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Review

Waste or valuable resource – a critical European review on re-using and managing tunnel excavation material

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ABSTRACT

Re-use of excavated rock and soil from subsurface tunnelling has become an essential legal and technical factor in underground construction projects. European Union initiatives have caused an emergence of legal documents and technical guidelines for re-using excavated material. An improving situation towards a homogeneous European legislation is missing and site-specific re-use solutions are still favoured within the framework of national legislation. In this paper, we present a detailed review of legislation and technical concepts within the scope of re-using excavated rock and soil across Europe focusing on the Alpine countries. Austria, Switzerland and France prove to be role models in re-using excavating material whereas Italy is providing a limited amount of national solutions. Excavated rock and soil are still considered waste, which hampers legislation procedures and efficient technical re-use as a potential resource. National guidelines and recommendations bear huge potential to serve as a basis for a homogenisation of European legislation. Technical limitations imply physical and chemical characterisation of excavated rock and soil as well as their positioning in relation to inert waste thresholds, which requires a sophisticated material flow analysis. We introduce a material flow analysis concept installed on a tunnel boring machine managing on-line analyses, conditioning, separation and transport to consumers of excavated material resource-efficiently within a mutual European legal framework. A dedicated European authority is suggested to undertake responsibility for the material management and governing a technical database obliged to aim for maximum, efficient re-use and public awareness.

1. Introduction

Construction and demolition (C&D) waste makes up about one third of total waste produced in the European Union (EU) with a re-use rate of 46% on average (European Commission, 2016a; Poulikakos et al., 2017). Hence, the question of resource-efficiency in the context of re-use is quickly raised, yet vaguely answered. Excavated rock and soil originating from underground tunnelling projects make up an essential part of the total amount of C&D waste but are sparsely addressed nor described in an independent framework (Whittaker et al., 2019). It is required to highlight this sub-category of C&D waste whose expectations range at more than 700 million tonnes within the next years due to an increasing rate of projects currently under construction or at feasibility check. We discovered a distinct lack of research articles within a both legal and technical scope of re-using excavated rock and soil from subsurface construction projects treated substantively from C&D waste. Therefore, this paper aims to review and compare national and EU re-use legislation and suggests a technical re-use material flow concept on a tunnel boring machine (TBM) applied across a mutual European re-use legislation framework, focusing on the Alpine countries Austria, Switzerland, France and Italy. The on-line material flow analysis aims to evaluate potential re-usability of excavated rock and soil from subsurface tunnelling projects emphasising material management and stating technical limitations.

The paper addresses the following research questions:

- What is the current legal state-of-the-art regarding European Union, Austrian, French, Swiss and Italian legislation within the scope of re-using excavated rock and soil?
- What are the thresholds and limitations of current legal frameworks?
- How can material management and material flow analysis be improved in terms of re-using excavated rock and soil from a mutual European legal and technical point of view?

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1.1. Initial re-use of excavated rock and soil

First re-use concepts were proposed in 1953 with landfilling as the ultimate solution, which soon turned out to have a negative impact on the environment (Savage et al., 1994) ranking at the bottom of valuable re-use scenarios. Environmental pollution since the 1970's caused European countries to develop institutional and technical tools to deal with soil contamination related to landfilling, industrial or mining activities (Brombal et al., 2015). The European Commission and the European Environmental Agency (EEA) were founded and developed a European Soil Data center (ESDAC) to survey European-wide soil contaminations (Panagos et al., 2012) as most severe problems stem from contaminated construction sites (Rahimzadeh et al., 2018). First innovative re-use ideas of tunnel excavation material apart from landfill date back to the 1990's when a lack of natural aggregates occurred on top of environmental issues (Gertsch et al., 2000; Kwan and Jardine, 1999).

Starting in the 2000's, new constructions and extensions of Europe's tunnel network (TEN-T) beard potential for excavated material to be re-used in a sustainable, circular economy (European Commission, 2005) since supply of natural resources from underground constructions results in millions of cubic meters of excavated material and were considered potential resources (DRAGON, 2014). Environmental regulations as part of the environmental impact assessment, and a general shift towards a more sustainable construction industry gave increased recognition to re-use of excavated rock and soil within the past 30 years. Up to now, research studies focused rather on a comparison of environmental impacts and treatment of C&D waste as a whole than separating each type of waste individually and highlighting discussions with legal background (Ghisellini et al., 2018). Even though limiting factors such as legislation and management issues are well-known and hamper recycled products in the construction industry (Gangolells et al., 2014; Silva et al., 2016), a clear and precise review on how to describe, treat and track excavated material from a legal point of view has neither been addressed nor requested in a European framework. However, the idea of a continuous material loop thrived within a circular economy and landfill mining emerged as a useful source (Altamura, 2013; Andrews, 2015), whereas illegal landfill disposal has been present from the start (Marzouk and Azab, 2014; Pacheco-Torgal, 2020).

1.2. Recent re-use of excavated rock and soil

Input material for re-use purposes stems from C&D waste, i.e. excavated rock and soil, which experiences recycling in a vast variety across Europe (Dahlbo et al., 2015; European Commission, 2020). Today, the question why excavated material needs to be processed originates from two reasons: a) due to legal regulations, which force the removal of waste status, and b) due to a proper preparation (pre-processing) of resources further used as e.g. concrete additives. Several European construction sites have successfully re-used excavated material in various scenarios, while concrete and geopolymer applications rank amongst the most applicable and recent re-use solutions (Blengini and Garbarino, 2010). Their examples imply projects requiring non-sophisticated pre-processing since raw excavated material already comprises good re-use quality (Galler and Voit, 2014; Resch et al., 2009). However, more sophisticated yet site-specific re-use solutions due to complex geology led to several technical approaches for classification.

Ritter et al. (2013) derived a computer-based tool named Decision Aids for Tunnelling (DAT) enabling uncertainty calculations for excavation material handling (Ritter et al., 2013). On top of that, valuable re-use of excavated rock and soil depicts efficient ways of resource exploitation with advanced GIS applications, concrete aggregate production, construction of road sections, handling of contaminated soil, sensor-based sorting, aerobic landfilling and a general improvement of environmental performance (Cabello Eras et al., 2013; Lafebre et al., 1998; Read et al., 2001; Robben and Wotruba, 2019; Robinson and Kapo, 2004; Rodríguez et al., 2007). Moreno and García-Álvarez (2018) developed a Resource-Efficiency Capacity Index based on 29 indicators in the *Roadmap to a Resource Efficient Europe* document, which results in Austria being amongst the top performers (Moreno and García-Álvarez, 2018).

