	0,9457889099	Sleeve filter weight: t
TvitaSCR	20000	E8 SCR system lifetime: h
Tvitabiofiltro	50	Biofilter lifetime: y
Pctotimpasp	137,279	Extraction system load losses: kg/sqm
Pbiofilter	3987,824	Biofilter weight: t
Tvitascrub	20000	Scrubber lifetime: h
Pscrub	0,3028	Scrubber weight: t

Table 17-48: Extraction of the "ACM chemical-physical treatment with mass allocation (emissions with extraction)" process input parameters

Calculated parameters	Expression	Comments
pressione600kPa	600*1000*1/101325 = 5,9215396	pressure from kPa to atm 1Pa=1/101325atm
pressione200kPa	200*1000*1/101325 = 1,973846533	
densaria59215atm	densaria1atm*exp(pressione600kPa-1) = 168,0867885	compressed air density at 5,9215atm
densaria2atm	densaria1atm*exp(pressione200kPa-1) = 3,243935903	density of compressed air at 1,9738atm assumes density variation with exponential pressure: p=p0*E
DT	(150+180)/2-25 = 140	thermal jump
cpsiero	cpsierocal*4,184 = 3,84928	whey specific heat: J/gK
Cpacfosfor	CpacfosforKcal*4,184 = 1,75728	specific heat of soda: J/gK
CpNaOH	Cpsodiumhydroxidemol/Pmolsodiumhydroxide = 0,01400101507	specific heat of soda: J/gK
CpAl	CpAlkcal*4,184 = 0,928848	specific heat Aluminium: J/gK
CpACM	CpACMKcal*4,184 = 0,778224	specific heat ACM: J/gK
CpH2O	CpHOKcal*4,184 = 4,56056	specific heat of water: J/gK
CpN2	1.04 = 1.04	specific heat of nitrogen: J/gK
Tusoreath	Tusoreatg*24 = 6000	Reactor usage time
Impegnoimp	(0,9*8+0,8*4)/12 = 0,87	plant use

Psieroreat1	5*ACM = 4849,745	weight of whey that must react in reactor 1 with the material deposited in reactor 1: 5 parts whey to one part Eternit.
Psieroreat2	Psierotot-Psieroreat1 = 5985,255	Masses of whey in reactor 2
Liquidodareat1	biopolimeri+idropittura+grassisapon+soda+CO_2prod+Psieroreat1 = 6324,74	supernatant liquid taken from reactor 1 to tank1
H2Odepreat1	Psieroreat1 = 4849,745	It is assumed that all the liquid put in tank1 is treated in the purifier
H2Odepreat2	Psieroreat2 = 5985,255	It is assumed that all the whey put into reactor 2 is converted into water and as such is treated in the purifier
ACMdopocarbonat	ACM-CaO-CO_2prod = 722,8103636	ACM after carbonation: t
Tusovascah	Tusovasca*24 = 6000	Tank usage time
Tvitavascah	Tvitavasca*250*24 = 300000	Tank lifetime
PCaCO3	(CO_2prod*1E6+CO_2prod*1E6/44*40+CO_2prod*1E6/44*16)/1E3 = 247138,6364	Calculation of the $CaCO_3$ present in the Eternit from the CO_2 produced, assuming that all the C content reacts to produce CO_2 It is assumed that the reaction taking place in reactor 1 is as follows: $CaCO_3$=>Ca+CO_2+O molecular weight Ca=40g/mol molecular weight CO_2=1*12*1+2*16=44g/mol atomic weight of oxygen=16g/mol nmol CO_2=CO_2*1E6/44 weight of Ca=CO_2*1E6/44*40 weight of O=CO_2*1E6/44*16
CaO	(CO_2prod*1E6/44*40+CO_2prod*1E6/44*1)/1E6 = 138,3976364	mass of CaO: metric tons
Entratavasca1	Soda+CO_2prod+Liquidoreat1 = 9183,372	Material exiting tank 1
Uscitavasca1	idropittura+biopolimeri+grassisapon = 899,726	Material entering tank 1
Entratreatt2	ACMdopocarbonat+Psieroreat2+Palluminio+Pacfosfor/2 = 6794,745364	Mass entering reactor 2
Uscitareatt2	Intermfertvasca5+Metallivasca4+Sgasi = 1451,764	Mass exiting reactor 2
Lungtubo	Areaimp^0,5*4 = 126,4911064	Length of pipe connecting the whey tanks and storage tanks: m estimated length assuming it is equal to the perimeter of the supposed square reception area: m

Nriempusoserb	Psierotot/(Volserb*denssiero) = 210,7976654	Number of whey tank fills in 250 days corresponding to 1 year
Nriempserbvita	Psierotot/(Volserb*denssiero)*60000/(Tusoserb*24) = 2107,976654	
Ptubo	Ptubounit*Lungtubo = 1,859798737	Tube weight: t
Potenzaelpompa	Portpompa/3600*Prevalpompa*9806,65/Rendpompa = 100,3604532	Pump power: W
Ttratth	Ttrattg*24 = 6000	Extraction time: h
Tvitabiofiltroh	Tvitabiofiltro*365*24 = 438000	

Table 17-49: Extraction of the "ACM chemical-physical treatment with mass allocation (emissions with extraction)" process calculation parameters

17.6.2.4. Environmental damage analysis

In the "ACM chemical-physical treatment (with mass allocation)" process, a mass allocation is carried out where the functional unit (product) is 969.949 metric tons of ACM while the co-products are water paint, fertilisers, saponified fats, biopolymers and metals that are generated during the treatment. The calculation was performed using the IMPACT 2002+010419indoor/locali_rif_IPCC+Amianto V2.12 method.

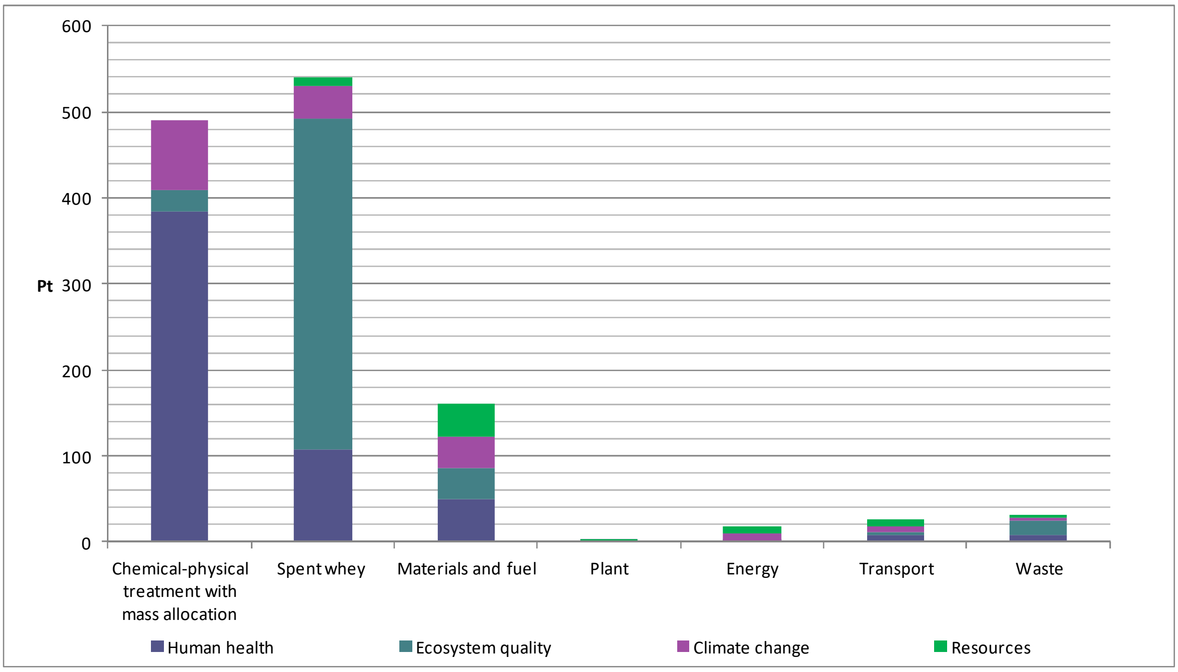


Figure 17-56: Diagram showing the assessment of the ACM chemical-physical treatment (with mass allocation) process

As shown in the figure above (Figure 17-56), the total damage is 1,182.64 Pt., with 45.63% related to the production and use of spent whey, followed by 41.42%, related to direct emissions from the ACM chemical-physical treatment process. All other processes account for less than 5% damage. Analysing the damage categories, the one that produces the greatest impact is **Human Health** with 46.4%, due to *Ammonia* in air, which represents a direct emission from the ACM chemical-physical treatment process. This is followed by **Ecosystem quality**, with 37.33% mainly related to the emission of *Zinc* in soil, which occurs almost entirely in the whey process (the process with the most impact in whey is Cattle Manure). Next is **Climate change**, with 12.6% mainly related to the emission of *Methane, biogenic*, a direct emission from the ACM chemical-physical treatment. Finally, is **Resources**, with 3.67%, mainly due to the use of *Gas, Natural/m^3*, primarily used for heating the reactors in the hydrothermal chemical phase.

17.6.2.5. Sensitivity analysis

17.6.2.5.1. LCA analysis with the ACM chemical-physical treatment process without co-products

The process allocates 100% of the damage to the treated ACM. The calculation for 969,949 metric tons of ACM was performed using the IMPACT 2002+010419indoor/locali_rif_IPCC+Amianto V2.12 method.

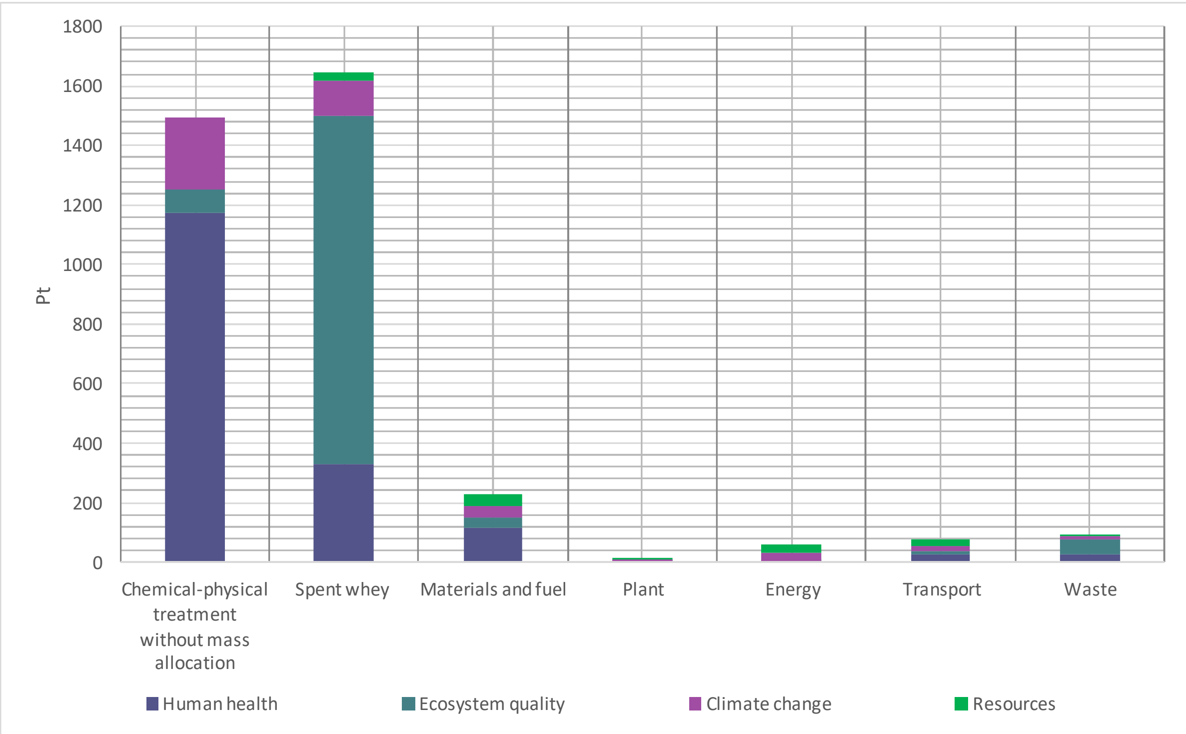


Figure 17-57: Diagram showing the assessment of the ACM chemical-physical treatment process

The damage of the process is 3.64362 kPt, with 41.07% due to direct emissions and resources, and 45.19% to whey production considered a co-product of the production of Parmesan cheese. In addition, 46.45% of the damage relates to **Human health**, 37.1% to **Ecosystem quality**, 12.64% to **Climate change**, and 3.81% to **Resources** (Figure 17-57).

17.6.2.5.2. Chemical-physical treatment plant with extraction of emissions

In the ACM chemical-physical treatment with mass allocation process, extraction of the emissions was considered by adding an air extraction and treatment plant equipped with a biofilter, scrubber, sleeve filter and selective catalytic reactor. In addition, the electricity used for extraction was added. The NOx and NH_3 emissions contained in the "*Sgasi*" item were reduced by the factor (1-efiltro), where "*efiltro*" is the assumed filter efficiency of 99%. The new process is the ACM chemical-physical treatment with mass allocation (emissions with extraction) process. The calculation of this process was carried out for 150 metric tons using the method: IMPACT 2002+010419indoor/locali_rif_IPCC+Amtot V2.12 / IMPACT 2002+.

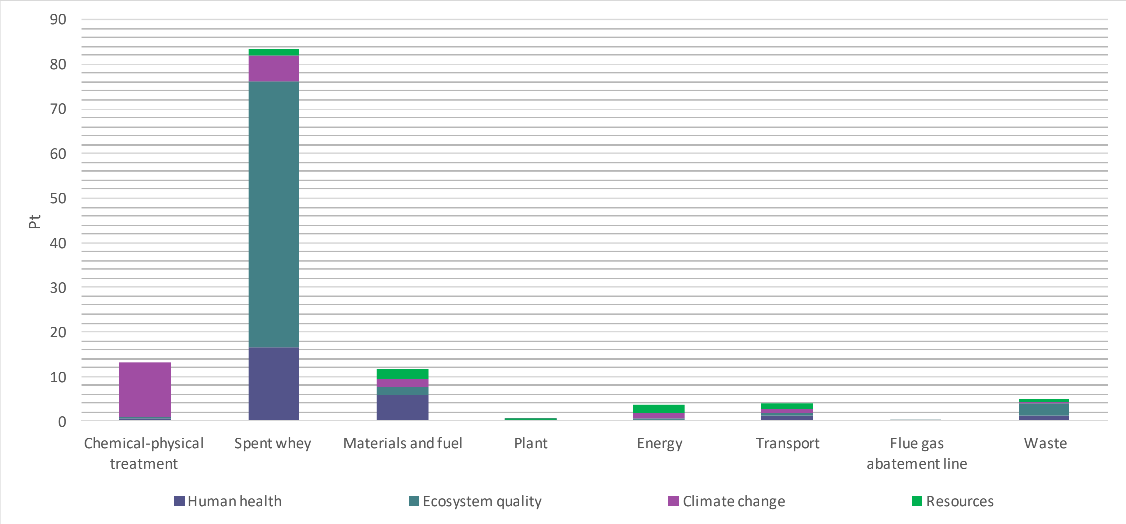


Figure 17-58: Diagram showing the assessment of the damage due to the ACM chemical-physical treatment with mass allocation (emissions with extraction) process

From the analysis of the results, it can be seen (Figure 17-58) that the total damage is 121.282 Pt, with 68.81% related to spent whey, considered a co-product of the production of Parmesan cheese, and 10.96% is due to direct emissions. Furthermore:

- 21.62% of the damage relates to **Human health**, 36.67% to *Ammonia* in air in whey production, and 15.52% to *Zinc* in soil in whey production;
- 53.47% to **Ecosystem quality**, 71.04% to *Zinc* in soil in whey production, and 19.46% to *Copper* in soil in whey production;
- 19.15% to **Climate change**, 71.39% to *Methane, biogenic* in air as a direct emission during treatment, and 21.76% *to Carbon dioxide, fossil* in air from the heating with natural gas of the solution to 165 °C;
- 5.75% to **Resources**, 32.64% to *Natural Gas* as a direct emission from treatment, and 25.26% to *Oil, crude* in the transport of plant.

17.6.2.5.3. Comparison between the treatment process with and without filtration

The processes ACM chemical-physical treatment with mass allocation (process examined in the first part of the study, i.e. the one prior to cost analysis and sensitivity analysis) and ACM chemical-physical treatment with mass allocation (emissions with extraction) were compared. The calculation was made for 150 metric tons using the IMPACT 2002+010419indoor/locali_rif_IPCC+Amtot V2.12 / IMPACT 2002+ method.

