Renewable energy retrofitting of existing tunnels for climate change mitigation (Tun.Re.Fit.)

ScuDo — Scuola di Dottorato – Doctoral School — WHAT YOU ARE, TAKES YOU FAR

Ph.D. candidate	Doctoral program in	Doctoral cycle	Supervisors	Ph.D. Day
Simone De Feudis	Civil and Environmental Engineering	XXXVII cycle	Prof. Marco Barla Dr. Alessandra Insana	Oct. 18th 2023

Context, motivations and objectives

Over the last decades, global warming has become one of the major issues to cope with: as it stands, human activities are responsible for a global surface temperature increase of approximately 1.1°C since the pre-industrial age. Climate change is directly linked to the level of global warming, thus leading to observed changes in weather extremes and irreversible losses in several ecosystems. In this view, energy geostructures have emerged as systems that can contribute to the production of clean, renewable thermal energy.

In partnership with Autostrade per l'Italia, the Ph.D. research is aimed at the:

- assessment of the suitability of instrumenting existing tunnels for geothermal energy exploitation, taking advantage of existing refurbishment techniques,
- construction of a real-scale experimental site to prove the feasibility of such thermal retrofitting and to test it on-site,
- assessment of the possibility of serialization of the novel thermal retrofitting approach for existing tunnels.

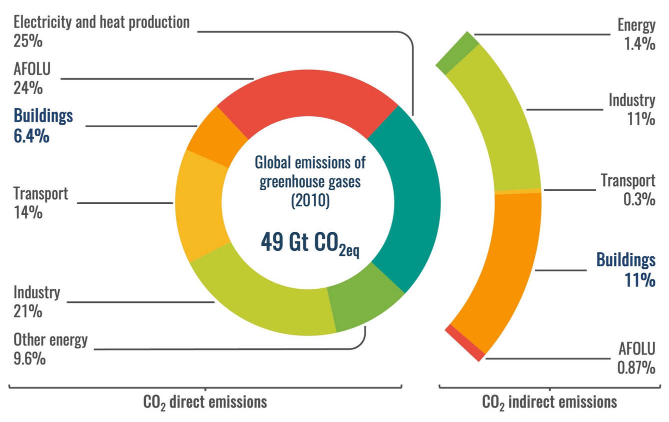

Fig. 1 – GHG emissions for different production sectors.

Thermal activation of geotechnical structures

Energy geostructures are ground-contact structures engineered to accomplish the twofold aim of structural support and heat exchange. The thermal activation of such structures is achieved by embedding heat exchanger pipes inside them. The circulation of a heat carrier fluid within these pipes, usually water or water-glycol mixtures, allows the extraction or the injection of heat from or into the surrounding ground.

Among them, energy tunnels have raised increasing interest in the past years. Indeed, these reap the benefits of:

- a larger surface lying in contact with the ground,
- the tunnel intrados interacting with the underground environment.

The latter, acting as a heat source or a heat sink, commonly positively affects the thermal efficiency of the energy tunnels.

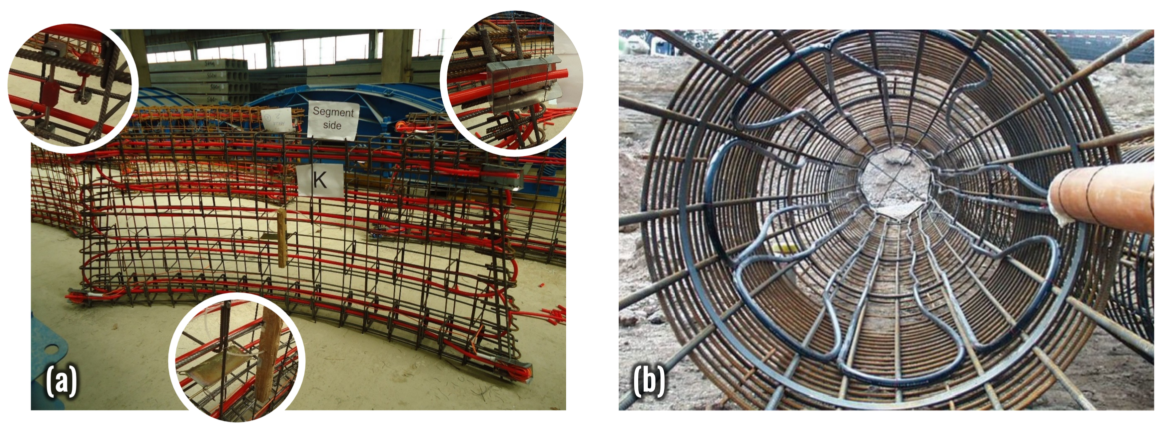
Fig. 2 – Heat exchanger pipes tied to steel cages of (a) an energy tunnel and (b) an energy pile.

