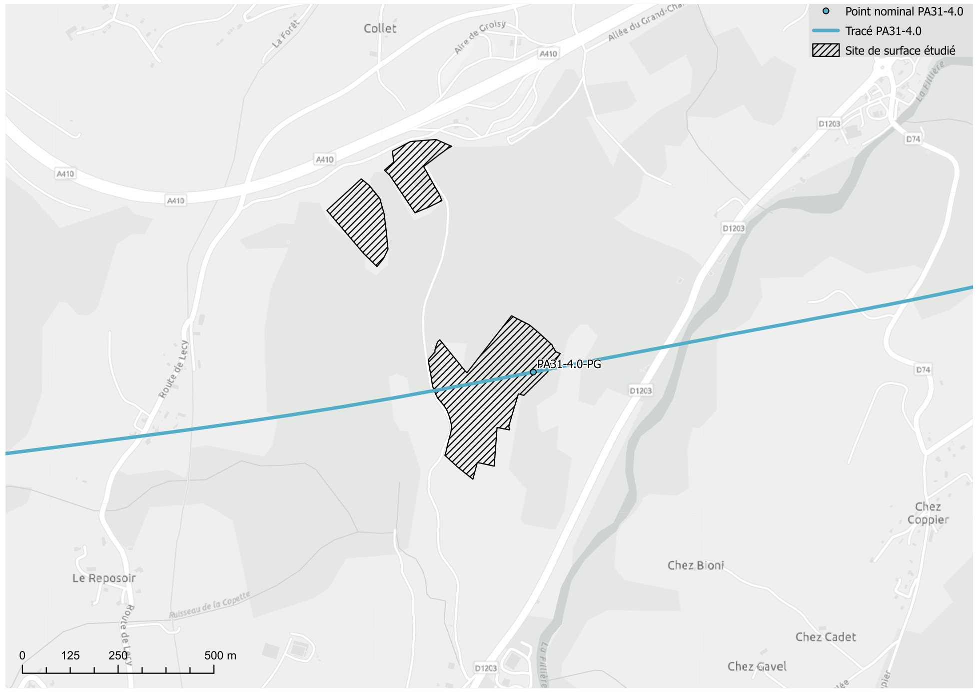


Fig. 2.39 PG surface site location in Charvonnex and Groisy, Haute-Savoie, France. the main site intersects the collider alignment, shown in blue. The two plots at the autoroute in the north serve for equipment that does not need to be necessarily located in the immediate proximity of the shafts. The areas also serve for handover of incoming construction materials and the evacuation of excavated materials

southern part of the plateau or existing brownfields in the forest. The site is on the edge of a steep slope towards the Route d'Annecy to the south, and must therefore remain on the top of the plateau. It is a quiet, natural area with exceptional views towards the Aravis mountain chain to the south. The location is exceptionally well suited to host a visiting facility with recreational facilities on the site. Measures will need to be taken to reduce noise and light pollution during the construction and operating phases.

Synergies and territorial potentials The possibility of reforestation compensates for the clearing of approximately 1.5 ha of forest. A forest road over flat land provides good access and makes it possible to create a route over approximately 800 m to the Groisy autoroute area and a wide road alongside the autoroute. Access to the autoroute during the construction phase for supplies and the removal of excavated materials has been studied and appears feasible. The use of a conveyor belt removes the need for trucks. There are two temporary storage areas for inert waste and other materials in the immediate vicinity of the site and the forest road. Annexes close to the autoroute could accommodate those elements most likely to generate disturbances, such as cooling towers and an electrical substation. The supply of residual heat from the cooling system appears to be possible. Several potential consumers have been identified in the vicinity, including public facilities (elementary school, middle school, fire station), a commercial zone and a veterinary clinic. There is also the possibility of creating a district heating network in Charvonnex and Groisy. The fire station can serve as a base for emergency services in the immediate vicinity of the site. Waste water from the cooling system could be used to feed the Fattes stream and wetlands in the forest. There is enough space on the site to build a visitor centre with recreational facilities that can be reached via the Groisy autoroute area or the Route d'Annecy. The site is located near Annecy, within easy reach for CNRS/LAPP staff. Sites for reusing excavated materials for agriculture and forestry have yet to be identified with the help of local authorities and notified government agencies (e.g., SAFER, DDT, DREAL).

2.6.10 Site PH

Description of the site location The technical site PH is located right along the D203 road in Cercier, Haute-Savoie in France (see Fig. 2.40 and Fig. 2.41). The site is located in the forest, straddling the municipalities of Cercier and Marlioz, stretching out to the west down a slope. It is far from dwellings and is not visible. It is in a nature setting. The defined area, located in an area with less biodiversity, is 8.2 ha.

Known constraints The environmental field investigations revealed that the part of the forested sector to the north of the site is of great value (rich biodiversity, natural environment). Therefore, use of the forest needs to be minimised and the specific locations of buildings and accesses in the forest need to be carefully developed during a subsequent design phase. The site will respect the buffer zone for the gas pipeline to the north. Considering

Fig. 2.40 Aerial view of candidate location for surface site PH

Fig. 2.41 PH surface site location in Cercier and Marlioz, Haute-Savoie, France

the quiet, natural setting, noise and light pollution must be given particular attention. A dwelling is located approximately 200 m to the south. There is no co-visibility between the site and the dwelling. Given the small size of the road, it is necessary to identify nearby reuse sites for excavated materials, so that they can be used in agriculture or for reforestation. Materials would mainly be transported away to the north or the west by conveyor belt to avoid road constraints. The location is well suited to host the radiofrequency system since a 400 kV grid line passes less than 2 km to the north. RTE, the national grid operator will have to take into account the need to supply electricity via buried cables when carrying out the study for the creation of a substation for access to the 400 kV line.

Should for any reason the site preferred location at the nominal point not be considered feasible, an alternative placement about 900 m in the clockwise direction of the collider has been identified as an alternative. This site is located on agricultural fields next to the D2 departmental road. It would be suitable as the location for the electrical substation in case of placement on the nominal point or when displaced since the electrical substation does not necessarily need to be in the immediate vicinity of the shaft.

Synergies and territorial potentials There is a great deal of interest in reusing water from the particle collider infrastructures for agricultural activities around the site (e.g., apple and pear trees). A water basin exists nearby, to the northeast. In case further, more detailed scenario developments are considered, a study will have to be carried out to find a way of integrating those opportunities with the site. It is advisable to work with local stakeholders to identify potential consumers of the residual heat, for instance, in the fruit and vegetable sector.

2.6.11 Site PJ

Description of the site location The experiment site PJ is located in a field on a slope to the north of the A40 autoroute and to the west of the Valleiry autoroute area, at the junction of the Chemin des Tattes and Chemin de Maigy roads across the communes of Dingy-en-Vuache and Vulbens, Haute-Savoie, France (see Fig. 2.42 and Fig. 2.43). To the west is a small stream. The site is far from any dwellings. The surface area of the site is 6.1 ha.

The site is accessible by the existing paved rural path Chemin des Tattes towards the north to Vulbens. This path has to be enlarged and refurbished.

Known constraints A wildlife corridor exists that needs to be respected in the development of the surface site. If possible, the corridor should be improved, as it currently functions poorly. An area with higher biodiversity in the middle of the site will have to be re-created at the border of the site in conjunction with the wildlife corridor. Site design will also have to take into account plans to improve soft mobility between Dingy-en-Vuache and Vulbens.

Synergies and territorial potentials The site is surrounded by numerous sloping farmlands. It will be necessary to work with local authorities and government notified bodies (e.g., SAFER, the agricultural chamber, DDT, DREAL) to determine where agricultural activities can benefit from the reuse of excavated materials. The site can also benefit from nearby developments to the south, over the same time frame (e.g., new national police station). It seems feasible to make residual heat available to public institutions and nearby business districts in Vulbens and Valleiry. In particular, it would be advisable to work with the department on integrating educational and training infrastructures with the surface site-related activities to generate local added value. The creation of a visitor centre would enable the development of high-quality, sustainable tourism. The connection to the Valleiry autoroute service area for removing materials and receiving supplies via the autoroute has been analysed and is feasible. To avoid trucks, a conveyor belt would be used to transport the materials to the autoroute area. Incoming materials could be transported via a temporary 700 m long road to the site. There is interest in developing synergies for the reuse of waste water to feed streams and for crop irrigation.

2.6.12 Site PL

Description of the site location The working hypothesis for the location of the technical site PL in Challex, Ain, France has been determined through various iterations with the municipality in 2023 and 2024. The reference site location at the nominal point can be seen in Fig. 2.44 and Fig. 2.45.

The site is at the nominal point in the middle of the technical straight section, near the border between France and Switzerland on an agricultural field. The perimeter includes two houses which would have to be integrated in the surface site project. The location still needs to be optimised in close cooperation with the municipality and architects. This option, located far from the village, requires the creation of an access road approximately 1.3 km long to the D89 departmental road. The route of this road will be developed by an expert company in close cooperation with the commune, respecting the existing environmental constraints. The area of the site is 5.5 ha. A large part of this space is foreseen for rewilding.

Fig. 2.42 Aerial view of candidate location for surface site PJ

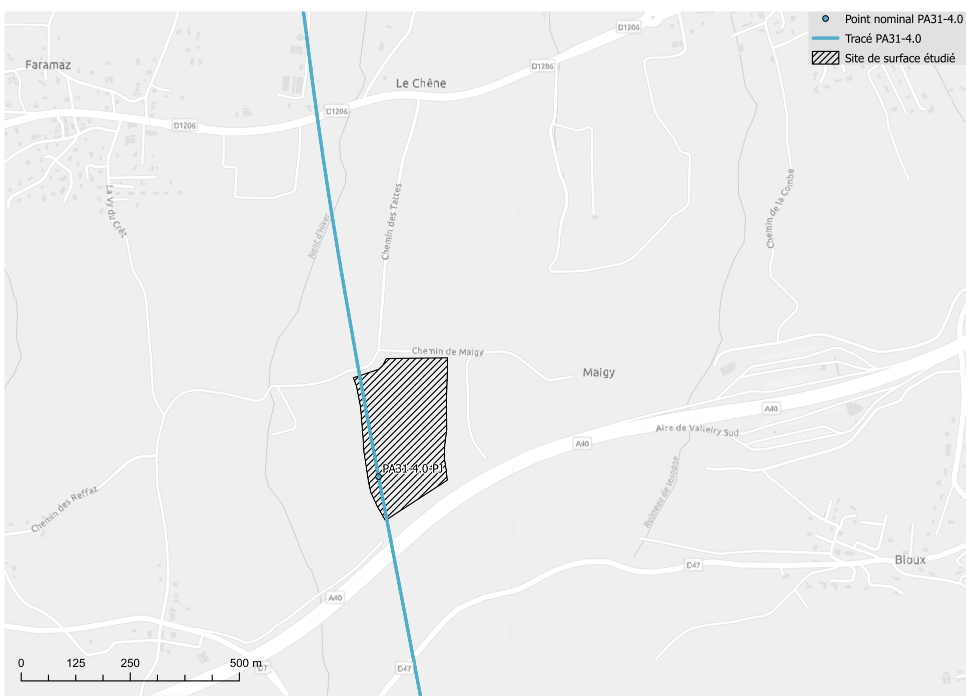


Fig. 2.43 PJ surface site location in Dingy-en-Vuache and Vulbens, Haute-Savoie, France