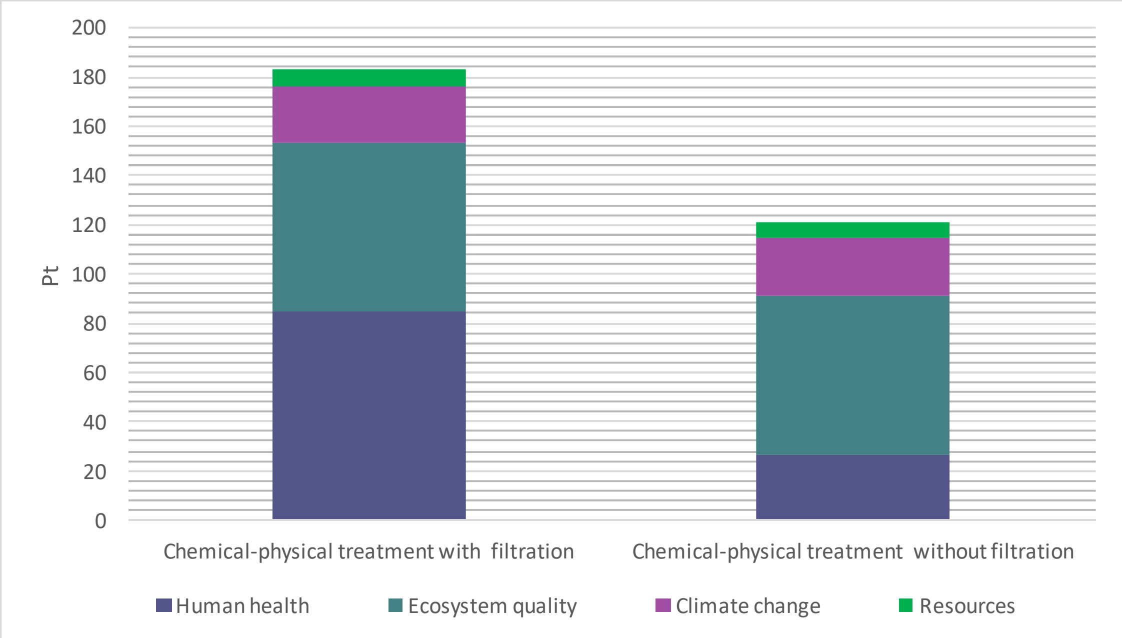


Figure 17-59: Diagram assessing the comparison between the processes ACM chemical-physical treatment with mass allocation and ACM chemical-physical treatment with mass allocation (emissions with extraction)

It should be noted that the chemical-physical treatment with air extraction filtration reduces its damage by 33.69%, going from 182.89257 Pt to 121.28206 (Figure 17-59). In the case of chemical-physical treatment without extraction, the greatest increase relates to **Human Health**, with a 223.7% rise mainly due to the increase in *Ammonia* and *Nitrogen Oxide*. This is followed by an increase in **Ecosystem quality** of 5.27% due to the increase in the emission of *Ammonia* in air.

17.6.3. No removal of asbestos cement sheets: effects over time

A scenario was developed in which the removal of asbestos cement sheeting does not take place, in order to assess the effects on human health and ecosystem quality due to scenario 0 (no action).
In particular, it was considered that:

- Italian Law no. 257 of 27 March 1992 "*Regulations concerning the cessation of the use of asbestos*" prohibits the extraction, import, export, marketing and production of asbestos and asbestos containing products;
- The functional unit of this process is 150 metric tons of ACM;
- The asbestos fiber content in the sheeting is on average 13.5%, therefore the asbestos fiber content in 150 metric tons of asbestos cement sheeting is 0.135*150 = 20.25 metric tons;
- In 2019, existing sheeting was at least 27 years old.

The following assumptions were made:

- 50% of this sheeting dates back 12 years: 1980, and the other 50% dates back to 1992;
- The concrete structure of asbestos cement sheeting has a duration of 30 years before it starts to deteriorate;
- Degradation takes place linearly over the period of time considered;
- Degradation is gradual and ends after 50 years with the complete release of fibers i.e. the degradation would end in 2030 (1980 + 50 years=2030);
- The sheets installed in 1980 begin their degradation process in 2010 (0% dispersion), while sheets laid in 1992 begin their degradation process in 2022 (0% dispersion). The sheets

installed in 1980 will degrade completely by 2060 (100% dispersion), while sheets installed in 1992 will degrade completely by 2072 (100% dispersion).

Based on these assumptions, and considering 2030 as the time horizon, airborne fibers are:

1. for sheeting installed in the 1980s:
    - 100%/(2060-2010)=x/(2030-2010) x=40% (percentage degradation)
    - The mass released is: 0.135*150 metric tons *0.4 =8.1 metric tons of airborne fibers
2. for sheeting installed in 1992:
    - 100%/(2072-2022)=x/(2030-2022) x=16% (percentage degradation)
    - The mass released is: 0.135*150 metric tons * 0.16=3.24 metric tons of airborne fibers

If it is assumed that all the airborne fibers are inhaled by humans, the total damage of the process in question is 65.429 kPt (*100% Asbestos fiber tumours*) .

17.6.4. Comparison between different ACM management processes

The processes analysed include:

- ✓ No removal of asbestos containing sheeting (scenario 0);
- ✓ ACM treatment with landfill;
- ✓ ACM treatment with inertisation by firing;
- ✓ ACM treatment with chemical-physical plant with mass allocation (with extraction of emissions).

The comparison was made for 150 metric tons using the IMPACT 2002+010419indoor/locali_rif_IPCC+Amianto V2.12 / IMPACT 2002+ method.

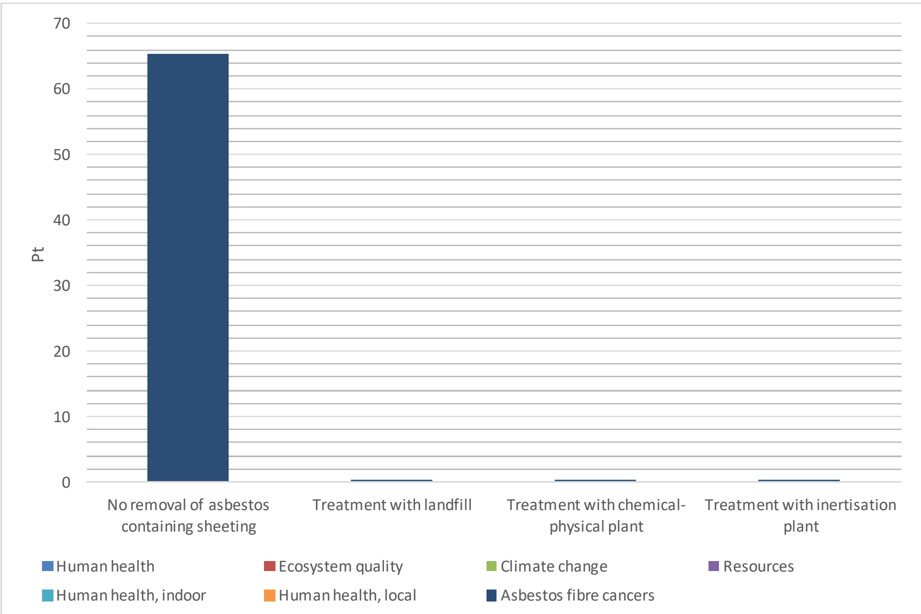


Figure 17-60: Diagram assessing the comparison between the processes No removal of asbestos containing sheeting, ACM treatment with landfill, ACM treatment with chemical-physical plant with mass allocation, ACM treatment with inertisation by firing

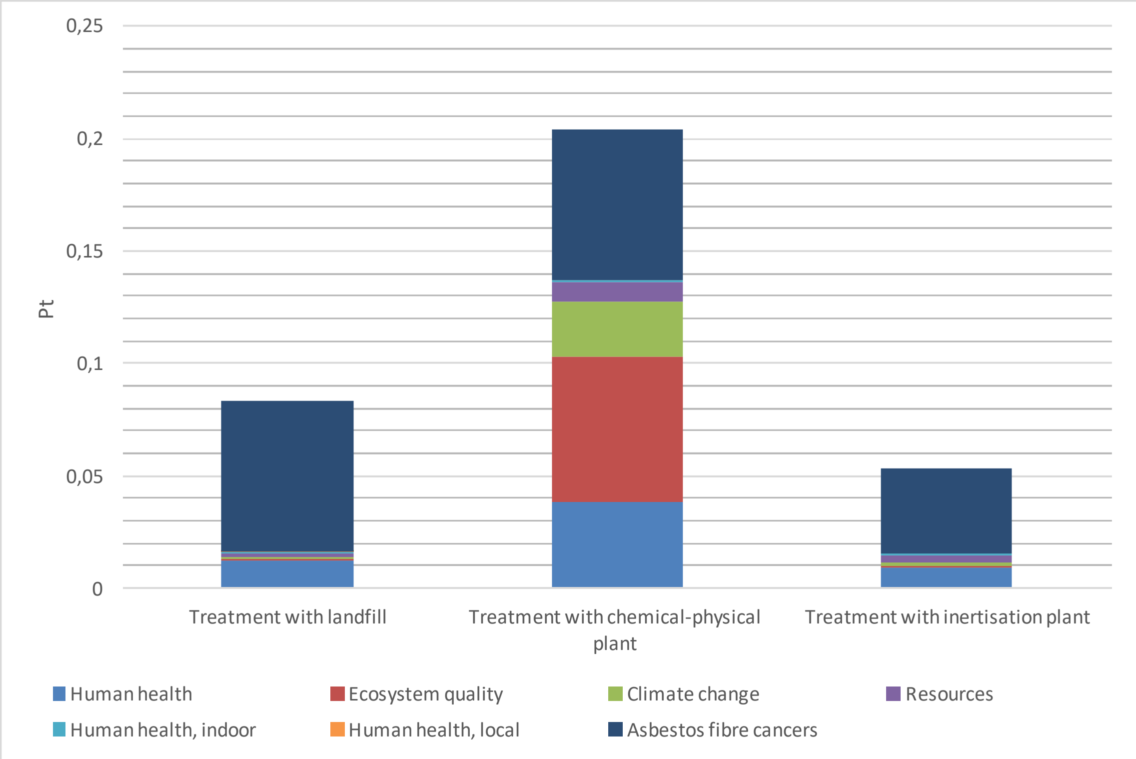


Figure 17-61: Diagram assessing the comparison between the processes ACM treatment with landfill, ACM treatment with chemical-physical plant with mass allocation, ACM treatment with inertisation by firing

From the comparison assessment (Figure 17-60), it can be seen that:

- the damage due to no removal is 65.429 kPt.
- The damage due to treatment in landfill for special waste is 0.083 kPt. In relation to ACM management with chemical-physical treatment, the damage category with the greatest variation is **Ecosystem quality**, with -99.33%, mainly due to lower emissions of *Zinc* and *Copper* in soil. This followed by **Climate change** with -91.08% (mainly due to the absence of *Methane, biogenic*) emissions, **Human Health** with -76.32% (mainly due to the lower emissions of *Ammonia* and *Nitrogen oxide* in air and *Zinc* in soil), and finally **Resources** with -65.57% (mainly due to the lower use of *Gas, natural/*m^3 and *Oil, crude, 42.6 MJ per kg*)
- The damage due to chemical-physical treatment (with extraction) is 0.204 kPt.
- The damage due to inertisation by firing is 0.053 kPt. In relation to ACM management with chemical-physical treatment, the damage category with the greatest variation is **Ecosystem quality**, with -99.27%, mainly due to lower emissions of *Zinc* and *Copper* in soil. This is followed by **Climate change** with -95.58% (mainly due to the absence of *Methane, biogenic*) emissions, **Resources** with -80.18% (mainly due to the lower use of *Oil, crude*, *Coal, hard* and *Oil, crude, 42.6 MJ per kg*), and finally **Human Health** with -68.24% (mainly due to the lower emissions of *Ammonia* and *Nitrogen oxide* in air and *Zinc* in soil).

18. Analysis of the internal and external costs of mapping, of the removal and treatment with crystallization plants for materials containing Asbestos (ACM) inside the eight towns which make up the Lower Reggiana union

18.1. Purpose of the study and field of application

18.1.1. Purpose of the study

The purpose of this study is to evaluate the economic impact on finances and on external effects, namely, to quantify in economic terms the environmental damage to man and to the ecosystem in the Lower Reggiana Union area:

- a survey of asbestos containing materials (ACM) using drones;
- restoration of roofs made in asbestos-cement (CA) by removal;
- transporting wastes containing asbestos (ACW) from the work site to the storage plant;
- Treatment of ACW with storage plant in D15 or R13;
- Treatment of ACW by inertisation;
- Treatment ACW with disposal at the waste disposal landfill for special and dangerous wastes.

18.1.2. Field of application

18.1.2.1. Function of the system

The system functions by managing the ACM in the eight towns of the Lower Reggiana Union (Boretto, Brescelllo, Gualtieri, Guastalla, Luzzara, Novellara, Poviglio, Reggiolo).

18.1.2.2. The system studied

The system studied is the management of the manufactured goods containing asbestos in the Lower Reggiano area using two different types of treatment: Inertisation with continuous furnace, and a disposal plant for dangerous and non dangerous wastes.

18.1.2.3. Functional Unit

The functional unit varies according to the analyzed process:

1. Mapping by means of drones: 150 metric tons of ACM;
2. restoration by removal: 1.5 sqm or 17 kg of ACM;
3. Transporting RCA: 1.5 sqm or 17 kg of ACW;
4. Storage plant: 1.5 sqm or 17 kg of ACW;
5. Treatment by inertisation: 342 metric tons of ACW;
6. Treatment by disposal: 2,467,655,586 metric tons of ACW.

The totality of the above processes are retrieved in the main process for 150 metric tons of ACW or ACM processed.

18.1.2.4. System boundaries

The system begins with the detection of the ACM and ends with the final treatment.

18.1.2.5. The quality of the data

To evaluate the economic costs (internal and external) and profits, the code SimaPro 9.1.0.8. The data used to create the processes are, moreover, primary in that they are gotten directly from the companies and/or the plants working in this sector. Where the primary data are missing, they are estimated. The methods used to evaluate economic damage are, for internal costs, "*IMPACT 2002+010419indoor/locali_rifIPCCAmlavCint V2.12 / IMPACT 2002+*" and for outdoor costs, "*EPS 2015d con Mesotelioma V1.00 / EPS 2015*" and "*IMPACT 2002+010419indoor/locali_rifIPCCAmlavCint V2.12 / IMPACT 2002+*". The difference in the method used to evaluate environmental damage, "*IMPACT 2002+010419 indoor/locali_rif_IPCC+Amianto V2.12 / IMPACT 2002+*", is that this method takes into account the damage done to a worker who inhales the asbestos fibers during the removal of a sheet of asbestos-cement. The following chapters give a detailed description of the methods of calculation used.

18.1.2.5.1. Modification of the methods to calculate external costs

18.1.2.5.1.1. The calculation of external costs using Eco-indicator 99

As stated in the technical report from 2015 of the LCA Working Group "*RT_35_analysis of external and internal costs*" in order to obtain a monetary evaluation of the damage, it was decided to convert into Euros, the damage calculated with Eco-indicator 99 (modified) through the following operations. To convert the damage in category Human Health it is assumed that one year of life lost from the entire European population (1 DALY) generates an external cost equal to the annual gross salary of an average European citizen, estimated to be 31,150.€. In this case the criterion used to calculate the external costs takes account of the loss that the European GNP experiences for the effect of losing the work of a European citizen. The cost is 31,150 € / (DALY). The estimate for damage in the Ecosystem Quality category was made based on the costs of reintroducing an animal species into the environment. As an example, the Kite was reinstated into the Frasassi Park. To reinstate this species, it cost 61,974,83 € per year. In addition, we obtained information about reinstating the Abruzzo Camoscio buck in its habitat, (145,000 € / year to create a population on the Sibilini mountains, 145,000 € to create a population on Sirente Velino, 120,000 € per year for genetic studies, 170.000 € a year for the capture and radio localization, 20,000 € a year for various expenses, for a total of 600,000 € per year) and for the chicken Sultano in Sicily and Sardinia, (200,000 € per year to create the reintroduction, 100,000 € a year for monitoring and research, 1,400,000 € a year to renew the environment, 2,250,000 € to create a humid area, for a total of 3,950,000 € per year). We can make an arithmetical average of the cost of reinstating three European species that we considered and attribute that cost to reinstate any other European species: C_{ripr}: (61,974,83 + 6000,000 + 3,950,000)/3 = 1,537,325 [€/species)]. The Eco-indicator 99 method, calculates in the Ecosystem Quality category of damage, the value of the PDFsqmyr which represents the the increase in the percentage of the fraction of vanished species in Europe (relationship between the number of at risk species and the total number of species). The species existing in the European territory are 215,000 of which 24% are at risk (affected) And so considering that the surface area of Europe is equal to $2.16 \cdot 10^{12}$ sqm and to reinstate one species it must be done in three area, it's possible to calculate the economical damage associated with the quality of the ecosystem following this procedure:

- percent of vanished species in respect to the total number of species: PDFsqmyr / (2.16×10^{12}sqm×1yr) = PDF
- Number of "disappeared" species" = NSD
- PDF = (NSD / number of species total) ×100 = (NSD / 215,000) ×100 from which we get: NSD = PDF ×215,000 / 100 = PDF ×2,150
- The cost to reinstate the vanished species because of the damage equal to PDFsqmyr: 1,537,325[€] × 3 areas × NSD = 1,537,325[€] × 3 × PDF × 2,150 = 1,537,325[€] × 3× 2,150 × PDFsqmyr / (2.16 $\times0^{12}$sqm×1yr) = 4.5906×10^{-3} PDFsqmyr.

