UNIVERSIDAD POLITÉCNICA DE CARTAGENA

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA DE CAMINOS, CANALES Y PUERTOS Y DE INGENIERÍA DE MINAS

Analysis of improvements in recycling tunnel spoils. Case study: Brenner Base Tunnel.

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Mis apreciaciones van a los componentes del proyecto BBT (Brenner Base Tunnel) por proporcionar datos esenciales.

RESUMEN

Este estudio presenta una investigación sobre el uso de los CDWs (residuo de construcción y demolición) utilizando dos proyectos como estudio tipo: el BBT (Túnel Base del Brenner) que, al mismo tiempo, utiliza SWIFTLY (SWEDEN-ITALIA Freight Transport and Logistics) Y el otro proyecto es el DRAGON (desarrollo de Tecnologías Subterráneas Avanzadas y Eficientes de Recursos). El proyecto del túnel BBT cruza los Alpes de Innsbruck (Austria) a Fortezza (Italia) con una ruta de 55 km. El proyecto DRAGON convierte el material de excavación en un valioso recurso para otros procesos.

El trabajo se divide en tres partes. La primera parte es el estudio de los CDW (residuos de construcción y demolición), sus tratamientos, clasificación y usos, también incluye dos ejemplos de costos para transportar los CDW a vertederos. Como se dice en la Directiva 2008/98 / CE, que se aplica para los CDW en Europa. Para 2020, la preparación para la reutilización y el reciclado de los residuos debe aumentarse hasta un mínimo del 50% en peso en total. También añade que para 2020 la preparación para la reutilización, el reciclado y la recuperación de otros materiales para residuos no peligrosos debe aumentarse a un mínimo del 70% en peso de la construcción y las demoliciones.

La segunda parte, que es el objetivo principal, es la comparación de dos proyectos similares SWIFTLY (método utilizando el proyecto BBT) y DRAGRON (proyecto europeo que estudia la reutilización de residuos de tunelación). Ambos proyectos utilizan la tecnología de las tuneladoras TBM y obtienen un alto valor de material de reciclaje, por lo que la tercera parte del proyecto se dedica al estudio de los diferentes sistemas de TBM, tipos, clasificación, descripción etc.

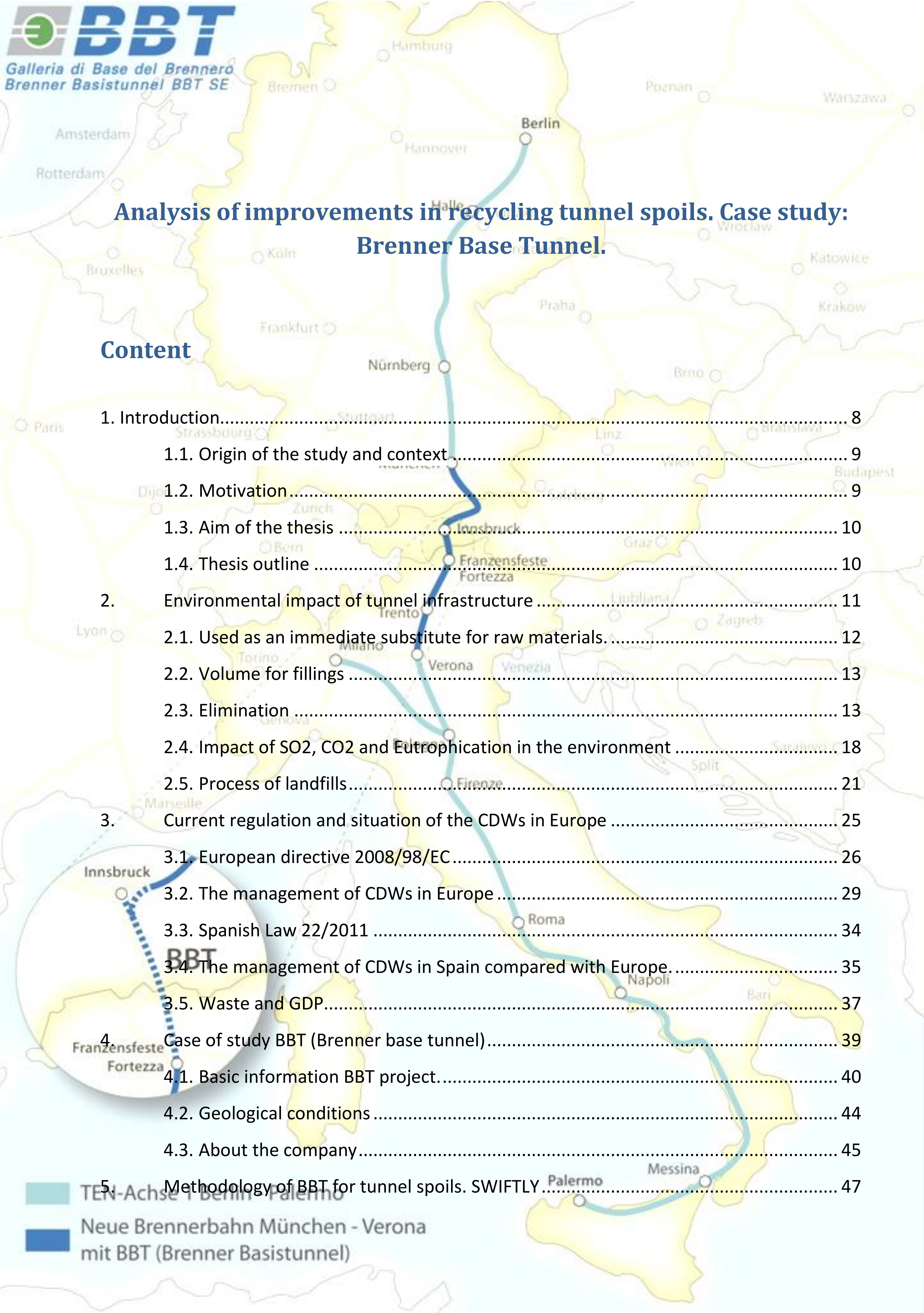
ABSTRACT

This study presents an investigation of the use of CDWs (construction and demolition waste) using two projects as case studies: the BBT (Brenner Base Tunnel), which uses SWIFTLY (SWeden-Italy Freight Transport and Logistics) as methodology, and the other project is the DRAGON (development of Resource-efficient and Advanced Underground Technologies). The BBT tunnel project crosses the Alps from Innsbruck (Austria) to Fortezza (Italy) with a route of 55 km. The DRAGON project turns the excavation material into a valuable resource for other processes.

The work is divided in three parts. The first part is the study of CDWs (construction and demolition waste), their treatments, classification and uses, also includes two example of cost to transport CDWs to landfills. In Europe directive 2008/98 /EC estate is applied for the CDWs. Such directive estate that, by 2020 the preparation for the re-use and recycling of waste must be increased to a minimum of 50% overall by weight. It also mentioned that by 2020 the

preparation for re-use, recycling and other recovery of materials for non-hazardous waste must be increased to a minimum of 70% by weight from construction and demolitions.

The second part, which is the main objective, is the comparison of two similar projects SWIFTLY (method using the BBT project) and DRAGRON (European wide project that studies the reuse of waste from tunneling). Both projects use the technology of the TBM (tunnel boring machine) tunneling machines and obtain a high value of recycle material, whereby the third part of the project is dedicated to the study of the different systems of TBMs, types, classification, description etc.



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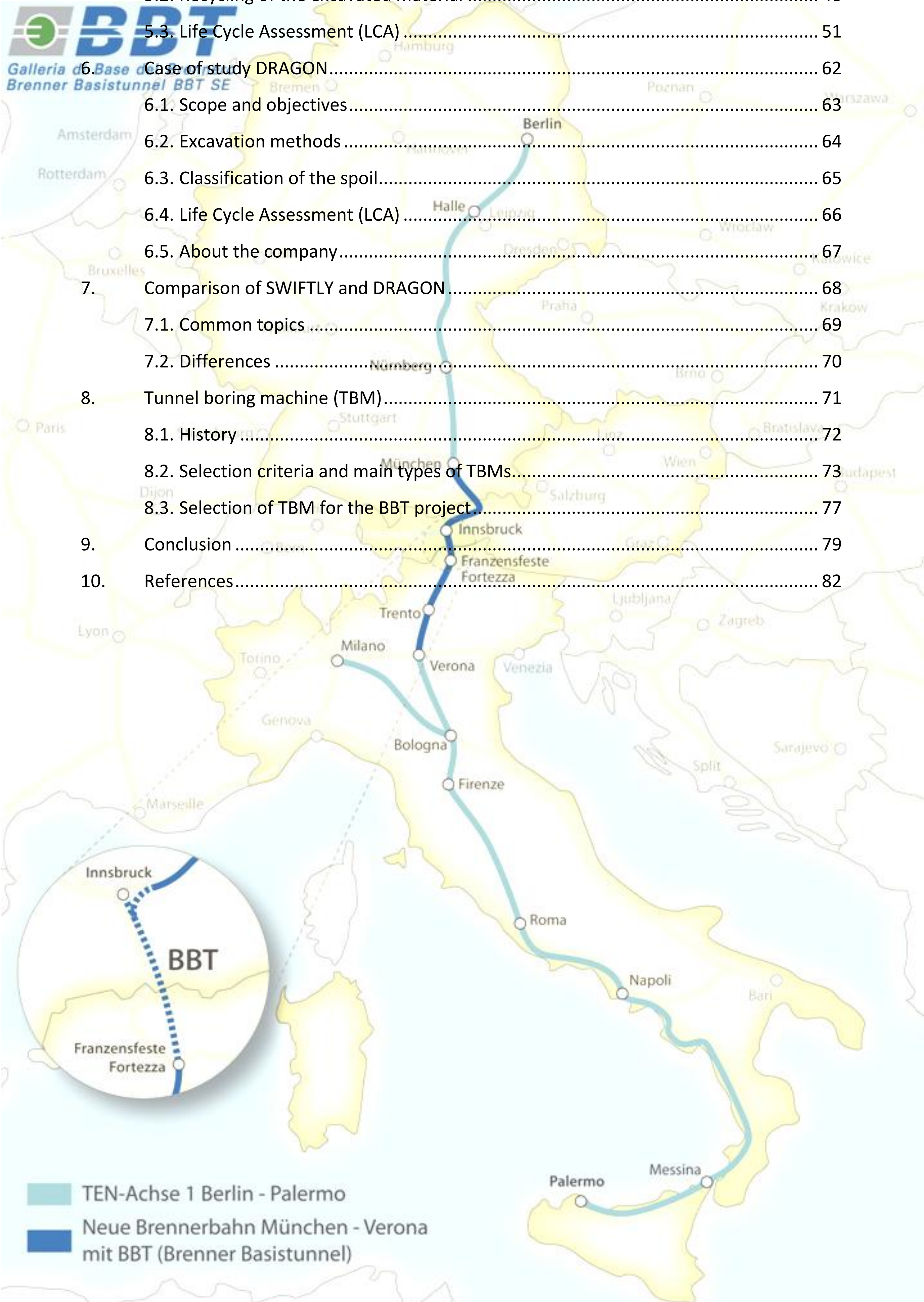
Content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Neue Brennerbahn München - Verona
mit BBT (Brenner Basistunnel)

1. INTRODUCTION

In a world where recycling and sustainability is so essential, I thought about doing a project dedicated to that. The objective of this document is to elaborate and analyze the use of construction and demolition waste (CDWs) of construction works, especially in tunnel constructions.

1.1. Origin of the study and context

In the first place, CDWs are, therefore, essentially inert waste generated in excavation, new construction, repair, remodeling, rehabilitation and demolition works, including minor works and home repair.
In this project it is established a comparison between projects that use this format and common application styles for the different projects that are presented currently in Europe.
The cases to study in this project are:

- BBT (Brenner Base Tunnel), a tunnel that cross the border of Italy and Austria through the Alps with a volume excavated of 17 million m^3. At the same time, this project use another project for the use of CDWs and this project is called SWIFTLY (Sweden-Italy Freight Transport and Logistics).
- DRAGON (development of Resource-efficient and Advanced Underground Technologies), this project turns the excavation material into a valuable resource for other processes. It has a volume of excavation of 700 million m^3.

1.2. Motivation

The motivation for this study is to achieve a lower environmental impact in construction works of this type, as well as reduce the cost in work of materials that can be recycled with the CDWs, for example shotcrete.

As it says in directive 2008/98 /EC, that is applied for the CDWs in Europe. By 2020 the preparation for the re-use and recycling of waste of materials must be increased to a minimum of 50% overall by weight. Also adds that by 2020 the preparation for re-use, recycling and other recovery of materials for non-hazardous waste must be increased to a minimum of 70% by weight from construction and demolitions.

To achieve this massive recycling of CDWs, TBMs (tunnel boring machine) play an important role in the development of these projects. In all the cases of projects that are studied in this thesis, are used TBMs.

1.3. Aim of the thesis

The objectives that are intended with this type of recommendations are the following:

• First, prevent CDWs from being wasted. Therefore, maintaining a classification and separation rules will avoid its misuse.
• Second, avoid contamination of environmentally harmful materials. The objective of this should be strictly focused on the reuse of these CDWs.
• Thirdly, to influence the idea of the use of TBMs for excavations of large-scale projects that would act in a beneficial way for the classification and extraction of materials.
• Fourth, remember that the TFG presented is a comparison of projects using similar technologies and are of greater importance in the EU.
• Finally, and in the fifth place, the TFG should expose both the environmental and economic advantages of using TBMs and reuse CDWs.

1.4. Thesis outline

The work is divided into three parts. The first part is the study of CDWs (construction and demolition waste), their treatments, classification and uses, also includes two examples of cost to transport CDWs to landfills.
The second part, which is the main objective, is the comparison of two similar projects SWIFTLY (method using the BBT project) and DRAGRON (European wide project that studies the reuse of waste from tunneling).
Both projects use the technology of the TBM (tunnel boring machine) tunneling machines and obtain high value of recycle material, whereby the third part of the project is dedicated to the study of the different systems of TBMs, types, classification, description etc.

2. ENVIRONMENTAL IMPACT OF TUNNEL INFRASTRUCTURE

The main impact of a tunnel is the geomorphologic impact cause by amount of material extracted in the excavation; these residues will be directed to different treatments and processes for their reuse or disposal. Moreover, there is other relevant environmental impacts cause by some of the content of the waste, for instance the SO2, CO2 and Eutrophication.

The common uses for the material extracted from the excavation of a tunnel project are very wide. From the millions of cubic meters excavated in a tunnel project there are several possible ways:

- Used as an immediate substitute for raw materials or products produced from primary raw materials.
- Volume for fillings
- Elimination

2.1. Used as an immediate substitute for raw materials.

This option consists of the reconversion of waste into new raw materials used in the manufacture of new products to be used in new works.

The composition of the CDW (construction and demolition waste) varies according to the type of project, but not of its components, also varies with the type and percentage distribution to the raw materials used by the sector.

Residues arriving at landfills contain 75% of debris broken down into the following materials in table 1.

MATERIAL	*% BY VOLUME*
Bricks, tiles and other ceramics	54
Concrete	12
Stone	5
Sand, gravel, granite and other aggregates	4
Glass	0.5
Plastics	1.5
Metals	2.5
Asphalt	5
Plaster	0.2
Paper	0.3
Trash	7
Other	4

Table 1. Per cent of Material

In Austria between 40 - 45% of basic construction and demolition waste of the excavated material in constructions are recycled. The factors that have implemented in recycling in this country, they are about the waste management policy that has used economic (landfill taxes) and legal (selective demolition, voluntary agreements, planning and control) instruments.

Spain presents a situation of CDW recycling that can be described as marginal. Only 25% of CDWs produced in Spain are recycled. It is increasing the new methods of recycling in the last years but still very far from the rest of European countries.

The most dangerous fact is that, in Spain, around 49% of the construction and demolition waste produced is managed incorrectly, illegally and in many cases causing serious environmental and landscape impacts, wasting a necessary raw material and compromising the existence of the recycling and recovery sector. (Residuos profesional, 2016)

2.2. Volume for fillings

When the material is selected and clean, part of the residue is in perfect condition to be reused on site. This use reduces the costs of transportation due to the using of materials on site.

The materials excavated in the tunnel of the section that are considered suitable for the construction of fills of the railroad, correspond almost in their totality to the solid mass of the granite formations. It is possible also to use it for other projects. (ADIF, 2011)

As it is shown, in the table 1 above the third element Sand, gravel, granite and other aggregates represents a high proportion of the volume that arrives at the landfills.

2.3. Elimination

As the last alternative to the final destination of the CDW, it should be landfill disposal. In Austria the 35% of the waste is sent to landfills. In Spain still the 75% is disposed to landfills or illegally. The dumping of these materials is the option that represents the biggest impact on the environment, due to the fact that these CDWs could be recycle and make more use of its usefulness.

Another worrying aspect is the illegal dispose of these CDWs, which represent the 49% in Spain as written before. In other countries of Europe for example Austria, Italy or Germany this fact is very controlled by authorities and it only represent a 10%.

- The impact of not sending CDWs to landfill and dispose them as a illegal form, affects negatively to many aspects:

  A) Physical environment

- Air for example causes odors from the system, gas emissions, dust level
- Soil, soil and / or subsoil contamination by infiltration
- Water, contamination of groundwater and / or surface by leaching

B) Biotic Medium, Flora and Fauna

- Affection of natural vegetation due to filler gases
- Deterioration of the quality of the surrounding species in the area
- Reproduction and feeding of diseases (flies, rats, etc.)

D) Landscape Quality

- Adverse, perceived or actual discomfort and aesthetic impacts
- Aesthetic degradation by spreading garbage and clandestine dumps for lack of places of deposit

- The impact of sending CDWs to landfills is:

A) Advantages

- Provide the community with a healthy environment, free of germs, debris and vectors, a pleasant landscape and housing.
- Provide an appropriate and efficient collection of solid waste in the urban environment.
- Provide environmentally safe and technically practical disposal.

B) Disadvantages

- Lower proportion of recycled material, which, therefore, has a greater impact on the environment.
- Higher cost, due to the transport of all this material to the landfill and also cost in cubic meter of CDWs sent to landfill.
- Lower proportion of raw material that can be used for the project on site and also minimizes the cost of the project.
- Greater occupation of the ground by a necessary storage space.

Now, as already written before, the cost of sending the CDWs to landfills is quite high and depends on several factors:

- Proportion of recycled material and percent of material transported to the landfills
- Cubic meter price of CDWs for treatment at the landfill, which also depends on the country or region located.
- Taxes of the country they aim to internalize the cost.
- Mode of transport of the waste to the landfill for example conveyor belt or trucks.
- Distance from the landfill to the construction site, gasoline price etc .