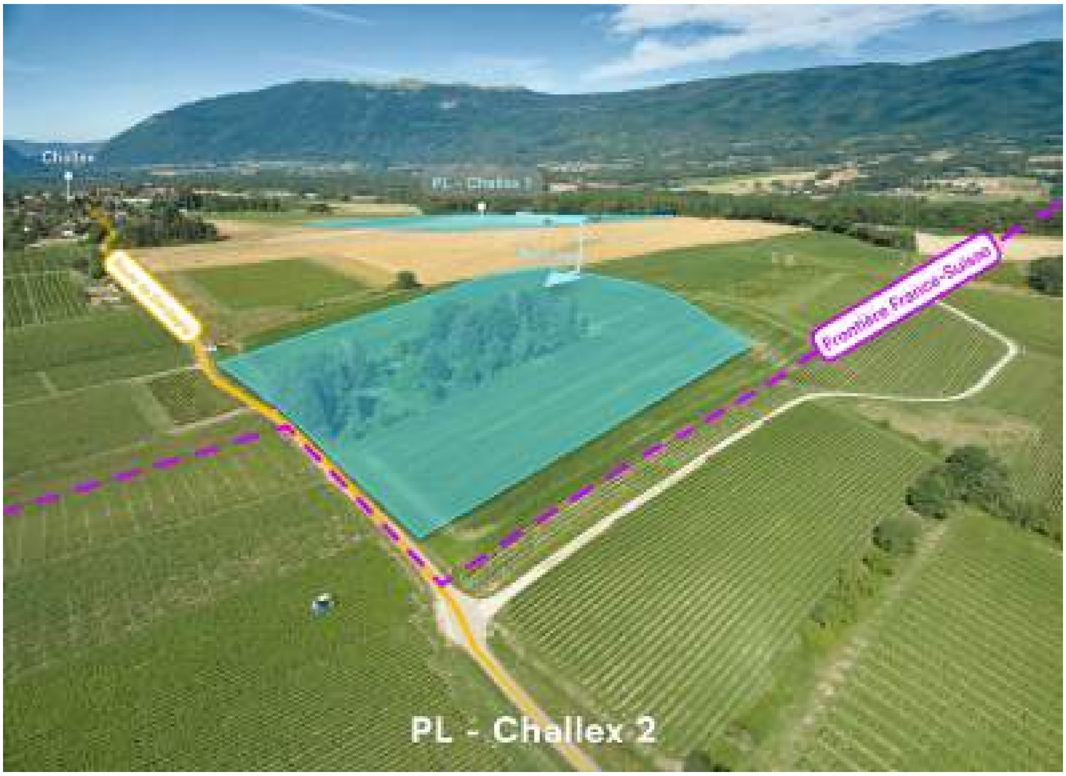


Fig. 2.44 Aerial view of candidate location for surface site PL

Fig. 2.45 PL surface site options studies in Challex, Ain, France

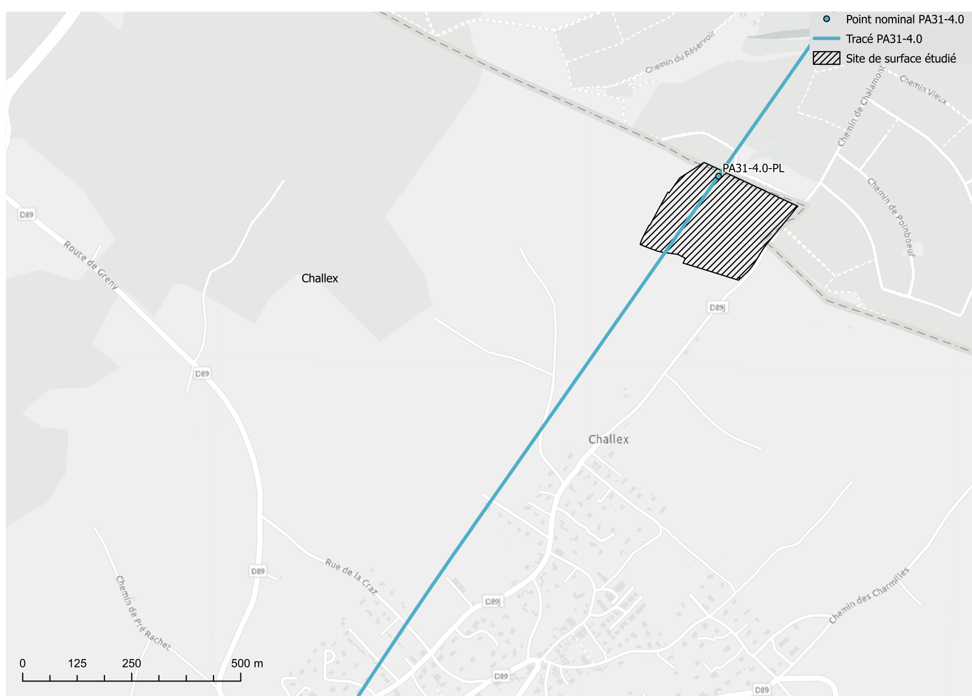


Fig. 2.46 Alternative location for site PL in Challex, Ain, France. The plot is located on the outside of the collider tunnel, which calls for an underground connection tunnel and a more complicated access to the radiofrequency gallery and the collider tunnel for equipment installation and maintenance

Should for any reason the implementation at the nominal point turn out to be unfeasible, an alternative location has been identified at a distance of 800 m in counter-clockwise direction along the straight section. This location would require the creation of an access shaft about 150 m outside the line of the collider and would therefore result in significantly higher costs (Fig. 2.46).

Known constraints

Option with location at nominal point The proximity of the Franco-Swiss border, close to vineyards, presents a challenge, as there are no roads or other infrastructure. However, one remote dwelling in the vicinity would be affected by disturbances and would therefore have to be acquired. This plot would be integrated into the surface site and serve for rewilding and visibility protection. Access to the site through the village is ruled out. The roads are too narrow and the disturbance would be unacceptable. Building a new access route through the fields to the north of the village is complicated but feasible. The theoretical point is separated from the main roads (Route de Greny and Rue de la Craz) at the entrance to the municipality by natural areas. The forest to the north of Challex is a zone rich in biodiversity. On the Swiss side, the forest is a zone reserved for absolute protection (Ramsar site), the vineyards are protected, nature zones are protected, the village is a cultural heritage indexed zone and the slope is too steep for surface site construction. A suspected, temporary, shallow water table was added to the Swiss maps in 2023. If this is the case, it will be confirmed through ongoing geotechnical investigations. Technically, the creation of a shaft is feasible, even if there is a temporary water table in this location. In the present, the investigations will also determine its seasonal nature and the possibility of cross-border connections. The positioning of the shaft and the entire site can be optimised according to the results of these subsurface investigations. Following an analysis conducted with the local municipality, it has been determined that this location option is preferred.

Option for the location 800 m east of nominal point (not selected) A location 800 m east of the nominal point would not allow access inside the ring (see Fig. 2.46).

The site would be approximately 150 m from dwellings, 5 to 10 m lower than the municipality, on a gentle slope of approximately 3%. It would be visible from certain dwellings. The site would partially affect the protected natural area, but the impact would remain limited since it is currently a field, and the biological corridor passes further to the east of the site. It would be necessary to build an access road to the D89 (approx. 400 m long) or to the Rue de la Craz road (approx. 300 m long). This scenario was used as a basis for discussions with the municipality to find an alternative to the location at the nominal point.

A technically feasible solution for access from the outside of the ring, albeit at a higher cost, has been developed. The shaft would be located about 150 m outside the ring (see Fig. 2.47). The verification regarding its visibility from isolated dwellings on the outskirts of the municipality has shown that this location should not be prioritised.

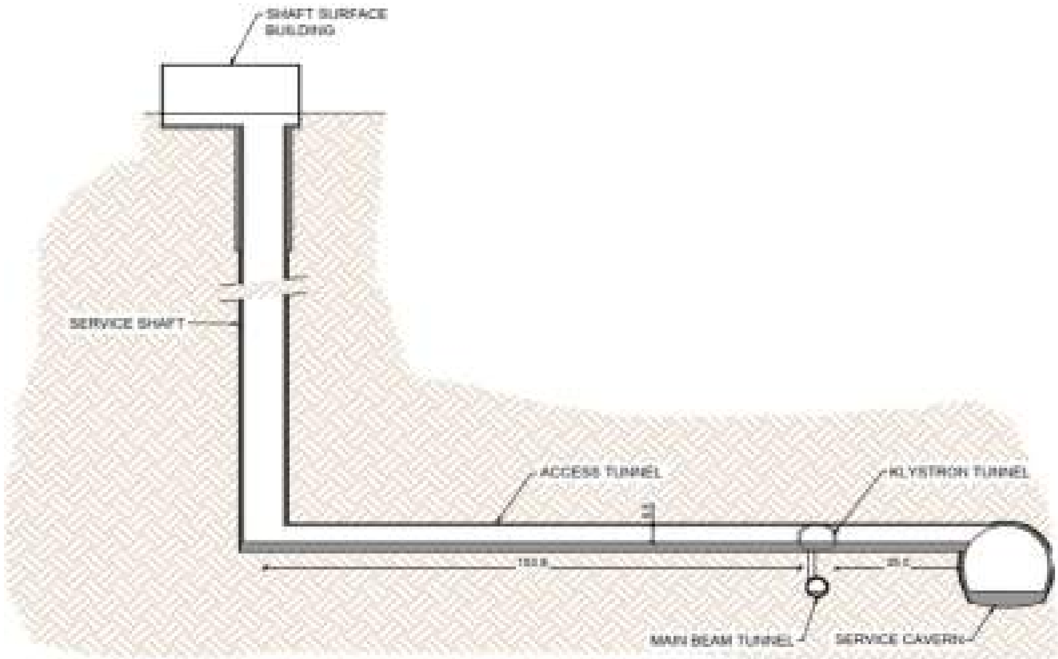


Fig. 2.47 Access to the main tunnel from the exterior via an underground connection. This approach is more complicated and induces additional costs

Synergies and territorial potentials The proximity of the CERN sites (Prévessin in France and Meyrin in Switzerland) represents an exceptional opportunity to benefit from synergies for the installation, operation, maintenance and repair of equipment in the shortest possible time. The fields to the north of the municipality appear to be suitable for reusing excavated materials for agricultural purposes. There is no direct visibility from the village. The proximity of the former Collonges train station at a distance of 12 km via the de-commissioned railway tack represents an opportunity for removing materials and providing supplies, avoiding trucks as much as possible by using conveyor belts. A connection to the La Plaine train station in Switzerland would be technically possible, but would be subject to an agreement between France and Switzerland. It could also provide an opportunity for material removal via a combination of conveyor belts and railway systems. The improvement of the local power grid, necessary for the construction phase, would benefit the municipality and its residents. It would enable increased use of renewable energies and more robust vehicle recharging stations. Improving the public transport network, starting at the construction phase, can also be of benefit to residents of the municipality, who currently mainly use private vehicles on the D884 in France and travel to Meyrin and La Plaine in Switzerland. Challex has traditionally been home to employees of international organisations, many of whom work at CERN. Strengthening the infrastructure would therefore benefit both the community and the project. Residual heat from the particle collider could be used for heating individual and collective residences (e.g., the Les Cyclamens long-term care centre), as well as for the Val Thoiry commercial centre approximately 7 km away. Other nearby communities such as Greny, Saint-Jean-de-Gonville, Péron and La Plaine (Switzerland) could also benefit from this heat supply. The company Firmenich (perfumes and fragrances), based in La Plaine in Switzerland, could also benefit from this heat. Heat could also be used in innovative ways for fish farming, aquaponics, market gardening, and greenhouses.

2.6.13 Prévessin site

The aim of the placement studies for the injector facilities is to maximise the use of existing CERN infrastructures. Considering the strong territorial constraints that have been identified and documented throughout a 7-year period, the needs for electricity, raw water, a more than 1 km long space on the surface for a linear accelerator and associated workshops, offices and storage zones, the existing CERN Prévessin site emerged as the most suitable location for a working hypothesis. This site has the space to host the electron and positron sources, linear accelerators, damping rings and optional experimental facilities to leverage the powerful electron-positron injector as an additional scientific instrument that can be used even before the electron-positron collider enters operation. In addition, the site is at a reasonably close distance from the existing LHC surface site P8, which together with additional space in the immediate vicinity, forms the surface site PA. Hence, the implementation of the transfer line, also leveraging the existing SPS subsurface structures, leads to an advantageous configuration.