The coefficient of the cost is: 4.5906 $\times10^{-3}$ €/ PDFsqmyr. The estimated economic damage for the category Resources is made considering for the MJ surplus, the actual European average cost of an electric kWh, that is 0.075 €/kWh=0.075€ / 3.6 MJ = 0.0208 €/MJ, The coefficient of cost is: 0.0208 €/MJ

18.1.2.5.1.2. The calculation of the external costs with IMPACT 2002 + 010419 indoor/rooms _rifIPCCAmlavCint V2.12/ IMPACT 2002

On the basis of the indicators made for Eco-indicator 99,we proceeded, as "*RT_35_analysis of external and internal costs*" as sited previously, to the modified method IMPACT 2002+ for Human Health, Ecosystem Quality, Climate change, Resources. In relation to the same indicators used previously for the category damage to Human Health, the category "*Tumors from Mesotelioma*" was added with the relative factor of characterization (Chapter 17.4.2) The method used is IMPACT 2002 + 010419 indoor/rooms _rifIPCCAmlavCint V2.12/IMPACT 2002. The characterization factor was calculated in chapter 18.1.2.5.1.2.2.

18.1.2.5.1.2.1. Coefficient of damage assessment for the calculation of costs Human Health external

- Carcinogens: 31,150 € / DALY * 2.8E-6 DALY / kg C_2H_3Cleq = 0.08722 €/kgC_2H_3Cleq
- Non carcinogens: 31,150 € / DALY * 2.8E-6 DALY / kg C_2H_3Cleq=0.08722 €/ kgC_2H_3Cleq
- Respiratory inorganics: 31,150 € / DALY*7E-4 DALY/kg PSQM.5 eq=21.805 €/kg PSQM.5 eq
- Ionizing radiation: 31,150 € / DALY*2.1E-10 DALY / Bq C14 eq = 6.5415E-6 €/Bq C14 eq
- Ozone layer depletion: 31,150 € / DALY*1.05E-3 DALY /CFC-11eq=32.7075 €/CFC-11 eq
- Respiratory organics: 31,150 € / DALY*2.13E-6 DALY / C_2H_4 eq = 0.0663495 €/ C_2H_4 eq

Ecosystem quality

- Aquatic ecotoxicity: 4.5906E-3 €/PDF*sqm*yr*5.02E-5 PDF*sqm*yr / kg TEG water = 2.3044812E-7 € / kg TEG water
- Terrestrial ecotoxicity: 4.5906E-3 € / PDF*sqm*yr * 7.91E-3 PDF*sqm*yr / kg TEG soil = 3.6311646E-5 € / kg TEG soil
- Terrestrial acid/nutri: 4.5906E-3 € / PDF*sqm*yr * 1.04 PDF*sqm*yr / kg TEG soil = 4.774224E-3 € / kg SO_2 eq

- Land occupation: 4.5906E-3 € / PDF*sqm*yr * 1.09 PDF*sqm*yr / kg TEG soil = 5.003754E-3 € / sqmorg.arable

Climate change

- Climate change: 7.81E-3 € / kg CO_2 eq

Resources

- Non-renewable energy: 0.0208 € / MJ primary * 1 MJ primary / MJ primary =0.0208 € / MJ primary
- Mineral extraction: 0.0208 € / MJ primary * 1 MJ primary / MJ surplus= 0.0208 € / MJ surplus

Tumors from Mesothelioma

- Tumors from Mesothelioma: 31,150 € / DALY * 30 DALY / kg = 934,500 € / kg

18.1.2.5.1.2.2. Normalization coefficients to restore the damage assessment

The normalization factors for the above damage categories are listed below:

Human Health

- fn = 141 $DALY^{-1}$/ 3,1150 € / DALY = 4.526E-3$€^{-1}$

Ecosystem quality

- fn = 7.3E-5 $(PDF*sqm*yr)^{-1}$ / 4.5906E-3 € / (PDF*sqm*yr) = 0.016 $€^{-1}$

Climate change

- fn = 0.000101 $(kg\ CO_2\ eq)^{-1}$ / 7,81E-3 € / kg CO_2 eq = 0.013 $€^{-1}$

Resources

- fn = 0.00000658 MJ^{-1} / 0,0208 € / MJ = 3.163E-4 $€^{-1}$

Tumors from Mesothelioma

- fn = 141 $DALY^{-1}$/ 31,150 € / DALY = 4.526E-3$€^{-1}$

18.1.2.5.1.3. Metodo EPS 2015d con Mesotelioma V1.00 / EPS 2015

If we calculate the coefficient of characterization of the asbestos fiber which is inhaled by the worker while removing a sheet of asbestos-cement, with the method EPS 2015d (*Steen Bengt,2015*) the factor of damage assessment is 0.0013 cases /kg*30 DALY* cases= 0.04 DALY = 0.04 person/yr (assuming that 1 person Yr = 1 DALY). The damage assessment factor has been taken as equal to YOLL (years of life lost) or 50,000 ELU (Environmental load unit) / kg. As with IMPACT2002 the substance considered is Asbestos fiber on the working person while the category pf impact is the malign tumor of mesothelioma. The characterization factor 0.04 YOLL/kg asbestos/year was gotten by multiplying 0.001 cases/kg asbestos/year con the 30 YOLL/ case. Taking the factor of characterization obtained with the IMPACT2002+ method, ie. 1.055 cases/kg, and multiplying by the 30 YOLL/case we get 31,668 YOLL. The name of this modified method is EPS 2015d with Mesothelioma V1.00/EPS 2015.

18.1.2.5.2. Modification of method of internal costs

To calculate the internal costs, as in the technical report from 2015 of the LCA Working Group "*RT_35_analysis of external and internal costs*" we proceeded to the modified method IMPACT 2002 + for Human Health, Ecosystem Quality, Climate Change and Resources. The methods used to evaluate the economic damage are, for internal costs, "*IMPACT 2002+010419indoor/locali_rifIPCCAmlavCint V2.12 / IMPACT 2002+*" in the above sited methods the damage due to fibers inhaled by a worker during removal of a sheet of asbestos-cement is taken into account (Chapter 17.4.2).

18.2. Inventory analysis

The items of the cost used to construct an inventory and which allow for the construction of an economic model, are the following:

- costs of projection and construction;
- cost of use of third party assets;
- cost of software;
- general and management costs (these have been divided only in the waste disposal process) ;
- maintenance costs, ordinary and extraordinary;
- cost of equipment;
- fuel costs;
- costs of supplies;
- labor cost;
- costs of depreciation and devaluation;
- machinery costs;
- financial charges;
- taxes;
- costs of disposal of waste products from the plant;
- costs of environmental compensation;
- postmortem costs;
- costs of decommissioning.

Regarding the items of income, only the entry "Revenue" was used.

18.2.1. Survey and mapping

In the following process an economic analysis was made of the map using drones in the eight communities of the Lower Reggiana Union. The data was provided directly from the company which did the mapping and represents the expenses incurred for the maps made of the territory in question.

The economic sum takes into account the following aspects:

- The functional unity of the process and the quantity of ACM managed between 01/04/2016
- and 31/12/2017 (MACMsmalt) which is 150 metric tons;
- The ACM considered in the census (MACMcebs) was 33,048 metric tons;
- the surface area considered from the biplane was 313.90 ksqm total;
- The number of roofs found in asbestos-cement is 6,184;

- In order to create the algorithm, 2 up to date laptops were used;
- There are 72,048 inhabitants in the eight communities of the Lower Reggiana Union;
- The total surface area of ACM is 2,203,174 sqm;
- The drone made 7 trips;
- For all the expenses sustained, only the share of the cost inherent to the mapping (ex, for the cost of the filming from the air, the flights of the drone and the creation of the algorithm), only the time used in the mapping was counted.

The economic model for this phase takes into account the following items (Economic issues):

✓ the costs of projection (and construction) including the analysis of feasibility and the successive planning of the entire study presented;

✓ the costs of personnel, representing 300 hours of workmanship (2 lab technicians and a drone pilot) for the project;

✓ the costs of depreciation (and devaluation) including the share of depreciation of the immobilization used;

✓ the costs of the use of third party assets represented by the biplane used for the aerial shots;

✓ the costs of software including the software license used to create the algorithm and for the interpretation of the images filmed;

✓ general costs and those not directly attributable to the previous items (ie, cost of the trip to to reach the drone);

✓ the costs of decommissioning are represented by the costs of decommissioning the machines and equipment used to create the algorithm, for the biplane, and the drone, these are estimated costs.

Following is the table (Table 18-1) itemizing the costs for the economic analysis. The total costs allocated for the F.U. is 181.55 €.

Cost of planning and construction	€	5,000
Labor cost	€	11,000
Cost of depreciation and devaluation	€	1,000
Cost of use of third party assets	€	10,000
Cost of software	€	5,000
General and management cost	€	4,000
Decommissioning costs	€	4,000
Total cost for mapping 33,048 metric tons	€	40,000
Total costs for 150 metric tons (F.U.)	€	181.55

Table 18-1: Itemizing costs for the process of mapping ACM in eight communities of the Lower Reggiana Union

Lastly, in the following tables, (Table 18-2 and Table 18-3) are shown the extraction of the process and the relative parameters. An economic allocation was made where the "p" represents the € spent per 150 metric tons of ACM mapped.

Economic issues	**Amount**	**Unit**
Cost of planning and construction	5,000/MACMcens*MACMsmalt=22.694	p
Labor cost	11,000/MACMcens*MACMsmalt=49.927	p
Cost of depreciation and devaluation	1,000/MACMcens*MACMsmalt=4.538	p

Cost of use of third party assets	10,000/MACMcens*MACMsmalt=45.388	p
Cost of software	5,000/MACMcens*MACMsmalt=22.694	p
General and management cost	5,000/MACMcens*MACMsmalt=22.694	p
Decommissioning costs	4,000/MACMcens*MACMsmalt=18.155	p

Table 18-2: Extraction of the process "Mapping ACM in eight communities of the Lower Reggiana Union"

Parameter of Input	**Amount**	**Unit**
MACMcens	33,048	Amount of coverage mapped:t
MACMsmalt	150	Amount of coverage dispose of:t

Table 18-3: Parameters of input for the process "Mapping ACM in eight communities of the Lower Reggiana Union"

18.2.2. Site of decontamination of sheets of asbestos-cement by removal

In the following process, an economic analysis was made of the decontamination by removal of the coverings in asbestos-cement. The data was provided directly by the company in this sector and represent the costs sustained by the company in one year of operation.

The economic quantification considered the following aspects:

- The weight of one sheet is 17 kg/sqm and its area is 1.5 sqm;
- The functional unit is 25.5 kg (17 kg/ sqm*1.5 sqm);
- The sqm removed in one year are 28,000;
- The cost city authorization includes taxes and seals;
- The cost of equipment for work safety includes no. 2 scaffoldings, no. 2 platforms, no. 1 flexible net and all equipment necessary to set up the site (grids and signposting etc);
- The cost of the life line (with certification) is the average cost to install the life line in the 90 work sites studied;
- It is foreseen installing the life line in half of the work sites (45 work sites);
- The cost of personnel includes the personal protective equipment necessary to carry out the activity and the courses of formation, general and specific;
- Included in the costs of equipment are no. 2 vacuum cleaners with absolute filters, and no. 270 spare filters, no. 2 drills, no. 2 low pressure pumps and a series of manual tools;
- Included in the cost of consumable goods calculated for the total of the sqm removed in one year, are no. 300 sheets in PE, no. 500 type-tested big bags, adhesive tape and legal adhesive;
- It has been considered that for every work site that the company must direct, in addition to the work plan, a city permission to begin the work;
- The cost of maintenance both ordinary and extraordinary of the PLE vehicles and the trucks with a crane hoist is the average cost of maintenance sustained in 5 years of depreciation of the assets;
- The cost of maintenance both ordinary and extraordinary of the equipment is the average of the costs of maintenance sustained in 2 years of depreciation of the assets;
- The cost of the authorization in the register of the managers in category 10A is composed of the share of the part of the cost of inscription plus the annual entitlements;

- The market price for a reclamation with removal of a covering of 300 sqm in asbestos-cement is about 15 €/sqm;

The following table 18-4 shows the data for the calculation of the costs of the process:

DESCRIPTION	U.M.	VALUE
Sqm of covering removed in one year	sqm/year	28,000
Average sqm of covering removed	sqm/site	300
Kg of covering removed in one year	kg/year	490
Number of work sites (an average on the basis of sqm removed)	no./work site	90
Number of files and work plans with AUSL	n/file	90
Cost of work plans with AUSL	€/plan	300
Cost of city permits	€/permit	800
Purchase cost of PLE	€	60,000
Purchase cost of truck with crane	€	180,000
Years of depreciation of PLE and truck with crane	years	5
Insurance and stamps	€/year	1,000
Km done with PLE and truck with crane	km/year	15,000
Cost of fuel gas	€/liter	1.1
Cost of maintenance for vehicles ordinary and extraordinary	€/year	5,000
Fuel consumption truck	km/liter	3.5
Fuel consumption PLE	km/liter	7
Number of personnel assigned to removal	no.	3
Cost of personnel assigned to removal	€/person	23,000
Number of office workers	no.	2
Cost of office workers	€/person	40,500
Cost for the technician responsible 10A	€/year	3,000
Rights of enlistment in register of environmental managers and sureties cat.10A	€/year	1,500
Quantity of encapsulants type D	kg/sqm	0.25
Costs of encapsulants type D	€/kg	0.8
Cost for safety equipment	€	10,000
Years of depreciation for safety equipment	years	2
Maintenance costs ordinary and extraordinary	€/year	8,000
Cost of installing life line with certification	€/life line	1,800
Cost of miscellaneous equipment	€	5,000
Years of annual depreciation of equipment	years	2
Maintenance costs ordinary and extra	€/year	5,000
Cost of consumables	€/year	6,000
Decommissioning costs for PLE, truck and miscellaneous equipment	€/year	6,500

Table 18-4: Data to calculate the process cost "Removal of asbestos-cement sheets"

The economic model for this phase takes into account the following items (Economic issues):

- The cost of depreciation (and devaluation) includes the share of depreciation of vehicles and equipment belonging to the company;
- The costs for personnel include the annual gross pay for those assigned to the removal and to the office workers;
- The costs of maintenance both ordinary and extraordinary includes all the maintenance done to the vehicles and equipment belonging to the company;
- The fuel costs include the cost of fuel for the vehicles and equipment;
- The cost of consumable materials represents the cost of consumable materials used for the operation of reclamation;
- The costs for equipment are the costs for the planning and the installation of the life line;
- General and management costs are all those costs not directly attributed to one of the previous items (costs to obtain authorization in the professional register of managers, cost for the top technician, etc);

- The costs of decommissioning are represented by the cost of decommissioning the machinery and the equipment.

Table 18-5, here below shows the itemized costs used for the economic analysis. The total costs allocated for the F.U. is 23.44 €.

Depreciation and devaluation costs	€	55,500
Labor cost	€	150,000
Maintenance ordinary and extraordinary costs	€	18,000
Costs of consumable materials	€	15,200
Fuel costs	€	6,927
Costs for equipment	€	81,000
General management costs	€	104,500
Decommissioning costs	€	6,500
Total costs for 28,000 sqm (or 490,000 kg)	€	437,627
Total costs for 1.5 sqm (or 25.5 kg)	€	23.44

Table 18-5: Itemized costs for the process "Removal of sheets in asbestos-cement"

Lastly, in the following table (Table 18-6 and Table 18-7) is shown the extraction of the process and the relative parameters. An economic allocation was made where the "p" represents the € spent per 1.5 sqm of sheet removed

Economic issues	**Amount**	**Unit**
Depreciation and devaluation costs	55,500/Areatotlastre*area = 2.946	p
Labor cost	150,000/Areatotlastre*area = 8.036	p
Maintenance ordinary and extra cost	18,000/Areatotlastre*area 0.964	p
Consumable materials	15,200/Areatotlastre*area = 0.8142	p
Fuel costs	6,927/Areatotlastre*area = 0.37109	p
Equipment costs	81,000/Areatotlastre*area = 4.339	p
General management costs	104,500/Areatotlastre*area = 5.598	p
Decommissioning costs	6,500/Areatotlastre*area = 0.348	p

Table 18-6: Parameters for input per process " Removal of asbestos-cement sheets"

Parameters of Input	**Amount**	**Unit**
Areatotlastre	28,000	Area of covering removed in a year :sqm
area	1.5	Area of one sheet:sqm

Table 18-7: Parameters of input for the process " Removal of asbestos-cement sheets"

18.2.3. Transport daily from the removal site to the storage plant

In the following process an economic analysis was made of the daily transport of the coverings in asbestos-cement previously removed. The data were provided directly from the company in this sector and represent the costs sustained by the company in a year of operation.