2.3.1. Examples of elimination CDW costs

In this part it is described the approximate costs of transportation of the CDWs to the landfills and the cost of the treatment of these materials in the landfills. All of this will give an idea of the general cost for elimination of CDWs.
We have chosen two examples with similar characteristics of length, quantity of material excavated, and other factors, it can be appreciated these costs.
The following cases have been chosen as examples:

- **Guadarrama Tunnel, Spain**

Figure 1.Guadarrama railroad tunnel

This project has been excavated through TBMs. Its main characteristics are:

- Length 28377 m
- 4 million cubic meters of excavated rock
- Recycled material in the manufacture of dovelas, platforms and various fillings is 22% of the total, so the material that has been transported to the landfills, is 78% which is equivalent to 3120000 cubic meters. (Adif, 2005)

$$3120000\ m^3 = 3120000\ tones$$

- Excavation waste from the tunnel is transported with conveyor belts with a capacity of 1250 tons/ hour and sent to landfills.

$$\frac{3120000\text{tones}}{1250\ tones/hour} = 2496 \text{ hours}$$

That type of conveyor belts use 20.5kWh (Stone Crusher, 2017), if the cost of the kilowatt is 0.13€ it will be:

$$20.5\ kWh\ x\ 2496\ hours = 51168\ kW$$
$$51168kW\ x\ 0.13€ = 6652{\sim}6700€$$

The cost of installation of a conveyor belt is 120000€ approximately. (Amela, 2016)

- Costs of transportation and costs of landfills are provided by the university based on usual costs of local projects:

Cost of landfills	5-10 €/ton
Taxes	3€/ton
Costs of transportation by trucks	3€/ton

Data selected:
7€/ton for cost of landfill
Taxes 3€ for Spain
Cost of installation of conveyor belt 120000€and energy costs 6700€

Other option with trucks: Cost of transportation 3€/ton

Final calculations:

Transport with conveyor belt	120000+6700=126700€
Transport with trucks	3x3120000= 9360000€
Treatment at the landfill	7x3120000=21840000€
Taxes	3x3120000=9360000€
Final costs with conveyor belt	**31,326,700€**
Final costs with trucks	**43,680,000€**
Cost per tons	**7+3+3=13€/tons**

- **Brenner Base Tunnel (BBT), Austria**

Figure 2.BBT railroad tunnel

This project will be explained more fully throughout this document but is also used for this example of CDW costs. It is also excavated by TBMs and its main characteristics are:

- Excavation material 17 million m^3
- Length 55 kilometers from Innsbruck (Austria) to Fortezza (Italy).
- Estimated per cent of recycled material is 82% of the total, so the material that has been transported to the landfills, is 8% which is equivalent to 1360000 cubic meters. (SE, 2016)

$$1360000\ m^3 = 1360000\ tones$$

- Excavation waste from the tunnel is transported with trucks with a estimated costs of 3€/ton from the construction site to the landfill.
- Costs of transportation and costs of landfills are provided by the university based on usual costs of local projects:

Cost of landfills	5-10 €/ton
Taxes	3€/ton
Costs of transportation by trucks	3€/ton

Data selected:

7€/ton for cost of landfill

Taxes 4€ for Austria

Cost of transportation 3€/ton

Final calculations:

Transport	3x1360000=4080000€
Treatment at the landfill	7x1360000=9520000€
Taxes	4x1360000=5440000€
Final costs	**1,904,000€**
Cost per tons	**7+3+4=14€/tons**

Comparison of results

In the first place it is shown that the percentage of recycling of materials in each project is very different, as it is explained before Spain represents in this field a much delayed situation compared to the rest of Europe.

Secondly, the amount of excavated material differs considerably, being the BBT project much larger than the Guadarrama tunnel.

In third and last place there are different ways of transportation a conveyor belt and another one by trucks, it can be seen that the conveyor belt is very profitable for short distances.

Compensating with the percentage of recycling and the amount of material excavated the costs do not differ so much in these projects.

2.4. Impact of SO2, CO2 and Eutrophication in the environment

In this chapter it is shown the impact of the CO2, SO2 and eutrophication. As we introduced at the beginning of chapter 2, these elements can affect to the environment and to the human health.

2.4.1. S02 (Sulfur Dioxide)

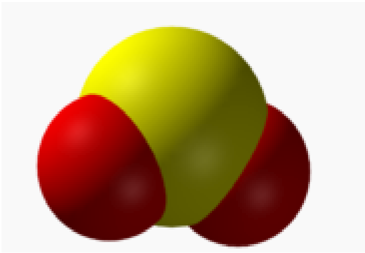


Figure 3. Molecule of SO2

Sulfur dioxide (SO2) is a colorless polluting gas with an unpleasant odor that originates in the combustion of coal and oil.

This gas affects both the environment and human health. Sulfur dioxide is the main cause of acid rain since it is converted into sulfuric acid in the atmosphere. It is released in many combustion processes for this reason it is tried to eliminate this compound before its combustion.

Sulfur dioxide is one of the most important compounds in the chemical industry. 98% of technical SO2 is used for the production of sulfur trioxide as precursor of sulfuric acid.

SO2 air pollution causes the following effects:

- Corneal dullness (keratitis).
- Difficulty breathing.
- Inflammation of the respiratory tract.
- Eye irritation by sulphurous acid formation on moist mucous membranes.
- Psychic alterations.
- Pulmonary edema.
- Heart attack.
- Circulatory collapse.

Sulfur dioxide (SO2) has also been associated with asthma and chronic bronchitis problems, increasing morbidity and mortality in the elderly and children. (medioambiente, 2017)

Coming back to the sulfuric acid, there is no doubt that acid precipitation decreases the mineral reserve of the soil. On calcareous grounds, the calcite (calcium carbonate) of rocks quickly neutralizes acids. In siliceous soils, on the contrary, the acidity increases.

Another important problem is the use of chemical substances, such as biocides (substances that eliminate different life forms, such as pesticides, fungicides, herbicides and insecticides), which accumulate in the soil causes an important source of pollution and degradation.

2.4.2. C02 (Carbon Dioxide)

Carbon dioxide is a colorless, odorless, vital gas for life on Earth.

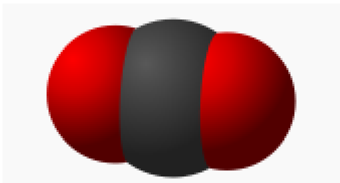


Figure 4. Molecule of CO2

This gas is a greenhouse gas, which absorbs and emits infrared radiation at its two active vibration frequencies in infrared. This process causes carbon dioxide to warm the surface and lower atmosphere and cool the upper atmosphere.

This compound greatly affects soil and vegetation. Increasing carbon dioxide causes the plants to have fewer pores and release less water into the atmosphere.

Soil is an important element of the climate system. It is the second carbon deposit, after the oceans. According to the region, climate change could lead to increased carbon storage in plants and soil due to vegetation growth or higher carbon emissions into the atmosphere. The recovery of essential ecosystems on land and sustainable land use in rural and urban areas can help us to mitigate and adapt to climate change. (AEMA, 2016)

2.4.3. Eutrophication

Eutrophication is a type of chemical contamination of water. It occurs when there is an excessive supply of nutrients to an aquatic ecosystem, which is severely affected by it.

Phosphorus and nitrogen are the main causes of eutrophication, but also any other substance that may be limiting for the development of different species such as potassium, magnesium and different organic products.

In the case of CDW the main component which could cause the etrophication process is the P04.

It can also be considered to also affect soils that have undergone abnormal nitrogen enrichment and in which there is a tendency for the growth of plants related to the abundance of inorganic nutrients, mainly nitrogen.

Eutrophication alters the environmental characteristics of aquatic ecosystems by altering the food chain and increasing the entropy (disorder) of the ecosystem. The result is ecosystems with reduced biodiversity, with opportunistic species occupying niches previously occupied by other species.

Figure 28 shows the process of eutrophication in the sea and how it affects the soil, this process is performed in several stages:

- First stage (Oligotrophic stage): This is the normal and healthy state of the ecosystem in it opportunistic and cosmopolitan species have a marginal space and there is a dynamic balance with seasonal fluctuations. The water has a considerable transparency and there is an abundance of animals that breathe by filtering the oxygen of the water (fish, mollusks, aquatic arthropods).
- Second stage: The contribution of nutrients causes an explosive growth of plants and algae. The vegetation below the new photic threshold dies; many of the floating algae also die and sink to the bottom due to nutrient depletion caused by exponential growth.
- Third stage (eutotrophic): The dead organic substance of the bottom is decomposed by bacteria that consume the oxygen and also can generate toxins lethal for plants and animals. The absence of oxygen causes the bottom mollusks to die and the fish and crustaceans die or escape to unaffected areas.

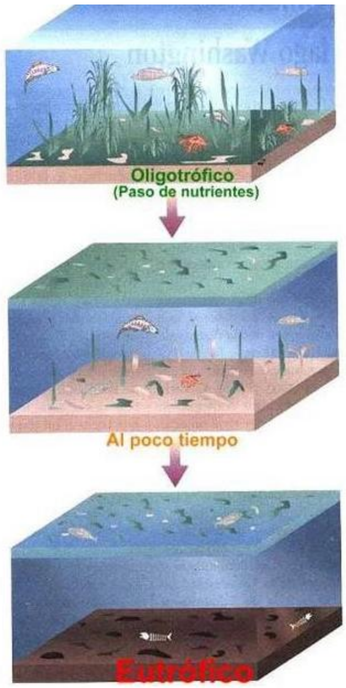


Figure 5. Eutrophication phases

2.5. Process of landfills

Waste from debris that arrives at a sorting plant for its classification and recycling of: concrete, partitions, stones, wood, metals, paper and board, plastic, etc.

The process is summarized in the following diagram:

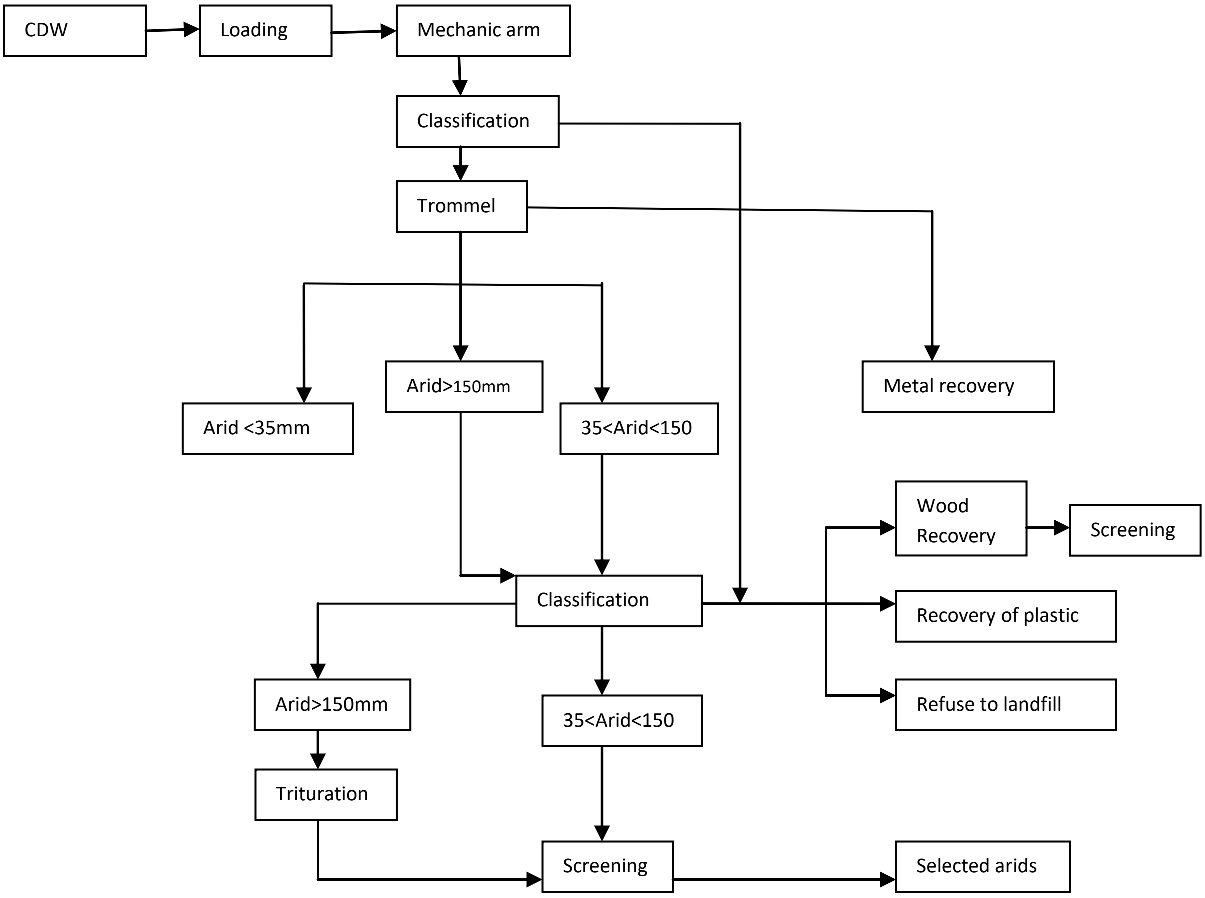


Diagram1. Process of landfill

The installation has a control cabin with a weighing scale, a parking and waiting area, the grading room itself, in which there is a manual triage cabin and also various mobile machinery such as loader, octopus, crusher and screen.

In the interior of the ship they are the trommel, diverse straps of transport, etc… necessary for the first phase of the classification. The second classification phase is carried out in an esplanade of the landfill. A mobile crusher crushes the material over 150 mm and a mobile screen allows obtaining the desired granulometry. In the crushing phase it is possible to recover mechanical materials by electromagnet.

Waste received is deposited in the discharge yard after a visual inspection of the waste. Once unloaded in the reception area, a first classification is performed segregating the bulky residues by means of a mechanical arm.

Figure 6.Mechanical arm

The CDW selection plant consists of two parallel sorting lines to which the material is fed with a loader through a chute. A tape is used to feed a trommel as shown in the figure 7, before the materials are manually selected on two conveyor belts.

Figure 7.Trommel

The conveyor belt, as it is shown in the figure 3 below, from the feed chute sends the waste to a threshing machine that classifies the debris according to granulometry, depending on the selected sieve:

- The fraction 0-35 mm is deposited by gravity in containers.
- Fractions 35-150 mm and greater than 150 mm pass to hand conveyors.

An electromagnet secretes the metal material of the trommel by depositing it in a specific container.

Figure 8.Conveyor belt

In order to obtain a high quality shear, the fraction greater than 150 mm is crushed in a mobile crusher, which also has an electromagnet for the recovery of metallic materials which are mostly obtained by the fragmentation of reinforced concrete. Subsequently it is sieved with a screen, also mobile, being able to obtain up to 3 different granulometries to demand of the client.

Figure 9.Mobile crusher with electromagnet

Figure 10.Mobile crusher

The wood is crushed in a mobile crusher and is destined for sale or to the composting plant. The plastic, according to its nature, is managed directly with the final recycler. Similarly, cartons are sent to the paper and cardboard sorting line. The metal obtained in the different stages of classification is sold for recycling.

Figure 11.Paper and cardboard crusher

Materials not classified in any of the families selected, either because they are in poor condition, or because they do not belong to any of the same, constitute the rejection of the selection process that is transferred to the landfill of inert for final disposal. **(Cogersa, 2011)**

3. CURRENT REGULATION AND SITUATION OF THE CDWS IN EUROPE

3.1. European directive 2008/98/EC

Currently for the EU waste legislative framework is the Directive 2008/98 / EC of the European Parliament and of the Council on waste.
The legislation applicable to CDWs in Spain includes Law 22/2011, of July 28, on waste and contaminated soils.

Both laws, Spanish and Austrian, for the use of CDWs are reflected in the European directive 2008/98/EC.

This directive is applied from 12 December 2008. EU countries had to incorporate it into their national legislation by 12 December 2010 at the latest.

Purpose and scope

The Directive sets out measures to protect the environment and human health by preventing or reducing the adverse impacts of waste generation and management, reducing the overall impacts of resource use and improving efficiency of this use.

3.1.1. Key points

The European establishes:

- Exclusions from the scope of application:

1) The following shall be excluded from the scope of this Directive:

   a) Gaseous effluents emitted into the atmosphere
   b) Land (in situ) including contaminated non-excavated soil and buildings in permanent contact with land
   c) Uncontaminated soil and other natural material excavated during construction activities when it is certain that the material will be used for construction purposes in its natural state at the site from which it was extracted
   d) Radioactive waste
   e) Declassified explosives
   f) Fecal matter, straw and other non-hazardous natural, agricultural or forestry material, used in agriculture, forestry or energy production based on this biomass, by procedures or methods which do not harm the environment or In danger to human health.

2) The following shall be excluded from the scope of this Directive in so far as it is already covered by other Community legislation:

a) Sewage
b) Animal by-products, other than those intended for incineration, landfills or used in a gas or composting plant
c) The carcasses of animals which have died differently from slaughter
d) Waste resulting from the prospecting, extraction, treatment or storage of mineral resources, as well as quarrying

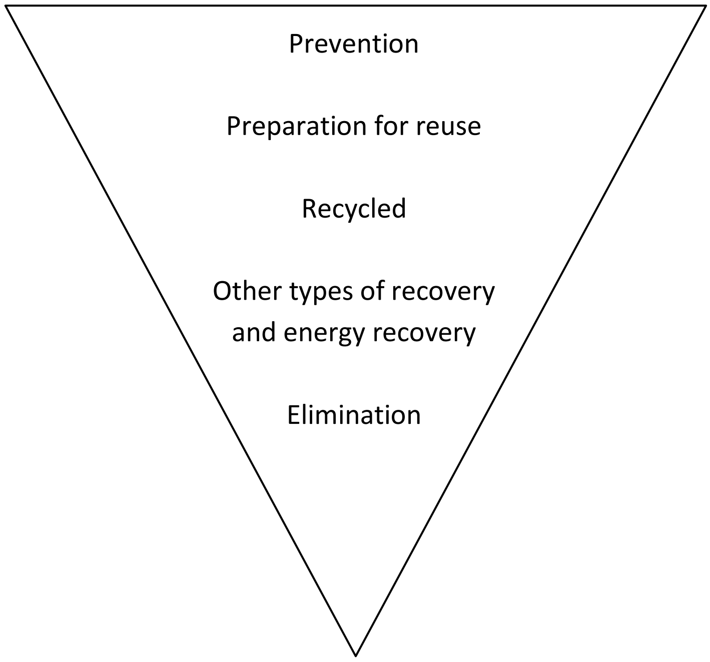
3) Without prejudice to the obligations imposed by other applicable Community legislation, sediments relocated within surface water shall be excluded from the scope of this Directive for the purposes of water and inland waterway management. Prevention of floods or mitigation of the effects of floods or droughts or land reclamation, if such sediments are shown to be non-hazardous.