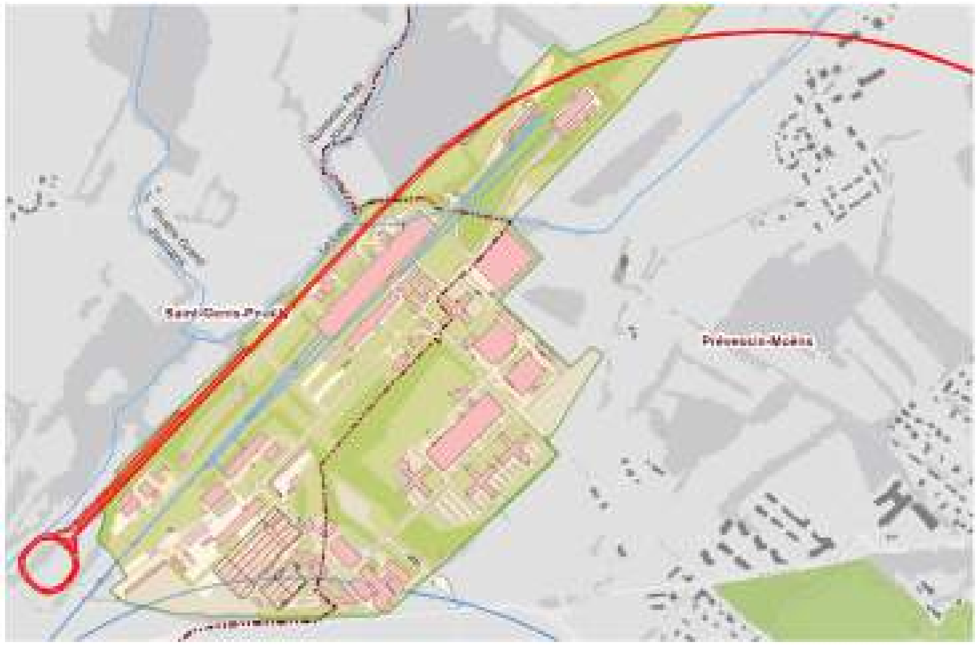


Fig. 2.48 Sketch of the current working hypothesis for a linear-accelerator based injector that has a length of about 1.2 km. A definitive placement remains to be developed in the frame of a design phase, considering environmental, existing experimental facility, territorial development and engineering constraints

Numerous technical infrastructures such as the existing 400 kV grid connection, water supply and treatment, offices, computing facilities, room for construction activities permit the efforts that are typically linked to territorial development for a new site to be kept within limits. At the current stage of conceptual development, the injector would have a total length of approximately 1.2 km. It could almost fit into the fenced space of the Prévessin site.

Common work with the authorities and further optimisation according to the 'avoid-reduce-compensate' approach will be performed so that any unavoidable territorial extension will be kept as small as possible and to assure that ultimately a suitable reference scenario for the injector placement can be identified.

Initial explorations have excluded the possibility of extending the site towards the north and east due to numerous nature, agriculture, and visibility constraints. The current, unfinished, working hypothesis shown in Fig. 2.48 is based on a placement between the 'Lion' creek and the North-Area beamline. The requirements and constraints of various technical concept elements, such as the exact size and shape of the damping ring, the widths and lengths of the accelerators and their integration, are today not yet at a level that permits freezing of the exact placement on the site. The analysis work carried out so far permitted, however, confirming the technical and territorial feasibility in principle and helped to identify the constraints to be considered for subsequent activities.

During a subsequent technical design phase, environmental analysis will guide the optimisation of the placement to ensure that natural constraints are respected, the required extension of the existing fenced domain is kept as small as reasonably possible, and that existing experimental facilities are not significantly impacted. A preliminary concept for the underground transfer line alignment avoids as much as possible conflicts with the projected construction areas on the surface. A definitive design will require more detailed environmental analysis, including geology and hydrogeology. The estimated efforts for these analysis and design activities are in the order of two to three years. They need to be integrated in the overall project environmental authorisation process.

2.6.14 Conclusion

Table 2.6 shows the status of the feasibility analysis for the surface site locations in scenario PA31-4.0. Technical feasibility was assessed using maps and data available to those working on the study and to contractors. The assessment was also based on fieldwork and environmental studies carried out by specialised companies, discussions with the relevant technical departments of the two host states, and with local elected officials (mayors, town councillors, departmental councillors, and regional councillors), who represent the citizens and act in their interests.

2.7 Territorial infrastructure needs

2.7.1 Introduction

To be able to construct, install and operate the particle-collider facility and its associated experiments, a number of different territorial infrastructures are required. The development of the implementation scenario put an emphasis

Table 2.6 Status of technical feasibility assessment for surface sites of PA31 scenario

Site	Location	Technical feasibility	Feasibility conditions
PA	Ferney-Voltaire, Ain, France	Confirmed	Limit impact on the landscape, enhance the natural area and the existing compensation zone. Maximise synergy with LHC point 8. Compensate for the loss of agricultural space. Develop a visitor centre, for example, on the LHC Point 8 site. Develop synergies based on heat recovery with municipalities within a 10 km radius, including Swiss municipalities and the Geneva airport.
PB	Presinge, Geneva, Switzerland	Confirmed	Define the exact location of the site on the plot and initiate discussions with the municipality. Identify an area to compensate not only for the loss of agricultural but also natural space. Limit impact on the landscape. Take into account the sensitive location of the site in a natural setting. A detailed conceptual design of the road access is to be developed and approved by the Canton of Geneva. Reach an agreement to recycle excavated materials, preferably locally. Develop synergies based on heat recovery around the site with local stakeholders and authorities.
PD	Nangy, Haute-Savoie, France	Confirmed	There are no specific blocking points, but the major issues in this sector call for careful joint development of the site in coordination with local stakeholders. Limit the loss of agricultural space by working on a smaller surface site. Compensate for the loss of agricultural space. Maintain compatibility with the proposed connection between the RD903 and the A40. Estimated start of construction: first quarter of 2025. Develop a transport concept for the construction phase to limit impacts on a sector that is already overburdened. Develop synergies with the communities around the nearby hospital (CHAL), the Scientrier waste water treatment plant (STEP) and the industrial zone to the north.
PF	Éteaux, Haute-Savoie, France	Confirmed	The north option along the RD1203 was confirmed, provided that nearby wetlands are avoided. Limit the loss of agricultural space. For a potential southern extension option, a decision would be required before the start of phase 2 of the ISDI (inert waste storage facility) in La Roche-sur-Foron in 2027. This would allow earthworks to be carried out on the western part for a smaller site, rather than wait for a complete development for the ISDI. Otherwise, annexes would need to be constructed on top of the inert waste. An agreement must be reached with the ISDI operator and the landowners. The access layout should be developed for this option. Any economic loss suffered by the ISDI operator must be taken into account when developing synergies between the site and the operator. Develop synergies with local authorities in terms of site development with emergency services.
PG	Charvonnex and Groisy, Haute-Savoie, France	Confirmed	The site straddles the forest and the plateau, which includes unexploited grasslands. Two annexes close to the autoroute area will accommodate certain facilities (e.g., water cooling system, electrical substation) to avoid any disturbance to the wooded area. Plan a visitor centre to develop high-quality, sustainable tourism. Develop synergies with the municipalities of Groisy and Charvonnex to develop the site with neighbourhood services for on-site researchers and emergency services. The loss of woodland can be compensated by reforestation around the site. The layout of the existing access route to the north is suitable.
PH	Cercier and Marlioz, Haute-Savoie, France	Confirmed	Limit the site's footprint and remain within the wooded area to avoid impacts on the dwellings to the south of the site. Reduce the impact on natural habitats and biodiversity. Compensate for the impacts on woodland, habitat and biodiversity that cannot be avoided and reduced. Respect the easement for the gas pipeline near the site, and decide what distance to maintain between the pipeline and above-ground infrastructure. Consider a split or displaced site location along the straight section.
PJ	Dingy-en-Vuache and Vulbens, Haute-Savoie, France	Confirmed	Compensate for the loss of agricultural space. Preserve ecological corridors. Integrate the planned projects to develop soft mobility between Dingy-en-Vuache and Vulbens. Foresee a visitor centre to develop high-quality, sustainable tourism. Work with the municipalities to develop synergy for the site with regard to neighbourhood services for on-site researchers, emergency services and schools.
PL	Challex, Haute-Savoie, France	Confirmed	The location at the nominal point has been discussed with the municipality. Compensation for the loss of agricultural space. A joint optimisation of the site with the municipality is in progress.

Table 2.6 (*Continued*)

Site	Location	Technical feasibility	Feasibility conditions
CERN	Prévessin and Saint-Genis Pouilly, Ain, France	Confirmed	The location of the injector at the existing CERN Prévessin site has been verified, and its technical feasibility has been confirmed in principle. Optimisation of the placement within the site remains to be done based once detailed technical requirements and invariants are available and the state of the environment has been analysed. Territorial development outside the fenced perimeter will be kept as low as reasonably possible. The alignment of the underground transfer line to site PA will be designed considering geology, hydrogeology and the project of constructed areas on the surface.

Fig. 2.49 Noteworthy road, electricity, water treatment infrastructures, emergency services and border crossings in the vicinity of the surface sites indicated by red circles

on leveraging existing infrastructures as much as possible (Fig. 2.49). The well-developed transport, electricity, and water networks in the region around CERN are one of the motivations to propose the facility in this region. The main infrastructures required and described in this section are: roads that provide access to the surface sites, autoroutes to evacuate excavated materials and to supply construction materials and equipment, railway lines to support possible excavated materials and construction materials transport, electricity for the construction phase, direct access to the French high-capacity power grid for the operation, and raw water for cooling purposes.

2.7.2 Road access

The road network is dense along the reference scenario footprint (see Fig. 2.50). For the site access roads, in order for two heavy goods vehicles to pass each other at reduced speed, a width of 5.50 m of roadway with two 0.50 m shoulders is required. Subject to environmental constraints, the lanes of reinforced roads or new roads may be smaller: widths of 4.00 m for the roadway and 0.50 m for the shoulders are acceptable if possibilities for passage in both directions are foreseen. This reduced section will require instructions to be given to the drivers of the vehicles concerned.

Several surface sites can profit from direct road access (PA, PD, PF, PH) and some others require minor reinforcement of existing road access (800 m of forest path to be paved for PG, 600 m of rural path to be paved

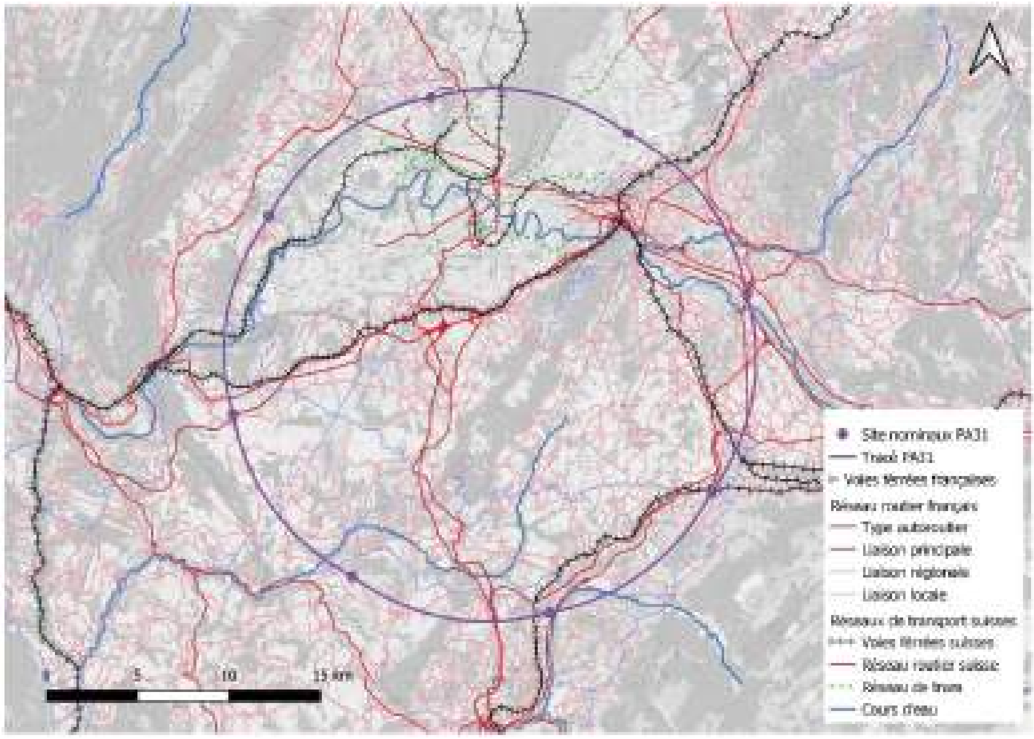


Fig. 2.50 Overview of the road and railway transport network in the perimeter of the reference scenario

for PJ). Site PD requires the creation of a 300 m long dedicated access. Site PL requires the creation of an approximately 1300 m long dedicated access. In total, less than 3 km of road have to be created. Figure 2.51 presents an overview of the road access concepts.