With more than 700 million tons of C&D waste produced each year in the EU (Iacoboaea et al., 2019) and predictions of more than 800 million tonnes of excavated rock and soil within the next years (DRAGON, 2014), European initiatives drew the construction sector's attention continuously to fostering resource efficiency as the guiding principle for EU policies. The Alpine countries Austria, Switzerland, France and Italy make up a big part of the proposed excavated material due to their tunnel infrastructure applied in a vast variety of complex tunnelling conditions. These conditions have justified a general trend towards site-specific re-use scenarios (Ghisellini et al., 2018), which is still the current case. For each construction site, material is analysed and specifically prepared for processing in factories on-site or at dedicated sites in the near vicinity aiming for minor environmental impacts.

On one hand, several researchers revealed environmental advantages when re-using excavated rock and soil on-site (Cabello Eras et al., 2013; Chittoori et al., 2012; Lafebre et al., 1998). The reduction of transport ways, the diminution of pollutants as well as the recycling of the excavation material bear large environmental protection potential. On the other hand, the presence of polluted material plays a major factor during excavation, which impacts landfill prices depending on regulatory national thresholds and integration of risk in the mechanism for adjusting execution time. Polluted material always involves purification and pre-processing. Research has shown that economic benefits result in costs tending to be lower than investing in new material or disposing excavated material (Ritter et al., 2013) leading to a reduction of material management costs by up to 85% (Chittoori et al., 2012). Depending on the geological composition of the material, it is possible to re-use up to 100% of excavated material. In fact, re-use of excavated material was set to a certain percentage level across Europe (Vieira and Pereira, 2015), whereas limited data is available for re-using merely excavated rock and soil in the EU (Magnusson et al., 2015).

Table 1
Europe's approach to resource-efficiency within the scope of EU initiatives and directives encouraging re-use of excavated rock and soil in Europe. EU member states are obliged to transpose EU law in national law.

Name of document	Date of publication	Legal entity
EU construction and demolition waste wanagement protocol	18.09.2018	European Commission
A Stronger European Industry for Growth and Economic Recovery	10.10.2012	European Commission
Roadmap to a Resource Efficient Europe	20.09.2011	European Commission
A European strategy for smart, sustainable and inclusive growth	03.03.2010	European Commission
Directive 2008/98/EC on waste (Waste Framework Directive)	19.11.2008	European Commission
The Raw Materials Initiative - Meeting our Critical Needs for Growth and Jobs in Europe	04.11.2008	European Commission
Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan	16.07.2008	European Commission

1.3. Europe's initiatives impacting re-use of excavated rock and soil

Between 2000 and 2010 European initiatives as indicated in Table 1 proposed a clear direction to efficient re-use of resources causing increased commencements of national legislation and guidelines. Legal considerations were thriving, however, its resulting heterogeneity and bad communication of future legislation are still one of today's key issues (Mittal and Sangwan, 2014).

The definition of C&D waste, respectively excavated rock and soil (Blengini and Garbarino, 2010; Coronado et al., 2011; Hiete et al., 2011; Simion et al., 2013) is not treated homogeneously from a legal perspective, even though all countries favour a transformation of waste into a resource. European initiatives culminated in different researchers' opinions stating that e.g. full implementation of European waste legislation will increase micro-pollutant recycling (Knapp et al., 2017; Lee et al., 2014). These results conclude that regulations are required to guarantee adequate quality control measures, whereas Arm et al., 2017 state that European Directives are very sensitive to legal definitions interpreted amongst the member states. The EU waste framework directive does not distinguish between various recovery processes and refers to a weight-based approach, which favours large and heavy waste streams (Arm et al., 2017). Gálvez-Martos et al. (2018) criticise the use of weight percentages in several law texts as it results in a focus on dense mineral fractions rather than on fractions with higher potential environmental impact (Gálvez-Martos et al., 2018). All authors indicate the argument of separation of type of fraction in the directive, substantiated by our research. While national and European legislations have increased since the year 1990 (Fischer and Werge, 2009) and achieved reasonable results in comparison with e.g. China (Brombal et al., 2015), it appears that the current legal framework is not sufficient and an urge for mutual technical guidelines.

Mutuality and homogenisation come with several limitations and issues. The responsibility of monitoring and enforcing re-use is scattered across many authorities at national, regional and provincial or cantonal levels across Europe. Landfill is still commonly chosen for re-using excavated rock and soil, which requires a transparent legislation for landfill mining. Quality and quantity of deposited resources transformed into marketable recyclables are partially addressed including how environmental legislation and subsidies apply to landfill mining (Krook et al., 2011). The EU deals with an increasing shortage of land, hence landfill reduction is preferential (Magnusson et al., 2015).

European strategies include the reduction and closure of landfills for excavated rock and soil to foster on-site re-use, as this was the case for total C&D waste in 2009 (European Environment Agency, 2009).

The EU's ten-year strategy invested great efforts in smart, sustainable and inclusive growth (European Commission, 2010) for a transition towards a resource-efficient, low-carbon economy to achieve sustainable growth by 2020 (European Commission, 2012). It is mentioned that treatment and excavation of natural resources should be in accordance with a protecting environment and circular economy. The *Roadmap to a Resource-efficient Europe* visualises that *"…by 2050 the EU's economy has grown in a way that respects resource constraints and planetary boundaries, thus contributing to global economic transformation"* (European Commission, 2011). It connects resource policies to initiatives such as the *Raw Materials Initiative* and suggests to provide excavated material as raw material input for construction (European Commission, 2008a). The EU *Thematic Strategy on the Sustainable Use of Natural Resources* outlined decoupling resource usage and economic growth (European Commission, 2016b). In the *Sustainable Consumption and Production and Sustainable Industrial Policy* the European Commission aimed to give further impetus to resource-efficiency and eco-innovative production processes, to reduce dependency on raw materials and to encourage optimal, high-quality re-use (European Commission, 2008b; Velis and Brunner, 2013). The European goal has been set to recycle at least 70% of excavated material, whereas an actual 50% missed the target already for 2019 (European Commission, 2018a). France has implemented this plan into national legislation and constituted that 70% of excavated rock and soil material must be re-used per region (République Française, 2015).

Within the next years, global population will grow to estimated 9 billion whereas 3 billion people are expected to reach the middle class having a huge impact on the demand of resources and space (Rios, 2018). Resource potential is proposedly lying in current and future subsurface projects. Within the scope of the *Trans-European Transport Network (TEN-T) Initiative* considerable input material is available for re-use within the upcoming years (European Commission, 2018b, 2005). However, these numbers underline the urgency of first, a legal homogenisation for excavated rock and soil across Europe and second, a review of potential technical re-use concepts to stem increasing excavation volumes (Brombal et al., 2015). There are plenty of resources available from the construction sector, whereas key issue will be how to re-use them in the most efficient way in both legal and technical terms (Allwood et al., 2011; Pacheco-Torgal and Labrincha, 2013).