4) Specific or supplementary provisions of this Directive, intended to govern the management of certain categories of waste, may be laid down by means of specific Directives

- It begins with some key definitions and here it is chosen some of the most important definitions:

  - 'Waste' means any substance or object from which the holder is detached or has the intention or the obligation to discard;
  - 'Hazardous waste' means a waste having one or more of the dangerous characteristics
  - 'Re-use' means any operation by which products or components other than waste are used again for the same purpose for which they were designed;
  - "Recycling" means any recovery operation whereby waste materials are transformed back into products, materials or substances, whether for the original purpose or for any other purpose. It includes the transformation of organic material, but not energy recovery or transformation into materials to be used as fuel or for filling operations;
  - 'Disposal' means any operation other than recovery, even where the operation has the secondary consequence of the use of substances or energy. Annex I contains a non-exhaustive list of disposal operations.

- The legislation establishes the following waste hierarchy will serve as a priority in legislation and policy on waste prevention and management:



- It confirms the 'polluter pays' principle, whereby the original waste producer must pay the costs of managing such waste.
- It introduces the concept of "extended producer responsibility". It imposes an obligation on manufacturers to accept and dispose of returned products after they have been used.

- Distinguishes between residues and by-products.
  A by-product is a substance or object, resulting from a production process, the primary purpose of which is not the production of that substance or object may be considered as a by-product and not as waste only if the following conditions are met:

  a) it is certain that the substance or object is to be used subsequently;
  b) the substance or article may be used directly without further processing than normal industrial practice;
  c) the substance or object is produced as an integral part of a production process; and
  d) Further use is legal, is the substance or object meets all relevant requirements for specific application related to products and environmental and health protection, and will not produce general adverse impacts on the environment or the environment and human health.

- Waste management must be carried out without creating risks for water, air, soil, plants or animals, without causing discomfort due to noise or odors and without affecting the landscapes or the places of special interest.

- Producers or holders of waste must treat them themselves or have them treated by an officially recognized operator. These must be authorized and inspected periodically.

- The competent national authorities should establish management plans and waste prevention programs. And also a special condition applies to hazardous waste, waste oils and bio-waste.

- Reuse and Recycling:

  1) At present, Member States shall take measures to promote high quality recycling and to establish waste separation, where technically, economically and environmentally feasible and adequate, to meet the required quality criteria for the relevant recycling sectors. Before 2015 the distinguishing signs of the collection separated for, less, the following matters: paper, metals, plastic and glass.

  2) It introduces recycling and recovery targets to be achieved before 2020 for household waste (50%) and waste from construction and demolition (70%).
  In order to achieve the objectives of this Directive and to move towards a high-efficiency European recycling society, the member states shall take the necessary measures to ensure that the following objectives are achieved:

  a) by 2020 the preparation for the re-use and recycling of waste of materials such as at least paper, metals, plastic and glass of waste must be increased to a minimum of 50% overall by weight Domestic and possibly from other sources to the extent that these waste streams are similar to household waste;

  b) by 2020 the preparation for re-use, recycling and other recovery of materials, including filler operations using waste as a substitute for other materials, for non-hazardous waste must be increased to a minimum of 70% by weight From construction and demolitions.

- Some types of waste, such as radioactive waste, declassified explosives, feces, and waste water and animal carcasses, are outside the scope of legislation.
  (Directiva 2008/98/EC, 2008)

3.2. The management of CDWs in Europe

The management of construction and demolition waste in Europe is given by directive 2008/98 / EC. Since we still do not have strict minimum percentages of recycling of these wastes there is a great difference of these between European countries.

The European Union established a classification of CDWs by category. According to statistics, in the EU there are large differences in countries and others, ranging from less than 10% to more than 90% of recycling and waste recovery.

The table 2 shows the percentage of material used for recycling and for filling of volumes according to each country of Europe in 2011. We can appreciate that countries like The Netherlands (NL) have almost 100% of reuse of the wastes are obtained in the construction or demolition of works. Austria (AT) moreover has one of the highest in Europe 90%.

Then we have Spain (ES) whose values, shown in the table, indicate that it is close to 65% nothing further from reality, as an error in the methodology was found. This is described hereinafter. Another characteristic country is the Czech Republic (CZ) which uses these wastes for other activities besides the filling of volumes. And finally we have countries like Greece (GR) that have a percent not even 10% and they do not almost recycle this waste.

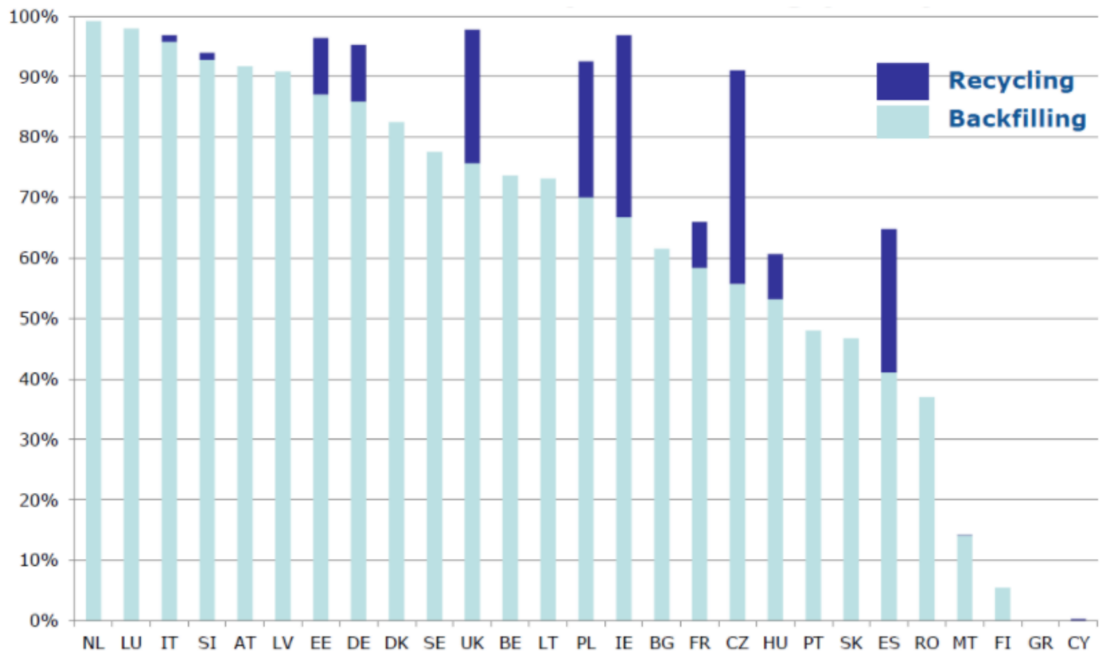


Table 2.European percent of material recycled (Barrientos, 2017)

While the statistics presented in the table above are used officially by the National Statistics Institute, the FERCD (Spanish Federation of Construction and Demolition Waste) as well as other federations collect and report data, which vary from these official statistics. In the chapter 3.4 it is shown the currently official statistics of Spain.

The figure 12 shows graphically the treatments in percent that have had the CDW in countries of the European Community. In such figure the increase of recycling, as expected evolution for this treatment in the coming years. (Machado, 2012)

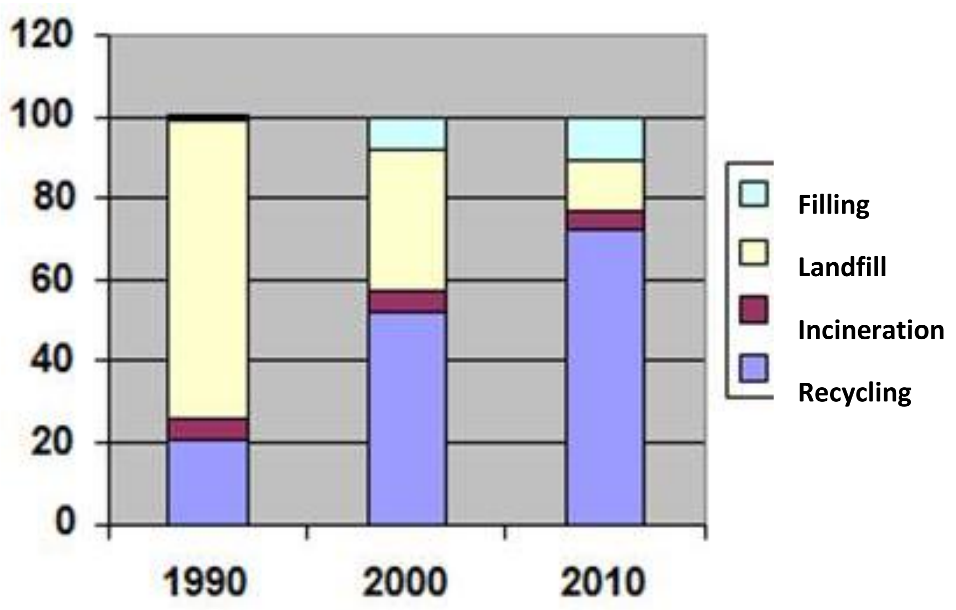


Figure 12.Treatment for CDW in the EU countries

The fast rise of the recycling of concrete and masonry debris, as well as waste in the production of prefabricated concrete elements and ceramics, is fundamentally due to four factors:

- The need to solve the problems caused by CDW to the environment.
- The increase in the demand for the production of aggregates.
- The scarcity of natural resources for the production of aggregates in some countries.
- The possibility of facilitating a lesser travel in transportation, thus guaranteeing the reduction of costs and air pollution.

(Machado, 2012)

Coming up next, we comment the countries more characteristic of table 2 above to see the general evolution of the recycling of waste in countries of Europe.

Austria (AT)

According to the Waste Framework Directive (2008/98/EC) 70% of non-hazardous construction and demolition waste has to be reused or recycled by 2020. The figure10 on the right shows the share of different treatment methods. It can be observed that the total recovery rate amounted to around 86%, while around 555,000 t (6.6%) ended up in landfill. Export (5,500 t) or incineration (5,000 t) played a minor role (0.1%). (Commission, 2016)

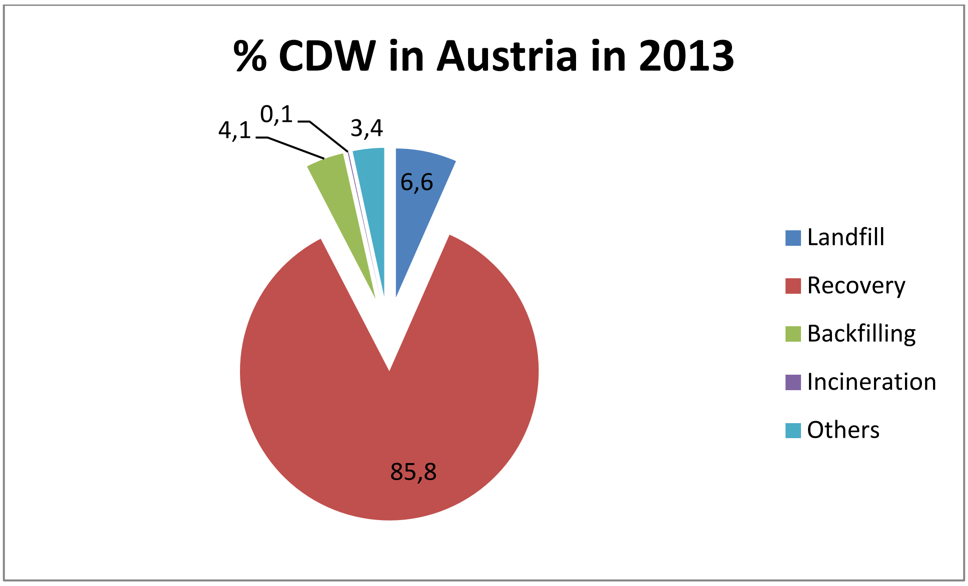


Figure 13.CDW in Austria 2013

Italy (IT)

With regard to treatment only 2,778,780 tons (which are around 6% of CDW generated in 2013) were landfilled. Energy recovery, backfilling and incineration only account for a small amount of treated CDW. No detail on the recycling treatment for 2013 is available.

More specifically, the amount of construction and demolition waste recovered in backfilling operations amounted to approximately 337,000 tons in 2010, to about 240,000 tons in 2011 and about 165,000 tons in 2012. (Commission, 2016)

The Netherlands (NL)

The source of the data in the table below and the data provided in the accompanying excel file of both the waste generation and treatment of CDW is the data of Rijkswaterstaat, which is part of the Ministry of Infrastructure and Environment. This data was directly obtained from the waste helpdesk of Rijkswaterstaat.

In 2012, according to these statistics in the figure 11, over 98% of the CDW is recovered (recycling, energy recovery and other recovery) of which 94% is recycled. Moreover, this has been over 90% since 2006.

The amount of landfilled CDW is dropping: in was 11.69 Ktonnes in 2006, in 2012 only 477 Ktonnes was left. This corresponds to 2% of all the CDW. (Commission, 2016)

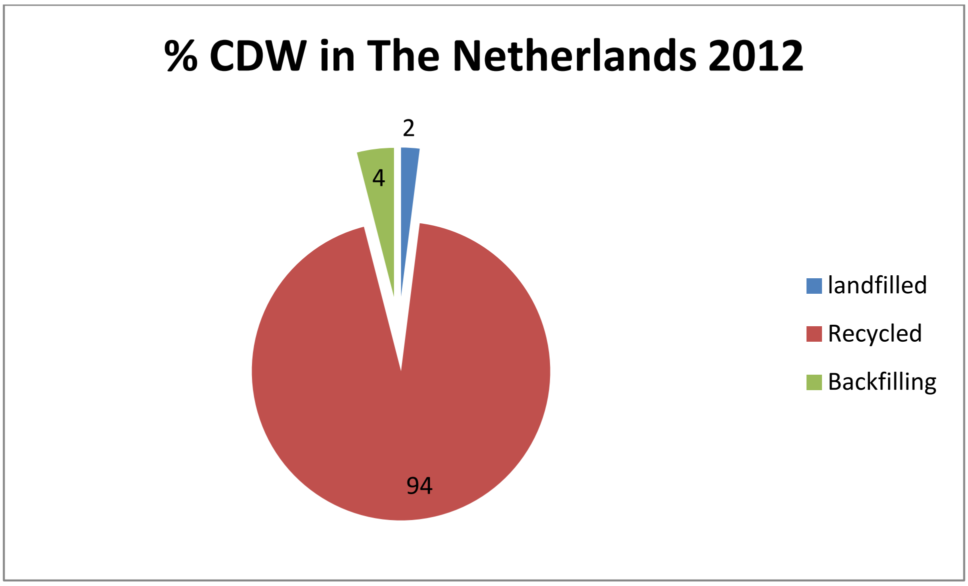


Figure 14.CDW in The Netherlands 2012

Greece (GR)

The latest available data on CDW treatment presented in Table 2 refer to the year 2012. Since CDW treatment data is not published yet by the Greek Statistics Office (ELSTAT), Eurostat data is used to present the treatment situation in Greece for 2012.

Year 2012 was the first year of operation of the first three CDW management systems in Greece and the amount of 2567 tons of recovered CDW is attributed to the operations of the systems. Prior to 2012, there was no reported data for recovery of CDW. Backfilling was used mainly for landscape rehabilitation within construction projects, excavated materials re-used on site. However, in general practice CDW treatment on site is not reported as CDW management but it is integral part of the construction project activities. Storage of CDW for recovery at a later point in time is not performed in Greece. Some sources indicate that the re-use and recycling rate of CDW in Greece was about 5% in 2011, although solid data is lacking in order to support this allegation. (Commission, 2016)

3.3. Spanish Law 22/2011

This is the current law that is used for the treatment of CDWs in Spain; this law covers all aspects given in the directive 2008/98/EC.

Purpose and scope

This Law aims to regulate waste management by promoting measures to prevent their generation and mitigate the adverse impacts on human health and the environment associated with their generation and management, improving the efficiency in the use of resources. It also aims to regulate the legal regime of contaminated soils.

Area of application

1) It is applicable to all types of waste, excluded:

   a) Emissions to the atmosphere regulated by the Law on air quality and protection of the atmosphere, as well as carbon dioxide captured and transported for the purpose of geological storage and effectively stored in geological formations. Neither shall it apply to the geological storage of carbon dioxide made for research, development or experimentation of new products and processes, provided that the expected storage capacity is less than 100 kilotons.

   b) Non-contaminated soil excavated and other natural materials excavated during construction activities, when it is certain that these materials will be used for construction purposes in their natural state in the place or work where they were extracted.
   c) Radioactive waste.
   d) Declassified explosives.
   e) Fecal matter, straw and other non-hazardous natural, agricultural or forestry material used on agricultural and livestock farms, in forestry or in the production of energy based on this biomass, by procedures or methods which do not jeopardize Human health or damage the environment.

2) Nor do the following waste fall within the scope of application:

   a) Waste water.
   b) Animal by-products covered by Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October 2009 (animal by-products and their derived products are not included here, when used for incineration, To landfills or to be used in a biogas or composting plant).
   c) The carcasses of animals which have died differently than the slaughter

d) Waste resulting from the prospection, extraction, treatment or storage of mineral resources, as well as the exploitation of quarries covered by Royal Decree 975/2009, of June 12.

Costs of waste management.

1) Following the 'polluter pays' principle, these costs will have to be borne by the original waste producer, the current holder or the previous holder of waste.

2) For the determination of domestic and commercial waste costs in Local Authorities, the actual cost of collection, transportation and treatment of waste, including monitoring of these operations, and post-closure maintenance, shall be included. The landfills.

3.4. The management of CDWs in Spain compared with Europe.

The management of construction and demolition waste in Spain is given by the law 22/2011.

Leaving aside the illegal dispose of waste in Spain, a worrying fact that we discussed in section 2.3, in Spain it is recycled around 25% of the CDWs that are generated due to the FERCD's data. Construction companies benefit from the reduced amount of waste generated by reducing the costs associated with landfilling and reducing the budget devoted to the purchase of raw materials. (Demolición), 2015)

Most of the waste that is not recycled goes, at best, to controlled landfills, occupying large dumping spaces and causing them to be filled more quickly.

In Spain, between 20 and 30 million tons of CDW are generated each year. These regulations apply to the legislation in force both in the State and in the Autonomous Communities that regulate the proper management of this waste under the concept of "sustainable construction", is recycled to become building materials. 80% of the CDWs can be recovered, transformed by 35% into recycled aggregates and restored by specialized managers (metal, wood, plastic, and paper-board).