Road traffic analysis [38] has been carried out for all sites, and the feasibility of the construction was verified with this work. Technical designs for road accesses have been developed for sites PB, PD and PF to ensure the feasibility in areas that are subject to particular road traffic constraints linked in PB to visibility and road safety, in PD due to a major road enlargement and autoroute development project and in PF to ensure road safety. Detailed road access designs have now to be carried out for all sites for the development of a coherent design package that is required for environmental impact assessments and project authorisation.

2.7.3 Autoroute access

The study examined the feasibility of connections to the autoroute network for the removal of materials and the supply of equipment during the construction phase [39]. The possibility of obtaining autoroute connections, either directly, via conveyor belts or via temporary gravel paths during construction is a goal in the general interest, aimed at limiting the impact of the project, particularly during the construction phase. The specific technical choices will be made later, during the project development and preparation phase. To verify the technical, legal and financial feasibility of direct access to autoroutes, files with conceptual design plans and descriptions were compiled and submitted for review on 14 September, 2022 to the competent authority for granting concessions: the Direction générale des infrastructures, des transports et des mobilités (DGITM), Direction générale des infrastructures, des transports et des mobilités / Direction des mobilités routiéres / Sous-direction des financements innovants et du contrôle des concessions autoroutières / Chef du Bureau des services aux usagers et de la comodalité and the Direction générale des infrastructures, des transports et des mobilités / Direction des mobilités routières / Sous-direction des financements innovants et du contrôle des concessions autoroutières / Chef du Bureau du patrimoine et de l'aménagement.

The feasibility of four new connections to the autoroute network was analysed and confirmed to be in principle feasible (see Fig. 2.52) for the following sites:

1. PD site in Nangy (on the A40 autoroute),
2. PF site in Éteaux/La Roche-sur Foron (on the A410 autoroute),
3. PG site in Charvonnex/Groisy (on the A40 autoroute),

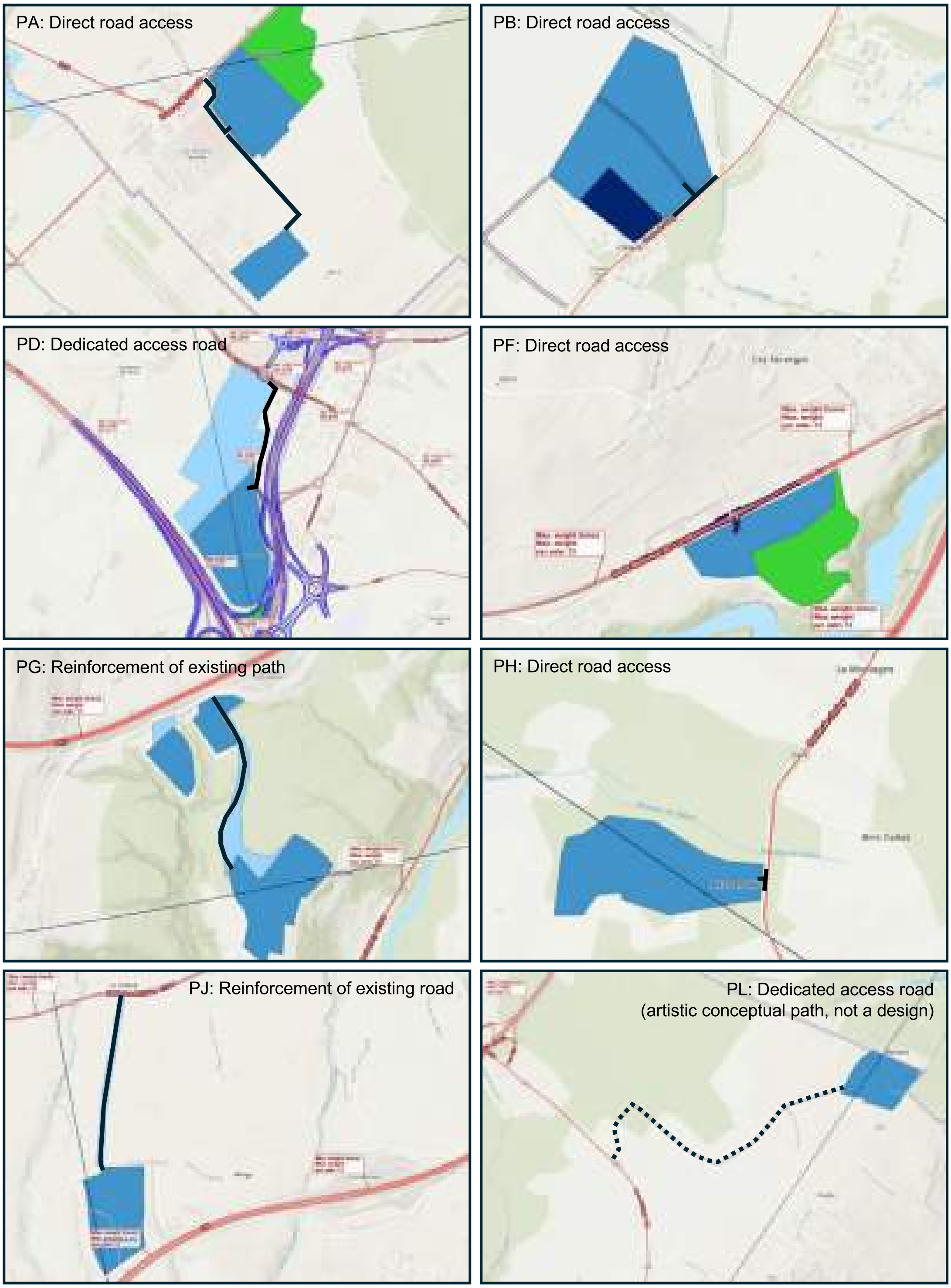


Fig. 2.51 Overview of road access concepts for each individual surface site

4. PJ site in Dingy-en-Vuache/Vulbens (on the A410 autoroute).

   The conclusions of the interactions with the DGITM were as follows:

- The access concepts and loading/unloading areas provided are in principle acceptable.
- Adjustments will be needed, with the final decisions to be made with the autoroute operator in the project phase.

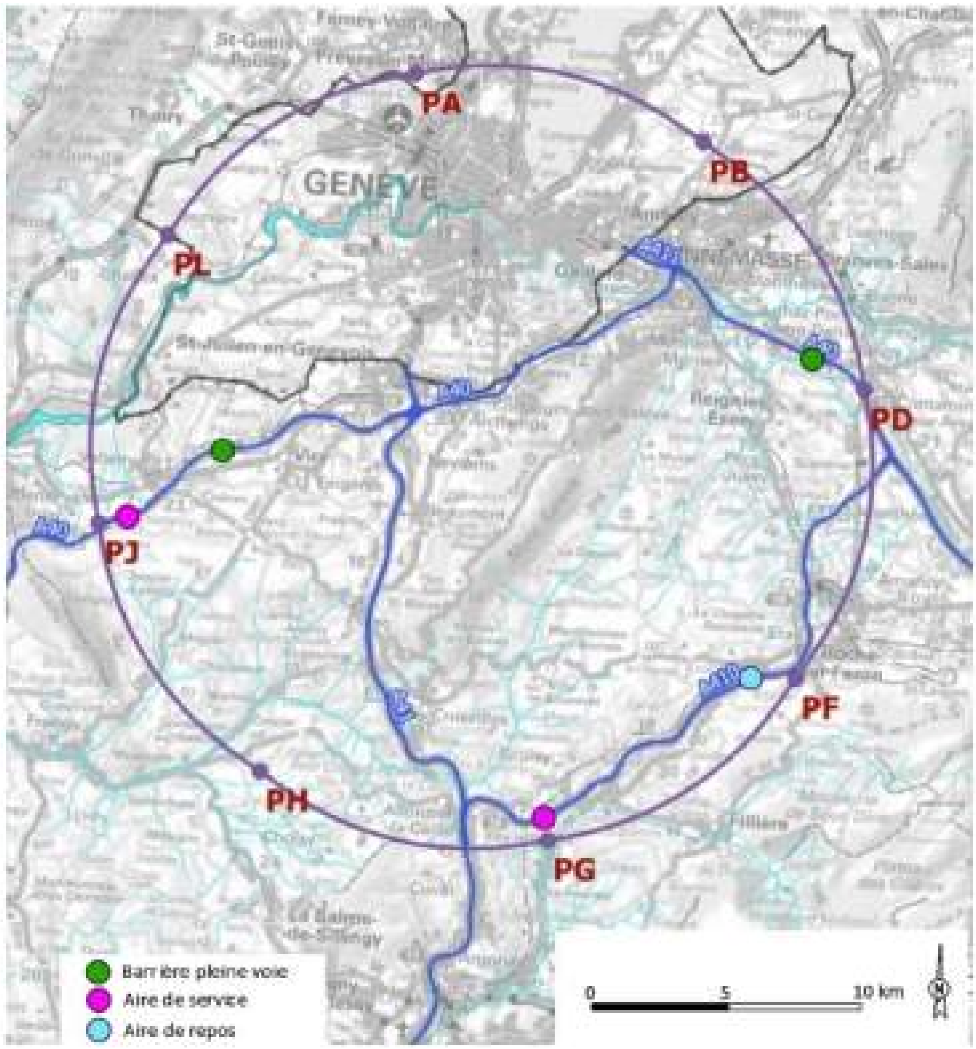


Fig. 2.52 Location of the autoroute connections, which were studied using existing service and rest areas. Blue dots correspond to autoroute rest areas, magenta dots indicate autoroute service stations and green dots indicate toll stations

- Detailed plans have to be developed and presented.
- The procedure for submitting an application in the future was specified.
- The proposed justifications, in the general interest, are acceptable;
- Entrances and exits will need to be equipped with detection devices to manage tolls.

2.7.4 Railway access

To reduce the need for truck traffic, to generate further opportunities to supply quality construction materials from further distances and to open possibilities to transport excavated materials to appropriate deposition sites and re-use locations in an environmentally friendly and high capacity way, railway access studies have been carried out by a qualified domain-expert company [40–48].

The current reference scenario was taken as a working hypothesis for analysing the opportunities and feasibilities concerning accessing the railway system via existing installations (goods loading and unloading facilities) and concerning the creation of new accesses (so-called ITE, 'Installation Terminal Embranchée' in French).

The studies used a multi-criteria analysis that considered the following indicators:

- Proximity of the surface site with a suitable railway track.
- Technical and administrative compatibility for access with the French and Swiss railway infrastructure.
- Presence of an existing service or ITE that could be leveraged.
- Feasibility of creating a transport connection between the site and the railway track access.
- Minimum space requirements for railway access and available space.
- Number of convoys required for evacuating all excavated materials.
- Capacity availability and limitations on each railway line analysed.

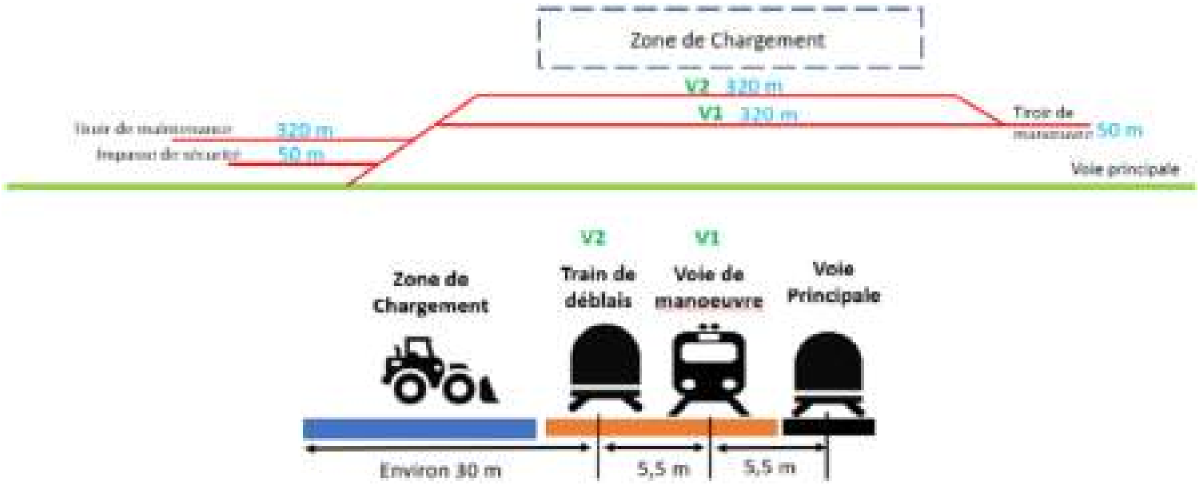


Fig. 2.53 Minimum space requirements of a new railway access for goods transport

Table 2.7 Railway access opportunities for each surface site

Site	Distance	Feasibility	Description
PA	Less than 5 km	Unsure	Requires crossborder transport of materials
PB	Less than 5 km	Low	Requires crossborder transport of materials
PD	No opportunity within 10 km	Unfeasible	
PF	Less than 1 km	Medium	Space and ISDI constraints
PG	Less than 2 km	Medium	Implementation constraints
PH	No opportunity within 10 km	Unfeasible	
PJ	Less than 5 km	High	
PL	Less than 10 km	High	Via existing, unused station at Collonges

It is important to keep in mind that each new railway access requires a space of about 400 m by 40 m, i.e., 1.6 ha of land (see Fig. 2.53).