2. Re-use legislation for excavated rock and soil across Europe

The European Union waste concept is defined in the Waste Framework Directive 2008 and sets out measures to protect the environment by reducing the overall European impacts on resources (European Commission, 2008c). Excavated rock and soil are part of the waste regime and thus under the validity of the Waste Management Act. The objective definition of waste is not fulfilled for tunnel excavation material recycled on construction sites according to EU directives. To re-use excavation material from tunnelling construction sites, it is necessary to reach the end of waste status. Waste can be recycled if the same requirements as for primary raw material is fulfilled. The fact that most excavated material is not available in a form for instant re-use and that possibilities for recycling must be carefully measured, satisfies the objective's definition of waste. Legal waste terminology is regulated by federal governments and EU directives that must be transposed into national law of each member state. A comprehensive list of legislation, guidelines and recommendations for Austria, Switzerland, France and Italy within the scope of re-using excavated rock and soil from subsurface tunnelling sites is summarised in Table 2.

In Austria all 9 counties are obliged to follow national laws and regional guidelines are not common. The Federal Act on Sustainable Waste Management (AWG) contains the definition of waste, its life-cycle, methodological order of avoidance and elimination as well as rights and obligations of the waste owner, transport regulations, cross-border transport and limit thresholds for each waste category (Bundesministerium Landwirtschaft Regionen und Tourismus, 2002). The Federal Waste Management Plan is published every six years and initiates objectives of the AWG 2002 (Bundesministerium Klimaschutz Umwelt Energie Mobilität Innovation und Technologie, 2017). The recycling building materials regulation (Bundesministers für Land- und Forstwirtschaft Umwelt und Wasserwirtschaft, 2015) standardises requirements and unifies designations and technical assessments of recycled construction material. The Austrian trend of recognizing material flow analyses to increase re-use has been introduced by many researchers at an early stage (e.g. Allesch and Brunner, 2017) making Austria a European role model in re-using excavated rock and soil.

France is structured in a decentralised hierarchy and distributes legal power in descending order from national legal entity in Paris (*l'ètat*) to its 13 *régions* and 101 *départements, pays* and *communes*. French waste law is in accordance with EU law and Article L541–1–1 of the French Environment Code, which has partly incorporated EU directives (République Française, 2003).

Switzerland is subdivided into 26 cantons, which have autonomous legal power for re-use legislation. This implies that each canton can derive their own cantonal recommendations and guidelines. The re-use case must be credible and detailed in a specific document to meet the requirements of Federal Ordinance on Waste Limitation and

Table 2
Chronological overview for re-use legislation of excavated rock and soil material from underground tunnelling constructions across Europe.

Country	Original name of legislation*	Date of commencement	Date of latest version	Authority or publisher
Austria	Recycling-Baustoffverordnung	29.06.2015	27.10.2016	Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft
	Deponieverordnung	30.01.2008	27.10.2016	Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft
	Abfallverzeichnisverordnung	23.12.2003	23.12.2008	Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft
	Abfallwirtschaftsgesetz	16.07.2002	25.05.2020	Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft
	Bundes-Abfallwirtschaftsplan	1992	2018**	Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie
	Altlastensanierungsgesetz	07.06.1989	29.10.2019	Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft
	ÖBV-Richtlinie zur Verwendung von Tunnelausbruchmaterial	–	01.10.2015	Österreichische Bautechnik Vereinigung
Switzerland	Verordnung über die Vermeidung und Entsorgung von Abfällen	01.01.2016	01.04.2020	Bundesamt für Umwelt
	Verordnung des UVEK über Listen zum Verkehr mit Abfällen	01.01.2006	01.01.2018	Bundesamt für Umwelt
	Verordnung über den Verkehr mit Abfällen	01.01.2006	01.01.2020	Bundesamt für Umwelt
canton Geneva	Loi sur la gestion des déchets	05.08.1999	21.03.2015	Le Conseil d'état de la République et canton de Genève
canton Geneva	Règlement d'application de la loi sur la gestion des déchets	05.08.1999	12.09.2018	Le Conseil d'état de la République et canton de Genève
	Basler Übereinkommen über die Kontrolle der grenzüberschreitenden Verbringung gefährlicher Abfälle und ihrer Entsorgung	05.05.1992	06.05.2020	Several contracting parties
	Verordnung über den Verkehr mit Sonderabfällen	07.10.1983	12.07.2005	Bundesamt für Umwelt
	Bundesgesetz über den Umweltschutz	07.10.1983	01.03.2020	Bundesversammlung der Schweizerischen Eidgenossenschaft
	Verordnung über die Sanierung von belasteten Standorten	01.10.1998	01.05.2017	Bundesamt für Umwelt
	Grenzüberschreitender Verkehr mit Abfällen (gilt für das Fürstentum Liechtenstein und die Schweiz)	–	05.05.2020	Bundesamt für Umwelt
	Messmethoden im Abfall- und Altlastenbereich	–	08.12.2017	Bundesamt für Umwelt
canton Geneva	Déchets - Diagnostic de Pollution - Gestion des Terrains Pollués	–	01.11.2017	République et Canton de Genéve & service de géologie, sols et déchets
canton Geneva	Plan de gestion des déchets de chantier	–	01.09.2017	République et Canton de Genéve & service de géologie, sols et déchets
	Baustellen-Entsorgungskonzept	–	01.07.2017	Swiss cantons, Bundesamt für Umwelt, ARV-Verband, VBSA-Verband
	Grenzüberschreitender Verkehr mit Abfällen	–	05.05.2017	Bundesamt für Umwelt
	Klassierung von abgetragenem Ober- und Unterboden	–	01.04.2017	Bundesamt für Umwelt
canton Geneva	Guide pour la réutilisation des matériaux d'excavation non pollués, 1ère édition	–	01.04.2016	République et Canton de Genéve & Service de géologie, sols et déchets
	Bewirtschaftung und Wiederverwertung von Ausbruchmaterial (Gestion et valorisation des matériaux d'excavation)	–	2016	Fachgruppe für Untertagbau
	Herleitung von Konzentrationswerten und Feststoff-Grenzwerten	–	29.01.2014	Bundesamt für Umwelt
	Richtlinie für die Verwertung mineralischer Bauabfälle	–	25.05.2010	Bundesamt für Umwelt
	Abfall- und Materialbewirtschaftung bei UVP-pflichtigen und nicht UVP-pflichtigen Projekten	–	20.11.2006	Bundesamt für Umwelt
	Richtlinie für die Verwertung, Behandlung und Ablagerung von Aushub-, Abraum- und Ausbruchmaterial: Aushubrichtlinie	–	01.06.1999	Bundesamt für Umwelt
France	La loi du transition énergétique	17.08.2015	27.12.2019	La République Française
	La loi NOTRe et la nouvelle organisation territoriale	07.08.2015	16.11.2018	La République Française
	Code de commerce	2007 (1807)	07.11.2018	La République Française
	Code de l'environnement	28.02.2002	15.05.2020	La République Française
	Recommendations of AFTES (GT35RIA2): Management and use of excavated materials	–	2019	Association Française des Tunnels Et De L'Espace Souterrain
	Guide méthodologique de comblement de cavités à l'aide de matériaux alternatifs	–	12.2016	Bureau de recherches géologiques et minières
	Natural Geological Materials Excavated during Underground Works	–	2016	Le Centre D'Etudes des Tunnels