The figure 10 shows the current percentage of recycling in Spain is currently around 25% of production compared to a European average of 70% approximately according with the European Commission although we have countries such as The Netherlands or Germany with a reuse ratio close to 100%. (Barrientos, 2017)

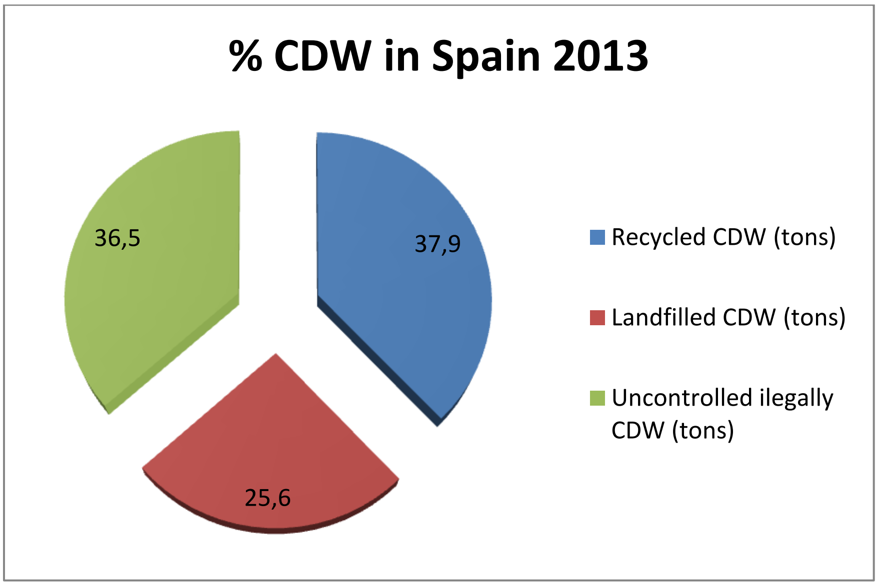


Figure 15.Recycling of CDW in UE and Spain

As seen below in the Figure 16 and 17 with the FERCD's data, wide discrepancies can be seen with the data of the table2.

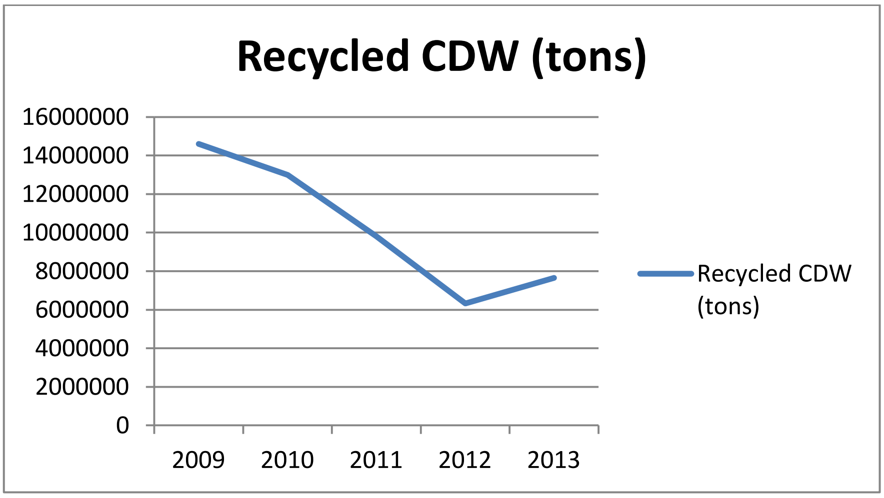


Figure 16.Recycled CDW in Spain

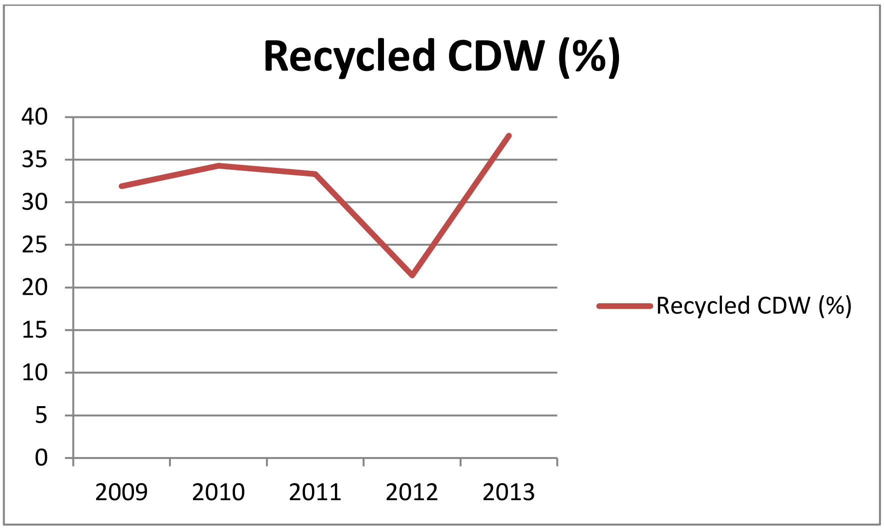


Figure 17.Recycled CDW in percent in Spain

Year	2009	2010	2011	2012	2013
Recycled CDW (tons)	14603106	12995937	9805543	6323032	7647071
Recycled CDW (%)	31,9	34,3	33,3	21,4	37,8

Table 3. FERCD's data

3.5. Waste and GDP

An interesting value to make the comparison of the amount of waste in each of the countries is the comparison of the amount of waste generated in tons between the GDP (Gross Domestic Product) of that country in Billions USD.

So we take the values compiled in sections 3.2 and 3.4 to know the amount of waste generated and divided between the GDP:

- Spain= 20185709 tons/1,199 billions USD= 16,835,453.71 $\frac{tons}{billions\ USD}$
- Austria= 16363000 tons/0,3741 billions USD= 43,739,641.81$\frac{tons}{billions\ USD}$
- Italy= 48587386 tons/1,815 billions USD= 26,769,909.64$\frac{tons}{billions\ USD}$

- The Netherlands= 25710000 tons/0,7525 billions USD= 34,166,112.96$\frac{tons}{billions\ USD}$

Here we can see that the highest value is the one of Austria and The Netherlands and the lowest one of Spain and Italy. Thus we confirm that the countries with better recycling policies, like Austria and The Netherlands, are also the countries which relatively extract more produces more CDWs.

4. CASE OF STUDY BBT (BRENNER BASE TUNNEL)

It is the longest underground railway connection in the world. It is a new link through the Alps. The Brenner Base Tunnel connects Austria and Italy crossing through the Alps.

4.1. Basic information BBT project.

The Brenner Pass lies 1371 meters above the sea level. When the tunnel is completely finish a big percent of the traffic will move over the Brenner Pass and the rest will go over it.

The Brenner Base Tunnel is the heart of the Scandinavian-Mediterranean corridor. This project is high priority for the EU, for being part of the longest railroad in Europe and it is also important for European economy and mobility.

This railway makes possible crossing the Alps in 25 minutes, passenger trains can pass through the tunnel at over 200km/h, currently, travel time is 80 minutes.

As shown in the figure 18, the tunnel is 55 kilometers long from Innsbruck (Austria) to Fortezza (Italy). (SE, 2016)

Figure 18. BBT Map

The BBT Tunnel includes:

- the rescue tunnel Tulfes
- the access tunnel Ampass
- the emergency station Innsbruck
- the exploratory tunnel Ahrental

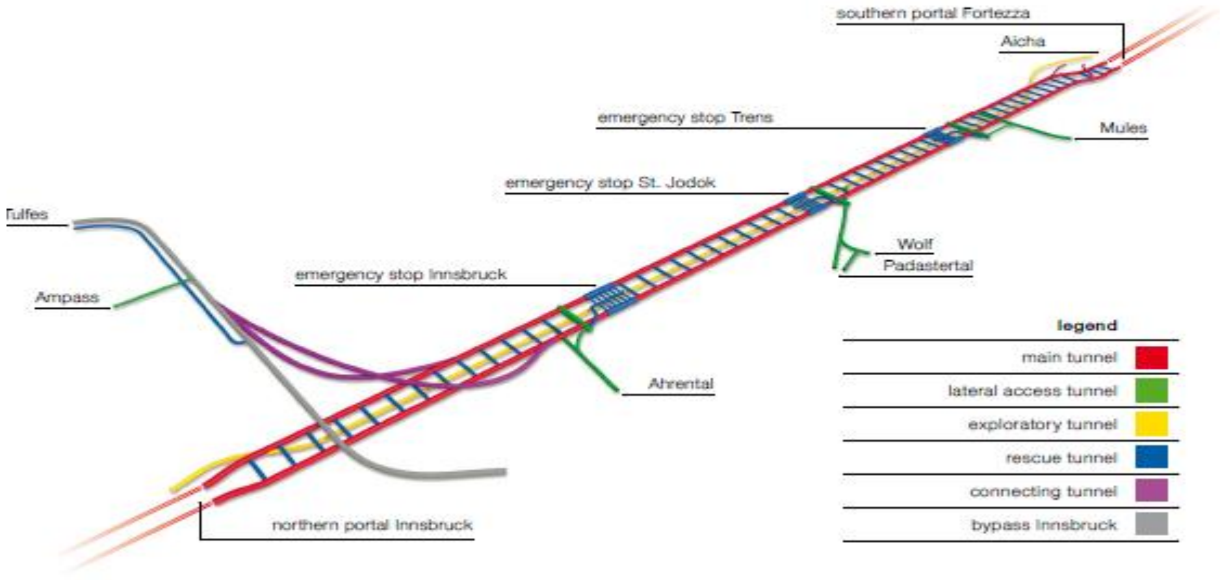


Figure 19.Tunnel Overview

Key data

Excavation material	17 million m^3
Excavation methods	30% by blasting
	70% by TBM

Some parts of the project are excavated by drilling and blasting whilst and most parts are excavated with the tunnel boring machine (TBM). The exploratory tunnel will be excavated by using an open hard rock TBM. The most of the tunnel will be done by TBM, only the parts of difficult access will be excavated by drilling.

By TBM

The mechanical excavation will be done with a TBM of approximately 180-400 meters long (as it is shown in the figure 20, and it is composed by a drilling head and a trailing structure.

The drilling head has a diameter about 10 meters and it is composed by several drilling bits that press against the rocks and break them into small pieces. The trailing structure supplies the excavation and removes the excavated material. The machine also has rock stabilization, ventilation and dust collection equipment.

The advantage of this TBM it is the high quantity of material excavated per day.
This type of excavation methods is only economical economically doable for longer stretches. (SE, 2016)

Figure 20.TBM Brenner Base Tunnel

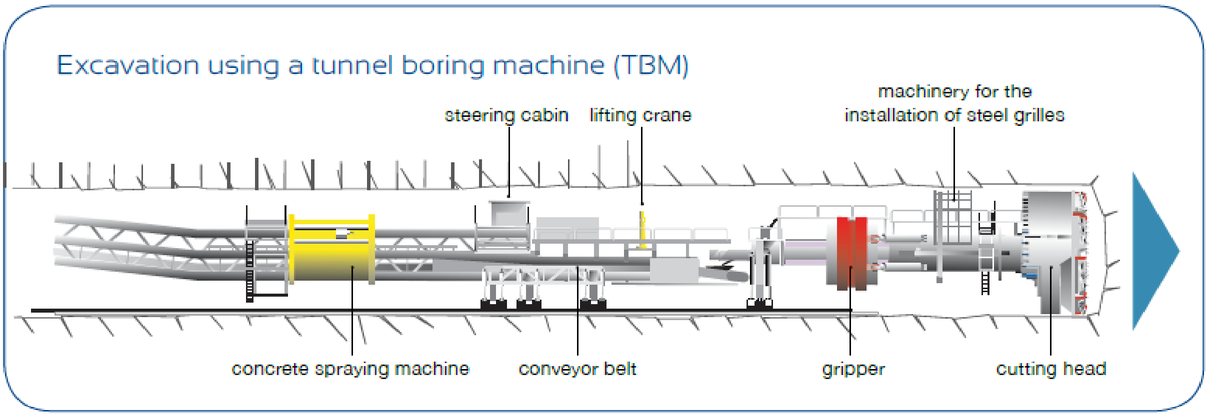


Figure 21.Tunnel Boring Machine

Conventional excavation (drill and blast)

This method use shotcrete support and it is very flexible for many types of materials.

In this project it will be used only for some sections of the main tunnel, the two connecting tunnels in Innsbruck, and the access tunnels completely and the connecting tunnel emergency.

The process consists in blast holes that are drilled first, after that they are loaded with explosives and then the explosion takes place. When the breakout material is removed, tunnel support is made with shotcrete, anchors and reinforcement mats.

After the blasting cycle is finished, the process starts over again. (SE, 2016)

Figure 22.Drill and blast excavation machine

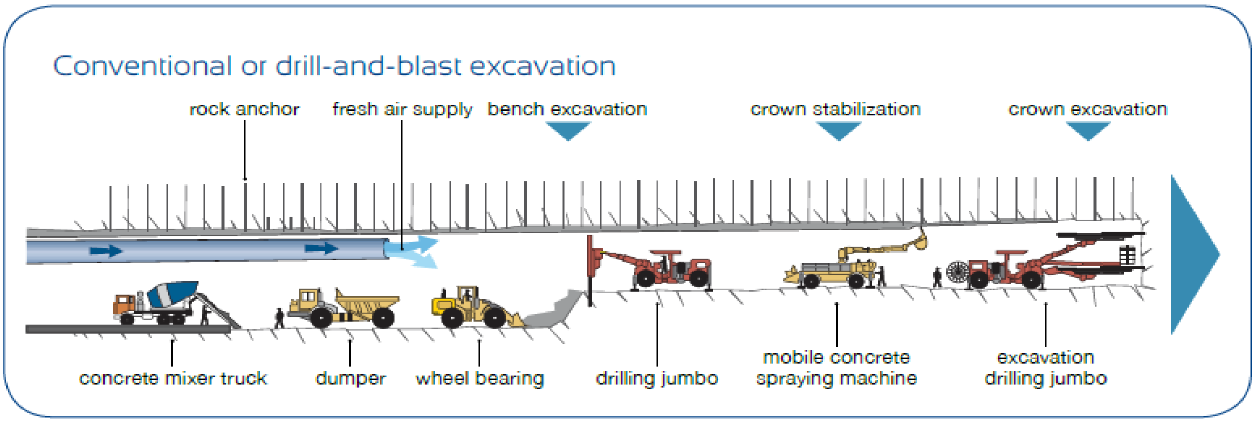


Figure 23.Drill and blast process of the BBT project

4.2. Geological conditions

This information cannot be precisely predicted even using the new technologies. But projections by experienced geologists, exploratory drilling and the exploration tunnel, which runs from end to end of the tunnel system, minimize construction risk.

This information is determined by boreholes drilled at different points over the project area. To determine the appropriate route for the Brenner Base Tunnel over 35,000 meters of boreholes were drilled at various points over the project area, some of these down to tunnel level.

With this method is provided information about the nature of the rock and it is obtained four general main different rock types in the tunnel section:

- Quartz phyllite
- Schist
- Gneiss
- Granite

(SE, 2016)

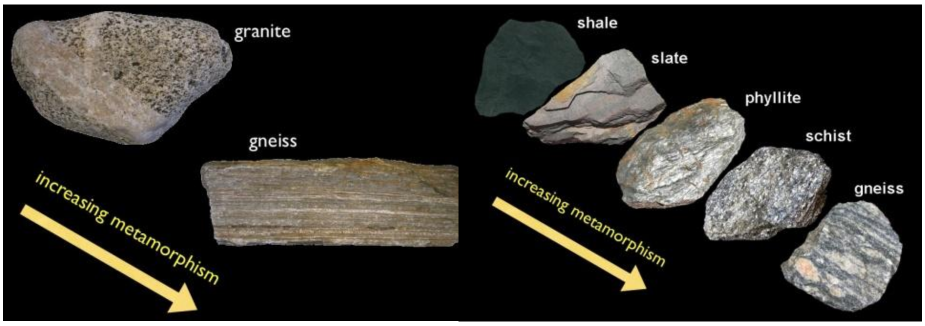


Figure 24.Comparison of Phyllite, Schist, Gneiss and Granite

The picture 25 represents the s the geology of the BBT tunnel section, which can be subdivided into two main areas:

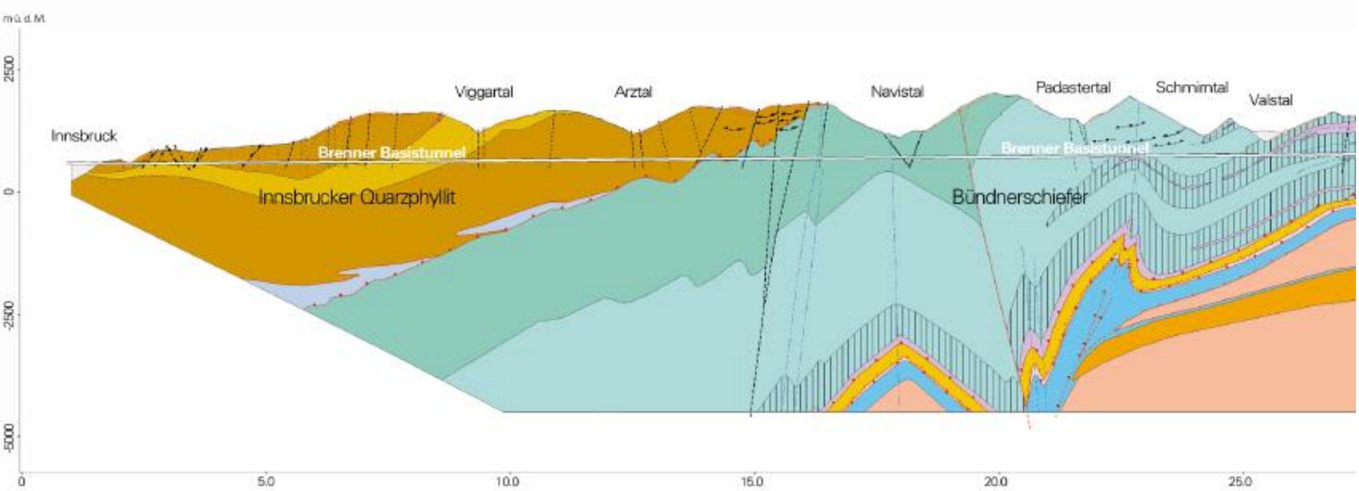


Figure 25.Geological longitudinal section between Innsbruck and Fortezza

- Area 1: Innsbrucker Quarzphyllit (Innsbruck quartz phyllite)
- Area 2: Bündner Schiefer (Grisons slate)

Area 1:

- quartz phyllite 75%,
- limestone, marble, dolomite 5%
- slate (mica, green, chlorite,..) 15%
- quartzite, gneiss 5%

Area 2:

- phyllite (black,calcite) 65%
- slate / quartzite, calcite, ...) 25%
- marble (limestone, quartzite,..) 10%

Geology alternates and changes over the entire length of the tunnel. Moreover, the rock is often fractured and unhomogeneous.