The train line 890000 through Meyrin, Collonges, today provides the necessary free capacity. Line 902000 in Vulbens and line 897000 passing in Éteaux and in Groisy have only limited capacities.

The analysis (summarised in Table 2.7) revealed the following 'in principle' opportunities for railway access:

Based on the analysis, today, the most likely accesses to the railway system are the existing and unused train station in Collonges for site PL, new access north of Vulbens for site PJ and a new access west of Groisy for site PG. While the old train station of Collonges is 13 km from the surface site PL in Challex, a connection with a conveyor belt can be a suitable approach, avoiding truck traffic.

The feasibility in principle for the creation of access in La-Roche-sur-Foron on the site of an inert waste storage facility (I.S.D.I.) exists once that facility has been filled. However, the amounts of materials produced at site PF are limited compared to other sites, and the constraints due to the status of the facility (ICPE in France) and space limitations require a careful cost/benefit and administrative feasibility analysis in addition to the technical analysis.

The technical and administrative feasibility of railway access at Geneva Airport in Switzerland for site PA in France is subject to a specific analysis that will only be carried out in 2025. If it is technically feasible, an administrative challenge is to be addressed concerning the cross-border transport of materials in both directions: France to Switzerland for excavated materials and Switzerland to France for construction materials and equipment.

The creation of a new ITE requires about 10 years of planning, detailed development of the variants to be presented for authorisation, an economic demand study concerning use beyond the FCC construction phase, environmental impact assessment and the authorisation process. The implementation for use requires about 2 years.

If train access is to be used for the evacuation of materials and the supply of construction materials and equipment, a detailed design and common project together with the French and Swiss national railway network administration services would have to be started in a forward-looking way, starting in 2025.

2.7.5 Conveyor belt links

To reduce the need for temporary paths and truck traffic due to excavated materials and construction material-related transports between sites and autoroute accesses, example studies were performed to determine the feasibility of conveyor belt links [45, 49] by an expert company in the domain. Two sites have been selected for the case study: PJ (Vulbens and Dingy-en-Vuache, France) and PG (Charvonnex and Groisy, France). It is worth pointing out that the findings also apply to the other sites that were examined at a high level, but no technical designs have been developed. If a preparatory project phase is launched, detailed technical design variants for traces and conveyor technologies for a construction hypothesis have to be drawn up for all eight sites and submitted for authorisation in the frame of the project environmental authorisation process.

Conveyor belts would be operated with electricity with a capacity of 120 kW between the start and the end of the construction activities. Based on a speed of 2 to 2.5 m/sec and a width of 650 to at most 800 mm the following schedule has been established:

- 22 days per month.
- 226 days per year.
- Up to 8 hours per day.
- Operation between 08h00 in the morning and 18h00 in the evening.
- No operation during the night, weekends or holidays.

Various technologies for conveyor systems have been analysed, and their costs have been estimated for the two specific locations PG and PJ. Depending on the environmental conditions (topography, terrain, vegetation, urban constraints) different footprint and noise-limiting systems can be considered. In general, the choice is always determined by the goal to limit footprint and nuisances for the required capacities, limited by the available technical constraints. Public spaces would be leveraged whenever possible. New routes would be limited to 3 m width. The maintenance of new routes is limited: they are not permanent and the space used will be restored after use.

The feasibility of meeting the capacity requirements associated with a construction site that operates 2 tunnel boring machines (TBM) has been confirmed from a technical perspective and an environmental perspective. Noise levels are between 65 dB(A) directly at the conveyor and 47 dB(A) at a distance of 64 m with today's off-the-shelf technology. Example routes have been developed to confirm compatibility with the noise regulations in France for both study sites.

For site PJ, the conveyor can be created to the autoroute service station in Valleiry (distance 700 m) and/or to new railway access north of Vulbens (1565 m) outside any residential area. It has to cross the RD 1206 departmental road. Disturbances due to noise can be avoided in both cases.

For site PG, the conveyor can be created to the autoroute service area in Groisy (distance of about 800 m) and/or to new railway access at the north of the autoroute (925 m). The biggest challenge, although technically feasible (see Fig. 2.54) is the crossing of the A40 autoroute for a period of about 8 years. Residential areas are unlikely to be affected.

2.7.6 Electricity for the construction phase

For the supply of electricity during the construction phase, requests for hook-ups to local networks have to be made directly to the relevant national distributors (e.g., Enedis in France and SIG in Switzerland). According to information provided by company Herrenknecht, a leading TBM manufacturer, electricity requirements are around 3.7 MVA for a construction site using a single TBM and around 7.4 MVA for a construction site with two TBMs. The working hypothesis presented in Table 2.8 will be fine-tuned with the civil engineering companies during a subsequent design phase before the start of construction. This process will deliver the exact electrical power required during the construction phase. This will depend on the number and configuration of the TBMs around the ring and the specific machinery used. All that information will only be known with certainty shortly before the launch of the public works contracts. However, it has to be considered that planning, contracting, and implementing the local electricity connections for the construction phase will require several years and will need to be part of the overall environmental authorisation process.

2.7.7 Electricity for the operation phase

The FCC-ee scientific research programme is based on different collider operating modes (Z, WW, ZH, $t\bar{t}$ and an optional HH mode). Each mode uses a different equipment configuration. This equipment (acceleration systems by superconducting radiofrequency cavity, electrical energy conversion systems and cryogenic cooling systems) will be installed progressively during the maintenance and upgrade phases planned for these activities. One long shutdown (LS) is planned to install the radiofrequency systems for the $t\bar{t}$ and optional HH operation modes.

Fig. 2.54 Example of a conveyor crossing a major road

Table 2.8 Working hypothesis for connection to local electricity networks during the construction phase

Site	Location	Operator	Power
PA	Ferney-Voltaire, France	Enedis	7.0 - 13.8 MVA (= 400 A at 20 kV)
PB	Presinge, France	SIG	3.0 - 7.0 MVA (= 200 A at 20 kV)
PD	Nangy, France	Enedis	7.0 - 13.8 MVA (= 400 A at 20 kV)
PF	Éteaux, France	Enedis	3.0 MVA (= 100 A at 20 kV)
PG	Charvonnex, France	Énergie et Services de Seyssel	13.8 MVA (= 400 A at 20 kV)
PH	Cercier, France	Enedis	3.0 MVA (= 100 A at 20 kV)
PJ	Vulbens, France	Enedis	13.8 MVA (= 400 A at 20 kV)
PL	Challex, France	Enedis	3.0 MVA (= 200 A at 20 kV)

Each configuration is characterised by different electrical power needs (see Table 2.9), which serve as the basis for average consumption estimates.

The collider operates on a yearly schedule, with a limited period of beamline operation for physics research. The programme also includes phases for equipment testing and start-up, machine performance optimisation and routine maintenance. Depending on the operating mode, electrical energy consumption varies from year to year.

At this stage of the study, it is only possible to provide approximate yearly consumption figures (see Fig. 2.55). The annual electricity consumption varies between 400 GWh/year for basic services that are in use also without beam operation and 1770 GWh/year for the $t\bar{t}$ operation phase. On average, the annual electricity consumption over the operation period is slightly above 1200 GWh/year. The capacities required to supply the particle collider with the required energy exist in France. However, a plan for a specific power purchasing agreement portfolio will have to be established, allowing ample preparation time before the energy is required to obtain favourable conditions and to contract a suitable energy mix with a low carbon footprint [50, 51].

Table 2.9 Electrical power need estimations for the operation phase. Technical feasibility studies permitted reducing power requirements by almost 45% between 2020 (initial hypothesis) and 2024

Mode	Beam energy	Operation	Initial capacity estimation	Current capacity estimation
Z	45.5 GeV	4 years	65 MW - 240 MW	30 MW - 222 MW
WW	80 GeV	2 years	70 MW - 265 MW	33 MW - 247 MW
ZH	120 GeV	3 years	70 MW - 294 MW	34 MW - 273 MW
$t\bar{t}$	175 GeV	5 years	80 MW - 350 MW	40 MW - 350 MW
HH	182.5 GeV	1 year	50 MW - 384 MW	41 MW - 357 MW

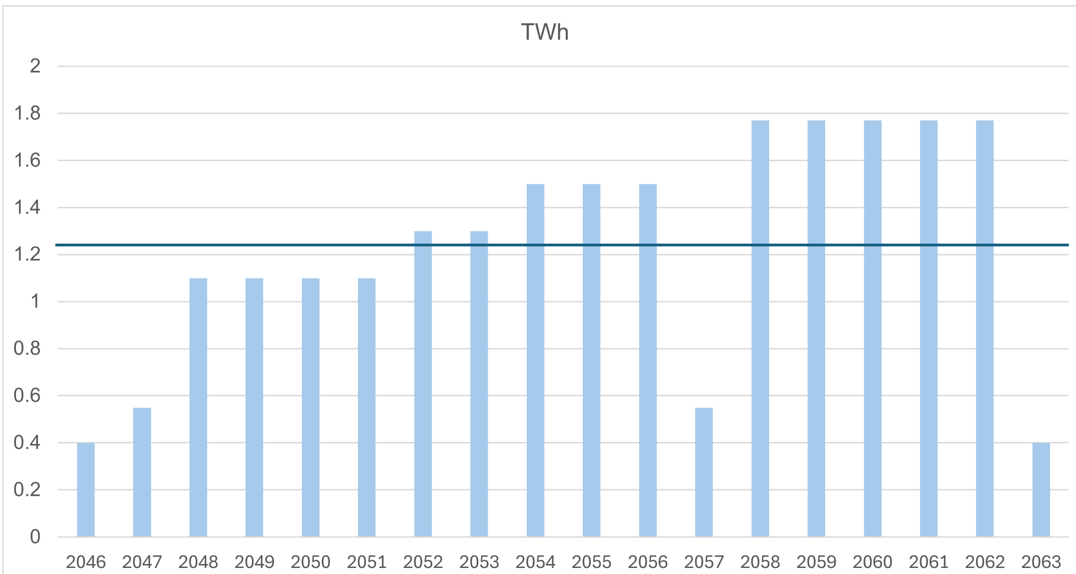


Fig. 2.55 Annual electricity requirements of the collider and its technical infrastructure. The average annual consumption over the programme is indicated by a blue horizontal line

Following the preliminary and exploratory studies, more detailed concepts to optimise the energy performance of the accelerator's equipment and to improve operations based on information provided by electricity infrastructure operators and energy suppliers are required.

This approach will be based on the usual Avoid-Reduce-Compensate methodology.

- Avoid: the overriding goal is to limit consumption according to a cost-benefit analysis, which includes, for example: the research infrastructure layout of four experiments; limiting maximum annual power consumption, which will have impacts on luminosity and extending the duration of the research programme; and ensuring that systems do not consume energy when not in use.
- Reduce: this means to optimise system efficiency and reduce losses. This includes, for example, improving the efficiency of electrical energy conversion for radiofrequency, reducing losses in internal distribution and equipment, energy recovery and storage, smart consumption based on needs (e.g., for ventilation and cooling), and developing systems that can switch more easily and quickly between operating modes (standby or operating mode).
- Compensate: lastly, the goal of compensating is, on the one hand, to recover, store and supply renewable energy for society, and on the other hand, to develop synergies for the transition to energy from renewable sources, increase renewable energy capacity and cooperate internationally for the supply of renewable energy. Examples of compensation with direct economic benefits include the creation of energy communities and pooling for pre-financial-investment-decision support to build up renewable energy sources, use of waste heat in industrial processes (e.g., cheese production), for greenhouse operations, crop cultivation and the heating of public establishments such as hospitals, schools, and shopping centres.