(*continued on next page*)

Table 2 (*continued*)

Country	Original name of legislation*	Date of commencement	Date of latest version	Authority or publisher
Italy	Misure urgenti per l'apertura dei cantieri, la realizzazione delle opere pubbliche, la digitalizzazione del Paese, la semplificazione burocratica, l'emergenza del dissesto idrogeologico e per la ripresa delle attivita' produttive	13.09.2014	11.11.2014	Repubblica Italiana
	Misure per la crescita economica	21.06.2013	–	Repubblica Italiana
	Regolamento recante la disciplina dell'utilizzazione delle terre e rocce da scavo	12.04.2006	21.09.2012	Repubblica Italiana
	Norme in materia ambientale	06.04.2006	14.04.2006	Repubblica Italiana
	Criteri di ammissibilita' dei rifiuti in discarica	03.08.2005	–	Repubblica Italiana
	Norme affinché gli uffici pubblici e le società a prevalente capitale pubblico coprano il fabbisogno annuale di manufatti e beni con una quota di prodotti ottenuti da materiale riciclato nella misura non inferiore al 30% del fabbisogno medesimo	08.03.2003	05.08.2003	Repubblica Italiana
	Regolamento recante norme concernenti le modalita' di prestazione della garanzia finanziaria per il trasporto transfrontaliero di rifiuti	10.11.1998	–	Repubblica Italiana

No date of commencement implies concepts, recommendations or guidelines. Swiss legislation is available in French, German, Italian and English language.

* Official languages of each country have been chosen for labelling legislation.

** Austrian waste plan revised each six years at random dates.

Elimination. Agricultural re-use may not be legally eligible except under certain conditions if evidence for benefits can be clearly demonstrated.

The Italian Republic consists of 20 regions divided into autonomous provinces regulated in the Third Book of the Italian Civil Code (Costituzione della Repubblica, 1942). The definition of waste is specified in the Italian law in Article 183 of *decreto legislativo nr. 152/2006* (*norme in materia di ambiente (Codice ambiente)* (Repubblica Italiana, 2006a). It serves as the main document of C&D waste regulations, including excavated rock and soil and sets the rules for regional plans for waste management and addresses responsibility to regions for waste management planning, whereas provinces are responsible for controlling waste management activities.

2.1. Heterogeneity and limitations of European national and trans-national re-use legislation

Re-use potential is strongly associated to waste status. National governments focus on regulations dealing with the definition of waste but use different approaches for its removal. In Austria, excavated rock and soil recycled in plants is sorted by different quality classes for unrestricted usability, restricted usability and limited usability. Based on chemical and mineralogical investigations, a substance must be addressable to waste according to the Waste Catalogue Ordinance (Bundesministerium Landwirtschaft Regionen und Tourismus, 2008a). Production of recycled material is eligible based on chemical composition and associated threshold values stated in the Landfill Ordinance (Bundesministerium Landwirtschaft Regionen und Tourismus, 2008b). The Landfill Ordinance provides procedures to prevent negative effects of waste landfill on the environment and human health. The Austrian Contaminated Site Remediation Act passes laws on how to secure and remediate contaminated sites (Bundesministerium Landwirtschaft Regionen und Tourismus, 1989). According to Austrian law, contaminated sites are old deposits or abandoned sites containing a significant risk to human health or the environment. Old deposits contain waste owned by authorised or unauthorised persons, whereas old sites host plants in which environmentally hazardous substances are treated. Unless an ordinance pursuant to the European Waste Framework Directive on Waste provides otherwise, existing substances are treated as waste until they or the substances derived from them are used directly as substitutes for raw materials or for products manufactured from primary raw materials. This results in the end of the waste status when recovery processes are completed.

In France, a similar situation applies for dangerous waste containing toxic or dangerous elements that represent risks for human health or the environment. Waste is classified as hazardous if it contains pollutants specified in Article R541–8 of the Environment Code, whereas non-hazardous waste is defined by excluding hazardous waste. These pollutants include polychlorinated biphenyls, polycyclic aromatic hydrocarbons, lead or asbestos and are specified in most national texts. Disposal is divided into three disposal classes based on pollutant thresholds including classes for inert, non-polluted waste (ISDI), non-dangerous and non-inert waste (ISDNDNI) and dangerous waste (ISDD). Ultimate waste is considered for no further re-use or recovery under current technical and economic conditions by extraction or reduction of its pollutants according to Article L541–2–1 of the Environment Code (République Française, 2003). Producers or holders of waste may dispose waste in predefined waste storage facilities. This is similar to Austrian or Swiss disposal classes based on grade of pollution of excavated material, which is re-used if similar contaminated thresholds are not exceeded (Swiss Confederation, 2016). According to the Federal Act on the Protection of the Environment, the obligation for remediation resides with the cantons, whereas costs are borne by the polluter (Swiss Confederation, 1983). If the polluter cannot be identified, the costs are allocated by the responsible communities.