The geology main characteristics of the rock are: The UCS (unconfined compressive strength) mean value is approximately 30 [MPa]. The cohesion varies from 1.4 to 2.5 [MPa] and the friction angle from 28 to 35 [°]. The water runoff is very low.

4.3. About the company

"In 1999, the Ministers of Transport of Austria and Italy established the European Economic Interest Grouping BBT EEIG. The company was set up to plan the Brenner Base Tunnel and was the basis for the company Galleria di Base del Brennero – Brenner Basistunnel BBT SE, established on December 16th, 2004. The preparations for the establishment of the tunnel began in 2006". The actual construction was started in 2007 and will be finish on the expected date of 2025. The tunnel will go into operation in 2026. (SE, 2016)

As it is shown in Figure 26, the consortium that composes this work consists of 50% Austria by the company OBB (Osterreichische Bundesbahnem) and 50% by Italy by the company TFB (Tunnel Ferroviario del Brennero).

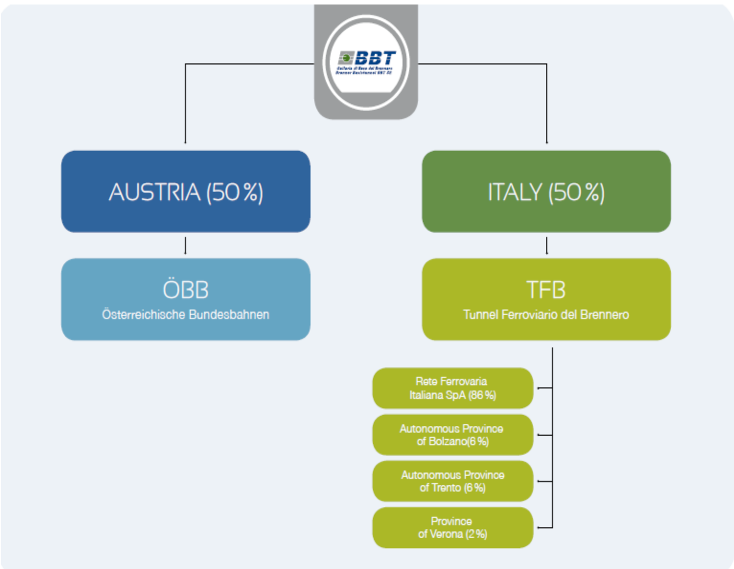
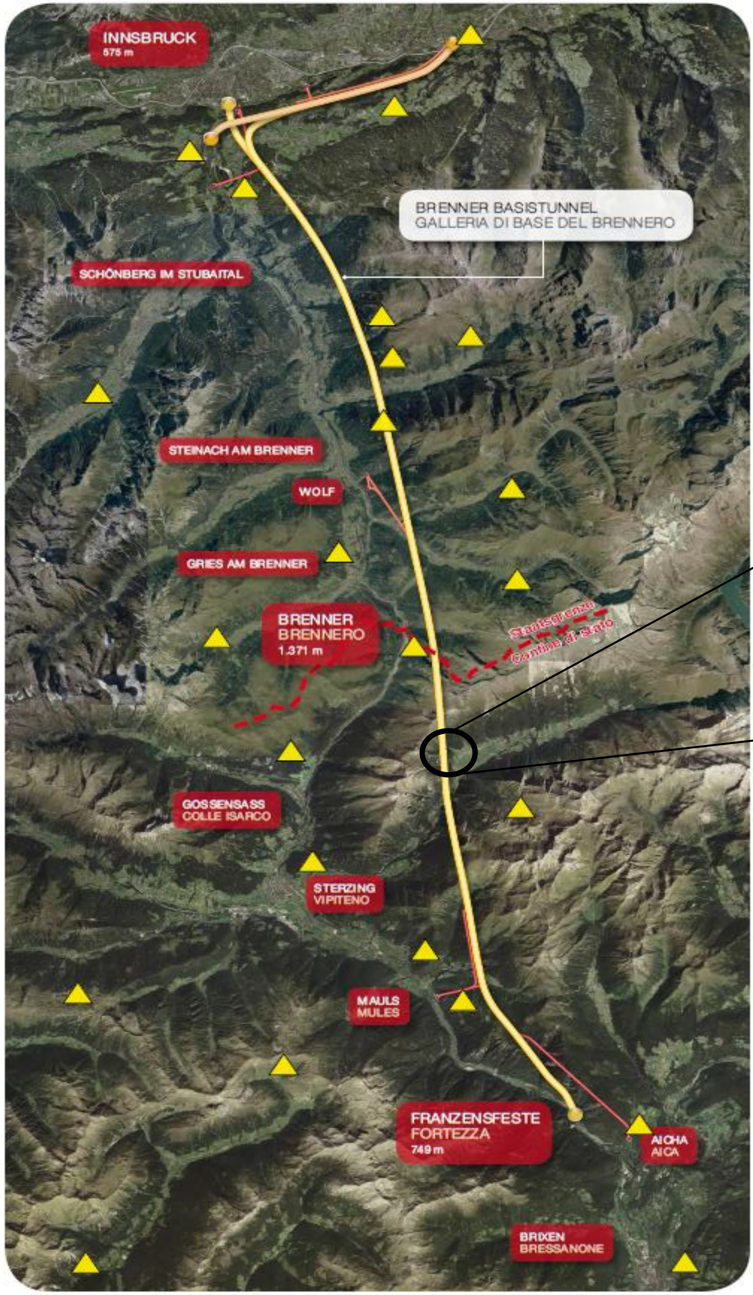
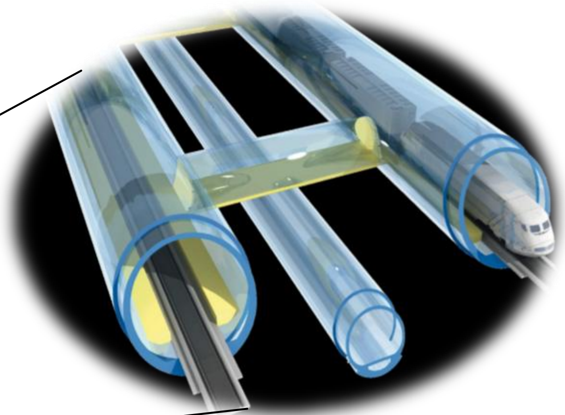


Figure 26.Consortium Austria and Italy



Here is the BBT line map:



The route of the tunnel is Innsbruck - Fortezza = 55 km.

The geodesic frame network is a network made up of measurement points (highlighted in yellow), which are distributed over a wide area and, in conjunction with the GPS system, form the basis for the measurement of the Brenner Base Tunnel.

Figure 27.Map BBT

5. METHODOLOGY OF BBT FOR TUNNEL SPOILS. SWIFTLY

The SWIFTLY (SWeden-Italy Freight Transport and Logistics) Green Corridor project is a European project, composed of "13 partners from Austria, Belgium, Denmark, Germany, Italy and Sweden develop a toolbox for green corridors in the TEN-T core network. The lead partner is CLOSER (Lindholmen Science Park AB, Sweden)." (Cordes, 2015)

5.1. Scope and objectives

This project includes the best-practices cases and selecting the measures to be green potential; it is composed by the most innovative methods. The measures used are the perfect guide to have green innovation implemented in the infrastructure planning.
To evaluate these measures a LCA's (life cycle assessment) is done to estimate the green effects.

The objective is to improve the efficient use of the materials. (Cordes, 2015)

5.2. Recycling of the excavated material

Tunnel spoil is considered waste this waste as we pointed out before, can be recycled and use it as a raw material. The recycling of the tunnel spoil reduces:

- cost of materials, due to the utilization of recycled materials instead of new ones
- cost of transportation, due to a production of the material on site
- cost of filler materials
- cost of dispose of waste material

As cost of the project is reduced, green efficient is increased. The aim is to recycle the spoil as filler and as an aggregate for concrete. The main interest is the aggregate for concrete due to the high cost of the concrete nowadays. (Cordes, 2015)

Main lithologies

The main lithologies in the area of the Brenner Base Tunnel are:

- Calcareous Schists: composed with a clearly layered structure and coarsely grained layers of calcite, quartz, muscovite and smaller amounts of chlorite and graphite. Resistance values 50-100 MPa.
- Limestone phyllites: laminated rock with a resistance of 25-50 MPa. Dark grey color.
- Black phyllites: high graphite and pyrite content. Resistance values of 25-50 MPa. Dark grey or black color.

Classification of the spoil

For using the spoil as an aggregate for concrete the requirements are quite important. This material will be tested in several parameters (composition, workability, resistance etc…).

- Visual assessment: the rock types (Calcareous Schists, limestone phyllites and black phyllites) can be already estimated with precision to decide the further treatment.
- Proportion of petrographically unsuitable components: rock strength using a hammer impact test. The next steps are:
  - Proportion of limestone phyllites, black phyllites and fault rock greater than 30% the material will be disposed of in the landfill.
  - Proportion of limestone phyllites, black phyllites and fault rock lower than 30%, the material will be taken to the ventilation chamber (hammer crusher) for further processing.
- Laboratory tests: it will be used Los Angeles test to determine the hardness of the rock
  - Determination water absorption
  - Verification of the chemical characteristics
  - Determination of the geometrical characteristics
  - Frost and de-icing resistance
  - Petrographic description

<u>The processing plant</u>

In the first place the entire spoil excavated is poured onto a grating with a grid width of 32 mm, which separates out the finer part of the spoil. Secondly, the material is put through a hammer crusher. After this crusher phase, the 4/8, 8/16 and 16/32 fractions are produced by shifting and the 0/4 mm sandy fraction by using a bucket wheel.

<u>Requirements for aggregates</u>

- Geometrical requirements (grain fraction, granulate composition)
  - Granulate composition
  - Grain form
  - Fines
- Physical requirements
  - Aggregate grain strength
  - Resistance to crushing
  - Resistance to polishing
  - Resistance to abrasion
  - Requirements for final lining
  - Workability
  - Stripping time, stripping resistance, resistance to cracking
  - Usage characteristics
- Chemical
  - Frost and de-icing salt resistance
  - Requirements for final lining

- Concrete and principles for concrete composition
- Usage characteristics

Characteristics of the aggregates produced

As far as the shape and distribution of the grains and the content in fines are concerned, the aggregates obtained have been quite satisfactory.
The 0/4 mm fraction, in particular, shows a continuous grading curve that exceeds expectations. The flakiness coefficient of the individual fractions can be seen in the table 3 as follows:

Grain factor	Flakiness coefficient	Fines grain fraction
4/8 mm	7	$f_{1,5}$
8/16 mm	12	$f_{1,5}$
16/32 mm	17	$f_{1,5}$

Table 3.Flakiness coefficient of the content

Flakiness coefficient means the specification for stone for bituminous surfacing, applied to aggregate coarser than 6.5 mm. It is expressed as the percentage by weight of particles (in a sample of more than 200) whose smallest dimension is less than 0.6 times the mean dimension. (science, 2017)

Types of concrete and characteristics

The construction site has its own concrete mixing plant which covers the daily needs; it produces around 100 m3 of shotcrete and another 150 m3 of lining concrete, using the tunnel spoil as aggregates. This construction concrete corresponds to the B3 short designation for concrete, according to [ÖNORM B 4710-1]. (The ÖNORM B 4710-1 is for us like the EHE-08 but in Austria.).
The table 4 shows the "recipe" for construction concrete and shotcrete:

Components	Amount of aggregate added [kg/m³] Construction concrete	Shotcrete
CEM I 42.5 R WT38 C3A-frei/HS	274.00	-
CEM I 52.5 N	-	420.00
AHWZ (Fluasit cement)	113.00	-
Water	188.00	2.00
Aggregate 0/4 mm	1096.00	1317.00
Aggregate 4/8 mm	-	436.00
Aggregate 8/16 mm	667.00	-
Superplasticizers	2.40	2.90
Air entraining agent	1.70	1.30

Consistency agents	-	0.42

Table 4.Recipe for construction concrete and shotcrete (Cordes, 2015)

The following table shows the characteristics of construction concrete and shotcrete:

Characteristics of fresh concrete	**Construction concrete**	**Shotcrete**
Age [min]	10	10
Slump flow diameter [cm]	56.0	63.5
Air bubble content [%]	3.1	7.8
Density [kg/m³]	2350	2220
Water content [kg/m³]	199	209
Temperature of fresh concrete [°C]	18.0	19.0
Characteristics of hardened concrete	**Construction concrete**	**Shotcrete**
Compressive strength [N/mm²]	41.75	42.77
Splitting strength [N/mm²]	1.94	1.86
Specific fracture energy [N/m]	87.99	81.14

Table 5.Characteristics of construction concrete and shotcrete(Cordes, 2015)

In table 5 it is shown the results for specific fracture energy, splitting strength and compressive strength of 28-day old concrete.

The values for splitting strength and specific fracture energy are relatively low in the shotcrete, which is presumably due to significantly lower aggregate size in the recipes used. (Cordes, 2015)

5.3. Life Cycle Assessment (LCA)

Life-cycle assessment (LCA, also known as ecobalance method) is a technique to assess environmental impacts associated with all the stages of a product's life from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. LCAs can help avoid a narrow outlook on environmental concerns by:

- Compiling an inventory of relevant energy and material inputs and environmental releases;
- Evaluating the potential impacts associated with identified inputs and releases;

- Interpreting the results to help make a more informed decision.

The goal of LCA is to compare the full range of environmental effects assignable to products and services by quantifying all inputs and outputs of material flows and assessing how these material flows affect the environment.

In this chapter, the ecological improvements achieved with the types of shotcrete were analyzed using the eco-balance method (LCA). This method, Eco Balance method also means the preparation of a list of input and output data on environmental impact to identify, quantitatively measure, and report environmental impact caused.

In this case, the eco-balance study, compares two types of shotcrete used (consisting of aggregates derived 100% from processed tunnel spoil and Portland cement (CEM I 52.5 R) or Portland composite cement (CEM II / AM (S-L)) to standard shotcrete for consolidation work in conventional tunnel excavations with primary aggregates and Portland cement or Portland composite cement.

The comparison was made for a functional unit of 1 m^3 of shotcrete, and considered all the process from the excavation of the raw materials to the finished production of shotcrete mixture that means from “cradle to factory”. Also taken into account was the fact that the recycled spoil did not have to be disposed of to landfill.

Some of the results are showed below:

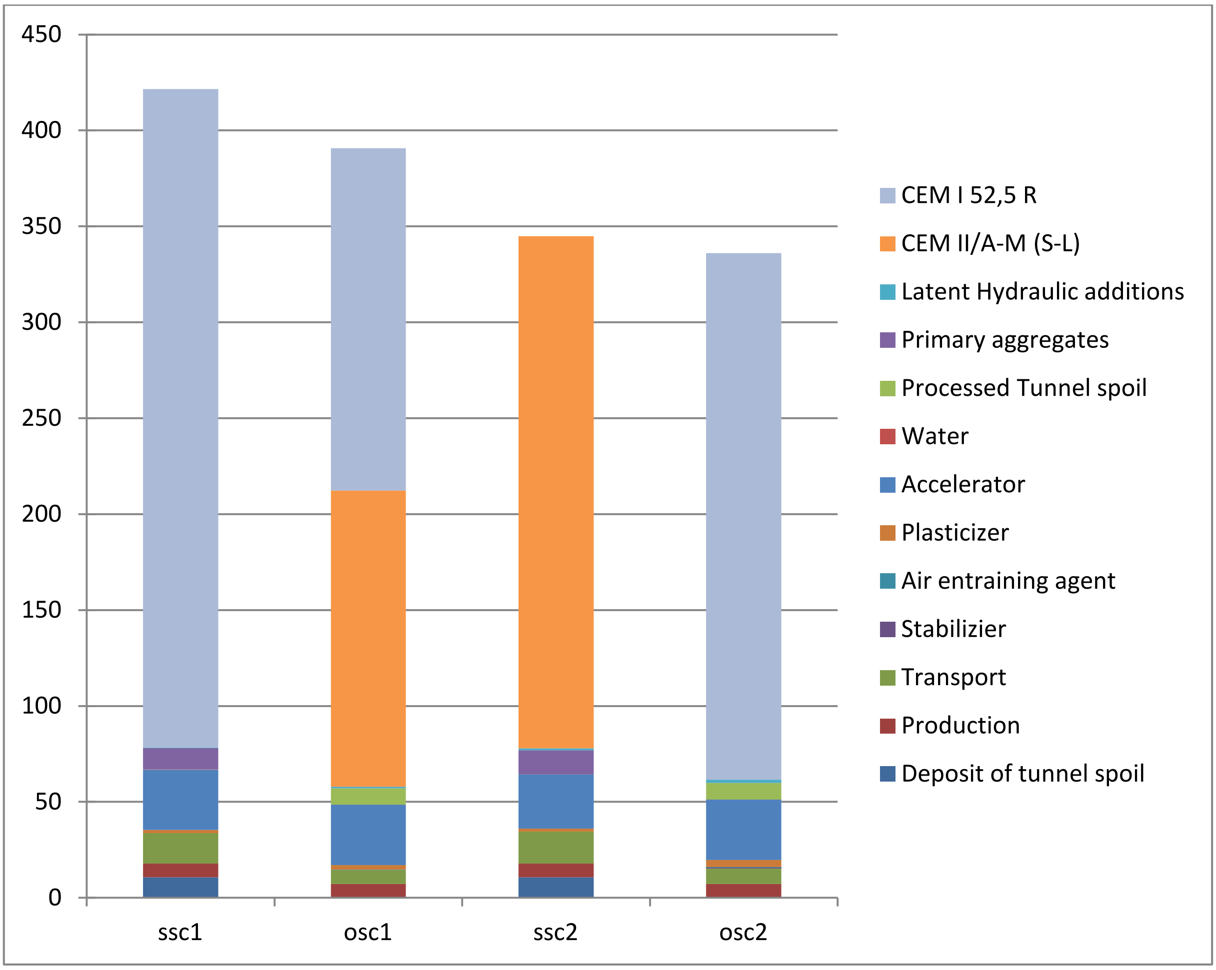


Figure 28. Comparison of Global Warming Potential Kg C02

	ssc1	osc1	ssc2	osc2
Deposit of tunnel spoil	10,65	0	10,65	0
Production	7,22	7,22	7,22	7,22
Transport	15,82	7,29	16,67	8,01
Stabilizier	0	0	0	0,42
Air entraining agent	0	0,14	0	0,48
Plasticizer	1,67	2,37	1,51	3,61
Accelerator	31,46	31,46	28,31	31,46
Water	0,06	0,06	0,06	0,06
Processed Tunnel spoil	0	8,6	0	8,6
Primary aggregates	11,26	0	12,41	0
Latent Hydraulic additions	0,33	0,82	1	1,67
CEM II/A-M (S-L)	0	154,3	267,07	0
CEM I 52,5 R	343,09	178,41	0	274,47
Sum	421,55	390,66	344,89	335,98

Table 6.Data kg CO2

The figure 28 shows the comparison of kg/m3 of CO2, it compares the two types of concrete (ssc1, ssc2) with same types of optimized concrete (osc1, osc2). Such figure contains the amount of material saved in each type of concrete. For example we can see that for the first type of concrete7.32% is saved compared with the same type of concrete without optimizing.