All these measures will need to be improved over the fifteen years of the technical design and construction phases. They are an effective way of limiting electricity consumption and its impact.

With regard to the various phases of the collider maximum power requirements are only necessary during the $t\bar{t}$ operation phase, and during an optional phase at the end of the programme (hh) when all the radiofrequency equipment is installed. On average, during the scientific research phase, the FCC-ee would consume approximately 1.3 TWh per year. Over its entire lifetime, including shutdown periods and commissioning, its average electricity consumption would be around 1,3 TWh per year. To provide a context for the impact of this electrical energy consumption, it can be compared to the electricity consumption of a state-of-the-art data centre. For example, the Altoona (IA) data centre in the USA, owned by the Meta company, most known for the Facebook, Instagram and WhatsApp applications, has an annual consumption of 1.24 TWh [52]. The carbon footprint of this data centre is 532,158 tCO_2(eq) per year. This corresponds to about the carbon footprint of the entire FCC infrastructure construction. The consumption of all Meta company's data centres is 15 TWh/year, i.e., a factor ten higher than the annual energy need of the FCC-ee. The total annual carbon footprint of all Meta's data centres totals to about 5 million tons CO_2(eq).

The specific energy needs will only be known after the detailed technical development phase, so it will be possible to take advantage of technical advances and development to improve energy efficiency.

RTE, which was entrusted with the task of managing the electricity transmission grid in France[1] through a public service contract dated 24 October 2005, which includes, among other things, the environmental integration of the grid (consultation, protection of landscapes and natural and urbanised environments) and safeguarding the public grid, is responsible for analysing the connection while taking into account technical choices; overseeing the hook-up process; and carrying out the necessary administrative procedures (connection agreement, grid access contract). RTE also carries out all works required to establish connections between surface site delivery points and the high capacity national electricity grid once the hook-up agreement has been signed.[2]

According to the results of the preliminary technical feasibility study carried out by RTE [53], which manages France's electrical grid, the connection to the high-power electrical infrastructure calls for three supply points in France at this stage. A backup power supply point in Switzerland can be considered, but if required, its technical and administrative feasibility remains to be studied.

At this stage, the footprint of the reference scenario is crossed by various power lines, mainly 63 kV and 225 kV. Two 400 kV lines cross the PA31 footprint from west to east (see Fig. 2.56). The 400 kV lines pass close to the PL sites (Ain department in France) and the PF and PH sites (Haute-Savoie department, France). A major distribution station (Cornier) is located close to the PD and PF sites in France. Electricity needs are higher at the PL and PH sites, as these are designed to house the radiofrequency systems that accelerate particles in the collider.

Three supply points are currently envisaged to achieve a well-balanced electricity supply scenario: One in PL connecting to the nearby 400 kV line. One in PD connecting to the Cornier substation. One re-using the existing CERN grid connection in Bois Tollot (Ain, France). A detailed design study is required by RTE to determine the route and specificities of the new 400 kV connections. It may be advantageous to connect site PF instead of site PD to the 400 kV line, leveraging the proximity of the RTE distribution point in Cornier and thus avoiding the need to cross the Arve river. It is worth noting that the planning, authorisation, contracting and creation of grid power connections require substantial lead times. Ten years should be assumed for the entire process of one connection. In addition, for the entire particle collider project's environmental authorisation process, the availability of environmental impact studies of the grid connections is required. Therefore, the detailed designs of the connections and their route variants based on the environmental constraints, technical feasibility and cost must be developed with high priority now, even if, ultimately, the connections are only required after the civil construction phase.

2.7.8 Raw water supply

The particle accelerators need raw water mainly to cool the magnets. Synchrotron radiation is the main source of heat in addition to numerous mechanical and electrical technical infrastructure components. All raw water can be taken from an existing raw water supply line provided by the local Swiss company Services Industriels de Genève (SIG) [54] that sources the water from Lake Geneva, as is the case with CERN today. No raw water will be consumed from drinking water reservoirs or subsurface water layers.

The technical solutions and equipment choices will not be known until shortly before the procurement of the technical infrastructures, mid-way through the subsurface construction phase, in order to take full advantage of

[1]Decree no. 2005-1069 of 30 August 2005 approving the status of the company RTE EDF Transport: https://www.legifrance.gouv.fr/loda/id/JORFTEXT000000812363.

[2]RTE, Instruction des demandes de raccordement, version 2, 17 Octobre 2019, https://www.services-rte.com/files/live/sites/services-rte/files/documentsLibrary/DTR%201.4.1%20Procedure%20Racc%20Conso%20L342-2%20v19%2010%2017_fr.

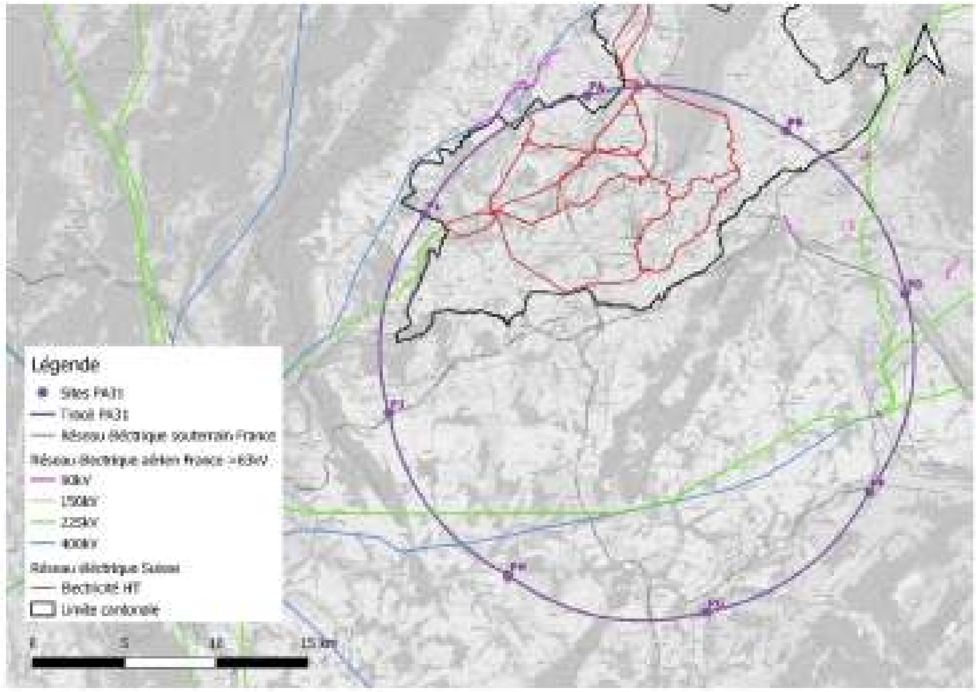


Fig. 2.56 Existing or planned electricity grids in France and Switzerland within the FCC perimeter. Sources: Public layer CAD_ELEMENT_CONDUITE from SITG 2023 for Switzerland (https://sitg.ge.ch/donnees/cad-element-conduite), available for consultation and extraction for free use; for France, Open Data Réseaux Énergies (ODRE, https://opendata.reseaux-energies.fr)

Table 2.10 Summary of the FCC raw water needs

Mode	Annual raw water requirement	Years
Z	1,604,861 m^3	4
WW	1,928,943 m^3	2
HZ	2,165,458 m^3	3
L.S.	163,817 m^3	1
$t\bar{t}$	3,077,591 m^3	5

Table 2.11 Summary of the annual raw water needs

Item	Raw water need	Description
SPS	944 m^3	BA2, BA4, BA5, BE2
LHC	795,070 m^3	LHC complex, LHC2, LHC3.2, LHC 3.3, LHC4, LHC5, LHC6, LHC7, LHC8
Meyrin, Prévessin	2,437,988 m^3	Meyrin and Prévessin sites main supply, SPS BA1 and BA6, LHC1 safe supply, clubs, Globe

technical advances, including those in cooling system efficiency. Estimates of the maximum water requirements, based on consumption by CERN's existing accelerator cooling systems and on the current technical concept developments, have been established (see Table 2.10). These values are the result of a gradual development of a concept that permitted reducing the raw water requirements from a maximum initial amount of 5,000,000 m^3 per year for $t\bar{t}$ operation to about 3,000,000 m^3 per year. The current reference water capacity needs to assume the use of closed-circuit water cooling systems with evaporation towers. The raw water consumption stems from the need to make up for the evaporated water in the secondary circuits of the cooling towers at each surface site. For comparison, the raw water consumption at CERN in 2022 is summarised in Table 2.11.

Water for cooling purposes at CERN is today, mainly from Lake Geneva via the Services Industriels de Genève (SIG). It undergoes pre-treatment, including filtration, and is delivered through the existing supply network. The raw water supply scheme for the FCC builds on CERN's existing infrastructure, with a confirmed available capacity of 604 m^3/h—equivalent to more than 5 million m^3 per year—sufficient to meet the FCC's needs. This was established through exchanges with SIG in 2022 and reaffirmed in August 2023, when SIG confirmed the technical feasibility of the supply within the current contractual framework. Two options were identified: (i) constructing a

Table 2.12 Water-saving potentials with the introduction of waste heat supply scenarios and use of treated waste water

Mode	Conservative waste heat reuse	Realistic waste heat reuse	Treated waste water use
Z	356,800 m^3/year	476,800 m^3/year	685,000-1,000,000 m^3/year
WW	382,400 m^3/year	523,200 m^3/year	685,000-1,000,000 m^3/year
HZ	409,600 m^3/year	571,200 m^3/year	685,000-1,000,000 m^3/year
L.S.	96,000 m^3/year	96,000 m^3/year	685,000-1,000,000 m^3/year
$t\bar{t}$	473,600 m^3/year	678,400 m^3/year	685,000-1,000,000 m^3/year

new 200-metre connection with a 500 mm nominal diameter between the Tuileries-La Berne pipe and LHC Point 8 in Ferney-Voltaire (France), or (ii) upgrading two existing internal CERN pipelines.

To make the distribution of water along the entire length of the accelerator technically easier and economically more advantageous, two additional water supply points can be considered in France from the Arve and/or the Rhône rivers. To this end, a specific territorial study would be needed, which would have to integrate the quantitative management plans available for water resources (PGRE). Such water intakes would require the creation of water filtration and treatment plants.

In an effort to reduce further the water capacity needs, initial studies have been carried out to identify promising levers (see Table 2.12). First, the introduction of waste heat recovery and supply from the onset permits reducing the water intake needs significantly since less water needs to be evaporated if the heat is supplied to consumers. The conservative scenario indicates the water-saving potential without adaptation of the classical operation schedule. Some commercial consumers need heat throughout the year. It has to be pointed out that the realistic waste heat reuse indicated requires adaptation of the particle collider operation to the season during which heat is required. Even higher saving potentials than the ones indicated are possible, depending on the adaptation to seasonal territorial heat needs. Second, the adaptive operation of the cooling system and the evaporation towers using advanced supervisory control and potentially artificial intelligence would permit the reduction of consumption to the strict minimum required, compatible with the actual cooling needs. Third, the creation of an additional water intake next to site PD (Nangy, France) would ease the requirements on the overall system. Given that a dedicated water filtering and treatment facility would be required, an initial study aims to verify the use of waste water from the nearby Bellecombe/Scientrier waste water treatment plant (Syndicat des Eaux de Rocailles et Bellecombe). This installation discharges treated water at an average rate of about 550 m^3/h into the Arve River. While in principle technically feasible and economically viable (the annual operation cost per m^3 of water of a treatment plant required for the collider corresponds to the cost of a m^3 of raw water purchased from a water supplier), studies are currently ongoing to estimate the effort to reduce the residual dissolved calcium carbonate ($CaCO_3$) and germs in the water to render it compatible with use in the industrial cooling system.

At this stage, from quantitative and commercial points of view, the reference scenario for water consumption is technically, financially, and territorially feasible, since water extraction and consumption represent quantities lower than CERN's actual past consumption. The availability of a supply representing twice the total maximum requirement was confirmed in 2023.