To reach our purpose we noted that:

- The weight of one sheet is 17 kg/sqm and its area is 1.5 sqm;
- The sqm removed in one year are 28,000 (490,000 kg);

- The transport is made with a truck with a crane license B weighing 35 quintals;
- The maintenance costs both ordinary and extraordinary of the truck with crane is the average of the costs of maintenance sustained in 5 years of depreciation of the assets;
- The cost of authorization from the professional register of environmental managers in category 5 is made up of the share part of the inscription fee plus the annual fees;
- In one year, 1,800 hours of transport are done;
- In one year 90 work sites are considered;
- Included in the costs for personnel are the individual protection devises (DPI) obligatory and necessary for this work, and the training courses both generic and specific.

Table 18-8,below, shows the data for the calculation of the costs of the process.

DESCRIPTION	U.M.	VALUE
Square meter of covering removed in one year	sqm/year	28,000
Kg of covering removed in one year	kg/year	490,000
Average covering removed in one yeari	sqm/site	300
Number of sites (an average based on sqm removed) in one year	n./year	90
Number of forms refused	n/year	90
Cost sustained for refused forms	€/waste form	5
Purchase of a truck with a spider loader	€	60,000
Depreciation in years of the truck	years	5
Maintenance of truck and crane both ordinary and extra	€	2,500
Fuel consumption for truck	km/liter	7
Fuel costs	liter/km	1
Km traveled in one year	km/year	2,000
Road tax for truck	€/year	300
Insurance premium per year	€/year	500
End of life truck with crane	€	1,000
Authorization to transport Environmental managers register cat.5	€/year	500
Cost for a responsible technician for cat.5	€/year	2,500
Number of personnel trained for transport	no.	1
Cost of personnel trained for transport	€/year	41,000
Number of office personnel to compile forms to handle logistics	no.	0.2
Cost of office personnel to compile forms and handle logistics	€/year	45,000

Table 18-8: Data for an economic analysis for the process " Transport daily vehicle to remove sheets"

The economic model for this phase takes into account the following items (Economic issues):

- The cost of depreciation (and devaluation) including the share of depreciation of the truck with crane owned by the company;
- The costs for the personnel include the annual gross pay for the drivers and the office workers;
- Fuel costs include the cost of fuel for the daily means;
- The cost of equipment are the costs for the planning and the installation of the life line;
- General costs and management costs are all those transversal costs not directly attributed to one of the items above (cost of obtaining authorization from the professional register, cost for the responsible technician, road tax and insurance for the vehicle etc.);
- The decommissioning cost is represented by the cost of decommissioning the truck and crane.

The following Table 18-9, shows costs itemized with the explanation, used for the economic analysis. The total cost allocated for the F.U. is 3.83 €.

Costs of depreciation and devaluation	€	12,000
Labor cost	€	50,000
Maintenance ordinary and extraordinary costs	€	2,500
Fuel costs	€	4,875
General and management cost	€	4,250
Decommissioning costs	€	1,000
Total costs for 490,000 kg transported or 28,000 sqm	€	73,625
Total costs for 25.5 kg or 1.5 sqm	€	3.83

Table 18-9: Items of cost for the process "Transport daily means sheet removal"

Lastly in the following table (Table 18-10 and 18-11) the extraction of the process and the relative parameters are shown. An economic allocation was made where the "*p*" represents the € spent for 1.5 sqm of sheet transported.

Economic issues	**Amount**	**Unit**
Costs of depreciation and devaluation	12,000/Areatotlastre*0.643	p
Labor cost	50,000/Areatotlastre*area = 2.678	p
Maintenance ordinary and extra costs	2,500/Areatotlastre*area = 0.134	p
Fuel costs	4,875/Areatotlastre*area = 0.261	p
Management costs	4,250/Areatotlastre*area = 0.227	p
Decommissioning costs	1,000/Areatotlastre*area = 0.053	p

Table 18-10: Extraction of process "Transport of removed sheet daily means""

Parameters of Input	**Amount**	**Unit**
Areatotlastre	28,000	Are of covering removed in a year: sqm
area	1.5	Area of a sheet:sqm

Table 18-11: Parameters of input for the process "Transport daily means sheet removal"

18.2.4. Storage plant authorized in D15 (or R13)

In the following procedure an economic analysis was made of a storage plane for wastes containing asbestos (ACW). The data was provided directly from a company which works in the sector and represents the costs sustained by the company in a year's work. To reach this objective it is noted that:

- The functional unity of the procedure is the area of a sheet of asbestos-cement or 1.5 sqm;
- having the weight of 25.5 kg;
- The surface of the building is 1,270.5 sqm;
- It is hypothesized that the plant is situated in the town of Correggio;
- The plant is authorized to receive 25,000 metric tons of ACW a year;
- Proceeds and financial charges, as all funds and accruals, are considered equal to zero;
- The construction company and the owner of the plant is entirely capitalized (no debts toward banks or suppliers);

- Personnel working in the plant consist of no. 1 weighing office and management control, no. 2 forklift operators, no. 1 plant manager and no.1 administrative secretary;
- The purchase cost of the property including the property, the equipment and the machinery is represented by the cost of construction and the purchase of the warehouse building, of the cost of constructing the offices and the scale, the purchase of furnishings and the planning and construction of all the service plants (sewers, fireproofing, electrical system, heating plant and security system);
- Included in the cost of disposal of wastes from the plant are the first rainwater and water to wash the equipment, possible absorbent materials which have been contaminated, office wastes;
- Included in the general costs are all transversal costs (such as costs of security guards ,refuse forms, software costs, office supplies, etc.);
- To run the plant the following machines are present, no. 2 forklifts weighing 70 qq (7,000 kg) no. 1 telescopic weighing 60 qq (6,000 kg) and a 9 meter arm, no.1 automobile and no.1 truck with demountable body and 2 caissons of 30 sqm;
- The maintenance costs both ordinary and extraordinary of the forklifts and the telescopic, is the average cost of the maintenance costs sustained in 5 years of depreciation of the assets;
- The maintenance costs both ordinary and extraordinary of the plant is the average cost of maintenance sustained in 10 years of depreciation of the assets;
- In the present procedure included in the general expenses is the transport of 50 km with balance, from the storage plant to its final destination be that the waste disposal or the recuperation plant;
- Considering only the cost of the storage plant, (and not the transport) the price €/metric ton for storing is 52.70 €/ metric ton;
- The taxes, IRAP and IRES represent 28% of the results of operative management or operative income;
- The company’s profit is 20€/metric ton.

Following are general data concerning the factory (Table 18-12) from which the construction of the procedure began.

DESCRIPTION	U.M.	VALUE
Cost of purchasing land	€	500,000
Cost of obtaining authorization for wastes	€	20,000
Cost of purchasing property,furnishings, service systems	€	1,500,000
Cost of purchasing forklift	€	90,000
Cost of purchasing automobile	€	30,000
Cost of truck with demountable body and cassions of 30 m^2	€	250,000
Cost of purchasing a telescopic loader	€	100,000
Costs of maintenance ordinary and extraordinary - plant	€/year	50,000
Costs of maintenance ordinary and extraordinary forklift and telescopic arm	€/year	5,000
Years of depreciation of property, furnishings and equipment	years	10
Years of depreciation of forklift and telescopic arm	years	5
Years of depreciation of the land	years	33
Consumption of fuel oil for telescopic arm	l/h	8
Consumption of fuel oil for forklift	l/h	5
Consumption EE system	Kwh	15
Cost of waste disposal for the factory	€/year	5,000
Cost of demolishing warehouse and annexed plants	€/year	30,000
Cost of scrapping forklifts	€/year	4,000
Cost of scrapping telescopic loading arm	€/year	5,000
General cost	€/year	29,925
Fuel costs	€/l	1
Cost of EE	€/kw	0,6
Hours functioning /year - forklift and telescopic arm	hours/year	1,500
Hours functioning /year- factory	hours/year	2,000
Lifespan of the factory	years	50
Number of employees	no.	5
Average cost of employees / year	€/person	45,000
Km from storage point to disposal point	km	50
Cost of transport / km with balance	€/km	€ 1,50

Table 18-12: Data for constructing for the process "storage plant"

The economic model for this phase takes into account the following items of cost (economic issues):

- The costs of depreciation (and devaluation) including the share of depreciation of the land the property, and the vehicles owned by the company;
- The costs for the employees include the gross annual pay for the no. 5 employees working in the factory;
- The costs of maintenance both ordinary and extraordinary include all upkeep done on the equipment of the company;
- The cost for the electric energy used includes the cost for all the electricity used in the factory;
- Fuel costs include the daily cost of purchasing fuel for the vehicles;
- Costs for waste disposal for waste produced by the factory are costs of waste disposal which are produced during the normal working of the factory (first rainwater, water to wash vehicles, possible contaminated absorbent materials and office waste);
- General and management expenses are all those transversal costs which are not directly attributable to the list above (costs for obtaining authorization) and the costs for transportation from the storage plant to the final disposal point;
- Taxes are the taxes paid by the company (IRES and IRAP);
- Decommissioning costs are represented by the cost of decommissioning the vehicles.

In the following table (Table 18-13) are reported the combined annual costs. The total of the allocated costs per F.U. is 965.97 €.

Depreciation and devaluation costs	€	259,151.52
Labor cost	€	225,000
Maintenance costs, ordinary and extraordinary	€	55,000
Cost of electric energy	€	18,000
Fuel costs	€	27,000
Disposal of factory wastes	€	5,000
General costs	€	50,000
Taxes	€	140,027.58
Decommissioning costs	€	39,000
Total annual costs for a surface area of 1270.5 m² or 25,000 metric tons	€	818,179.09
Total annual costs for a surface area of 1.5 m² or 25.5 kg	€	965.97

Table 18-13: Items of cost for the process "storage plant"

Lastly, in the following tables (Table 18-14 and 18-15) the extraction of the procedure and the relative parameters are shown. The "*p*" represents the Euro spent for 25.5 kg of sheet stored in the plant.

Economic issues	**Amount**	**Unit**
Labor cost	225,000/Massatratanno*Plastra*1E-3 = 0.2295	p
Management costs	50,000 /Massatratanno*Plastra*1E-3 = 0.051	p
Depreciation and devaluation costs	259,151.52 /Massatratanno*Plastra*1E-3 = 0.2643	p
Maintenance costs	55,000/Massatratanno*Plastra*1E-3 = 0.0561	p
Cost of electric energy	18,000/Massatratanno*Plastra*1E-3 = 0.01836	p
Fuel costs	27,000/Massatratanno*Plastra*1E-3 = 0.02754	p
Decommissioning costs	39,000/Massatratanno*Plastra*1E-3 = 0.03978	p
Waste disposal costs	5,000/Massatratanno*Plastra*1E-3 = 0.0051	p
Taxes	140,027.58/Massatratanno*Plastra*1E-3 = 0.1428	p

Table 18-14: Extraction of the process "Storage plant"

Parameters of Input	**Amount**	**Unit**
Massatratanno	25,000	Quantity of ACW treated by the plant in a year: tons
Plastra	25.5	Weight of a 1.5 sqm sheet: kg

Table 18-15: Parameters of input for the process of the "storage plant"

18.2.5. Landfill for hazardous and non-hazardous special waste

In the following procedure an economic analysis was done of a waste disposal site for hazardous and non-hazardous special waste. The data was provided directly by the company in this sector and represent the costs and the profits for one year's work.

The economic quantification took into account the following aspects:

- The functional unit is represented by 2,467,655,586 metric tons of waste containing asbestos disposed of in 15 years of operation;

- In one year of operation 164,510,372 metric tons were disposed of (it is assumed that this remains in line for all 15 years);
- The post operative management is 30 years;
- The disposal site is considered operative for 310 days a year;
- We consider that the applied tariff at the entrance of the disposal site is 140,77 €/ metric ton;
- The unplanned incidents and works in economics are 5% of the amount of the works;
- The security charges in the planning stage are 1% of the amount of the works;
- The VAT on the works is 10%;
- The technical costs of planning and construction represent measurements, inquiries, project management, inspections and testing, environmental impact studies, security coordination;
- VAT on the technical expenses is 20%;
- The charges for the post operative management are represented by the withdrawals and the leachate treatment, by the maintenance of the green grass covering, verification of possible landslides and the consequent refilling, cleaning of the gutters, slopes, monitoring, and maintenance;
- Financial charges are 988,000 € average for every working year;
- Fuel use for the machinery is about 3,000 liters/day;
- The costs for surveillance is considered for 24 hr/day for 100 days;
- Electric energy consumed is 15,000 kwh/month;
- The lifespan for the vehicles on the work site and the machine which moves the dirt is 5 years;
- Lubricating oils are 10% of the cost of the fuel consumed;
- For the cost of personnel, reference is made to the national contract FISE;
- General costs of operation are considered taxes, postal charges, telephone charges, office supplies, certificates, medical visits for personnel, maintenance of office machines, bookkeeping;
- The cost of environmental compensation is 15€/metric ton delivered;
- General costs are 30% of the operative costs;
- The leachate collected in barrels and treated in a sewage plant is 13,170 m^3/year
- The expenses for ordinary maintenance include charges for sample withdrawal and analysis for monitoring environmental components
- The taxes IRAP and IRES represent 28% of the results of the operative management (or operative income);
- The company's profit is 18€/metric ton.

Following are the general data from which we started for the construction of the procedure. In this table (Table 18-16) are shown the list of costs of planning and construction of the disposal plant in question.

Proceedings for the completion of the general services	87,749.73
Charges for security services for the general services	7,877.5
Total	**95,627.23**
Work for constructing the first part of the permanent storage plant	27,739,748.99
Charges for security services for the first part of the disposal site	137,397.49
Total	**27,877,146.48**
work to realize the second part of the permanent storage plant	7,048,984.59
Security charges for the second part	189,489.85
Total	**7,238,474.43**
Cost of building the plant for recuperating inert waste	2,660,000
Security charges for the second part of the disposal site	12,600
Total	**2,672,600**
Total cost of the project	**37,883,848.37**
VAT (10%) on the work of the project	2,651,869.37
Total VAT on the work	**2,651,869.37**
Technical expenses for the service lot	39,781.36
Technical expenses for the first part of the disposal site	693,857.33
Technical expenses for the second part of the disposal site	1,656,923.72
Total	**2,390,562.41**
VAT on the technical expenses	478,112.48
Total	**478,112.48**
Social insurance contributions	47,811.25
Total	**47,811.25**
Costs of surface rights on the land for the service lot	882,000
Costs of the surface rights on the land for the first part of the disposal s	875,000
Costs of the surface rights on the land for the second part of the dispo	884,800
Total	**2,641,800**
Unplanned incidents and economy works for the service lot	39,781.36
Unplanned incidents and economy works for the first part of the site	693,857.33
Unplanned incidents and economy works for the second part of the sit	466,923.72
Total	**1,200,562.41**
Total necessary expenses	**9,410,717.92**
Total costs of planning and construction	**47,294,566.07**

Table 18-16: Costs of planning and constructing a "Landfill for hazardous and non-hazardous special waste"

In the following table (Table 18-17) the costs of operation in one year and 15 years are listed:

DESCRIPTION					Total costs for one year of operation	Total costs for 15 years of operation
Various machinery and diverse equipment						
Items	**U.M.**	**Quantity**	**Unit price (€)**	**Cost (€)**		
Inert material for the daily compaction of waste	mc	31,000	10	310,000		
Sample withdrawal by means of septic truck from the cistern of leachate and transported to the sewage plant	mc	13,170	120	1,580,400		
Lab costs (additives disinfectants,Ca(OH)2, rat traps,etc)	no.	1	150,000	150,000		
Surveillance on non working days (24 hrs x 100days) hours	hour	2,400	50	120,000		
Electric energy: an average of 15000 kwh/month is estimated	kwh	180,000	0.16	28,800		
Total costs for machinery and varied equipment				**2,189,200**		
Maintenance and monitoring of the factory						
Items	**U.M.**	**Quantity**	**Unit price (€)**	**Cost (€)**		
Maintenance charges, ordinary and extraordinary, of electro-maccanical equipment (pumps etc.)	months	12	236,387.14	2,836,645.68		
Total costs for maintaining and monitoring of plant				**2,836,645.68**		
Total costs for utilities and services					**€ 5,025,845.68**	**€ 75,387,685.2**
Personnel						
Items	**U.M.**	**Quantity**	**Unit price (€)**	**Cost (€)**		
Executive manager 150,000 Gross/Euros/year	no.	1	150,000	150,000		
Technical manager (employee on 8 th level earning 70,000 €/yr)	no.	2	70,000	140,000		
Construction site manager (5 th level) gross pay: 2 workers for every shift 1 shift of 8 hrs x 310 days	hour	2,480	25	62,000		
Workers responsible for moving materials (3rd level): 2 workers/shift 2 shifts of 8 hrs for 310 days	hour	9,920	17	168,640		
Generic support workers (2nd level): 2 workers / shift 2 shifts of 8hrs for 310 days	hour	9,920	15	148,800		
Reception and weighing worker (3rd level): 2 for each shift, 2 shifts of 8 hours for 310 days	hour	9,920	15,89	157,628.8		
Lab technician (8 hrs for 310 days): 1 technician	hour	2,480	20	49,600		
Office secretaries (4th level): 8 hrs for 310 days : 2 secretaries	hour	4,960	23	114,080		
Total cost for personnel					**€ 990,748.8**	**€ 14,861,232**
Insurance and Surety Bonds						
Items	**U.M.**	**Quantity**	**Unit price (€)**	**Cost (€)**		
Insurance	no.	1	200,000	200,000		
Surety Bonds	no.	1	250,000	250,000		
Total costs for insurance and surety bonds					**€ 450,00**	**€ 6,750,000**
Total costs of management					**€ 6,466,594.48**	**€ 96,998,916**

Table 18-17: Costs of the costs for operation for the process "Landfill for hazardous and non-hazardous special waste"

In the following table (Table 18-18) the costs of the machinery in one year and 15 years of operation.