This 7.32% is located mainly in the quantity of CEM I 52.5 R saved cement (from 343.09 kg/m3 to 178.41kg/m3).

In the second type of concrete is saved only 2.6% of CO2 is saved since many parameters have been increased to make the optimized concrete, as Processed Tunnel spoil, Accelerator, etc. The only parameter with noticeable CO2 decrease is the Transportation (from 16.67 kg/m3 to 8.01 kg/m3).

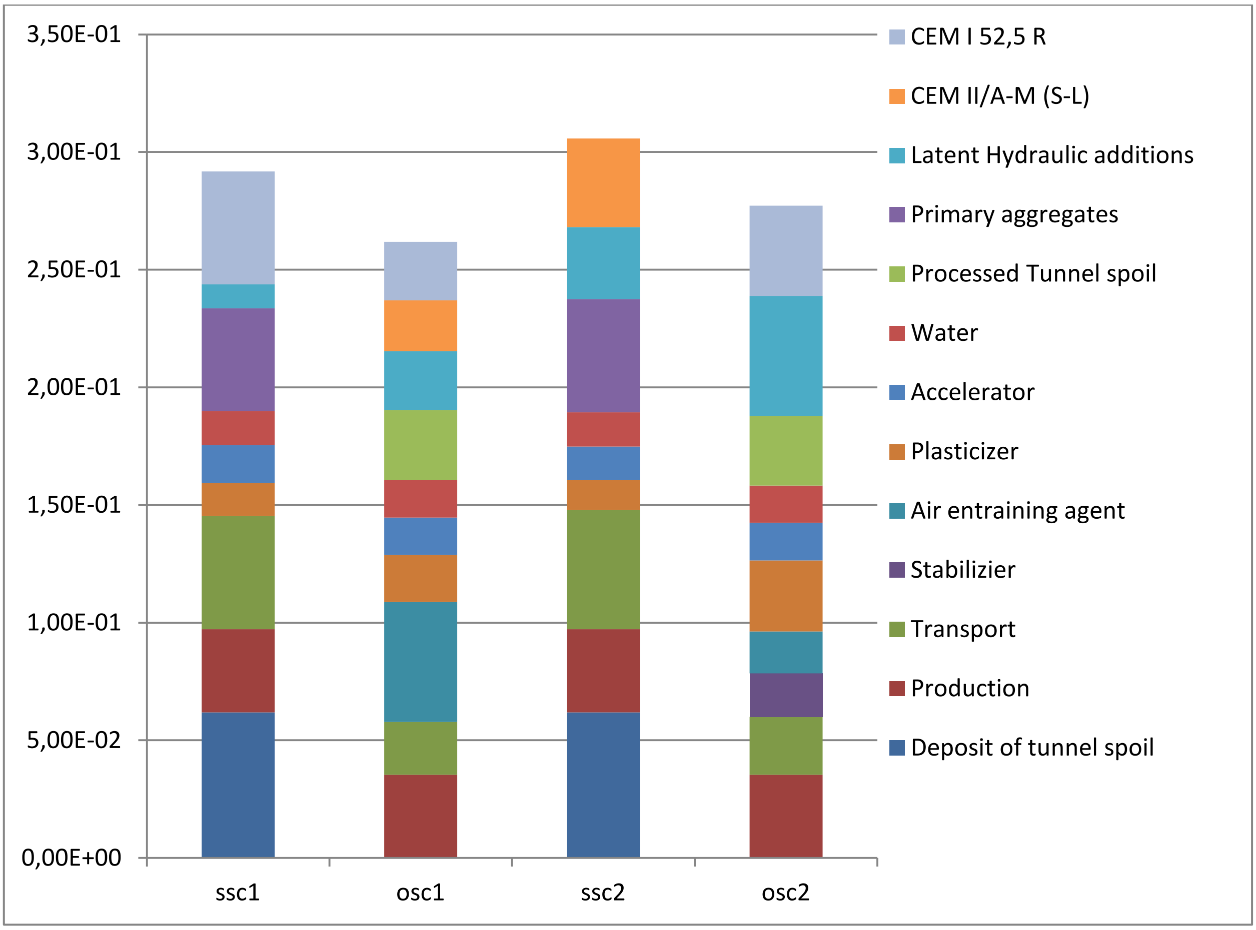


Figure 29. Comparison of the Acidification Potential Kg of SO2

	ssc1	osc1	ssc2	osc2
Deposit of tunnel spoil	0,062	0	0,0619	0
Production	0,035	0,0353	0,0353	0,0353
Transport	0,048	0,0225	0,0507	0,0246

Stabilizier	0	0	0	0,0185
Air entraining agent	0	0,051	0	0,0179
Plasticizer	0,014	0,0199	0,0126	0,0302
Accelerator	0,016	0,016	0,0144	0,016
Water	0,015	0,0159	0,0145	0,0157
Processed Tunnel spoil	0	0,0297	0	0,0297
Primary aggregates	0,044	0	0,0481	0
Latent Hydraulic additions	0,010	0,025	0,0306	0,051
CEM II/A-M (S-L)	0	0,0217	0,0376	0
CEM I 52,5 R	0,048	0,0249	0	0,0383
Sum	0,084	0,0738	0,0732	0,0672

Table 7.Data kg ofSO2

The figure 29 shows the comparison of kg/m3 of SO2, it compares the two types of concrete (ssc1, ssc2) with same types of optimized concrete (osc1, osc2). In this figure is the amount of material saved in each type of concrete. For example we can see that for the first type of concrete saves 12.14% with regard to the same type of concrete without optimizing.

This 12.14% is located mainly in Primary aggregates saved (from 0,044kg/m3 to 0 kg/m3) or in CEM I 52,5 R (from 0.048 kg/m3 to 0.0249 kg/m3), also it diminishes the Transport and Deposit of tunnel spoil.

In the second type of concrete saves 8.19% and this is mainly appreciated in the parameters Primary aggregates (from 0.0481 kg/m3 to 0 kg/m3) and in Transport. Other parameters have increased as is the case of Stabilizier or Air entraining agent.

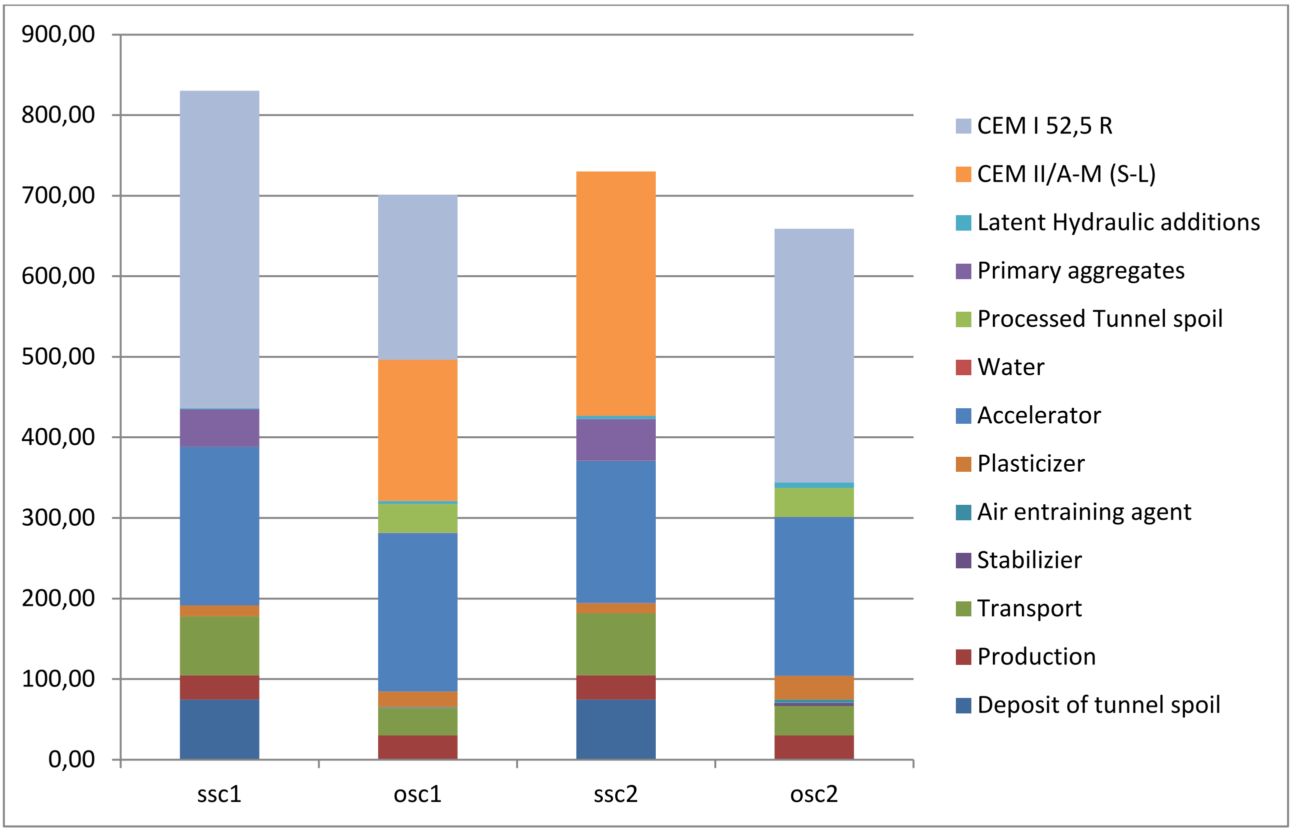


Figure 30.Comparison of the non renewable cumulative energy demand in kWh

	ssc1	osc1	ssc2	osc2
Deposit of tunnel spoil	74,75	0,00	74,75	0,00
Production	29,92	29,92	29,92	29,92
Transport	73,25	34,06	77,08	37,28
Stabilizier	0,00	0,00	0,00	3,39
Air entraining agent	0,00	1,11	0,00	3,92
Plasticizer	13,67	19,50	12,39	29,61
Accelerator	196,89	196,89	177,19	196,89
Water	0,22	0,25	0,22	0,25
Processed Tunnel spoil	0,00	35,94	0,00	35,94
Primary aggregates	46,44	0,00	51,22	0,00
Latent Hydraulic additions	1,39	3,39	4,14	6,89
CEM II/A-M (S-L)	0,00	175,22	303,28	0,00
CEM I 52,5 R	393,53	204,64	0,00	314,83
Sum	830,08	700,92	730,19	658,92

Table 8.Data kg of energy demand in kWh

The figure 30 shows the comparison of renewable cumulative energy demand in kWh of two types of concrete (ssc1, ssc2) and for the same types of optimized concrete (osc1, osc2). In this figure is the amount of material saved in each type of concrete. For example we can see that for the first type of concrete saves 15.56% with regard to the same type of concrete without optimizing.

This 15.56% is located mainly in Primary aggregates (from 46.44 kWh to 0 kWh) or in CEM I 52.5 R (from 393.53 kWh to 204.64kWh), also reduces the Transport and Deposit of tunnel spoil.

In the second type of concrete saves 9.76% and this is mainly appreciated in the parameters Primary aggregates (from 51.22kWh to 0kWh) or in Transport. Other parameters have increased as is the case of Stabilizer, Air entraining agent and Accelerator.

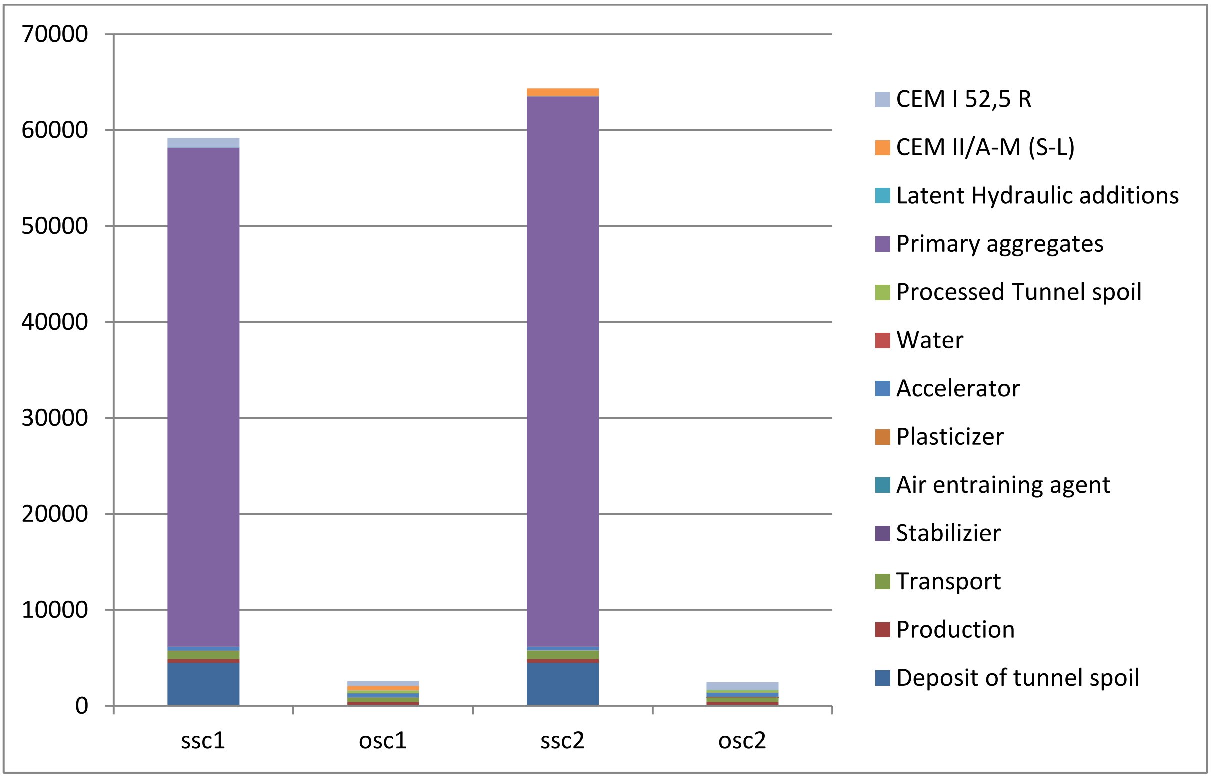


Figure 31. Comparison of mineral resources

	ssc1	osc1	ssc2	osc2
Deposit of tunnel spoil	4483,4	0	4483,4	0
Production	396,2	396,2	396,2	396,2
Transport	839,9	429,3	877,3	454,8
Stabilizier	0	0	0	8
Air entraining agent	0	2,9	0	10,1
Plasticizer	38,7	55,1	35,1	83,8
Accelerator	416,2	416,2	374,6	416,2
Water	2,8	3	2,8	3
Processed Tunnel spoil	0	272,4	0	272,4
Primary aggregates	52013,3	0	57340,7	0
Latent Hydraulic	8,4	26,6	25,3	42,1

additions				
CEM II/A-M (S-L)	0	461,5	798,7	0
CEM I 52,5 R	977,7	508,4	0	782,1
Sum	59176,6	2565,7	64334	2468,9

Table 9.Data mineral resources in UBP

The figure 31 shows the comparison of mineral resources in UBP, it compares the two types of concrete (ssc1, ssc2) with same types of optimized concrete (osc1, osc2). In the figure 24 is the amount of material saved in each type of concrete. For example we can see that for the first type of concrete saves 95.66% with regard to the same type of concrete without optimizing, which indicates to be the element that saves mainly in the recycling of the CDWs.

This 95.66% is located mainly in Primary aggregates (from 52013.3UBP to 0UBP) or in CEM I 52.5 R (from 977.7UBP to 508.4UBP), also it diminishes the Transport and Deposit of tunnel spoil.

In the second type of concrete saves 96.16%, also very high element that you can appreciate mainly in the parameters Primary aggregates (from 57340.7UBP to 0UBP) or in Transport. Other parameters have increased as is the case of Stabilizier, Air entraining agent and Accelerator.