To instrument tunnel linings for geothermal exploitation, two techniques are available depending on the tunnelling method:

- conventional tunnelling → heat exchanger pipes are generally fastened on fixing rails or attached to non-woven geosynthetics and then placed between the preliminary and the final linings,
- mechanised tunnelling → lining segments are instrumented and optimised for heat exchange since the prefabrication, with special moulds to allow the realisation of grooves at the ends of the segments for neighbouring pipe connections.

The full-scale implementations realised so far dealt only with new tunnelling projects. The sole exception is represented by the Seocheon tunnel testbed in South Korea. However, this was aimed at testing the thermal efficiency of energy textile modules, without proposing any approach for systematic solutions to instrument existing tunnels for geothermal energy exploitation.


Fig. 3 – Instrumentation of (a) conventional and (b) mechanised tunnels of heat exchange.

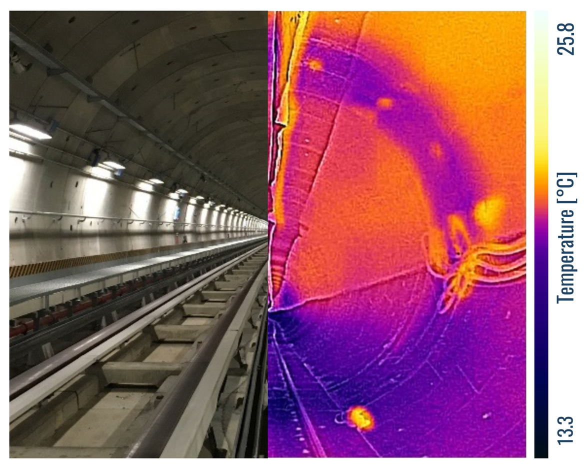

Fig. 4 – Thermal image of the ENERTUN prototype.

Existing tunnel refurbishment

Tunnels are resilient infrastructures whose actual service life is generally much longer than the nominal. However, their increasing ageing and decay require refurbishment to guarantee service continuation in safe conditions. To this end, four different strategies are generally considered:

- maintenance → involves minor repair works aimed at guaranteeing the nominal tunnel service life or slightly increasing it, awaiting major repair works to be designed and realised. E.g., protection for local block detachment,
- rehabilitation → involves major repair works aimed at extending the nominal tunnel service life. E.g., tunnel vault and/or invert integral/partial replacement,
- upgrading → involves major repair and construction works aimed not only at extending the nominal tunnel service life but also at changing its intended use. E.g., existing tunnel enlargement to host more motorway lines or railway tracks,
- disposal → involves repurposing operating or disused tunnels. E.g., hosting art exhibitions, bicycleways, etc.

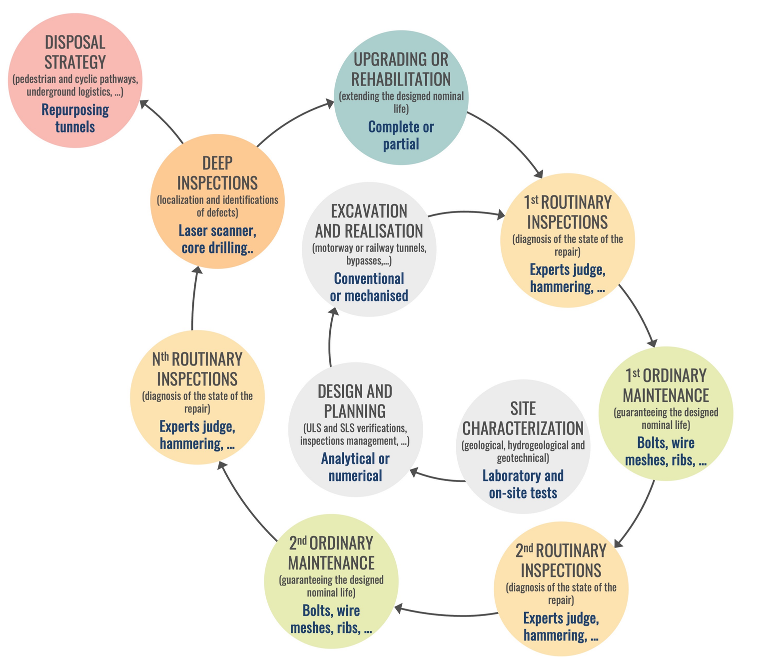

Fig. 5 – Schematisation of a tunnel life cycle.