Despite similar disposal classes compared amongst France, Austria

and Switzerland, French legislation distinguishes between *re-use* and *valorisation*. D*échets* (waste) aims for *valorisation* or *élimination*, while *matériaux*, i.e. excavated rock and soil material, refer to re-use as a secondary raw material. Hence, valorisation should be used only when implying a preceding waste status. In fact, the status *matériaux* is assigned to any kind of material on-site. A French project owner is entitled to re-use the excavated material as part of the construction, for a construction site being part of the same operation or applying no re-use. This is in compliance with many French guidelines, too and is similar to Swiss project owners who must provide the quality and the quantity of the forecasted waste and disposal chain. In case waste exceeds a quantity of 200 m^3 likely to contain hazardous polluting elements, tracking and evidence of waste elimination must be provided before the end of construction phase in France, Austria as well as in Switzerland. From a legal point of view, excavated rock and soil on French territory is not considered waste if the project owner re-uses the material on-site. This also includes spatially distributed locations contractually bounded to the same project owner. Thus, the material loses its waste status when temporarily stored on the construction site. For on-site re-use, the *préfet* issues authorization to the project owner filing an *installation classée pour la protection de l'environnement (ICPE)*. For treatment on a dedicated site, a third party may perform processing (grinding, crushing, sorting) on behalf of the project owner. After processing, the project owner retrieves the treated material and discard is excluded. In case of no re-use, the material is assigned with waste status and the *"…project owner remains responsible for these materials until their disposal or final recovery unless the materials come out of an ICPE classified facility or an IOTA classified facility in the conditions laid down by the end of waste order"* according to Article L.541–2 and L.541–4.3 of the Environmental Code (République Française, 2003). It is upon the French project owner's initiative in the context of an inert waste storage facility to verify the facility by the *service de la prévention des risques et des nuisances* (*DRIEE*) and the associated acceptance procedures will have to be recorded by the *préfet* in an additional decree. It must be disposed in a landfill site in accordance with Decision 2003/33/EC of 19 December 2002. Landfilling cavities (excluding active quarries) as ISDI former quarries that have received discharge under the mining code or that have been the subject of a report on the end of work are not subject to ICPE regulations. It is then possible to store waste under the status of a development subject to meeting the conditions of the following section or ISDI. This is unexceptionally applied in France. The ISDI regulations apply, except in the case of storage in underground caverns and water caverns. Storage in natural or artificial underground cavities or below the water table are excluded by Article 3 and 4 of the Decree (République Française, 2003). In case of damage caused by improper use of waste for recovery, the developer is responsible according to Article 1242 of the French Civil Code (République Française, 2016), which is also in accordance with Austrian and Swiss law. The use of excavated material for rehabilitation of quarries is considered as recovery when the operations carried out are consistent with the operation of the quarry or during its rehabilitation, also considering future use of the construction site.

In comparison to EU member states, Swiss legal hierarchy differs in terms of federal and cantonal empowering legislation. Each canton is eligible to pass own guidelines or recommendations published by cantonal authorities. Switzerland offers a suitable framework for the implementation of disposal facilities including legislation, regulatory guidance and a dedicated selection process defined in e.g. the Sectoral Plan Geological Repositories (Zuidema, 2015). Basic definitions of waste types include excavated rock and soil, its avoidance, mixture with other waste, legal obligation to recycle waste and re-use excavated material on-site or in various disposal classes as mentioned in the Ordinance on the Avoidance and the Disposal of Waste (Swiss Confederation, 2016). The Swiss *Convention de Bâle sur le contrôle des mouvements transfrontières de déchets dangereux et de leur élimination* (Swiss Confederation, 1989) (not available in English; commonly translated as *Basel Convention*) is exceptional among the Alpine countries and describes control of transborder waste transport and its associated elimination as well as the definition of waste acceptance from other countries whereas only non-polluted material is valid for export. According to the Basel Convention, exported material must be re-used and cannot be disposed in dumps, except when special exemption is granted by the Federal Environmental Office. Trans-national projects require a dedicated exportation and notification procedure including tracking and in case the excavated material remains in Switzerland, Federal Ordinance on Waste Limitation and Elimination applies. Further detailed explanations on international waste transfer are available in the document Transboundary Movements of Waste, Communication from the Federal Environmental Office and on the website of the confederation. The *Ordonnance sur les mouvements de déchets, OLED* (Swiss Confederation, 2005) (not available in English) assures that waste is treated on proper, non-environmental protected sites, regulates national and trans-national waste transport and gives definitions of transborder waste and demands waste reporting obligation. The threshold values therein allow for a material classification into polluted and non-polluted categories similar to Austria and France including requirements of a tracking system and regulatory thresholds for e.g. heavy metals such as lead, nickel, chrome or copper, aliphatic and aromatic hydrocarbons or polychlorinated biphenyl concentrations. Swiss responsibility of excavated material is attributed to the project owner, unless otherwise indicated in construction contracts. The issue of land ownership is handled in Switzerland in the sense that *"…the ownership of land extends upwards and downwards to the airspace and the ground, insofar as there is an interest in the exercise of the ownership."* (Swiss Confederation, 1907). Since 2019, Swiss law enables the re-use of polluted material on-site. This avoids transportation, carbon dioxide emissions and noise. Depending on the destination, material exceeding the thresholds depicted as non-polluted material can still be classified as such. The Swiss canton Geneva serves as a good example of recommended guidelines being incorporated into cantonal legislation. Following a convention between the Swiss Confederation and the canton Geneva on the delegation of execution tasks, the Swiss competent authority for the exportation of non-polluted excavated material coming from construction sites of canton Geneva is entitled by the *service de géologie, sols et déchets, GESDEC* (Swiss Confederation, 1999, 1998). This constitutes that construction site A and construction site B cannot collect their waste in a single transport. The guideline for recycling, treatment and disposal of excavated, overburdened and waste material regulates quality requirements and restrictions for excavated rock and soil to be re-used in Switzerland (Bundesamt für Umwelt, 1999).

In Switzerland, the project owner is responsible for disposal. This provision creates homogeneity so that disposal planning and execution responsibilities are attached to the client like in Austria and France. A quarry authorization is granted for the exploitation of a given material. The re-use of excavated material for rehabilitation of quarries is considered as recovery when the operations are consistent with the operation of the quarry or during its rehabilitation.

In contrast to Austria, France and Switzerland, Italy does not provide pollution threshold values. They are set by the authorities on specific cases, e.g. the Lyon-Turino project. Italian waste laws and directives are mainly adopted from EU legislation (Directive 2008/98/EC) and were implemented by the *decreto nr. 205/2010* amending Part IV of the *decreto legislativo nr. 152/06*. Article 184-ter describes technical criteria to end waste status as well as material flow and priority modes of procedure for implementing regulations. Within the past years, legislation for excavated rock and soil has evolved steadily resulting in the *decreto ministeriale nr. 161* of 10 August in 2012 and Article 41 of the *BIS DL 69/2013* (Repubblica Italiana, 2013, 2012). The former regulates the re-use of excavated material (*regolamento materiali da scavo, piani di utilizzo*). Article 41 c. 2 and Article 41-bis c.1e5 of the *decreto legislativo 69/2013 convertito* L. *98/2013* set the rules for the

piani di utilizzo, a re-use plan for excavated rock and soil. The *decreto ministeriale nr. 203 del 8/5/2003* sets a quota of 30% for recycled material and products in public procurement including construction material (Repubblica Italiana, 2003a). Article 185 of *decreto legislativo nr. 152/2006* excludes uncontaminated soil and other naturally occurring material from the definition of waste during construction activities. The material must be used in its natural state on-site (Repubblica Italiana, 2006a, 2006b), whereas strategies are set rather at regional and provincial levels (Repubblica Italiana, 2006b). Article 34 of the *decreto legislativo 12–9–2014 nr. 133* from 13 September 2014 allow the re-use in-situ of excavated material (Repubblica Italiana, 2014). The *decreto ministeriale 5/2/98* deals with dangerous and non-dangerous waste and contains criteria for construction waste considered as a secondary raw material (*materie prime secondarie*). The Italian Institute for the Protection of the Environment (ISPRA) is entitled to record regional and provincial data related to C&D waste, whereas no specific data is available for excavated rock and soil. In Italy soil is not implemented in C&D waste statistics (DELOITTE, 2015) even though definition of waste corresponds to EU legislation and waste management plans.