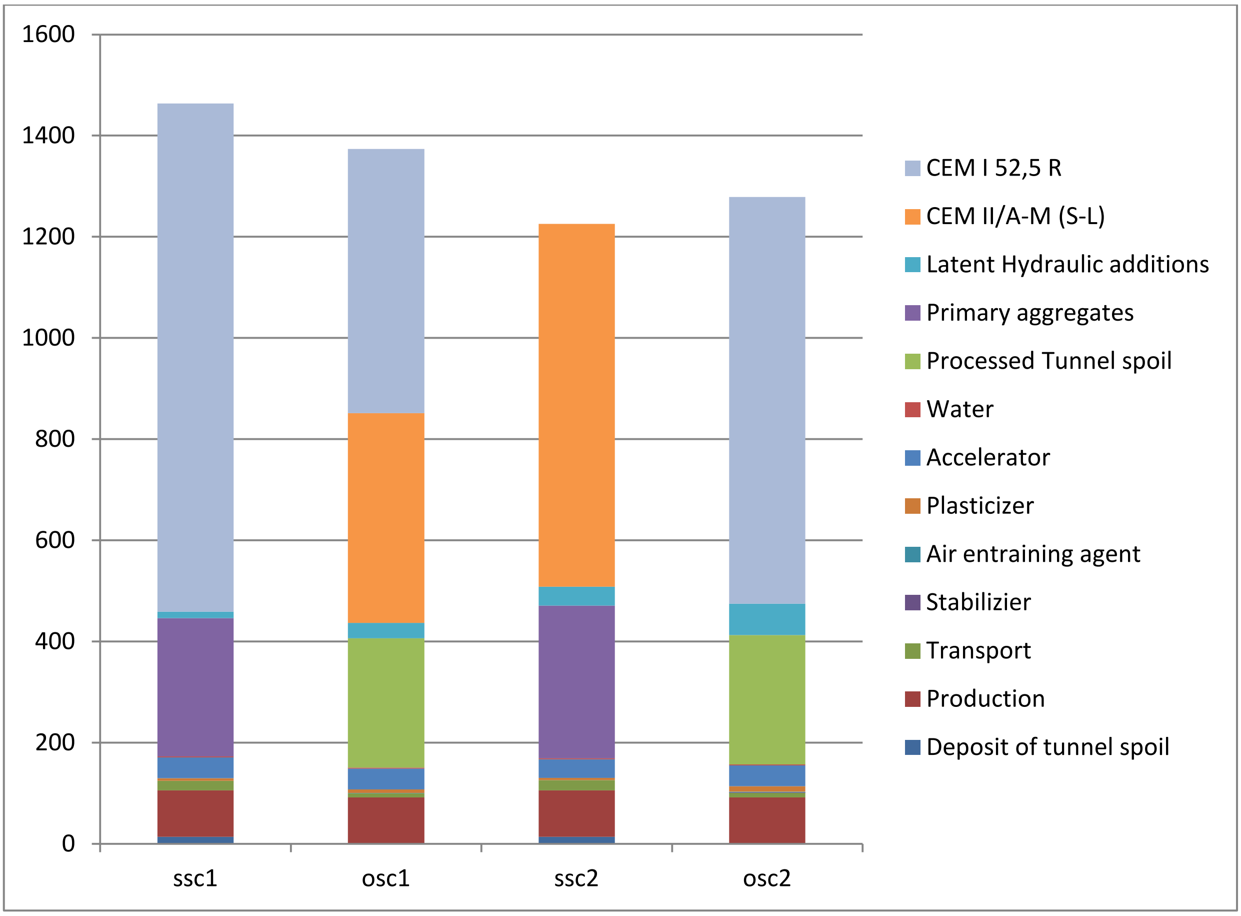


Figure 32.Comparison of shotcretes as concerns water demand

	ssc1	osc1	ssc2	osc2
Deposit of tunnel spoil	13,7	0	13,7	0
Production	91,7	91,7	91,7	91,7
Transport	19,2	8,5	20,3	9,3
Stabilizier	0	0	0	0,8
Air entraining agent	0	0,4	0	1,5
Plasticizer	5	7,1	4,5	10,8
Accelerator	41	41	36,9	41
Water	1,8	2	1,8	1,9
Processed Tunnel spoil	0	255,5	0	255,5
Primary aggregates	273,7	0	301,7	0
Latent Hydraulic additions	12,5	30,6	37,5	62,5
CEM II/A-M (S-L)	0	414,5	717,4	0
CEM I 52,5 R	1005	522,6	0	804
Sum	1463,6	1373,9	1225,5	1279

Table 10.Data water demand in m3

The figure 32 shows the comparison of water demand in m3, it compares the two types of concrete (ssc1, ssc2) with same types of optimized concrete (osc1, osc2). Such figure contains the amount of material saved in each type of concrete. For example we can see that for the first type of concrete saves 6.13% with regard to the same type of concrete without optimizing.

This 6.13% is located mainly in Primary aggregates (from 273.7m3 to 0m3) or in CEM I 52,5 R (from 1005m3 to 522.6m3), also decreases the Transport and Deposit of tunnel spoil.

The second type of concrete does not save anything. On the contrary, it increases the demand for materials by 4.36%. This increase can be seen in the CEM I 52.5 R (from 0m3 to 804m3), Latent Hydraulic additions (from 37.5m3 to 62.5m3) and others.

Eutrophication Potential

Another interesting comparison is the Eutrophication Potential measured in Kg PO4; it compares the two types of concrete (ssc1, ssc2) with same types of optimized concrete (osc1, osc2). It is shown the amount of material saved in each type of concrete. For example we can see that for the first type of concrete is saved very little percentage with regard to the same type of concrete without optimizing.

This low percentage is located mainly in Primary aggregates (from 0.0233kg/m3 to 0kg/m3) or in CEM I 52,5 R, also decreases the Transport and Deposit of tunnel spoil.

In the second type of concrete, very little quantity is also saved; the demand for materials decreases in a low percentage, this decrease can be seen in the parameters CEM II / AM (SL), Deposit of tunnel spoil and others, however there are other parameters that increase their demand as is the case of Latent Hydraulic additions, Stabilizier etc

Comparison of shotcretes concerning Cumulative Energy Demand

Another interesting comparison is the Cumulative Energy Demand, it compares the two types of concrete (ssc1, ssc2) with same types of optimized concrete (osc1, osc2). It is shown the amount of material saved in each type of concrete. For example we can see that for the first type of concrete is saved 15% with regard to the same type of concrete without optimizing.

This low percentage is located mainly in Primary aggregates (202.6 0) or in CEM I 52,5 R (1542 801.9) also decreases the Transport and Deposit of tunnel spoil.

In the second type of concrete, a saving of 8.86% is achieved. This saving can be seen in the demand for CEM II / AM (SL) (1180.8 0), Deposit of tunnel spoil and others, however there are other parameters that increase their demand as the case of Latent Hydraulic additions, Processed tunnel spoil etc

5.3.1. Interpretation of results

The use of tunnel spoil reduces the pollution very significantly what make this project green efficient and makes it an example to follow for the rest of Europe.

As the main result of this study, it can be said that the use of the tunnel spoil in the types of shotcrete used in the tunnel, spare a considerable amount of **mineral resources**:

- Standard shotcrete ssc1 = 59176.6 UBP
- Optimized shotcrete 0sc1= 2565.7 UBP
- Standard shotecrete ssc2= 64334 UBP
- Optimized shotcrete 0sc2= 2468.9 UBP
  UPB (environmental impact points per m^3)

With a saving of 95.66% for the first type of concrete and 96.16% for the second type.

The amount of mineral resources very useful for use them as raw materials. The use of tunnel spoil also reduces the environmental pollution, as it is shown in the table it can reduce several indicators as:

- Water demand (type 1=6.13% , type2=4.36%)
- Kg of $S0_2$ (type 1=12.14%, type2=8.19%)
- Kg of $C0_2$ (type 1=7.32%, type2=2.6%)

The use of tunnel spoil also has a positive effect on the results, but not as high as mineral resources, that can be due to the high demand of cement (CEM II/A-M (S-L), CEM I 52,5 R) for the types of shotcrete made with tunnel spoil, which slightly diminishes the positive effect of recycling the spoil.

The analysis also shows that the Transport and Production tunnel spoil always decrease their demands and the Production maintain its demand for all the comparison of the elements. (Cordes, 2015)

6. CASE OF STUDY DRAGON

The DRAGON PROJECT (development of Resource-efficient and Advanced Underground Technologies). Europe`s underground construction industry expects to excavate around 800 million tons of mineral resources from tunnels. In the past, this excavation material was usually disposed of in landfills, what it is not very efficient. Moreover previously mentioned at the beginning of the document is still a problem in some countries of Europe. This project wants to get an efficient use and recycling on site or in other industrial sectors. Therefore the project has a great economic and environmental interest. This would substitute a large amount of primary mineral resources and substantially reduce environmental problems and CO2 emissions involved in land filling and transport.
The following map shows the scope of application of the project:

Figure 33. DRAGON Project location

6.1. Scope and objectives

The DRAGON turns the excavation material into a valuable resource for other processes and sectors such as the cement, steel, ceramic or glass industries. The project sets out to solve this challenge by developing a prototype system for the automated online analysis, separation and recycling of excavated materials in underground construction sites.
The entire chain from characterization to classification and processing of the excavated material will be conducted completely underground. The use of excavation material for various

purposes is designed to save natural primary resources while also providing a high economic value.

To sum up, it will improve resource efficiency by increasing the amount of excavated mineral resources from tunneling that can be used by other industries.

Technical Concept

• It uses automated in situ analysis close to the excavation face to characterize the excavated material
• It separates mineral resources according to potential reuse options for the characterized material
• Some material can be processed and used directly on the tunnel boring machine to produce concrete, shotcrete, mortar etc. that is directly reused in the tunnel

Key data

Excavation material	800 million m^3
Excavation methods	10% by blasting
	90% by TBM

Total Cost: 4,554,771.26 €
The automated online analysis and processing units to be developed within the DRAGON project will constitute a real breakthrough in the underground construction sector. This will help European companies to gain innovation leadership and strengthen their competitive position in this promising market. (Galler, 2013)

6.2. Excavation methods

It is used photo-optical technologies, x-ray, gamma-ray and microwave units to analyze the mass flow of material directly behind the cutter head. This automated online sampling and characterization of physical, chemical and mineralogical properties provides the basis for evaluate the suitability of the excavated material for different use options.

Figure 34.DRAGON methodology for excavation TBM

The excavation of material at the heading face by the TBM's cutting wheel also includes characterization of rock properties using a disc cutter load monitoring system.
After that then the material goes to be splitting off the bypass material flow using a hammer sampler. (Galler, 2013)

6.3. Classification of the spoil

A downstream underground separation plant will handle the material depending on the online test results and requirements for intended re-use either as concrete aggregates on site or in various other industrial sectors. All systems will be mounted directly on the backup system of the tunnel boring machine and will thus need to be adapted to the harsh environmental conditions and space restrictions underground.
In order to prepare the material it is processed by crusher and bypass belt conveyor, followed by high-precision microwave moisture measurement and online x-ray elemental analysis. Then it takes place the photo-optical analysis for parallel determination of grain size distribution. Finally in-stream sorting of the excavated material is based on the online classification results. All this process is summarized in the following figure:

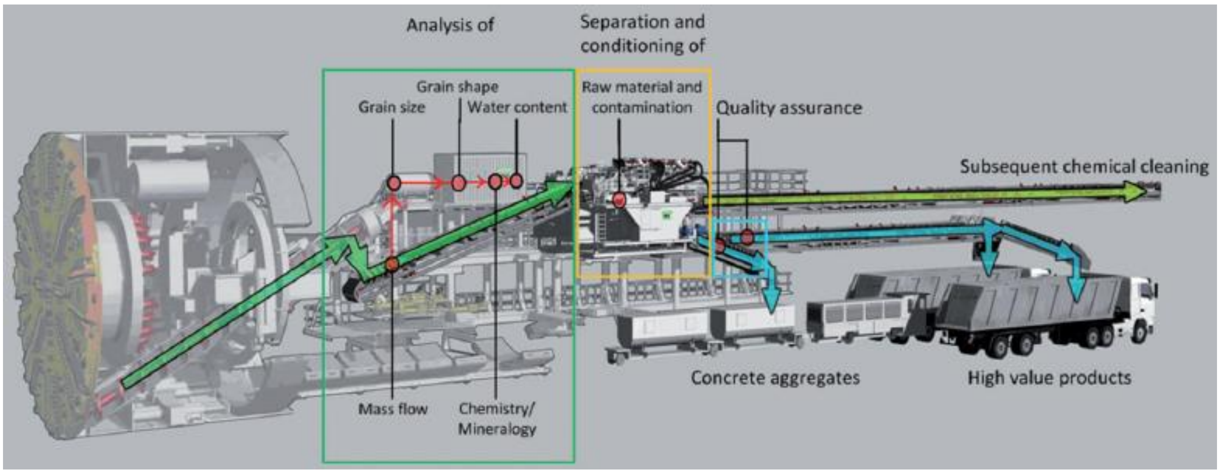


Figure 35.TBM DRAGON Project

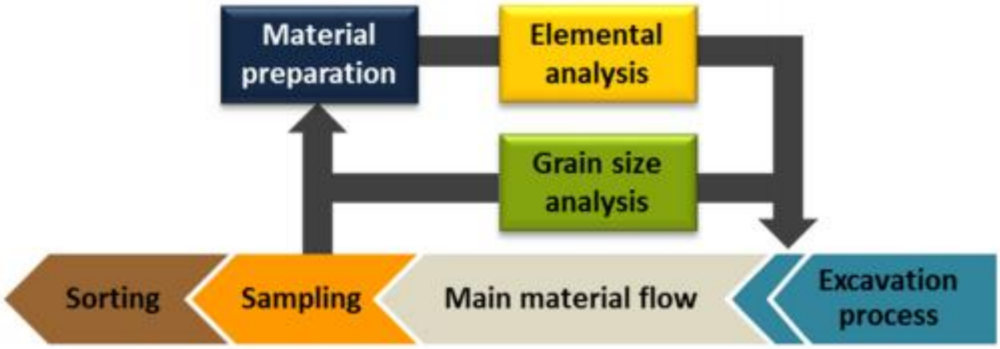


Figure 36.Process of classification of the spoil

6.4. Life Cycle Assessment (LCA)

Methods of Life Cycle Assessment (LCA) and Mass Flow Analysis will be used to compare different scenarios of use or disposal of the excavation material. It is also used to determine the potential environmental benefits of using DRAGON technology on future tunneling projects in Europe. To develop a LCA analysis it is necessary to follow a procedure, this process is shown below:

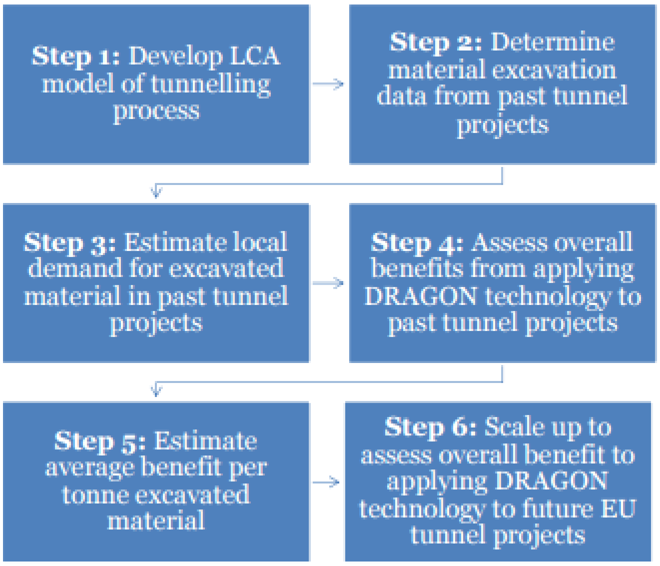


Figure 37.Process LCA analysis DRAGON

The LCA will benefit the project in different aspects:

- It will be useful to make a difference on a market where construction products will have to declare its environmental impacts;
- It will be beneficial for identifying system improvements and recognize areas of opportunity in the project;

- Product benefits can be quantified at building level being an excellent argument for the use of the product.

6.4.1. Interpretation of results

The DRAGON project will foster sustainable domestic supply of mineral resources within the EU by maximizing the re-use and recycling of excavation materials both on site and in a wide range of industrial sectors.
This approach to create valuable secondary mineral resources is estimated to generate a direct annual value of around 150 million EUR.
The key environmental benefits include a substantial reduction in environmental pollution, CO2 emissions and land use for the disposal of excavation material thus approaching the aim of achieving zero waste in underground construction.
For example:
Savings could rise up to 5 million tons of CO2-equivalent (equivalent to the annual greenhouse gas emissions of more than 460,000 European citizens).

6.5. About the company

The DRAGON research project is supported by the European Commission as part of the 7th Framework Programme. DRAGON is coordinated by a multidisciplinary network of partners was established to fulfill the objectives of the DRAGON project. It is composed by 7 partners from 5 different countries:
The Montanuniversität Leoben; the industrial partners are B+G AG – Betontechnologie und Materialbewirtschaftung, the Herren - knecht AG, Indutech Instruments GmbH, Jacques Burdin Ingenieur Conseil, PE North West Europe Limited and PORR Bau GmbH, which should guarantee the practical implementation.

Consortium

PROJECT PARTNERS	Country
Montanuniversität Leoben	AT
PORR Bau GmbH	AT
Herrenknecht AG	DE
B+G Betontechnologie + Materialbewirtschaftung AG	CH
Jacques Burdin Ingenieur Conseil	FR
PE North West Europe Limited	UK
Indutech instruments GmbH	DE

Figure 38.Partners BBT

(Galler, 2013)

7. COMPARISON OF SWIFTLY AND DRAGON

This chapter is a comparison of the SWIFTLY and DRAGON projects. Here it is appreciated the similarities and differences of the two cases of study proposed in this thesis.

7.1. Common topics

- Both are Austrian projects.
- Both use a very similar TBM for excavation material. Both TBMs are shown in the following figure:


Figure 39.TBMs BBT (left) and DRAGON (right)

- Both intend that the waste does not end in the landfill and that waste is used to create raw materials and thus reduce the cost of these.
- Both are green efficient, as they reduce CO2 and others harmful components to the atmosphere and the environment.
- *Key data SWIFTLY-BBT* *Key data DRAGON*

Excavation material	17 million m^3
Excavation methods	30% by blasting
	70% by TBM

Excavation material	800 million m^3
Excavation methods	10% by blasting
	90% by TBM

- Both aim to recycle the materials obtained and economize the use of raw materials.
- Both develop the LCA model (life cycle analysis) for tunneling projects to appreciate the progress and the impact of the project and the reduction of harmful components.
- Both manage the materials with a common process. One of the key points for the successful use and recycling of tunnel excavation material is the management of materials. This includes the following aspects:
  – Material classification,
  – Material separation,
  – Material transport,
  – Material intermediate storage,
  – Material processing,

– Material final storage.

- Both are an example to follow for futures similar projects

7.2. Differences

- SWIFTLY targets to European works whereas DRAGON aims to expand to over the world.

Figure 40.Comparison of location of the projects DRAGON and SWIFTLY

- Currently, DRAGON has a greater quantity of excavation than SWIFTLY. (DRAGON 800 million m^3, SWIFTLY 17 million m^3)
- DRAGON uses photo-optical technologies, x-ray, gamma-ray and microwave units to analyze the mass flow of material while SWIFTLY make excavation tests to analyze the ground.
- DRAGON uses the help of some partners to study the LCA but does not show the LCA detailed results through graphics as SWIFTLY does.
- SWIFTLY is more focused on reuse the material for shotcrete while DRAGON reuses for several applications in raw materials.

8. TUNNEL BORING MACHINE (TBM)

A tunnel boring machine (TBM), also called a "mole", it is a machine used for excavating tunnels with a circular section through several layers of soil and rock strata. They can also be used for micro-tunneling. They can drill through anything from hard rock to sand. Tunnel diameters range from a meter to 19.25 meters. TBMs are better to use when the tunnel's diameter is greater than 1 meter.

TBMs have the advantages of limiting the disturbance to the surrounding ground and producing a smooth tunnel wall. This reduces significantly the cost of lining the tunnel, and makes them suitable to use in railroads areas.

The major disadvantage is the upfront cost. TBMs are very expensive to construct, and they are very difficult to transport. (Wikipedia, 2017)

Figure 41.Cutting head TBM

TBMs were limited to projects that had specific soil conditions, but Tarkoy and Byram (1991) reported that, thanks to technological advances, TBMs can now be used to bore through harder and more difficult rock, and their popularity has grown. (Jae16)

8.1. History

The application of TBM is prominent in the present century:

- In 1825 the first TBM was developed to excavate the Thames Tunnel.
- In 1853 in the United States, the first boring machine to have been built was used during the construction of the Hoosac Tunnel.

- In 1863 the first TBM that tunneled a big distance was invented and in 1875 improved by British Army officer Major Frederick Edward Blackett Beaumont.