Description of vehicles and machinery	Vehicles and machinery for 5 yrs of operation	Vehicles and machinery for 15 yrs of operation	Unit price (€)	Buying price in 5 yrs of operation (€)	Buying price in 15 yrs of operation (€)
Work site 4x4 vehicle	1	3	40,000	40,000	120,000
Wheel loader	1	3	280,000	280,000	840,000
Truck loader	1	3	300,000	300,000	900,000
Bobcat	2	6	70,000	140,000	420,000
Box Truck for moving dirt	1	3	200,000	200,000	600,000
Truck with removable box to transport wastes with in the plant	2	6	190,000	380,000	1140,000
Waste compactor	2	6	360,000	720,000	2160,000
Total costs for machinery				**2,060,000**	**€ 6,180,000**

Table 18-18: Costs of machinery for the process "Landfill for hazardous and non-hazardous special waste"

Table 18-19, below, shows the financial charges paid in one year and in 15 years of operation.

Item of cost	€/year	Years of operation	€ for 15 years
Financial charges	988,000	15	14,820,000

Table 18-19: Financial charges for the process "Landfill for hazardous and non-hazardous special waste"

Table 18-20 here below shows the general expenses in a year of operation and in 15 years of operation.

Item of cost	€/year	Years of operation	€ for 15 years
General costs	1,939,978.32	15	29,099,674.8

Table 18-20: General costs for the process "Landfill for hazardous and non-hazardous special waste"

Table 18-21 shows post mortem expenses, (costs for operational management) in 15 years of management.

Item of cost	Metric tons in 15 years	€/ton	€ for 15 years
Post Mortem costs	2,467,655.586	40	98,700,000

Table 18-21: Post mortem costs for process "Landfill for hazardous and non-hazardous special waste"

Table 18-22 here below shows the costs of environmental compensation in 15 years of operation.

Item of cost	Metric tons in 15 years	€/ton	€ for 15 years
Costs for environmental compensation	2.467.655,59	15	37,014,833.79

Table 18-22: Costs for environmental compensation for the process "Landfill for hazardous and non-hazardous special waste"

Table 18-23 here below, shows the taxes paid in 15 years of operation: IRAP (4%) and IRES (24%).

Item of cost	Revenue (A)	Costs (B)	Results of operative management (A-B)	€ for 15 years
Taxes	391,789,677.3	330,107,990.6	61,681,686.73	17,270,872.28

Table 18-23: Taxes for the process "Landfill for hazardous and non-hazardous special waste"

The economic model for this phase takes into account the following items of cost (Economic issues):

- Planning (and construction) includes all the costs relative to the planning and the subsequent construction of the lots;
- The costs of depreciation (and devaluation) include the share of depreciation of the land, the mobile assets and the vehicles owned by the company;
- The costs for personnel include annual gross pay for the 5 employees of the factory;
- The costs of maintenance both ordinary and extraordinary include all the maintenance on the vehicles of the company;
- Electric energy costs are the costs for the electric energy used within the plant;
- Fuel costs include the cost for the purchase of fuel daily;
- The cost of waste disposal produced by the factory are costs of waste disposal produced during the normal operation of the factory (first rain water and water to wash the vehicles, possible absorbent material contaminated, office waste);
- General costs and management costs are all those transversal costs non directly attributable
- to the items listed previously, (costs for obtaining authorization) and the costs for transporting materials from the stockpiling plant to the final destination;

- Taxes paid by the company are IRES and IRAP;
- The decommissioning costs are the costs of decommissioning the vehicles.

The following table (Table 18-24) shows the list of all the items reported above:

Costs of planning and constructing	€	47,294,566.06
Management costs	€	96,998,916
Costs of the machinery	€	6,180,000
Financial charges	€	14,820,000
General costs	€	29,099,674.8
Cost of post mortem	€	98,700,000
Cost of environmental compensation	€	37,014,833.79
Taxes	€	17,270,872.29
Total costs in 15 years operation for 2.467.655,59 metric tons	**€**	**347,378,862.94**

Table 18-24: Total cost in 15 years for the process "Landfill for hazardous and non-hazardous special waste"

To complete the economic and financial analysis of the landfill, the following shows the revenues over 15 years of management (Table 18-25).

Revenue items	Metric tons in 15 years	€/ton	€ for 15 years
Revenue	2,467,655.586	158.77	391,789,677.39

Table 18-25: Total revenue in 15 years for the process "Landfill for hazardous and non-hazardous special waste"

Lastly, we report the result of operating the disposal plant studied, for a total of 2,467,655.599 metric tons put in the bank in 15 years of activity (Table 18-26).

Costs	€	347,378,862.94
Cost €/ton	€	140.77
Revenue	€	391,789,677.39
Revenue €/ton	€	158.77
Profit	€	44,410,814.45
Profit €/ton	€	18

Table 18-26: Results of the operating for the process "Landfill for hazardous and non-hazardous special waste"

Table 18-27 shows the extraction of the process studied. The "*p*" represents the costs and revenues in 15 years of operation and 2,467,655.59 metric tons of wastes handled.

Economic issues	Amount	Unit
Management costs	96,998,916.00	p
Planning and construction costs	47,294,566.07	p
Machinery costs	6,180,000.00	p
Financial charges	14,820,000.00	p
General costs	29,099,674.80	p
Post mortem costs	98,700,000.00	p
Cost of environmental compensation	37,014,833.79	p
Taxes	17,270,872.29	p
Revenue	391,789,677.39	p

Table 18-27: Extraction of the process "Landfill for hazardous and non-hazardous special waste"

18.2.6. The inertisation plant for wastes containing asbestos (WCA)

Below, we see an economic. financial study of the industrial process for thermo transformation of sheets of asbestos-cement using a continuous furnace (European patent 07425495.4-1253, "*Process for the thermal transformation of cement-asbestos slates using an industrial continuous kiln*" July 31st, 2007). The data used for the study were extrapolated directly from the business plan of the project covered by Italian patent application MO2006A000205.

In making this study, the following things were taken into consideration:

- The unity of functionality is represented by 342 metric tons of ACW treated in a complete cycle if inertisation (pre-cooked, cooked and cooling);
- One complete cycle of inertisation lasts 38 hours;
- The plant is operative 330 days a year 24 hours a day;
- 216 metric tons of ACW is inertized in 24 hours;
- In the business plan of the factory a seventh year of operation has been considered;
- The total cost of electric and thermal energy used and methane gas consumed is equal to 40 €/ton;
- The WCA treated at the plant in one year are 90,000 metric tons;
- The second raw material that comes out of the furnace is 80% of the ACW that went in;
- The price for transferring the ACW to the plant is 99 €/ton;
- The selling price of the output generated by the process (second raw material) is 21.6 €/ton (excluding transport costs);
- IRAP and IRES taxes represent 28% of the result of the operative management of the operative income.

In Table 18-28, below, are listed the fixed assets of the plant and the relative years and share of depreciation.

Description	Purchase Value (€)	Years of depreciation	Share of depreciation (€)
Building design	€ 200,000	25	€ 8,000
Environmental impact assessment	€ 50,000	5	€ 10,000
Land and urban planning	€ 720,000	25	€ 28,800
Preparation of yard area	€ 100,000	25	€ 4,000
Weights bridge	€ 30,000	20	€ 1,500
Storage warehouse	€ 700,000	25	€ 28,000
Forklifts	€ 135,000	10	€ 13,500
Factory building	€ 2,400,000	25	€ 96,000
Service facilities	€ 30,000	10	€ 3,000
X-Ray machines	€ 200,000	10	€ 20,000
Laboratory building	€ 30,000	25	€ 1,200
Instrument asset laboratory	€ 100,000	10	€ 10,00
Furnace	€ 5,998,700	10	€ 599,870
Post combustion	€ 1,220,000	10	€ 122,000
Officies	€ 150,000	10	€ 15,000
Computer system	€ 20,000	5	€ 4,000
Ordinary plant maintenance	€ 300,000	5	€ 60,000

Table 18-28: Fixed assets of the project "Treatment of WCA with inertisation"

In the table below,18-29, are listed the costs of the plant in one year of operation with 90,000 metric tons of ACW treated.

Cost of planning	€	8,000
Ordinary maintenance	€	168,243
Consumable materials	€	21,649
Fairs and exhibitions	€	16,561
Endorsements	€	16,561
Insurance	€	82,806
External collaboration	€	176,653
SGA	€	60,724
External services	€	110,408
Personnel	€	702,715
Depreciation quota	€	942,870
Financial charges	€	538,048
Taxes	€	1,476,385
Decommissioning costs	€	500,000
GPL cost	€	3,078,000
Electric energy costs	€	522,000

Table 18-29: Cost of the process "Treatment of WCA with inertisation"

The Economic model for this phase takes into account the following costs (Economic issues):

- The costs of planning (and construction) includes all the costs relative to the planning and installation of the buildings;
- The cost of the consumable materials represent the costs for lab materials and chemicals used in the line of treating of fumes;
- The costs of maintenance include all costs relative to the ordinary and extraordinary maintenance of the plant including the line treating fumes;
- Depreciation costs (and devaluation costs) include the quota of depreciation of the plot of land, the mobile assets and the vehicles owned by the company;
- The costs for personnel include the annual gross pay of the employees of the plant;
- Financial charges are costs used to sustain the debts to the banks;
- The costs of ordinary and extraordinary maintenance include all maintenance done in the factory and to the vehicles;
- General costs and those of management include the costs for electric energy, methane gas, insurance policies, external collaborators, endorsements, fairs and events;
- The taxes are those costs paid to the tax agency (IRES and IRAP);
- The decommissioning costs are those of decommissioning the factory.

In order to put the items of costs with the other processes studied, in ordered fashion, the following table (Table 18-30) was made:

Cost of planning	€	8,000
Consumable materials	€	21,649
Ordinary maintenance	€	168,243
Depreciation quota	€	942,870
Labor cost	€	702,715
Financial charges	€	538,048
General and management costs	€	4,063,713
Taxes	€	1,476,385
Decommissioning costs	€	500,000
Total of costs	**€**	**8,421,623**

Table 18-30: Items of cost together for the process "Treatment of WCA with inertisation"

In the table here below (Table 18-31) we see the list off the earnings of the factory in one year of operation with 90,000 metric tons of ACW treated and 72,000 metric tons of second raw materials sold.

Revenue from WCA	€	8,910,000
Revenue from inert sold	€	1,555,200
Total revenue	**€**	**10,465,200**

Table 18-31: Revenue for the process "Treatment of WCA with inertisation"

In table 18-32 we see the results of the operation of the plant studies, for a total of 90,000 metric tons treated in one year's activity.

Costs	€	8,421,623
Cost €/ton	€	93.57
Revenue	€	10,465,200
Revenue €/ton	€	116.28
Profit	€	2,043,577
Profit €/ton	€	22.71

Table 18-32: Results of operation for 90,000 metric tons for the process "Treatment of WCA with inertisation"

Lastly, Tables 18-33 and 18-34 show the extraction of the process and the relative parameters. An economic allocation was done where the "*p*" represents the €/342 metric tons of ACW treated at the plant with a cycle of inertisation.

Economic issues	**Amount**	**Unit**
Costs of planning	8.000/Massatratanno*MACMtrat38h = 30.4	p
Costs of consumable materials	21,649/Massatratanno*MACMtrat38h = 82.2662	p
Maintenance costs	168,243/Massatratanno*MACMtrat38h = 639.3234	p
Depreciation and devaluation cost	942,870 /Massatratanno*MACMtrat38h = 3,582.906	p
Labor cost	702,715/Massatratanno*MACMtrat38h = 2,670.317	p
Financial charges	538,048.20/Massatratanno*MACMtrat38h = 2,044.583	p
General and management costs	4,063,713/Massatratanno*MACMtrat38h = 15,442.109	p
Taxes	1.476.385/Massatratanno*MACMtrat38h = 5,610.263	p
Decommissioning costs	500.000/Massatratanno*MACMtrat38h = 1,900	p
Revenue	10.465.200/Massatratanno*MACMtrat38h = 39,767.76	p

Table 18-33: Extraction of process "Treatment of WCA with inertisation"

Massatratanno	90,000	Quantity of RCA treated in the plant in one year:t
MACMtrat38h	342	Quantity of RCA treated in the plant in 38 hours:t

Table 18-34: Parameters of input of the process "Treatment of WCA with inertisation"

18.3. Calculation of internal costs

18.3.1. Calculation of internal costs for the process ACM with inertisation

The process "*Treatment ACM with inertisation by means of the furnace Internal costs" was studied for 150 metric tons, applying the method IMPACT 2002 + 010419indoor/ locali_rifIPCCAmAmlavCint V2.12 / IMPACT 2002+. To see the description of the method, see Chapter 18.1.2.5.2.

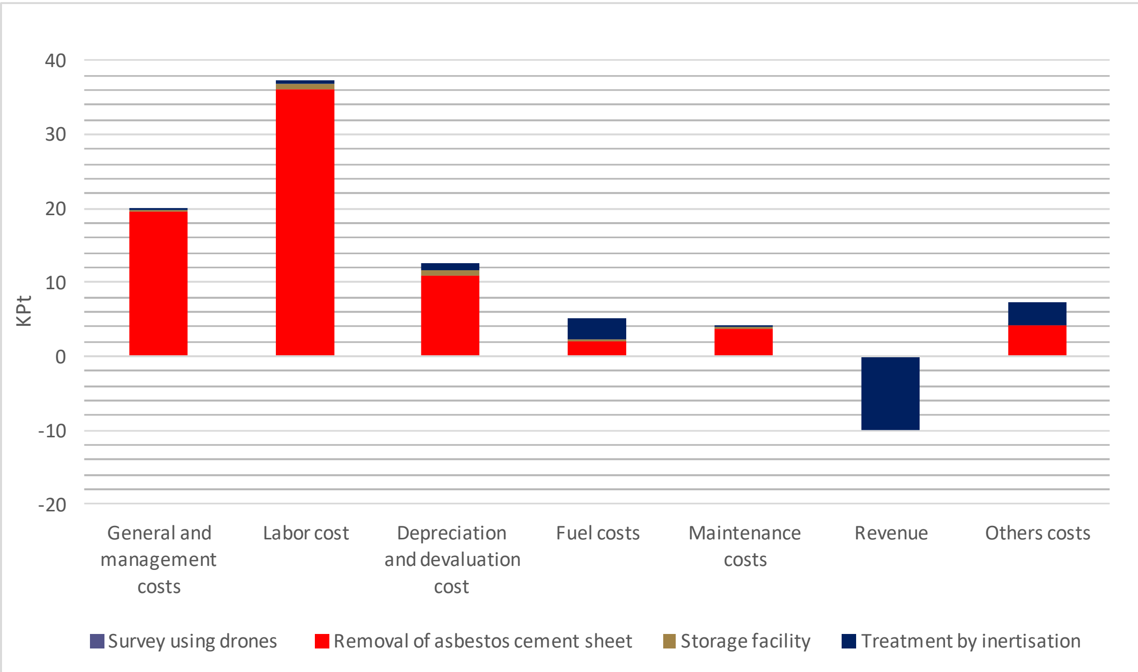


Figure 18-1: The diagram of the assessment for damage category of the process "*Treatment ACM with inertisation by means of furnace"

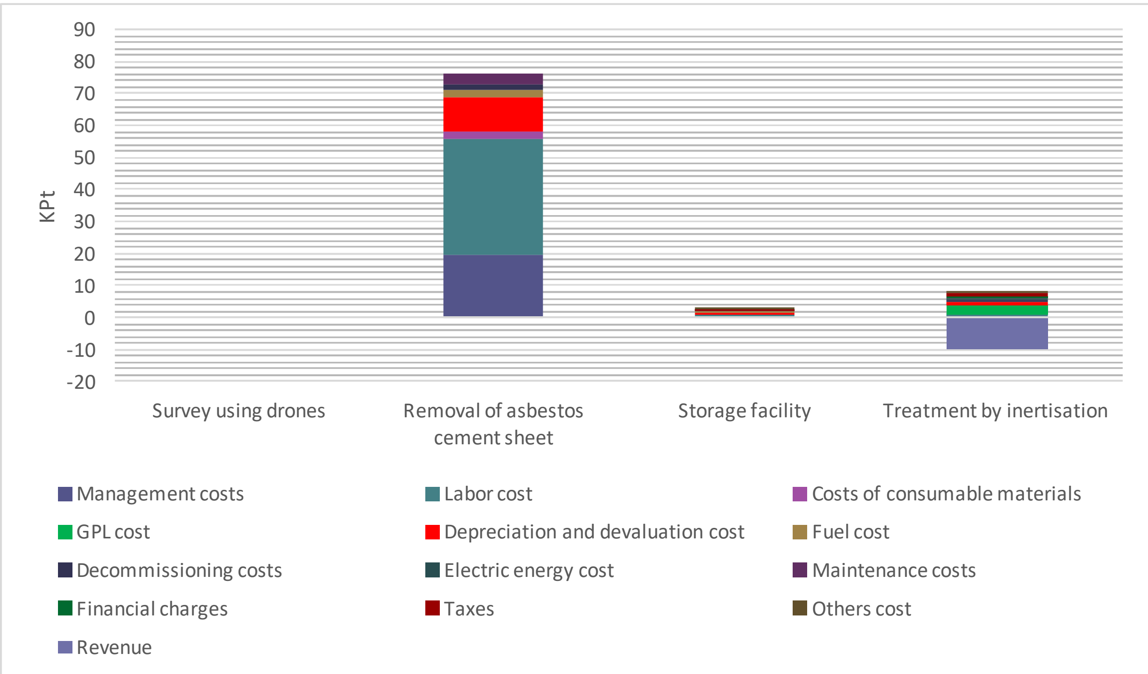


Figure 18-2: The diagram of the assessment for single score and for damage category of the process "*Treatment ACM with inertisation by means of furnace"

It was determined from the study of the results of the economic and financial assessment shown above, that the total cost for the management of 150 metric tons of asbestos-cement is valued at 76,558,377 €. 48.86% of this amount, that is, 37,403.06 € is due to the labor used in the various processes considered (92.29% to the removal process) (Figure 18-1). The revenues obtained from the process of inertisation of the sheets (9,966.86 €) concerns taking the ACW to the plant and the sale of the cementized material recuperated. These revenue are reduced on the basis of the allocation of the co-product made reported in chapter 17.2.5 "Output material working and second raw material KRYAS" (Figure 18-2).