An explicit lack of landfilling policies results in Italy's target to flexibly control landfilling by a specific tax. Landfilling is allowed for inert waste at specific sites without prior characterization according to Article 2 of *decreto ministeriale 13 marzo 2003* (Repubblica Italiana, 2003b). Waste may be temporarily stored for one year before disposal and three years before recovery. Exceptions are made for natural background contamination or the provincial government can approve exceptions in individual cases. If the polluter cannot be identified, or if the damage is the responsibility of the general public, the remediation costs are paid by the general public. Backfilling is a recovery option, which is suitable for waste used for reclamation in excavated areas or for landscaping and where waste replaces non-waste material. For transborder shipments of waste, EC Regulation 1013/2006 and the *decreto ministeriale* of 3 September 1998 *nr. 370* apply (Repubblica Italiana, 1998).

Italy's approach to inherit EU legislation is a step in the right direction for a future homogenisation but still lacks sophisticated development compared to Austria, France or Switzerland. It is worth mentioning that specific uses for excavated material are mentioned for which the by-product regulation is applicable: excavated material that originates from a production process but is not directly aim of production processes is considered a by-product, unless it is used as a substitute for raw materials or landfilling. Like in the Austrian Minerals Plan, European Commission proposes a platform for member states to exchange best practices in the area of land use planning. This should be emphasised by all member states and unified.

Both Switzerland and Austria constitute pioneering examples on how to deal with re-use of excavated material in both legal and technical matters. Responsibility for disposal is held by the project owner and cantonal and federal guidelines have been developed to characterise and valorise excavated rock and soil. This provision further creates uniformity for disposal planning, contamination thresholds and responsibilities attached to the client that are similar amongst Austria, France and Switzerland.

2.2. Requirements and limitations for a mutual European re-use legislation

Removing waste status makes it imperative to treat excavated rock and soil. Legislation plays a decisive role in the excavation of underground material and should be considered a helpful trend-setter rather than an enforced obligation. Site-specific negotiations years before actual start of construction are based on technical and legal questions from a client's and contractor's perspective and result in time-consuming and extensive procedures. The current heterogeneric approach is not in compliance with increasing re-use efficiency. The goal of a mutual European legal framework includes overcoming cultural, technical and legal discrepancies as well as economic interests of industrial companies. Once a homogeneous EU legislation is derived, Europe can serve as role model in world-wide re-use economy of excavated rock and soil as it is already shown be some Alpine countries. Extension of such a mutual legislation to the whole world might be feasible whereas national power and different governmental structures might be limiting factors. A first approach to a mutual legislation requires one single authority that deals with the re-use of excavated rock and soil across Europe instead of expelling site-specific re-use scenarios to each national government that further complies with EU legislation. This would also force construction companies to quantify excavated material and increase available statistical data of excavated rock and soil.

To avoid landfilling a standardised framework that forces evaluation of economic, environmental as well as technical performance should be incorporated into formal legislation leading to prohibition of illegal disposal. Austria, France and Switzerland developed guidelines on how to analyse and re-use excavated rock and soil during underground works emphasising avoidance of illegal disposal. A summary of these documents would bear potential as a mutual legal basis for Europe. These recommendations comprise similar scenarios for the management of excavated material from a project owner's perspective, indicate main uses, consider transport routes for excavated material or evaluate influence of the type of excavation method on final re-use via descriptions and analyses of physical and chemical properties. Such guidelines are published by associated authorities or industrial companies such as the *Österreichische Bautechnik Vereinigung, ÖBV* in Austria, (Österreichische Bautechnik Vereinigung, 2015), the *Française des Tunnels Et De L'Espace Souterrain, AFTES* (Association Française des Tunnels Et De L'Espace Souterrain, 2019), the *Guide* méthodologique de comblement de cavités à l'aide de matériaux alternatifs published by the *Bureau de recherches géologiques et minières, BRGM* (Bureau de recherches géologiques et minières, 2016) and *Le Centre D'Etudes des Tunnels, CETU* (Le Centre D'Etudes des Tunnels, 2016) in France as well as the *service de géologie, sols et déchets, GESDEC* (République et Canton de Genève, 2016) for the canton Geneva and the *Sectoral Plan Geological Repositories* (Zuidema, 2015) in Switzerland. The mutual legislation should facilitate construction companies to receive organisational resources and avoid inconsistencies in governmental management, which have been a key factor in restricting a common European legislation underlined by several researchers (Korhonen et al., 2018; Mangla et al., 2017; Ritzén and Sandström, 2017).

In current legislation, polluted and non-polluted excavated material takes on the status of waste. Chemical thresholds for contamination exist but strongly vary in each country. This is treated differently in the mining industry. Opinions of mining companies being more efficient and higher in quality compared to tunnel construction sites do no longer hold its ground as research has shown that for each ton of mined material more than 85% became waste, whereas this number increases to 99% for some materials (Pacheco-Torgal and Jalali, 2011). It does not make sense to give tunnel excavation material the status of waste since incorporated blasting substances such as nitrites and nitrates are similar for mining activities. Consequently, it must be favoured to combine re-use legislation and mining law. Since geological resources are detached from political borders, types of excavation, e.g. tunnel boring machine versus mining activities and the framed legal empowering system, mining and tunnel excavation limitations need to be overcome to guarantee a resource-efficient and sustainable re-use on a mutual scale. This incorporates reconsidering material flow analyses and material management concepts.

A future goal must be the establishment of close relationships with representatives of national environmental authorities, standardisation bodies and governmental organizations forming working groups to homogenise European re-use. Approaches could be applied to the whole world if guideline and recommendation documents would be adapted

from Alpine countries once enough data was available to prove its efficiency. Excavated material being less feasible for high-quality applications might be used for landscaping on-site instead of landfilling. The intention of re-use should not be competition to local raw materials companies but to make the material available at reasonable prices to save raw material deposits and increase environmental benefits. Excavation close to consumers is essential as it reduces transport costs, fossil fuel consumption and strengthens regional industries. It requires visionary thinking making these re-used resources available on a regional and global scale, demanding also advanced technical concepts.