When facing severe ageing conditions, cost-benefit analyses, as well as technical considerations, frequently demonstrate that rehabilitating existing tunnels represents the optimal solution compared to numerous local interventions of a limited lifespan. On the other hand, repurposing abandoned tunnels could enliven infrastructures which fell into disuse.

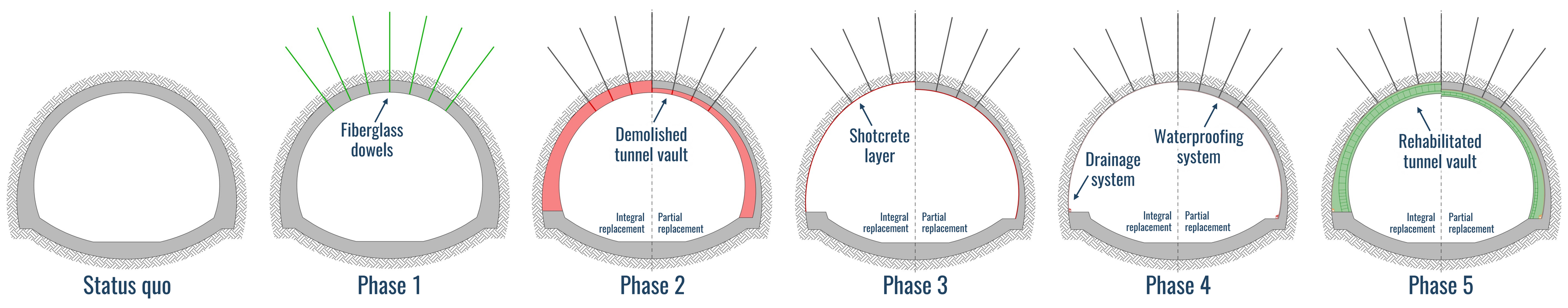

Fig. 6 – Tunnel rehabilitation procedure consisting of integral/partial demolishing and replacement of the vault.

Thermal retrofitting of existing tunnels

The Ph.D. research is aimed at fulfilling the research gap about a systematic approach to the instrumentation of existing tunnels for geothermal energy exploitation, taking advantage of different refurbishment strategies to be applied.

Thermal retrofitting of existing tunnels during rehabilitation

The thermal retrofitting would allow their thermal activation during interventions involving the partial or integral demolition and subsequent reconstruction of the tunnel vault. For this purpose, precast tunnel segments or arched precast predalles can be envisaged. The latter can function as disposable shuttering for casting in place the concrete lining. Alternatively, with the provision of selecting traditional moulds, lattice structures are previously arranged and fixed to the tunnel wall to work as steel reinforcement.

The former cases envisage heat exchanger pipes tied to the steel cages of the structural elements (just like ENERTUN segments), thus not increasing the workforce's burden during the rehabilitation.

The latter case envisages geothermal pipes clamped to the existing tunnel wall and then embedded in the regularisation shotcrete layer during the realisation of the rehabilitation works.

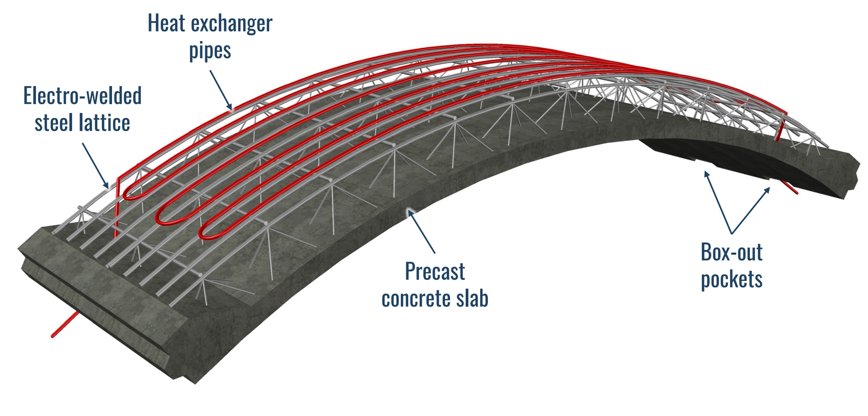

Fig. 7 – 3D view of an energy predalle in a likely ground configuration.