2.7.9 Waste water management

Connections to the local sewage infrastructure are required at all sites for the management of drainage water in the subsurface structures, rainwater collected and treated water that is purged from the raw-water based cooling systems. The collected rainwater can also be reused on the sites for different project-related purposes and to maintain green spaces. Where possible, all collected water will be filtered and treated on-site before it is released into the environment. From a territorial perspective, this approach is preferred over centralized wastewater management since it is beneficial for sustaining existing creeks, wetlands, and biodiversity in rewilding projects developed in association with the surface sites. Only where the water does not qualify for free release would it be directed into the sewage system (e.g., due to a higher percentage of non-soluble residuals or during periods of heavy rain).

Alternatively, a central waste water management concept based on returning all waste water to a CERN site (e.g., LHC P8 and PA in Ferney-Voltaire) can be considered. For the management of the cooling water, a 'zero liquid discharge' (ZLD) approach can also be considered. ZLD requires the collection of solids from each surface site at regular intervals. A definitive choice of technology has yet to be taken and calls for a comprehensive, wider Cost-Benefit Analysis over the entire project period, covering investments and operational factors. Water treatment technology is advancing rapidly due to environmental and sustainability constraints. It is, therefore,

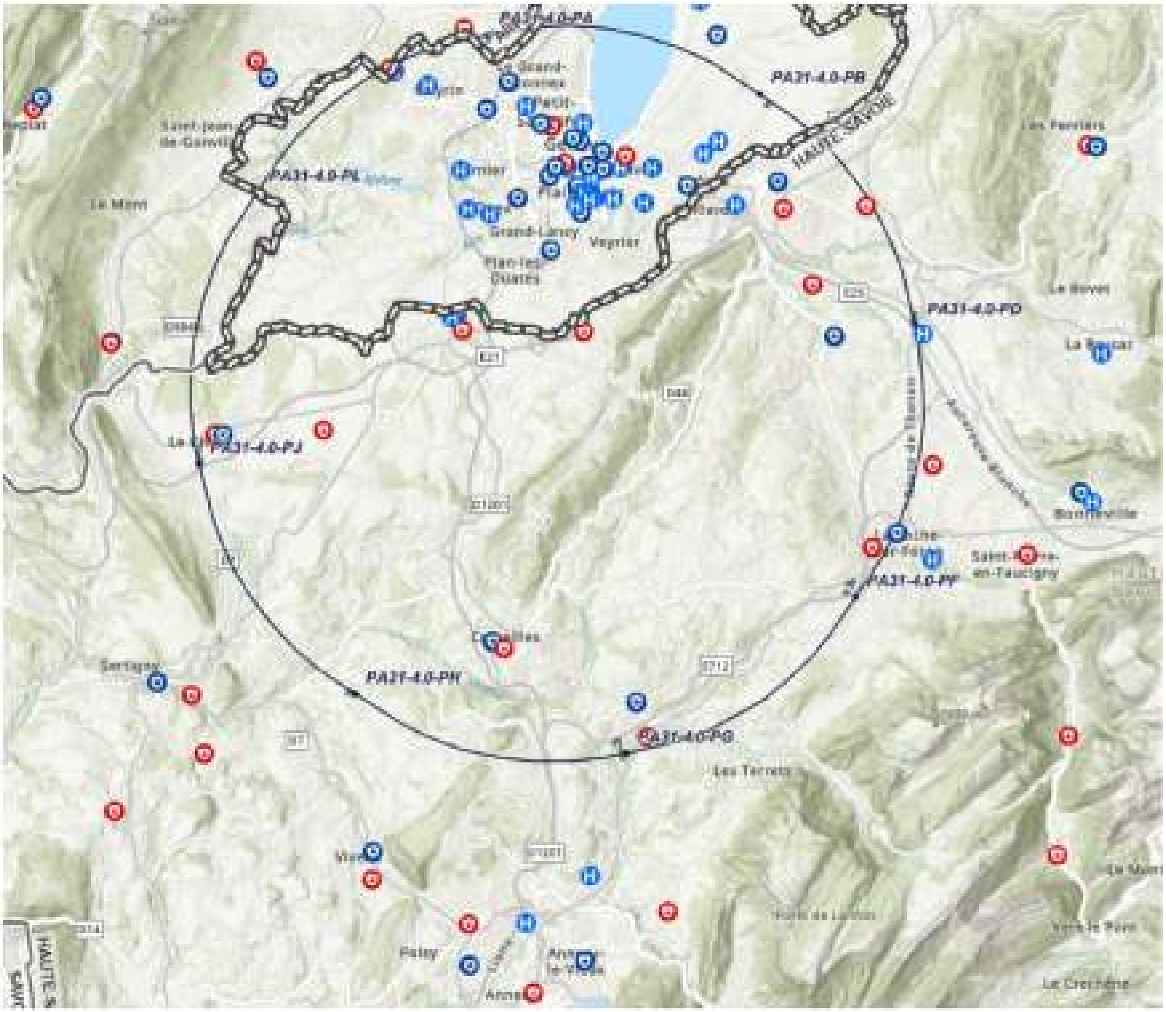


Fig. 2.57 Fire-fighting and emergency services in the perimeter of the reference scenario

wise to consult experienced companies and consider the various options in the frame of the environmental impact assessment before finalising the technology choice.

Waste water from human activities (toilets, sinks, offices, visitor centres, cafés and restaurants) will be directly evacuated via connections to the public waste water system. The design for the waste water network connections is to be developed in cooperation with local public administration services in a subsequent preparatory phase, involving companies' experts in the domain. At this stage, the following configuration is envisaged for the local connections to the waste water networks:

- Site PA: Connection to the waste water network via the LHC Pt8 in France.
- Site PB: Connection to the local waste water network in Presinge, Switzerland.
- Site PD: Direct connection to the waste water treatment station ('STEP') SRB in Scientrier, France.
- Site PF: Connection to the local waste water network in Éteaux, France.
- Site PG: Connection to the local waste water network via the Groisy autoroute station. Alternatively, connection to the network in Charvonnex at the D1203 in France.
- Site PH: Creation of a new local waste water network to the nearest connection point at 250 to 300 m distance in France. The waste water treatment station (STEP) in the vicinity of the site is not capable of accepting all of the waste water from the site in the most demanding cases. Therefore, either the STEP needs to be reinforced for the collider project or the excess water needs to be re-directed via a waste water network in the tunnel to sites PG and PJ. Developing the strategy is part of a subsequent design phase.
- Site PJ: Connection to the local waste water network 500 m away in between Vulbens and Valleiry in France.
- Site PL: Connection to the local waste water network in Challex, France.

Table 2.13 Selection of emergency services in the vicinity of surface sites

Site	Distance	Location	Capacity	Service
PA	1 km	Prévessin, France	66 persons	Departmental fire fighting station CIS Est-Gessien
PB	5.8 km	Chêne-Bougeries, Switzerland	30 persons	Cantonal fire fighting station
PD	0.3 km	Contamine-sur-Arve, France	n/a	Hospital, Centre Hospitalier Alpes-Léman
PD	9 km	Arenthon, France	11 persons	Fire fighting and first aid station
PD	12.1 km	Éteaux, France	68 persons	Regional fire fighting station
PF	3.2 km	Éteaux, France	68 persons	Regional fire fighting station
PG	2.3 km	Groisy, France	50 persons	Regional fire fighting station, emergency service
PH	10 km	Frangy, France	37 persons	Local fire fighting station
PH	14 km	Epagny, France	135 persons	Regional fire fighting station, emergency service
PH	1.3 km	Valleiry, France	26 persons	Regional fire fighting station, emergency service
PL	7.4 km	Thoiry, France	70 persons	Regional fire fighting station, emergency service

2.7.10 Emergency services

The analysis of the different implementation scenarios revealed that the continuation of the existing approach of serving surface sites of CERN's particle accelerators cannot be extended to the perimeter of the future particle collider without significant challenges. Although the surface sites are in the immediate vicinity of major road infrastructures, the distances and the traffic situation would call for intervention times, which would be too long if all sites had to be serviced from the CERN Meyrin site in Switzerland. Locating dedicated emergency service personnel on each of the surface sites is prohibitive from a financial point of view in terms of human resources and equipment, and would lead to challenges in the operational management of the facility. Subsequent analysis of a single dedicated support pole provides only limited improvements with respect to safety and emergency services. Therefore, a detailed geographical analysis was carried out to identify alternative approaches (see Fig. 2.57).

Apart from site PH, the surface sites of the reference implementation scenario are close to firefighting and emergency service stations (see Table 2.13). Some of them have recently been constructed. Therefore, the project scenario can consider making use of support for emergency and firefighting personnel at those stations, accompanied by regular common training and an emergency guidance centre at CERN. The strengthened collaboration of CERN with those services, the contribution of equipment, materials and training also leads to socio-economic benefits. These have been analysed and are part of the wider socio-economic impact assessment.

The build up of these resources and the transition to a new operation scheme require several years of preparation. The ten years of construction phase provide an adequate window of opportunity to launch this process, which requires agreements with the emergency and fire-fighting services.

2.7.11 Territorial aspects for the management of excavated materials

The management of excavated materials represents a socio-economic and project management challenge, beyond civil engineering considerations. The availability of suitable deposits for inert waste is decreasing, and corresponding deposit costs are increasing, with estimated final deposit costs between 385 million and 825 million euros depending on re-use potential [1].

The excavated volume of 6 million m^3 consists mainly of molasse (95%) and moraines (3%). While limestone fractions are re-used within the project, the management strategy for the remainder focuses on:

1. Alleviating pressure on deposit sites,
2. Reducing transport requirements,
3. Optimising project costs,
4. Generating socio-economic benefits by pioneering innovative re-use solutions.

The molasse basin spans across Switzerland, Germany, Austria, and Hungary, making advances in re-use methods broadly relevant. Within the FCC Innovation Study (FCCIS), the international challenge *Mining the Future* [55] was launched to identify technically and economically viable re-use pathways on the 2030 timescale.

Depending on national regulations in France and Switzerland, 15–30% of the molasse may be classified as naturally polluted (e.g., hydrocarbons, nickel, zinc, chromium) and thus require controlled disposal. Clean fractions are primarily targeted for quarry refilling and land rehabilitation.

Fig. 2.58 The OpenSyLab field laboratory on 1 ha of land marked with a red line, next to the CERN CMS Point 5 in Cessy, France, is developing quality managed processes for the transformation of excavated materials for use in rewilding and other societal applications. The field was prepared in the winter of 2025. The scientific development will last for at least four years

The *OpenSyLab* field laboratory on CERN premises (Fig. 2.58) develops quality-controlled processes enabling re-use in agriculture, forestry, rewilding, and construction. As the project commenced in 2025, detailed geotechnical sampling and borehole analyses along the tunnel alignment will define specific re-use pathways. Authorisations can only be requested after these validated, quality-managed processes are established.

Excavated materials currently hold waste status in national legislation due to formal criteria, regardless of origin or contamination level. This complicates the adoption of circular economy principles. A key ruling from the Court of Justice of the European Union (Case C-238/21) clarified that non-contaminated materials can lose waste status if quality-managed processes are in place. This supports their re-use when aligned with Directive 2008/98/EC [8].

To operationalise these principles, the project will implement a comprehensive monitoring system, covering material analysis, on-site processing, traceability, and post-delivery verification.

Transnational logistics require careful planning. Since the fair share principle yields an amount of materials under Swiss territory that is larger than the volume excavated on this territory, a solution for either the repatriation of excavated materials from France to Switzerland or a form of compensation needs to be developed before the excavation process can commense.

Suitable quarry locations have been identified in France (Fig. 2.59), with Swiss data under completion. Short-distance transport will rely on trucks and conveyor belts, while longer distances will favour rail transport for lower emissions.

The open question of railway transport, cross-border traffic and repatriation of excavated materials needs to be resolved. Finally, alternative re-use possibilities at larger distances should be investigated, since once materials are on a railway track they can be delivered with only a little additional carbon footprint. This opens up possibilities for re-uses that are currently not considered.

As a first step, a strategy for the management of excavated materials has been established as a joint effort of technical domain experts and organisations in host states that regularly accompany large-scale construction projects. This includes finalising re-use pathways, securing legal authorisations, and establishing agreements with end-users. Additional geological sampling will refine the re-use estimates, while industrial-scale validation (TRL 9) of treatment processes is targeted within five years. Cross-border transport solutions and expanded re-use options, including distant applications via rail, remain under active consideration to further reduce the environmental footprint of the project.