3. Material flow concept in mechanized tunnelling in a mutual legal re-use framework

Re-use applicability depends on geotechnical, petrophysical, mineralogical and geochemical properties of excavated rock and soil, and its underlying material management boundary conditions as indicated in Fig. 1.

Excavated material has a strategic impact on sustainable management of limited mineral resources, higher resource-efficiency and a sustainable environment. A material flow analysis concept with expected masses of excavated material should be prepared during feasibility phase of any underground project. Within the scope of an underground project, the constructor measures data of the subsurface via geophysical and/or geotechnical tests during site investigations and actual construction. Drilling samples or geophysical loggings should be analysed to obtain essential information regarding complex geological situation incorporated before construction. Based on the resulting geological profile, volume and properties of the future excavated material can be estimated in advance and fine-tuned as construction progresses. The concept is based on an on-line database derived by continuous analyses on a conveyer belt attached to a TBM as indicated in Fig. 2, and considers an environmental and sustainable storage of oversupply in excavated material to cover future demands and the usage of less quality material. Transport routes, material specific processing, intermediate storage and landfilling should be taken into consideration in terms of CO_2 emission but are neglectable for on-line analyses. The material management concept is a basis to prepare delivery contracts with potential industrial consumers.

The proposed on-line database contains a matrix with integrated specific requirement lists for relevant and possible re-use parameters at local and global level linked to economic and environmental transport routes. Processing of raw material could distinguish between hard, soft and mixed rock as well as different mineral phases and would combine its transport to eligible industrial consumers. The individual re-use scenarios could be derived from a requirement matrix like a risk mitigation matrix. Using the database, the constructor can thus immediately determine the re-use potential of the subsurface. Technical data would be continuously updated and linked to mutual legal contamination thresholds or trans-national transport legislation registered in the database. Intermediate purchasers and material processing companies were eligible to access the database and specifically store their demands and requirements such as material properties, time of demand, volume or maximum transport distances. Excavated material would be classified by real-time comparison with the required specifications in the on-line database as seen in Fig. 3 and framed by one European authority described in the previous section. It could be argued that legislation drives the requirements of technical concepts, whereas it must be considered that natural resources need to be pre-processed for construction material anyway. Economic re-use benefits would result from earnings by selling certain material quality and from savings, first from the substitution of purchased aggregates for the internal needs of the site with the excavated material and second, through reduced landfill costs.

Technical re-use concepts have become a mandatory part of environmental impact assessment procedures to receive construction approval.

Thus, sorting excavated material is possible before start of construction and during site investigations. In case properties of excavated material do not comply with quality requirements or industrial standards for application on-site, the material should be used for embankments (landfilling). However, this should be overcome by iterating the processes in the red dashed square in Fig. 3. On-line analyses ease the process of waste avoidance due to characterising the material on a conveyer belt without touching the surface leading to avoidance of waste status and tracking material flows. This would also give improved statistical insights into rare and critical metals (Ayres and Talens Peiró, 2013) also linking it to construction information models (BIM) and mining. A dedicated European authority should be responsible for the material management, which emphasises the development of a material management concept and governs the legal and technical database to publish reports on resource status similar to Austrian reports such as

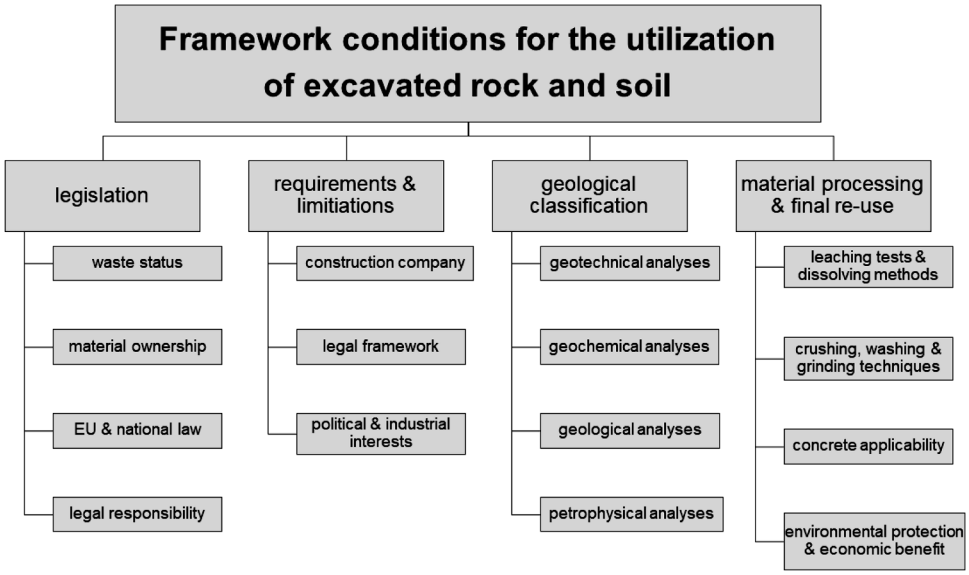

Fig. 1. *Re*-use organigram for excavated rock and soil specifying geology, processing techniques and laws. Mutual legislation must be the framing element for engineering re-use purposes.

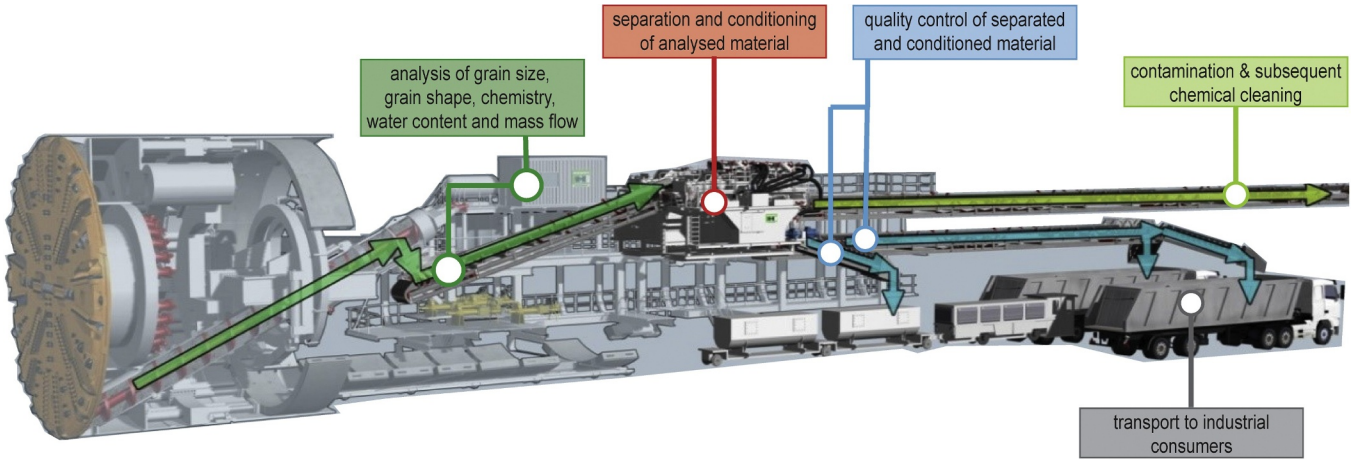

Fig. 2. Schematic on-line analysis of excavated rock and soil material shown on a tunnel boring machine (TBM) for mechanical excavation.