Thermal retrofitting of existing tunnels during disposal

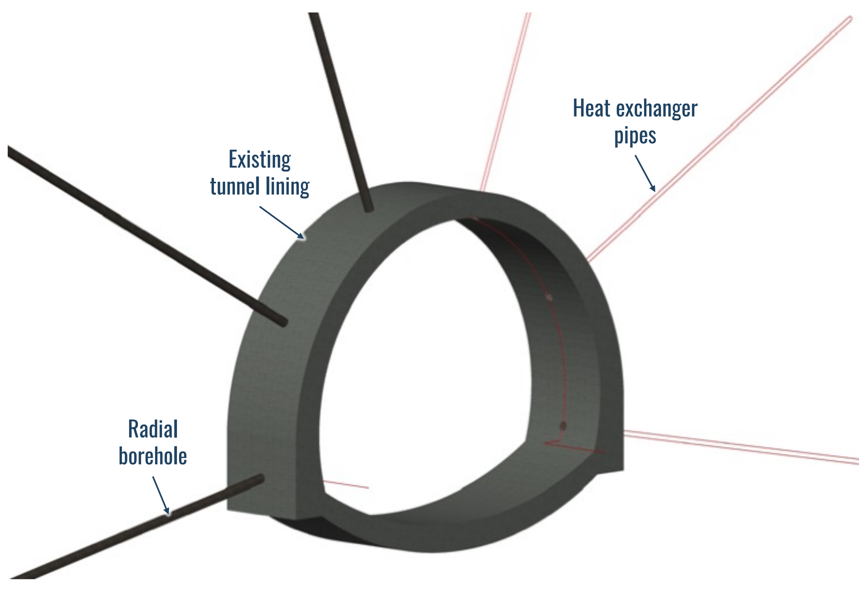

Fig. 8 – 3D view of radial borehole heat exchangers (rBHEs).

The thermal retrofitting would allow their thermal activation during tunnel repurposing. In addition to designating them for different purposes with respect to the original, abandoned or disused tunnels could be also used for geothermal exploitation. To this aim, two different solutions were conceived:

- drilling radial borehole heat exchangers → this would allow to take advantage of the existing tunnel overburden to reduce drilling costs. Thus, heat from the inner portions of geothermal reservoirs could be exploited, too,
- fixing heat exchanger pipes to the tunnel wall → similarly to the Seocheon testbed, this solution would allow mainly the exploitation of the heat from the underground environment and waste heat.

Preliminary numerical analyses to assess thermal efficiency

To assess the thermal efficiency of the proposed thermal retrofitting solutions, a numerical model was built using FEFLOW finite element code. To the aim of providing heat extraction and injection performance depending mainly on the solutions themselves, the positive influence of the groundwater flow was neglected and different aerothermal conditions of the underground environment were investigated.