18.3.2. Environmental analysis (damage * 1000) and the calculation of internal costs of the process of handling the ACM with the inertisation plant

The process *Treatment of ACM with inertisation using a furnace with asbestos fibers on the worker Internal costs" was studied for 150 metric tons applying the method IMPACT 2002+010419indoor/locali_rifIPCCAmAmlavCintot V2.12 / IMPACT 2002+. Using this method, not only was an economic analysis made but also an assessment of the environmental damage. To better visualize and interpret the graph below, (Figure 18-3), the value of the environmental damage (in the different categories) was multiplied by a factor of 1000.

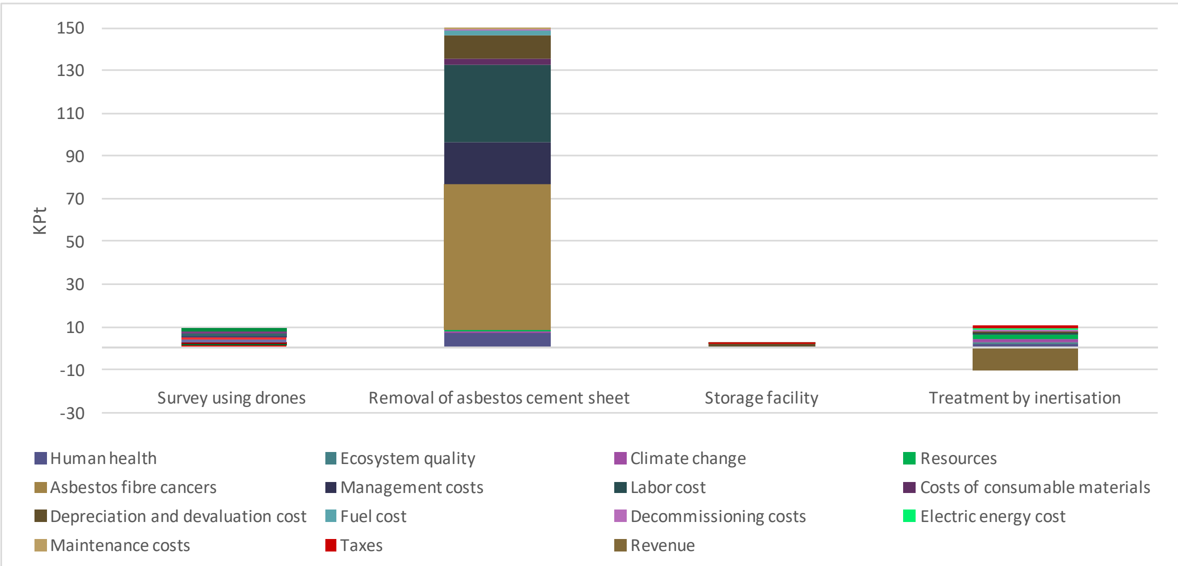


Figure 18-3: Diagram of the assessment for single score and for damage category of the process "*Treatment ACM with inertisation using a furnace"

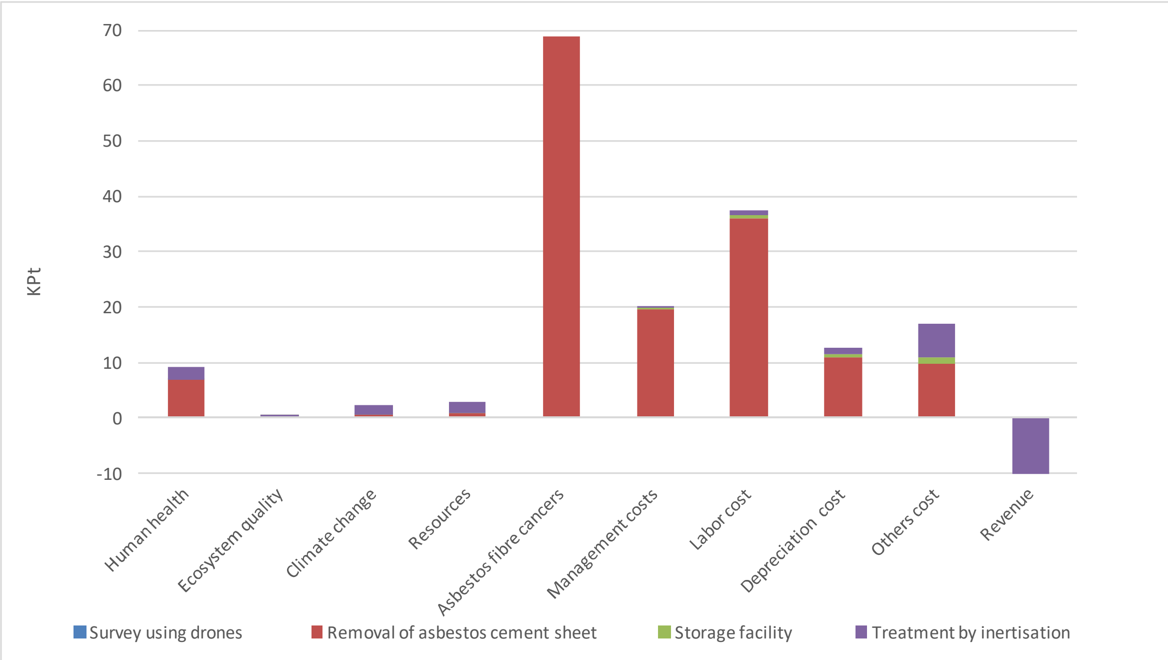


Figure 18-4: Diagram of the assessment per damage catergory of the process "*Treatment ACM with inertisation using a furnace"

In the process of removal, in addition to the cost of labor, the damage to the environment due to asbestos fiber inhaled during the work of reclamation is, 6,8767.32/1000=68.767 DALY (Figure.18-3 and Figure 18-4). The total damage equals 159.91031 Pt of which 68.767316 Pt is due to "*Tumors from Asbestos fibers*" (43.0037%)

18.3.3. The calculation of internal costs per the handling of ACM with landfill

The process "*Treatment ACM with the disposal plant Internal costs" was studied for 150 metric tons applying the method IMPACT 2002+010419indoor/locali_rifIPCCAmAmlavCint V2.12/ IMPACT 2002+.

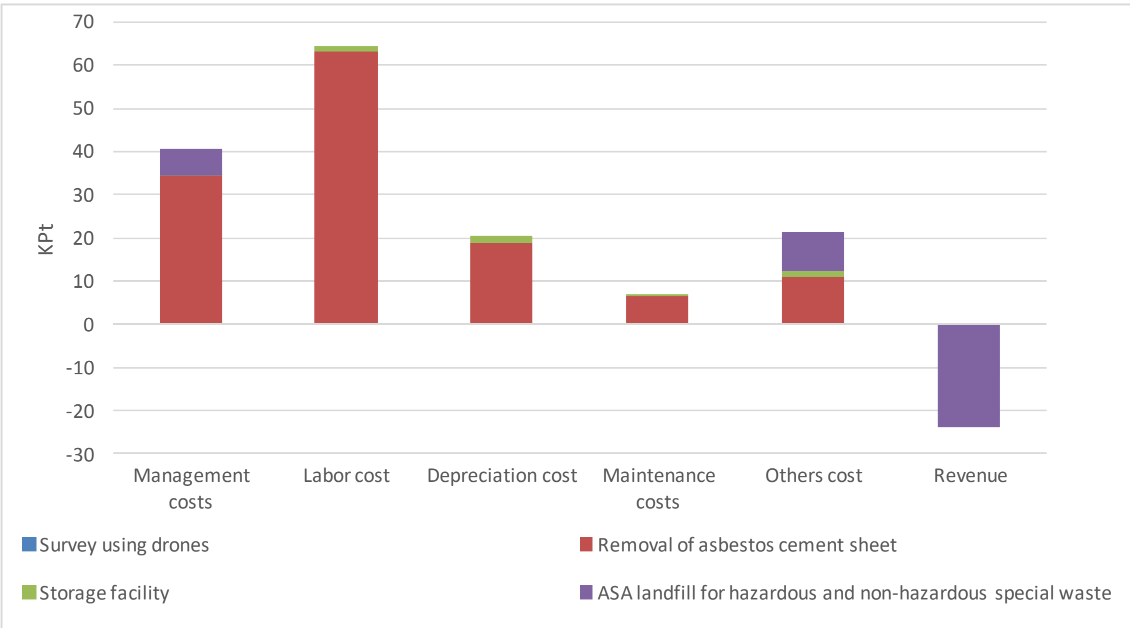


Figure 18-5: Diagram of the assessment per damage category of the process "*Treatment ACM with landfill"

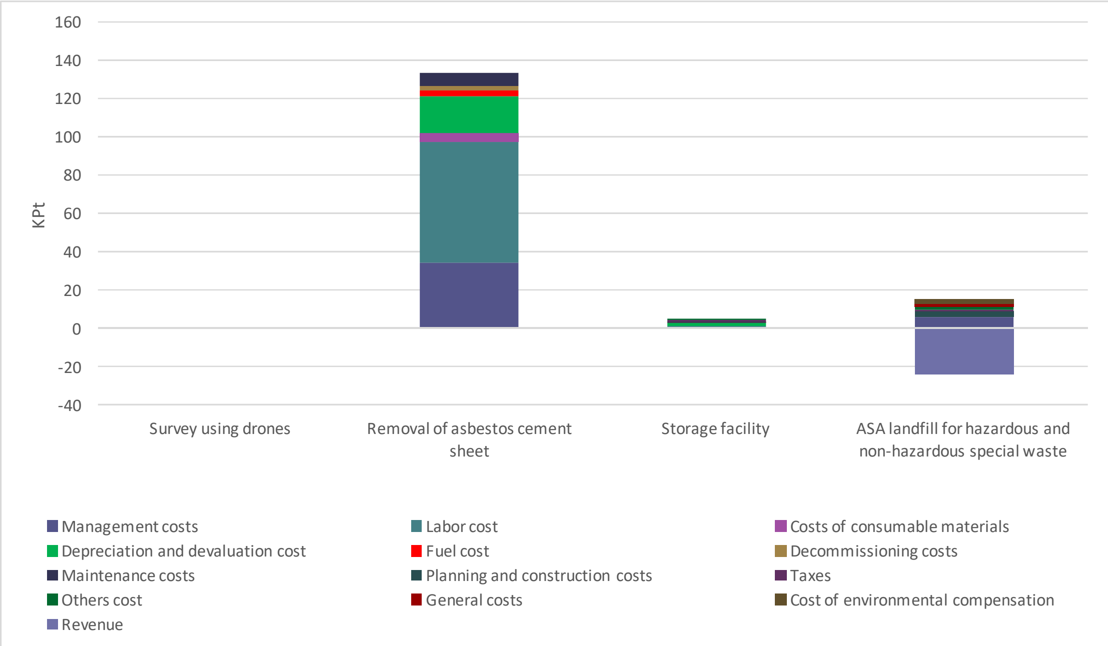


Figure 18-6: Diagram of the assessment per single score and per damage category of the process "*Treatment ACM with landfill"

The cost for 150 metric tons of ACW handled by the disposal plant, is 128,630.59 € and is due for 49.98% to the cost of labor and for 31.44% (40,445.94€) to the costs of management (Figure 18-5 and Figure 18-6). Within this above sited cost there are also the costs of the mapping process, the removal, transport and storage of the waste: The revenues derived from delivering the 150 metric tons of waste is equal to 23,815.5€

18.3.4. Sensitivity Analysis

18.3.4.1. Comparison between internal costs with inertisation plant and landfill

The process of life's end "*Treatment for inertisation of ACM rev3 interal Costs" and "landfill for special wastes, hazardous and not hazardous ASA (with TCF) (Multi-output) (Final)_ revCosts internal" applying the method IMPACT 2002+010419indoor/locali_ rifIPCCAmAmlavCint V2.12 / IMPACT 2002+. The comparison concerns only the processes of treatment ACM and not the entire operation (census, removal, transport and storage have not been considered).

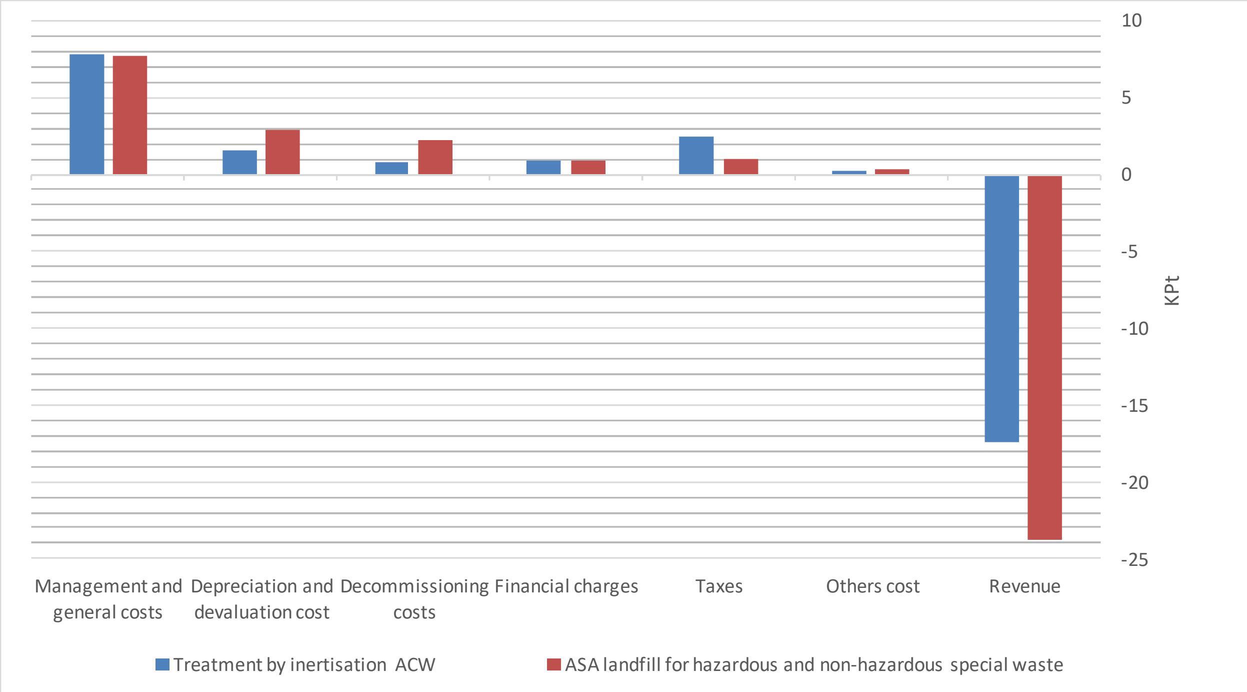


Figure 18-7: Diagram of the assessment of the comparison between the process "Treatment for inertisation of ACM rev3 interal Costs" and "landfill for special wastes, hazardous and not hazardous ASA (with TCF)"