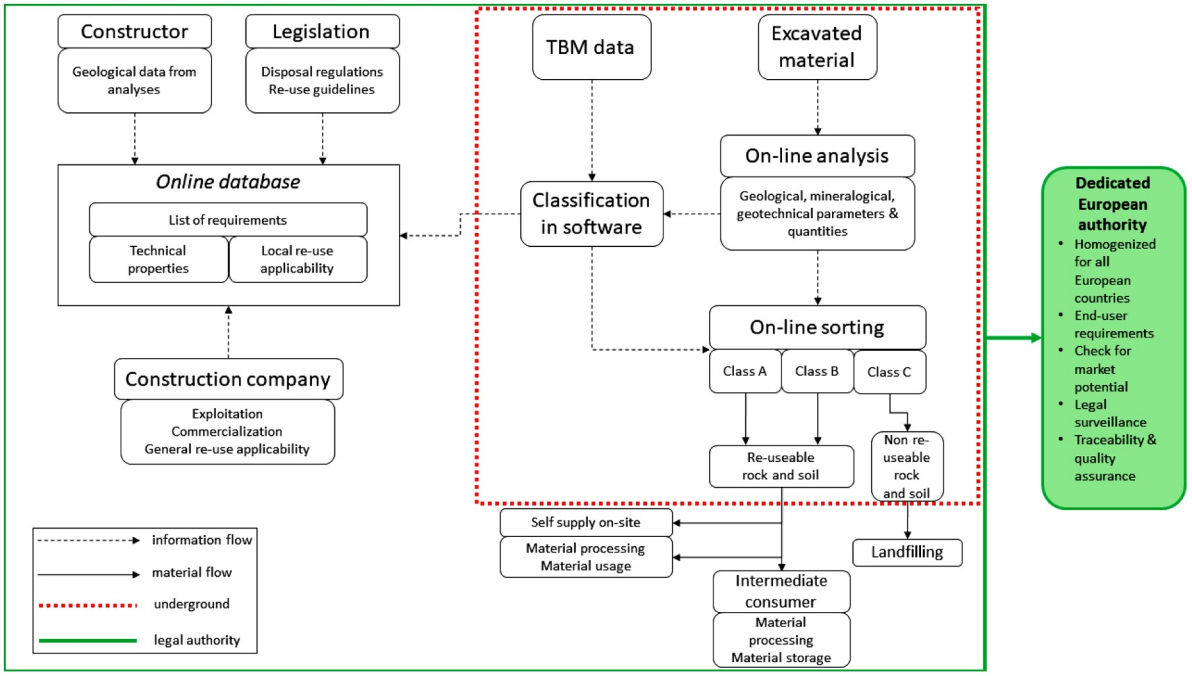

Fig. 3. Conceptual management and caption of re-use potential for excavated rock and soil framed by a legal European authority (green line). The red square indicates tasks to be conducted on-site, respectively underground.

Kritische Rohstoffe für die Hochtechnologieanwendung in Österreich (Luidold, 2013). Industries must be incorporated by the European re-use authority and support classification models including geotechnical, petrophysical, geological, mineralogical and geochemical parameters in their laws. The new authority should be responsible for the material usage and waste management emphasising the development of a material flow analysis and operating the technical database. Excavated material from subsurface construction sites would increasingly conquer European land masses. It should be the goal to maximise valorisation for final products to avoid landfilling. Re-use goals set to 90% or beyond should be outlined as a European standard and are likely achievable within a mutual legal and technical framework. The new and innovative technologies should be used for an on-line analysis of excavated material on tunnel boring machines. Such a concept has not been suggested before and bears potential for resource-efficient and sophisticated re-use collected in a single process. The concept of on-line analyses on the TBM, respectively conveyer belt additionally saves time by avoiding sending samples to laboratories.

4. Conclusions

In this paper, we elaborated a review of European Union and Alpine country legislation for the re-use of excavated rock and soil, which gained significance due to an increasing demand for subsurface tunnelling projects. An improving situation towards a homogeneous European legislation is present yet site-specific re-use solutions are still favoured within the framework of national legislation. However, EU initiatives have caused an emergence of re-using excavated material across Europe. Austria, Switzerland and France prove to be role models in re-using excavating material substantiated by solid legislation and national guidelines. Italy is lacking dedicated national solutions. Legislation for environmental protection such as landfill is completely absent. Alpine countries and the EU still consider excavated rock and soil as waste. This is a limiting factor and hampers legislation procedures and efficient technical re-use as a potential resource. Comparison and incorporation of mining laws might seem useful in a mutual legal context. Existing Austrian, Swiss and French laws and guidelines could

serve as a first European legal template published by a single authority with legal power. Especially national guidelines and recommendations bear huge potential to serve as a basis for homogenisation. Further limitations for the definition of relevant consumers contain the geophysical, mineralogical and geochemical characterisation of excavated rock and soil as well as their positioning in relation to inert waste thresholds as defined amongst different national legislations. An adaption and homogenisation of these thresholds is highly recommended amongst Alpine countries and could lead to a mutual European legislation by standardising technical measurements and legal approaches.

An advanced material flow analysis concept should be installed on a tunnel boring machine efficiently managing on-line analyses, conditioning, separation and transport to consumers of excavated material within a mutual European legal framework. A dedicated European authority is suggested to be responsible for the material management and a legal and technical database obliged to publish reports and data on resource status. The main goal must range at 90% re-use or beyond subsequent to aiming at avoidance of landfilling. These targets should be outlined in a mutual European standard document.

From a legal point of view, the focus within the next decade should be put on a strict convergence of national laws to one strong European legislation published by a single European authority in legal charge. Technical future work should be spent on finding analyses easily and efficiently applied on a tunnel boring machine. Furthermore, a comparison of on-line and laboratory results in terms of accuracy and type of excavation method, respectively mechanized versus conventional tunnelling is suggested as well as detailed analyses of contaminated excavation material originating from subsurface tunnelling and mining sites.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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