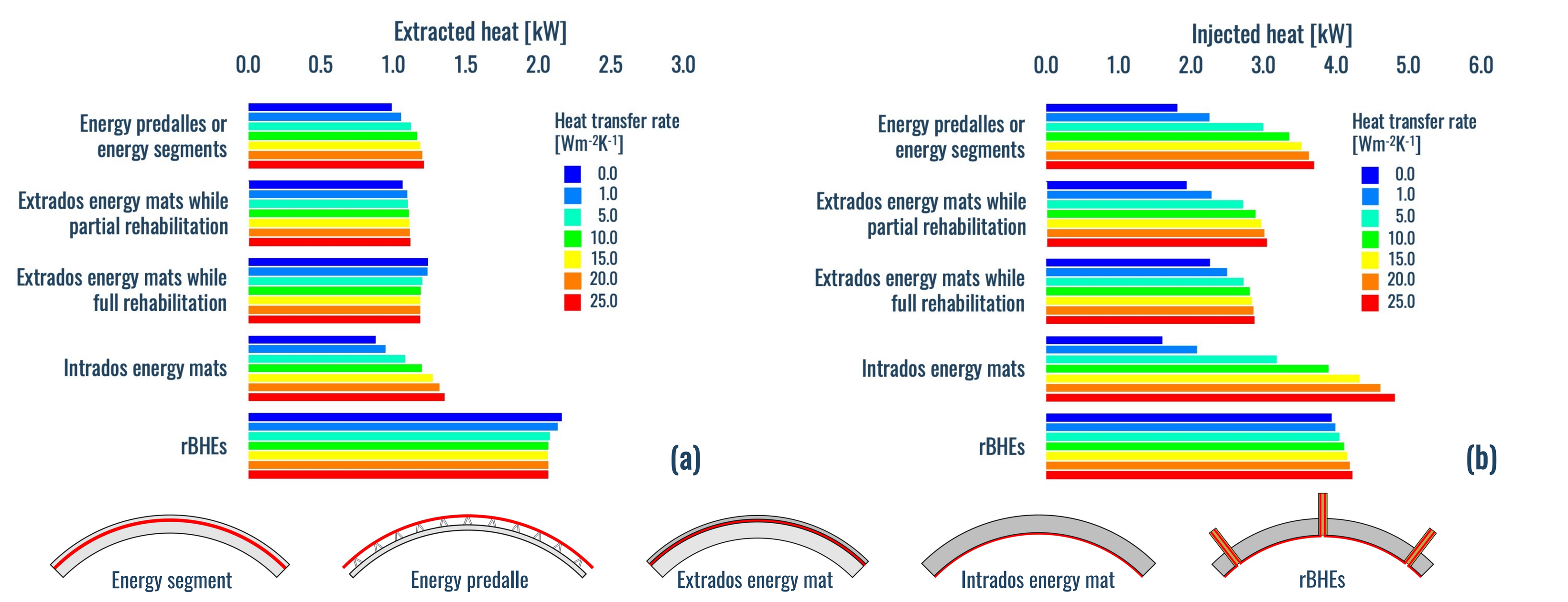

Fig. 9 – Exploitable geothermal power by the thermal retrofitting solutions during a) winter heat extraction and b) summer heat injection for a 3.6 m long activated tunnel portion.

The Lagoscuro tunnel thermal retrofitting

The very next step of the Ph.D. research will consist of the full-scale implementation of one of the proposed thermal retrofitting solutions.

During the realisation of its rehabilitation works, the Lagoscuro tunnel will be instrumented for geothermal exploitation clamping heat exchanger pipes between the aged and the rehabilitated tunnel lining portions, after hydro-demolition operations.

A monitoring plan to investigate the thermal performance of the prototype, as well as the structural implications, was drawn up. The heat extracted or injected from or into the innermost section of the tunnel will be used for heating up or cooling down the temperature of the motorway pavement at the tunnel entrance.

The results of the experimental campaign will be paramount in calibrating a new numerical model aimed at assessing the performance of the prototype for different weather conditions.

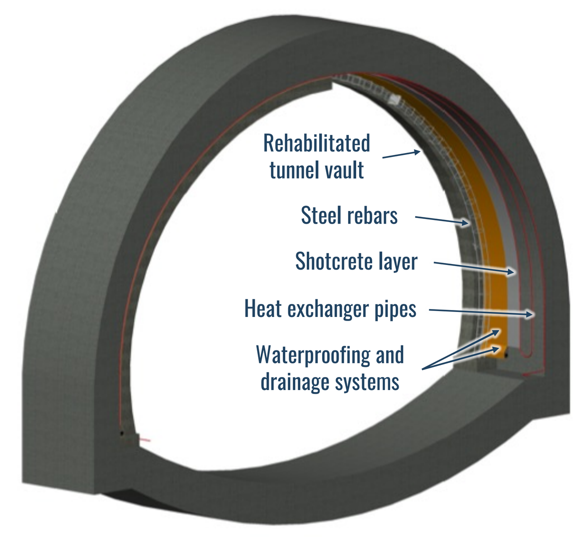

Fig. 10 – Thermal retrofitting solution for Lagoscuro tunnel.

Scientific publications

De Feudis, S., Insana, A., Barla, M. (2023). **A Simple Parametric Numerical Model to Assist the Design of Repair Works and Maintenance of Tunnels.** In: Ferrari, A., Rosone, M., Ziccarelli, M., Gottardi, G. (eds) Geotechnical Engineering in the Digital and Technological Innovation Era. CNRIG 2023. Springer Series in Geomechanics and Geoengineering. Springer, Cham. https://doi.org/10.1007/978-3-031-34761-0_79

De Feudis, S., Insana, A., & Barla, M. (2023). **An example of thermal retrofitting for the Piedicastello tunnel.** Symposium on Energy Geotechnics 2023, 1–2. https://doi.org/10.59490/seg.2023.533.

De Feudis, S., Insana, A., Barla, M. (2024). **Seizing the opportunity of thermal retrofitting of existing tunnels.** To be submitted soon for the special issue "Emerging technologies for a sustainable underground space: accelerating the energy transition and adaptation to climate change" of the journal "Tunnelling and Underground Space Technology".

De Feudis, S., Insana, A., Barla, M, Baccolini, L., Zilli, L., Mazzola, M. (2024). **Anti/de-icing using the heat recovered in the Lagoscuro tunnel.** To be submitted soon for "II Convegno FABRE".

Politecnico di Torino 1859

simone.defeudis@polito.it
www.rockmech.polito.it
linkedin.com/in/simonedefeudis/
simonedefeudis97
facebook.com/enertun/
Rockmech PoliTO