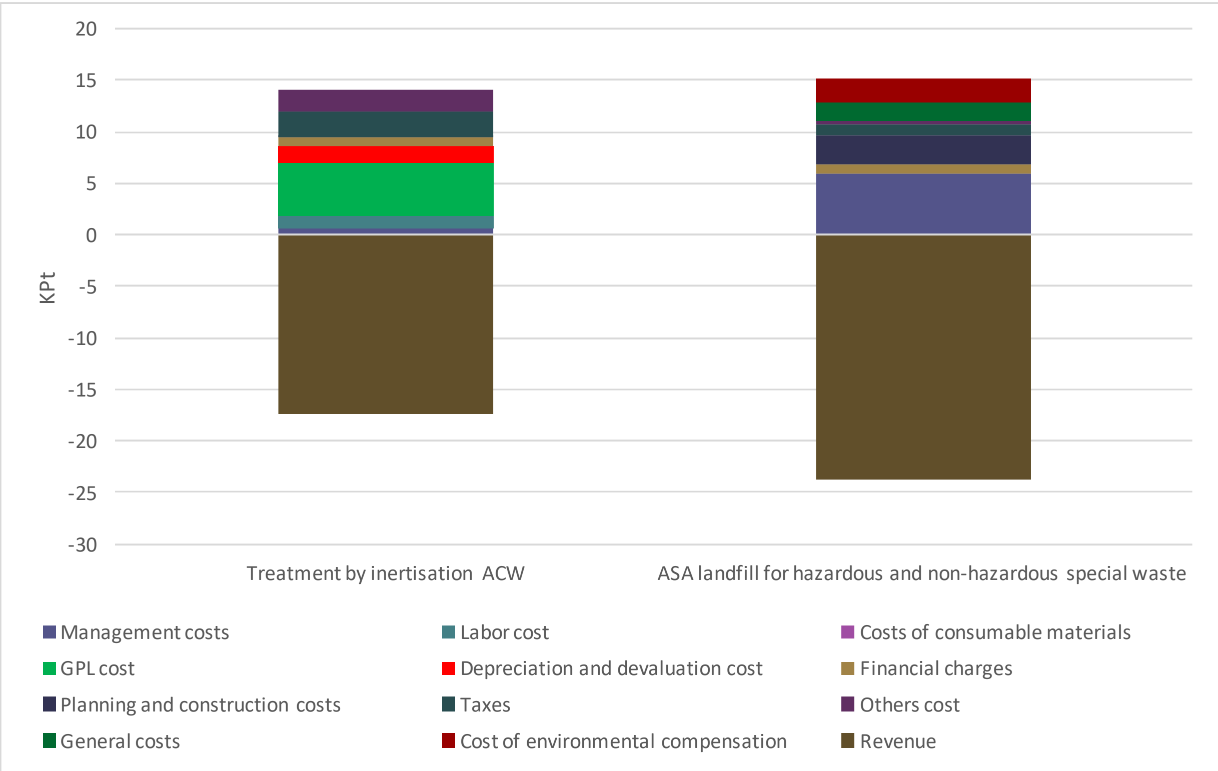


Figure 18-8: Diagram of the assessment per single score and per damage category of the process "Treatment for inertisation of ACM rev3 interal Costs" and "landfill for special wastes, hazardous and not hazardous ASA (with TCF)"

Comparing 150 metric tons "Treatment for inertisation of ACM rev 3 internal Costs" with 150 metric tons "landfill for special wastes, hazardous and non hazardous" to the inertisation plant we have an earning of 3,352,628 € while with delivering it to the disposal landfill we have an earning of 8,699,197 €. The major earnings at the disposal site rather than the inertisation plant is due to the absence of the co-product in the process considered. In fact, in the process of inertisation, 75% of the mass treated, and therefore of the earnings, is represented by the second raw material which comes out of the furnace (mass allocation). The details of revenues were calculated in chapter *Inventory analysis* 18.2.5 and 18.2.6.

18.3.4.2. Comparison between processes of handling ACM with an inertisation plant and with the handling of ACM with delivering to a disposal landfill

We made a comparison, with 150 metric tons of ACM, one processed with *Treatment ACM with delivery to disposal landfill* and *Treatment ACM with inertisation in furnace * using the method IMPACT 2002+010419indoor/locali_rifIPCCAmlavCint V2.12 / IMPACT 2002+.

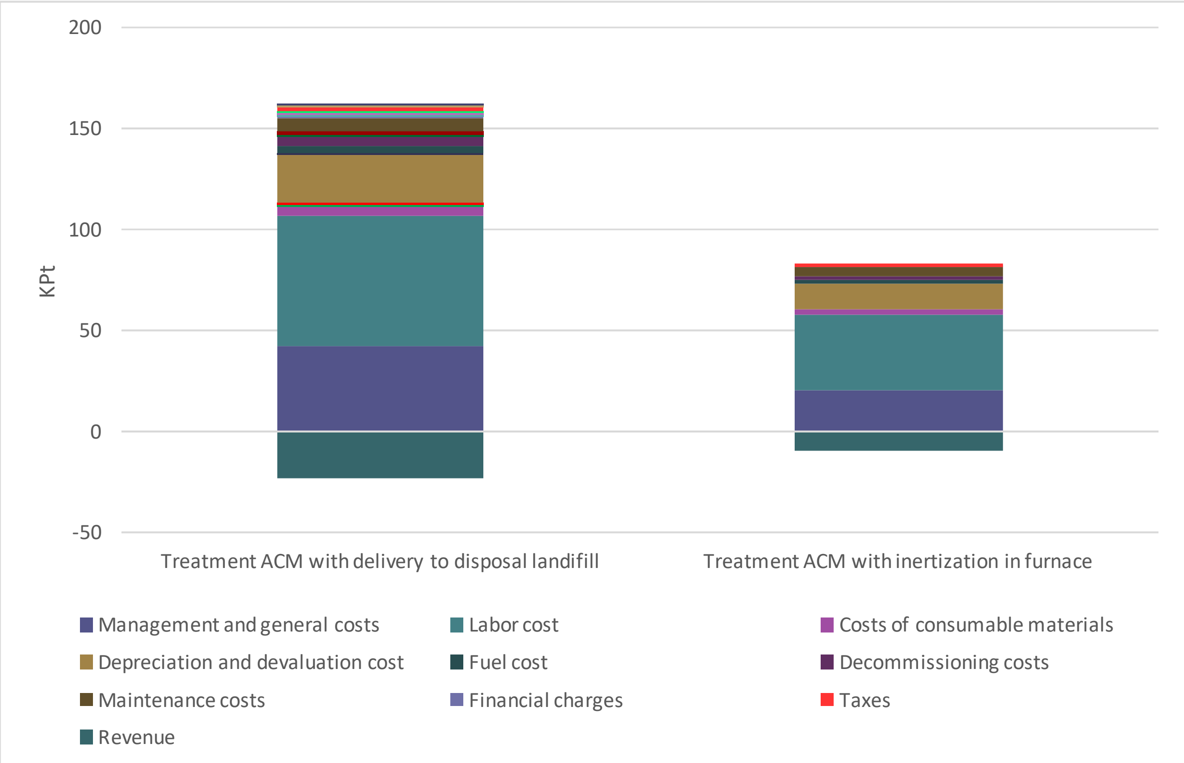


Figure 18-9: Diagram of assessment of the processes "*Treatment ACM with disposal landfill" and "*Treatment ACM with inertisation using furnace"

The treatment of 150 metric tons of ACW with disposal in a waste site has a cost of 128,630.59 € while, the same number of metric tons treated in a plant to inertizate it costs 76,558,377 € (Figure18-9). The difference is due to the fact that in the inertisation process there is a co-product (KRAYS coming out of the furnace) which reduces the cost of the process.

18.4. Calculation of external costs

18.4.1. Calculation of external costs with IMPAXT 2002+

18.4.1.1. The external costs of the process of treatment with inertisation calculated with IMPACT 2002+ modification

The process studied for 150 metric tons is "Treatment ACM with inertisation using a furnace (with asbestos fibers on a worker)" The method used is IMPACT 2002 + 010419indoor/ locali_rifIPCCAmAmlavCest V2.12. For the description of the method see chapter 18.1.2.5.1.2.

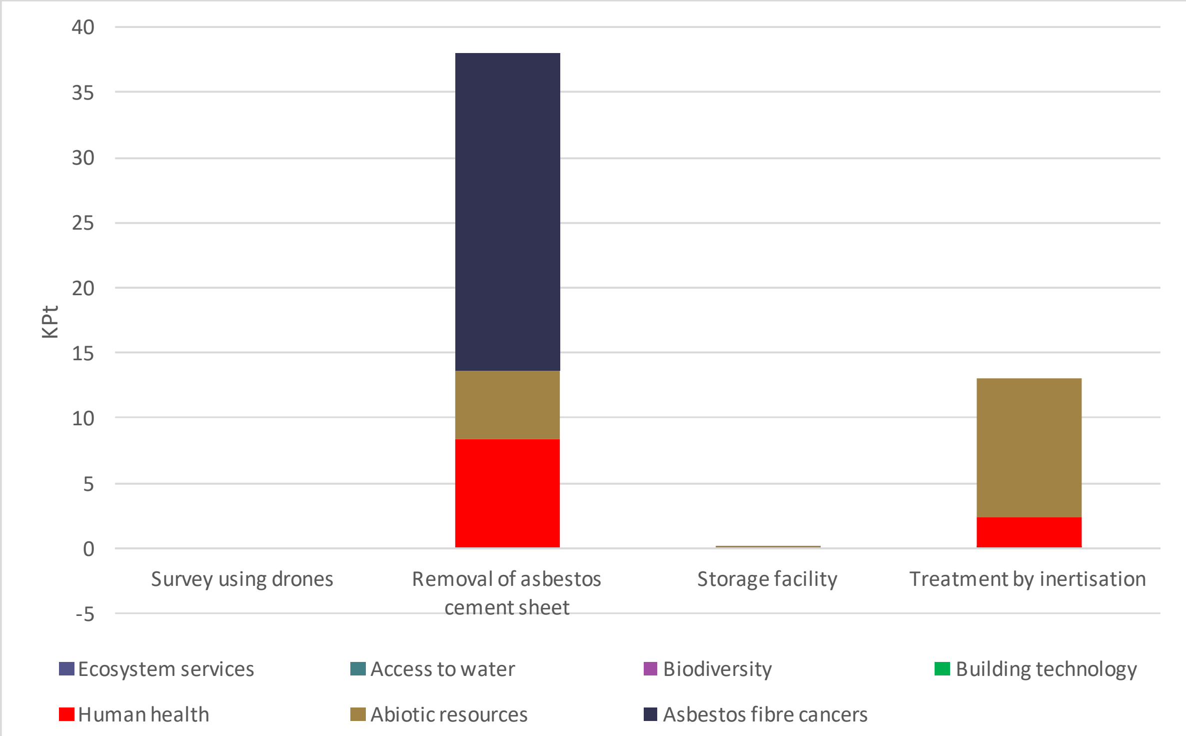


Figure 18-10: The diagram of external costs calculated with IMPACT 2002+ of the process "Treatment ACM with inertisation using s furnace (with asbestos fibers on a worker)".

The total external costs equal to 42,572.397 € is 66.95% due to **Tumors asbestos fiber**, 18.87% due to **Ecosystem quality**, 9.04% due to **Human Health** (Figure 18-10).

18.4.1.2. Comparison of external costs for the treatment with inertisation with that of the disposal applying the method IMPACT2002+ modified.

150 metric tons processed with "*Treatment ACM with landfill (with asbestos fiber on worker)" and the same amount processed with "*Treatment ACM with inertisation using a furnace (with asbestos fiber on a worker)" applying the method IMPACT 2002+010419indoor/rooms_rifIPCC_AmAmlav:Cest V2.12/IMPACT 2002+ were compared.

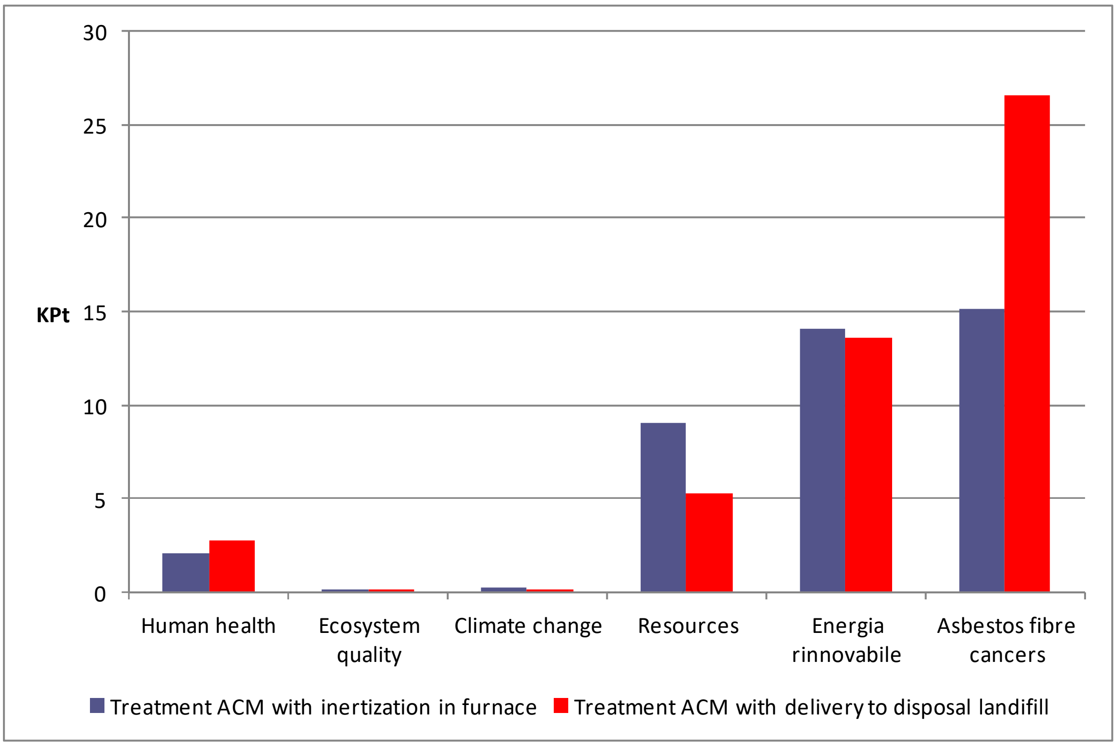


Figure 18-11: The comparison diagram between the external costs of the processes * Treatment ACM with landfill (with asbestos fiber on worker) and "*Treatment ACM with inertisation using a furnace (with asbestos fiber on a worker)"

The results of this comparison show that the treatment with disposal produces a higher cost (48,279.97 €) than the treatment with inertisation (42,572.40 €) .As we see from the graph above (Figure 18-11). This is due above all to tumors from asbestos fiber produced by the emission of fibers from the asbestos in the landfill plant.

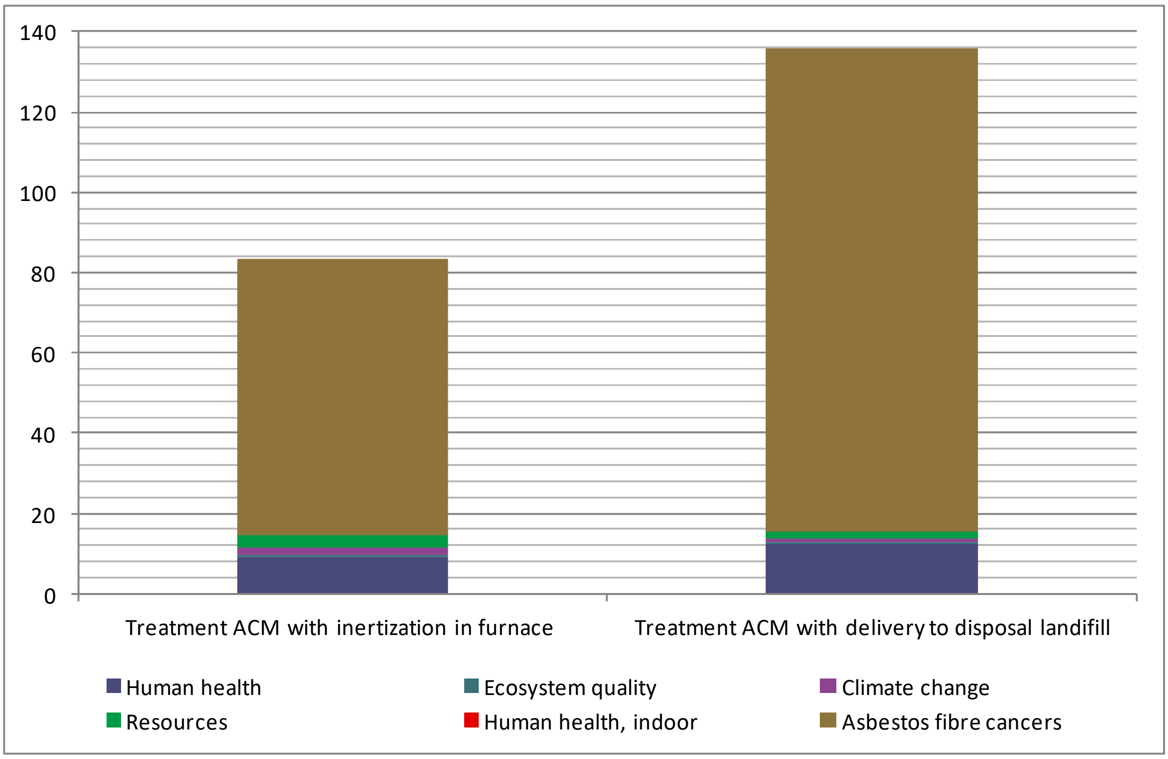


Figure 18-12: The comparison diagram between the external costs of the processes *Treatment ACM with landfill (with asbestos fiber on worker) and "*Treatment ACM with inertisation using a furnace (with asbestos fiber on a worker)"

As we can see in the above figure (Figure 18-12) the damage due to the disposal site is more than that due to the inertisation treatment mostly because of the co-product which in the latter plant, reduces the damage by 48% of the treatment considered (83.352 Pt against 135.859 Pt for the process with the waste disposal plant).