- During the late 19th and early 20th century, inventors continued to design, build, and test TBMs in response to the need for tunnels. A TBM with a bore diameter of 14.4 m was manufactured by The Robbins Company for Canada's Niagara Tunnel Project.

- In 2013 an earth pressure balance TBM known as Bertha with a bore diameter of 17.45 meters was produced by Hitachi Zosen Corporation.

- The world's largest hard rock TBM, known as Martina, (excavation diameter of 15.62 m, total length 130 m) was built by Herrenknecht AG.
  (Wikipedia, 2017)

8.2. Selection criteria and main types of TBMs.

The type of machine used depends on several factors.

- Geotechnical behavior of the ground
- Presence of ground water and pressure
- Boundary conditions of the project
- Experience of the contractor

8.2.1. Soft ground TBMs

Soft ground TBMs are shielded machines similar to Single and Double Shield TBMs.

Additionally, they have a closed excavation chamber to be able to operate under even high-pressure groundwater conditions. The soil water pressure must be compensated by a supporting medium which is essentially different between Mix shields and EPBs as explained in the following sections. This also influences the strategies of raw material extraction on soft ground TBMs.

There are two main types for **soft ground** TBM:

- TSlurry TBM

Developed and patented by NFM Technologies, it is used for tunnel-boring in highly permeable unstable terrain, or under civilian structures sensitive to ground disturbances.

When digging in highly unstable or liquid terrain, the pressure exerted by the terrain is directly governed by the depth at which digging is performed. It is therefore necessary to balance the pressure exerted by the terrain: the front shield of the Slurry TBM is filled with excavated material, with the exception of one air-filled part. The pressure within this air bubble is subject to fine control. Bentonite injection waterproofs the working face and improves its resistance.

- Slurry limitation: High content of fines < 0,06 mm requires expensive separation process

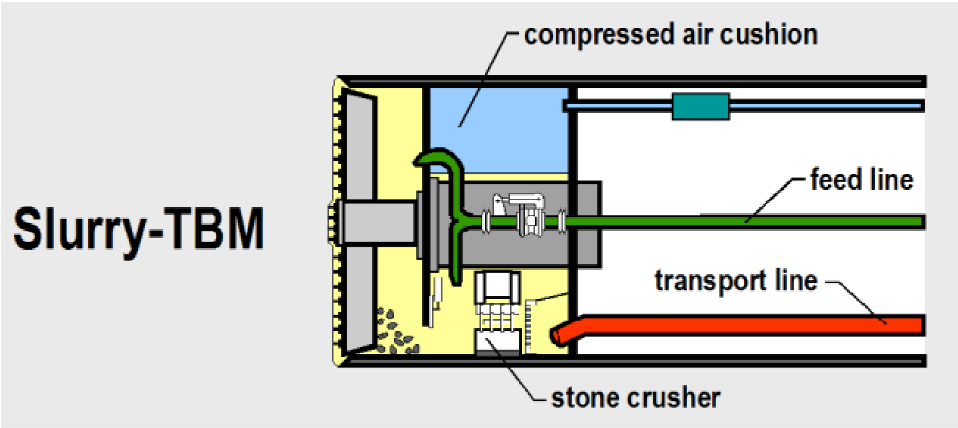


Figure 42.Slurry-TBM

- Earth pressure TBM (EPB TBM)

NFM Technologies initiated the earth pressure with additive process in Europe. The EPB technology is suited for digging tunnels in unstable ground such as clay, silt, sand or gravel.

The front shield of the EPB TBM is filled with debris extracted by means of a screw conveyor. This screw compensates the pressure difference between the working face and atmospheric pressure. Foam injection renders the material more homogeneous, thus facilitating its excavation.

- EPB limitation: High permeability k > 10^{-3} m/s requires intensive conditioning

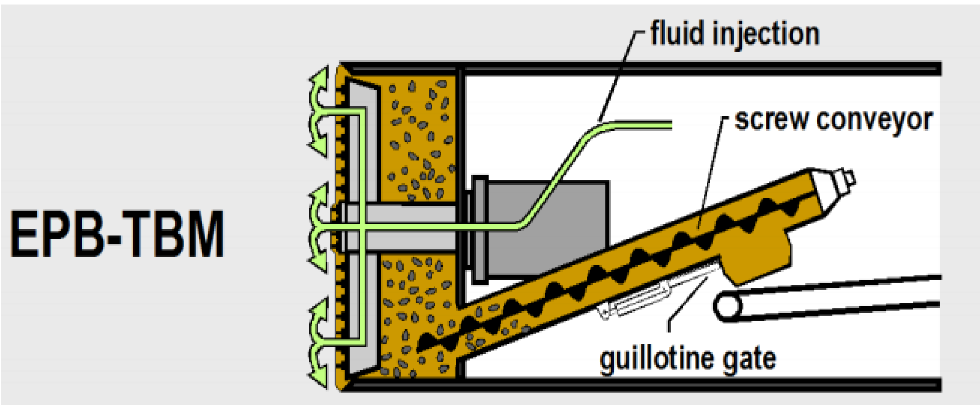


Figure 43.EPB-TBM

8.2.2. Hard ground TBMs

The modern hard rock tunneling tunnel boring machines (TBMs) compete with conventional drilling and blasting methods. In the hard rock world, the excavated face is predominantly stable, non-groundwater-bearing and with solid rock of different hardness and other properties and thus different potential for being used as raw material inside or outside the tunnel. TBMs allow for an almost continuous drilling through all kind of rocks combined with a semi-automated tunnel construction behind the machine.

Different hard rock projects need different machine types which are open (Gripper) or shielded (single or double shield) TBMs.

Here are three main types for **hard rock** TBM:

- Single shield TBM

A single shield machine uses pre-fitted segments to exert the blast force on the working face. Digging time represents approximately 80% of operating time, the remaining 20% corresponding to segment fitting.

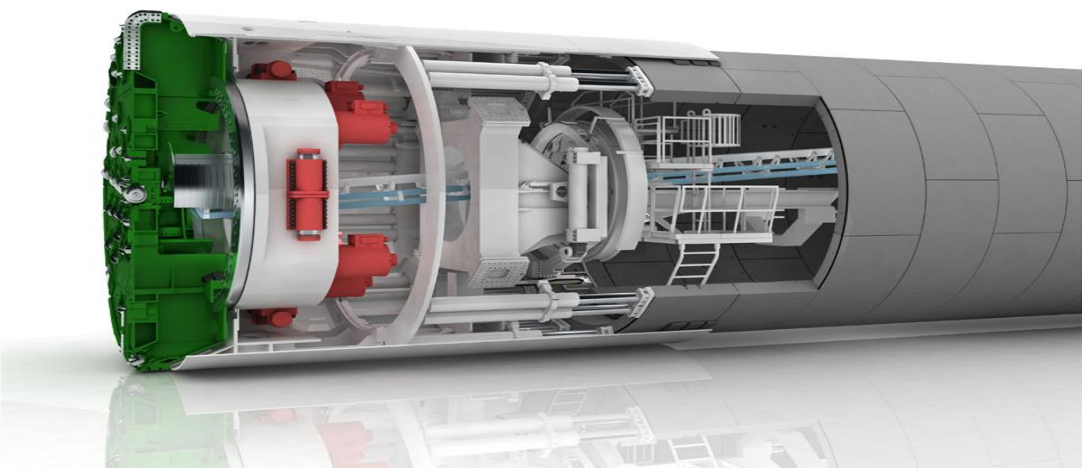


Figure 44.Single Shield TBM

- Double shield TBM

Double shield machines allow for raster tunnel excavation as the segments are fitted in concurrent operation time during blasting (digging). In this case, digging time approaches 100% of operating time. The rear shield is fitted with grippers.

Machine progress is a 3-step process:

1. Gripping of the rear shield onto the excavated surfaces,
2. Digging by the cutter head (front shield advance), and laying of the lining,
3. Rear shield advance (hence gripper advance) to the next digging position and back-up traction.

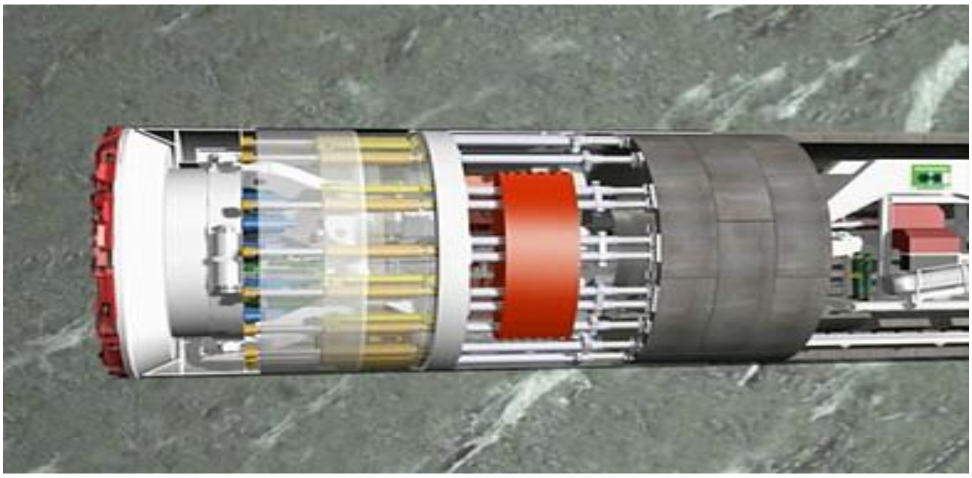


Figure 45.Double Shield TBM

- Gripper TBM

Grippers are shoes that press radially against the walls of the excavated tunnel. Contrary to shelded hard rock TBM, this tunnel-boring machine therefore does not rest against the lining. The force exerted by the grippers must be very high to prevent the thrust applied to the head from causing shield recoil. Due to the process-typical rock support method without segments, medium to high rock strengths are a requirement for high advance rates. (Babendererde, 2010)

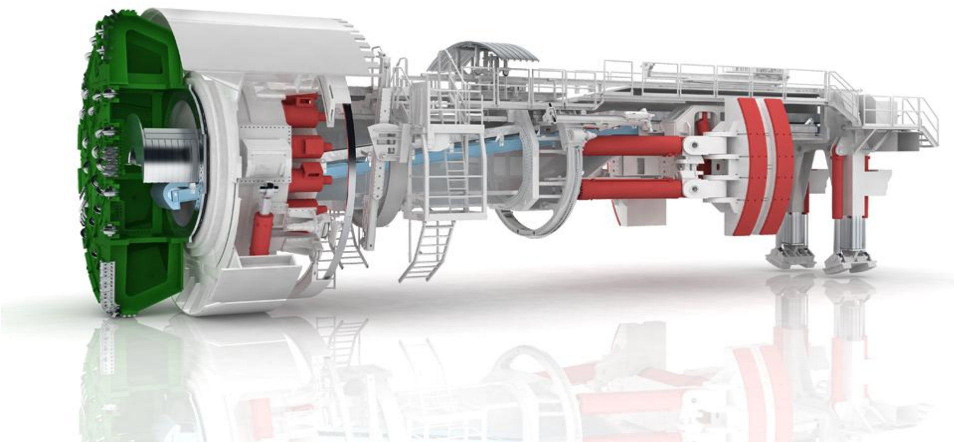


Figure 46.Gripper TBM

8.3. Selection of TBM for the BBT project

It is now possible to choose the type of TBM required for each project, taking into account the type of rock or soil it has. Coming over to the example of the project given before, BBT (Brenner Base Tunnel), it is possible to analyze the adequate TBM due to the type of rock:

Tunnel Name	Brenner Base
Country	Austria-Italy
Completion (Yr)	2026
Length (Mi)	34.0
Tunneling Method	TBM (tunnel boring machine) & CM (conventional method)
Topography	Mountain
Rock Classification	High/ medium
Ground Water	Yes
Speed (mph)	50
Configuration	Two single-track

Table 21.Characteristics of BBT project

As Brenner base tunnel has hard/medium rocks, with the criteria showed before it is selected that the best option for TBM is the Gripper TBM. (Pyeon, Trend Analysis of Long Tunnels Worldwide, 2016). As we said before Gripper TBM is adequate for high diameters and for presence of water, all the conditions we have in this project.

So it is possible to compare the TBM given in the draws of the project BBT and it shown to recognize that the classification of that TBM corresponds to a Gripper TBM:

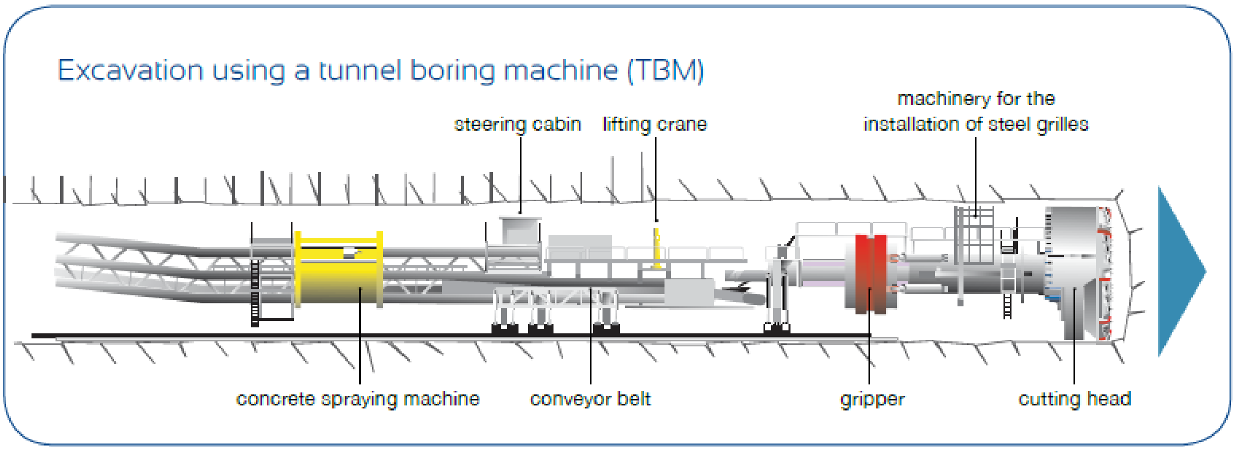


Figure 47.Gripper TBM of the project BBT

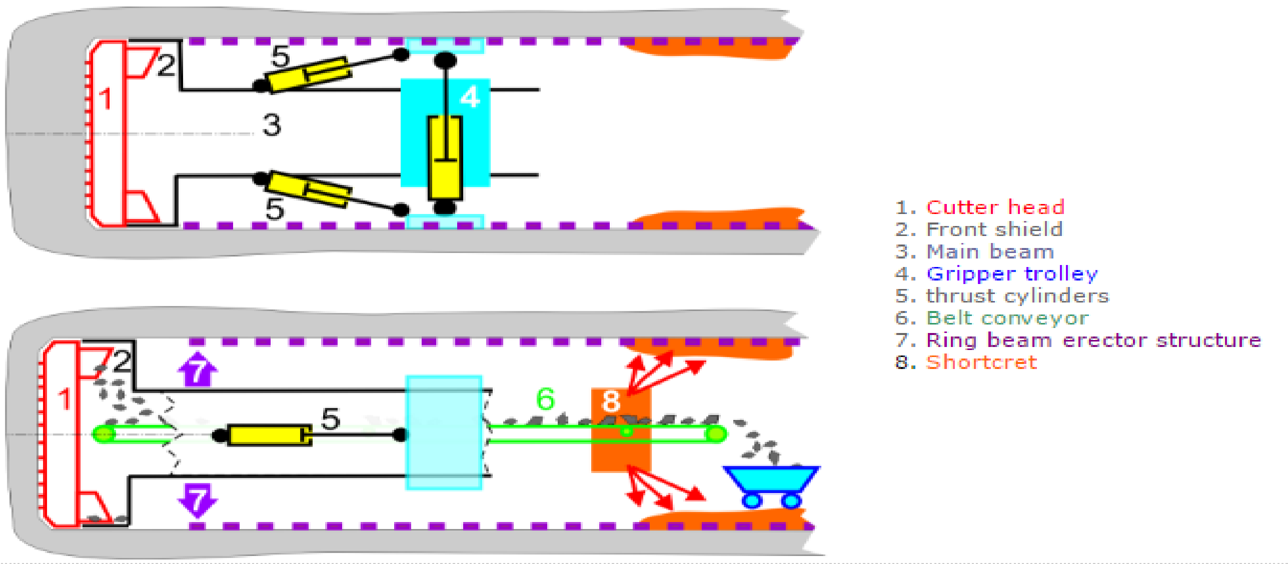


Figure 48.Gripper TBM diagram

9. CONCLUSION

This chapter embodies conclusions of two parts of the present thesis. The first one is concerned with the chapter 2 (Geomorphologic environmental impact of tunnel infrastructure). And the second offers conclusions of the principal investigation connected with the two examples of projects given in the thesis (BBT-SWIFTLY and DRAGON).

9.1. Geomorphologic environmental impact of tunnel infrastructure

In the chapter 2 I have described the main geomorphologic impact of a tunnel. However, it is hard to know this impact, it is appreciated that the excavated material is the greater issue in a project like this.

The common uses for the extracted material of the excavation of a tunnel project are described in chapter 2. Also in that chapter it is described the process of disposal of these CDWs (construction and demolition waste).

The disposal of this waste is carried out by its transport to landfills. This process is explained in this project. This option is the most harmful for the environment. So this is the last alternative for this kind of waste, the other alternatives are: being used as an immediate substitute for raw materials or as volume for fillings.

Disposal of this waste to landfills cause several impacts: lower proportion of recycled material, higher cost, reduction of raw material.

An additional part of that chapter is to calculate the cost of two examples of projects (Guadarrama Tunnel and BBT) to prove that this option of elimination of waste cause a higher cost in the project and a non-green efficiency method for the environment.

The results showed a big increment of this budget:

- Guadarrama Tunnel Final costs with trucks 13€/ton
- BBT (Brenner Base Tunnel) Final costs 14€/ton

This price also depends on the quantity of excavated material.

9.2. Cases to study SWIFTLY and DRAGON

The second conclusion explains how the BBT projects are carried out using the SWIFTLY methodology and the DRAGON project methodology. It is shown that the CDWs are recycled in a high proportion using the eco-balance methodology. It is also shown that they comply with the restriction of directive 2008/98 / EC (explained in the chapter 3) and also with the future restriction also given in this directive for the year 2020 'waste must be increased to a minimum of 70% by weight from construction and demolitions'.

The excavation of these materials is done by TBM, in particular the Gripper, for being more suitable in soils with rocks of high and medium hardness. The BBT project use TBM in a 70% of the excavated material and the DRAGON project in 90% of the excavated material, TBMs also classify materials at the same time as digging, facilitating the process of sorting and extracting material for a subsequent recycling.

Both projects are of great global importance and they can be used as an example for future projects of this type.

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