18.4.2. The calculation of external costs calculated with EPS 2015d modified to take into account Mesothelioma

18.4.2.1. The external costs of the process of ACM management with an inertisation plant

The process studied for 150 metric tons is the "Treatment ACM with inertisation using a furnace (with asbestos fiber on a worker)". The method used is "EPS 2015d con Mesotelioma V1.00 / EPS 2015".

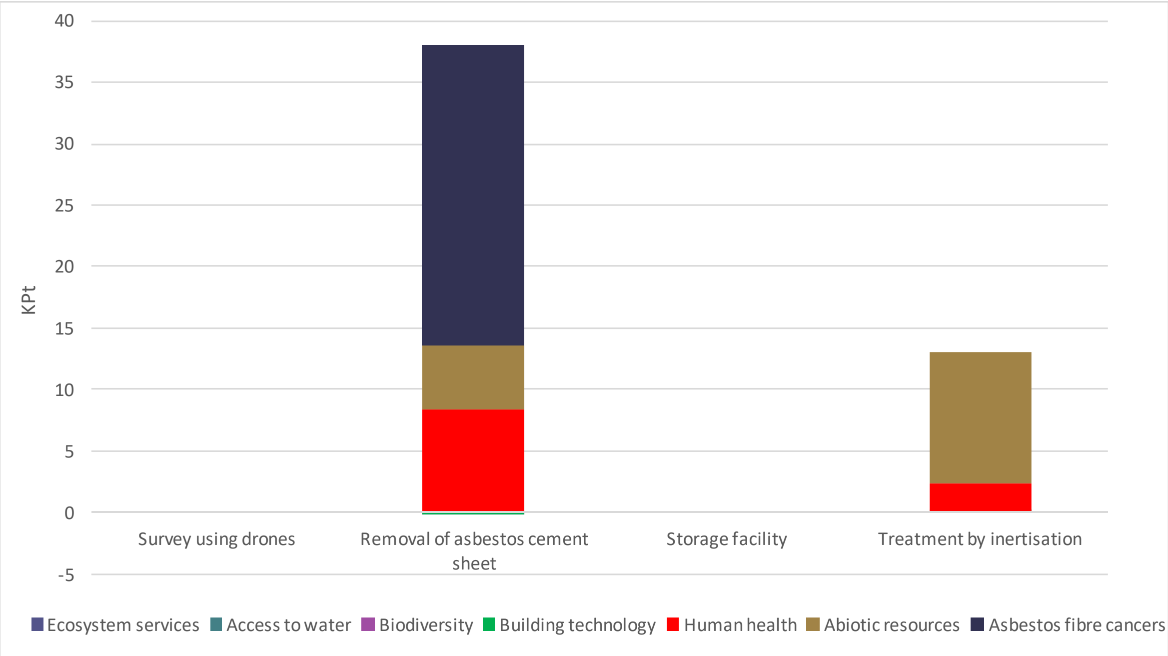


Figure 18-13: The diagram of external costs in kPt=ELU calculated with EPS 2015 of the process "*Treatment ACM with inertisation using a furnace (with asbestos fiber on a worker)"

As we see in the above figure, (Figure 18-13) the external costs calculated with EPS2015d modified, equal 51.077 k€ and is due for 47.74% to **Tumors asbestos fiber**, for 31.23% to **Abiotic resources** (due for 66.64% to *Gold*, for 66.94% in Treatment for inertisation of ACMrev3 and in particular for 94.41% in *Zinc concentrate {GLO} zinc mine operation| APOS,U*) and for 20.96% to **Human health** (due for 78.86% to *Particulates<2.5m*, for 92.47% in *Removal sheet of asbestos-cement rev2 (with asbestos fiber on the worker) and, in particular for 95.37% in the process itself as direct emissions.

18.4.2.2. Analysis of sensitivity

18.4.2.2.1. Comparison between external costs of processes managing ACM with life's end in the landfill and with the inertisation plant

As explained in chapter 18.1.2.5.1.3, the EPS2015d method was modified, introducing the category of Mesothelioma damage, so as to calculate the external costs of the processes "Treatment ACM with disposal (with asbestos fiber on the worker)" and "Treatment ACM with inertisation using a furnace (with asbestos fiber on the worker)".

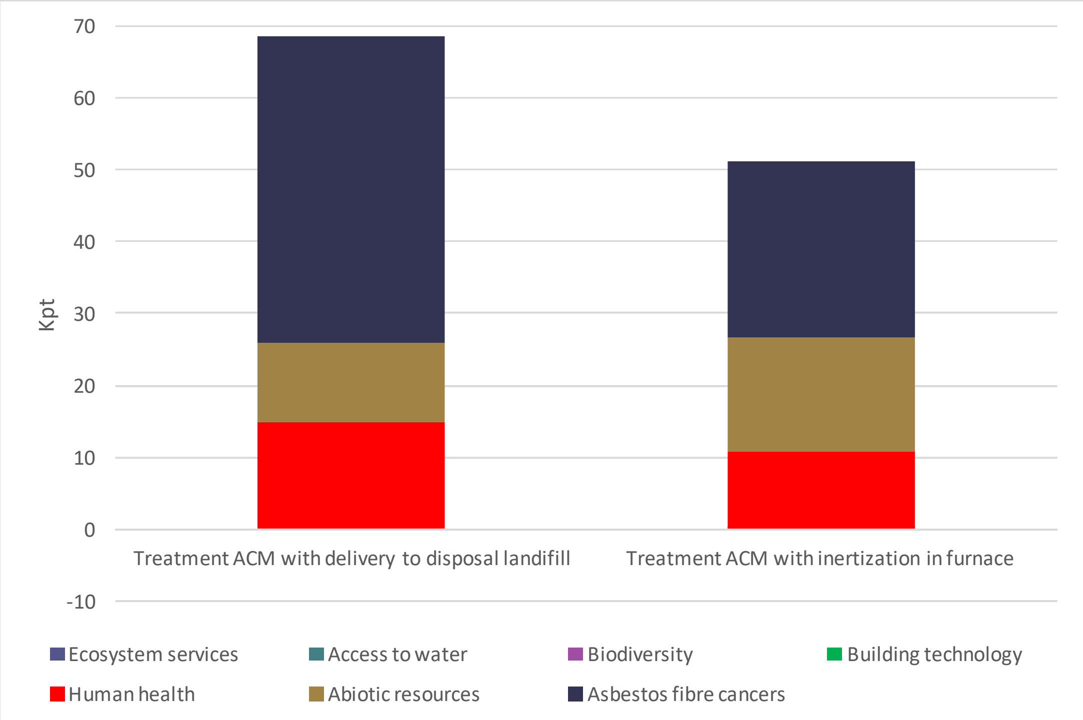


Figure 18-14: The comparison diagram of single score between the external costs of the processes *Treatment ACM with disposal (with asbestos fiber on worker) and "*Treatment ACM with inertisation using a furnace (with asbestos fiber on a worker)"

From this comparison, we see that with EPS, the external cost of the treatment with delivery in the disposal plant (68.644 kPt=k€) is greater than that treated with inertisation (51.085 kPt=k€).
The reason for the difference in the damage is due most of all to the fact that the product (KRAYS) obtained from inertisation is considered a co-product (Figure 18-14).

18.4.3. The table of external costs

The following table of external costs (Table 18-35) of the process "Treatment ACM with inertisation by means of a furnace, (with asbestos fiber on a worker)" with the method IMPACT 2002+010419indoor/locali_rifIPCCAmlavCest V2.12 / IMPACT 2002+ and EPS 2015d with Mesothelioma V1.00/EPS 2015".

	Human health [€]	Biodiversity [€] Ecosystem quality [€]	Climate change[€]	Abiotic resources [€] Resources [€]	Tumors from asbestos fibers+PSQM. 5 indoor [€]	Ecosystem services [€]	Access to water [€]	Building technology[€]	Renewable energy [€]	Total
EPS2015d modification	10,703.8	0.18		15,950.4	24,385.6	35.6	1.8	0.3		51,077.7
IMPACT 2002 modification	2,064.8	1,218.9	175.8	9,294.2	15,192.2				14,626.4	42,572.4

Table 18-35: The table of external costs of the treatment ACM with inertisation using a furnace (with asbestos fibers on the worker)

18.5. Conclusions

From the analysis of the results of the economic-financial evaluation using the method IMPACT2002+modified, it was determined that the total cost for handling 150 metric tons of asbestos-cement with inertisation is equal to 76,558.377 €. Within the cost shown above there are also the costs of the process of mapping, removal, transport and storage of the wastes. 48.86% of the total value, that is, 37,403.06 € is due to the labor used in the various processes considered (96.29% to the removal process). The revenue obtained (9,966.86 €) derives from taking the ACW to the plant and from the sale of cementized inertia material (KRYAS). This is reduced on the basis of the allocation of the co-product made. The earnings of the inertisation plant are equal to 3,352.628 €. Within the process of removal, over the cost of labor, the damage to the environment due to the asbestos fibers inhaled during the reclamation operation is considered, namely, 68,767.32/1000 = 68.767 DALY. From the economic-financial evaluation of 150 metric tons of asbestos-cement handled with the final destination, the landfill plant for hazardous wastes, instead, shows that the total cost is 128,630.59 € and is due, for 49.98% (64,284.16 €) to labor costs, and 31.44% (40,445.94 €) to handling costs. The difference in respect to the previous handling is due to the fact that, in the process for inertisation, there is a co-product, (KRAYS coming out of the furnace) which reduces the cost of the process itself. As in the previous analysis, within the above mentioned cost there is also the cost of the mapping, the removal, the transporting and the storage of the wastes. The revenue derived from taking the ACW to the landfill site is equal to 23,8115.5 € while the earnings are 8,699.197 €. The difference, in positive, in respect to the revenues and earnings of the operations with the inertisation plant is due to the lack of the co-product. After this we calculated the external costs with the IMPACT2002+ method modified and the EPS2015d modified. The externals, relative to the handling of 150 metric tons of asbestos-cement with the inertisation plant, calculated with the first above mentioned method equals 42,572.397 € due for 66.95% to Tumors from asbestos fiber, for 18.87% to Ecosystem quality and for 9.04% to Human Health. Considering, instead, a handling of ACM with the final destination being the waste disposal plant, the external costs are equal to 48,278.38 € (+13.4%). This is due to the asbestos fibers emitted from the waste site and in the presence of, in the process of inertisation, a co-product which reduces by 48% the damage of the process. Lastly, an analysis of external costs was made, of the handling of ACM in an inertisation plant using the method EPS2015d modified. The externals were equal to 51,077.74 € due for 47.74% to Tumors due to asbestos fibers, for 31.23% to Abiotic resources, and by 20.96% to Human Health.

19. General conclusions

This study relates to the economic and environmental impact assessment using LCA methodology of the mapping, remediation, transport and treatment of asbestos containing materials (ACM) in the eight municipalities of the Lower Reggiana area (Boretto, Brescello, Gualtieri, Guastalla, Luzzara, Novellara, Poviglio, Reggiolo). For all scenarios and treatment systems considered, reference was made to 150 metric tons of ACM disposed of in just under two years. The mapping stage that was carried out to determine the presence and relative condition of asbestos in the area was performed using drones and a series of analytical techniques that associate the interpretation of aerial multispectral images with low-altitude surveys through complex algorithms. Then, by overlapping the results with the municipal Regional Technical Map (CTR), it was possible to construct a risk map in order to establish priorities and order of actions. The result was the survey of 33,048 metric tons of asbestos cement (6.184 roof coverings) over an area of 2,203,174 sqm with 72,048 inhabitants. This means that in Lower Reggiana alone, there are 30.58 sqm of ACM per inhabitant and 7,018.71 sqm of ACM per ksqm. Subsequently, remediation by removing asbestos cement (AC) sheeting was analysed, as it was considered the only method currently in use (confinement, encapsulation and removal) which permanently eliminates the problem of the presence of AC in Lower Reggiana. However, removal is also the method for which there is potentially an increased risk of asbestos fibers being released into the air and inhaled by workers. This study analysed the environmental damage of the emission of asbestos fibers into the air and inhaled by those carrying out the work, through the development of a new indicator, "*Asbestos fiber tumours*", created within the IMPACT2002+ method. From the environmental analysis of the ACM management process, the sheet removal phase has an impact of 82.5% of the total damage, with 71.74% due to the asbestos fiber tumours damage category. The environmental damage of these fibers was also analysed using the Usetox method. In order to eliminate the likelihood that asbestos fibers will be released into the air or inhaled by workers during removal, the removal of AC sheets should be conducted as much as possible using hand tools (not battery operated) and vacuum cleaners with absolute filters (used both during removal and site cleaning). In addition, there should be greater use of water (both during removal and site cleaning) and appropriate personal protective equipment (PPE). The next stage was analysis of the transfer of the asbestos containing waste (ACW) to an authorised storage facility, where no waste handling or treatment operations are carried out, but only storage as part of the efficient transport of the waste to often very distant end-of-life facilities. In the stage described above, it was assumed that there is no release of asbestos fibers into the air or inhaled by workers as the waste had already been coated and packaged in accordance with Italian Ministerial Decree of 06/09/1994 and Ministerial Decree of 20/08/1999. The LCA analysis shows that the ACW storage process for the plant in question impacts 0.043% on the overall management. In the final part of the project, different engineering and technological solutions for the treatment of ACW were examined, in particular disposal facilities (landfill for hazardous and non-hazardous special waste) and recovery plants (inertisation and chemical-physical treatment). For each of the above end-of-life processes, an economic and environmental analysis of the entire treatment process was carried out, considering products and co-products, energy, materials or fuels, plant engineering, emissions and waste. The results of the environmental damage assessment show that treatment by inertisation plant produces less damage than landfilling and chemical-physical treatment due to the fact that the process generates a co-product (KRYAS) that can be used as a secondary raw material (SRM) (e.g. as cement mortar). If, on the other hand, the KRYAS material is disposed of at an inert waste landfill site, the inertisation process would result in over 10 times more damage than the landfill process. Among the end-of-life processes considered, chemical-physical treatment produces the greatest damage mainly due to the use of a large amount of spent whey, considered a co-product of the Parmesan cheese making process. In the process relating to the hazardous and non-hazardous special waste landfill, the damage related to the actual occupation of the land was not initially considered, nor any potential impact due to the rupture of the confinement of the sheets with the resulting release of asbestos fibers into the air. The release of fibers into landfill leachate has never been considered, although several studies have confirmed its presence. Changing the time period that the land is occupied from 40 to 1,000 years and the time that asbestos fibers continue to be released from 24 to 100 years, the landfill damage increases by 66.85%. Finally, a sensitivity analysis was carried out comparing the damage of the landfill process with that of a similar landfill site in Germany, where Italy exports more than 80% of its ACW. The sensitivity analysis shows that sending the ACW to a German landfill site increases the damage by 25.08% due the increased transportation. The study was completed by considering a scenario in which the AC sheeting is not removed, resulting in degradation and potential release of fibers over time. The comparison between the three treatment processes considered shows that the non-removal of AC sheeting produces greater environmental damage due to the complete release of asbestos fibers contained in the sheeting over time. With regard to the economic-financial analysis and the external costs of managing 150 metric tons of AC by inertisation plant, it was determined that the total cost is €76,558.377. 48.86% relates to the workforce employed in the various processes considered. Revenues of €9,966.86 derive from the transfer of ACW to the plant and the sale of KRYAS as an SRM. The profits from the plant amounted to €3,352.628. Subsequently, performing the same analysis on 150 metric tons of AC managed with end-of-life in a landfill, it was found that the total cost is €128,630.59, with 49.98% due to labor costs and 31.44% to management costs. The difference compared to the previous management method is due to the fact that for the treatment process with inertisation, there is a co-product (KRYAS furnace output) that reduces the cost of the process itself. Revenues from the landfill, deriving exclusively from the transfer of ACW, amounted to €23,815.5 while profits were found to be €8.699,197. The externalities calculated using the modified IMPACT2002+ method amounted to €42,572.397 for management with the inertisation plant and €48,278.38 for management with landfill disposal. The difference (13.4%) is due to the asbestos fibers released from the landfill and the presence, in the first process considered, of the co-product. Finally, an analysis of the external costs of ACM management with inertisation was carried out, using the modified EPS2015d method. Compared to the previous method, the external costs were 19.98% higher (€51,077.74), with 47.74% related to Asbestos fiber tumors, 31.23% to Abiotic resources, and 20.96% to Human health.

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