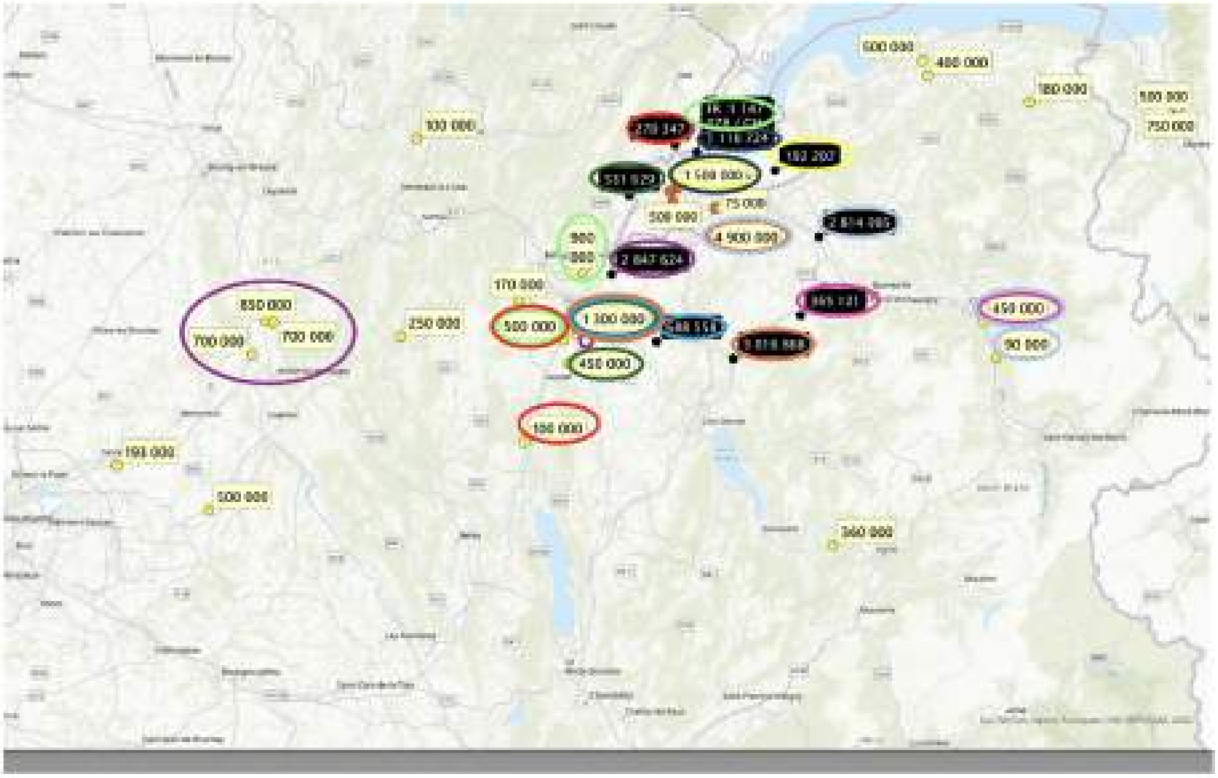


Fig. 2.59 Capacities of quarries that could be re-filled in the vicinity of the project on French territory and in the canton of Geneva in Switzerland. Capacities are indicated in tonnes

2.7.12 Transport and mobility

Concerning transport of materials and equipment and mobility of persons, the following topics are identified in the frame of the territorial implementation project development:

1. Transport of construction materials to the construction sites.
2. Evacuation of excavated materials from the construction sites.
3. Commute of construction workers to and from construction sites.
4. Transport of technical infrastructure and particle accelerator equipment to the surface sites.
5. Transport of goods and consumables to the surface sites for operation, maintenance, and repair.
6. Commute of personnel to and from surface sites for operation, maintenance, and repair.
7. Visitor-induced traffic at experiment sites.

The most important contributor to additionally induced traffic is the evacuation of excavated materials. The strategy for a future project is to limit the use of trucks for transport from the sites and to rely on alternative approaches such as conveyor belts and ropeways to create links to nearby major transport axes (e.g., autoroute service stations, railway terminals, multi-lane departmental roads). Such modalities are also suited for bringing in certain construction materials from the major transport routes to the sites. Where this is not possible, trucks bring in equipment from the major transport axes via temporary routes, e.g., for pre-cast concrete elements and bulky particle accelerator and technical infrastructure equipment. Only where such an approach cannot be avoided local roads will be used for limited construction and installation-related activities. Special transports will be unavoidable, but occur only very rarely and according to planned and authorised schedules and conditions. Construction materials-related traffic is very limited, typically less than 10 deliveries per site that features a tunnel boring machine. The traffic during the installation phase is of the order of 9 deliveries for a technical site and 18 deliveries for an experiment site. The limiting factor is the amount of materials and equipment that can be transferred from the surface to the subsurface, as well as the limited transport and installation capacities in the underground structure.

Today, a preliminary estimate of the number of construction workers per site shows that the presence varies between approximately 50 and 450 throughout the multi-year construction phase (Fig. 2.60). Significant differences

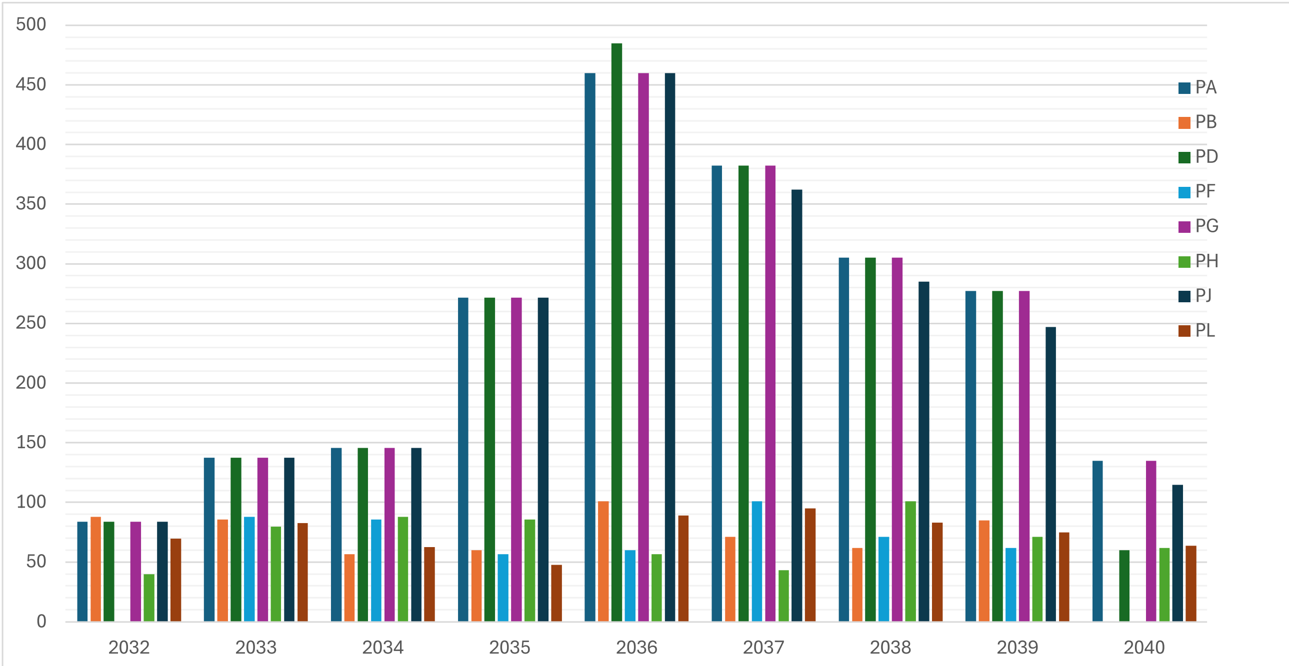


Fig. 2.60 Example scenario of construction workers per construction site and year. A specific personnel and mobility plan has to be developed in the frame of a preparatory phase project when construction activities are defined at a more detailed level

in workers on construction sites occur between sites with tunnel boring machines (PA, PD, PG, PJ) and sites without tunnel boring machines (PB, PF, PH, PL). Sites without tunnel boring machines do not see the presence of more than 100 persons at a time. The amount of workers exceeds 250 people only during the peak activity period between 2035 and 2039. A specific personnel mobility plan can only be developed once the construction activities are defined in greater detail during a preparatory phase project to prepare market surveys and tenders for the construction. To avoid that workers commute individually between the construction sites and their residences, the construction plan will have organised shuttle transfers as is best practice in construction and industrial operation. The same approach will be taken for the installation phase during which about 200 to 300 people would be active on experiment sites and about 100 people on technical sites. A small fraction of people will have to rely on individual car transport. However, it is foreseen to keep such traffic limited to cases where such transport is needed.

Personnel commuting during operation is negligible. For maintenance and repair periods, shuttle transfer can again be foreseen. This also supports the participation of members of the international collaboration who do not necessarily have individual transport means. No more than 10 to 30 people are expected to be present on a surface site, depending on the type: a technical site or an experiment site.

Visitor traffic to and from experiment sites is typically centrally organised with shuttles. If a site features a visitor facility or additional cultural, educational, and leisure infrastructure, capacities for individual traffic have to be planned. Assuming an expected presence of 25,000 visitors per year and per site and 50% of individual visitors with 2 persons per vehicle, the individual traffic is in the order of 5 to 10 vehicle round trips per site and day. It needs to be noted that visits only take place during about 250 days per year and during about 8 hours per day.

2.7.13 Landscape integration and architectural strategy

Context Generic technical designs of surface site buildings have been developed in the frame of the feasibility study to understand the space needs better, the compatibility of the required technical infrastructures with the numerous surface site location constraints (e.g., topography, relief, visibility, nature, technological risks, access, and many others) and the costs. These conceptual developments are not to be confused with specific surface site designs that are eventually turned into plans to be included in the environmental authorisation process. This activity also required and engagement of local stakeholders in participative workshops, compliance with numerous applicable requirements and constraints such as functional and structural performance requirements, zoning limitations (permitted land use), soil and subsurface protection, urban planning documents and regulations,

Fig. 2.61 Three examples of innovative projects designed by the company that was engaged in the feasibility study to develop and architecture guidance toolkit. From left to right: forest tower, living places, urban village

national and international norms, building codes and standards, energy efficiency regulations, safety, emergency response, noise protection, containment of artificial light pollution, accessibility, habitat and biodiversity protection (e.g., corridors and continuities), cultural and heritage considerations, landscape integration and ultimately, a societal licence to operate.

For these reasons and to prepare a potential subsequent project preparatory phase that needs to include the developments of the specific surface sites and the constructions on those sites, the feasibility study launched a first exploratory analysis to identify suitable components for an architectural toolkit that can guide this subsequent work. The architecture concepts have been developed by an expert company with experience in the field of innovative architecture, building design and urban development and planning. A multi-sectoral team of architects, planners, designers and urban planners came together to draw up the seeds that need to be further developed into a comprehensive architectural toolkit for the design phase.

The elements of the architecture toolkit are all based on actually implemented projects Three noteworthy examples (Fig. 2.61 developed by the contract company include:

1. The Forest Tower[3] at Camp Adventure Park in Gisselfeld Klosters Skove, Denmark. This project features a 900-metre boardwalk connected to a 45-metre-tall observation tower, allowing visitors to experience the forest from a unique vantage point. The continuous ramp design ensures accessibility for all visitors, regardless of physical condition.
2. The Living Places Copenhagen, which demonstrates a new way of building homes with a carbon footprint of $3.8\ \mathrm{kg/CO_2/m^2/year}$, three times lower than the current average. This project showcases working sustainability and innovative designs.
3. The Urban Village project develops a model for developing affordable and liveable homes. It comprises the designs of modular, affordable and low-carbon footprint buildings that can be easily assembled in constrained, urban environments.

Another example is the project CO-EVOLUTION, a Danish/Chinese collaboration on sustainable urban development in China, which was awarded the Golden Lion in 2006 at the Venice Biennale of Architecture.

Architectural toolkit The motivation for the development of an architectural toolkit is to support the integration of surface sites as early as possible into their territorial contexts which differ from site to site. An additional question that the toolkit aims to address is how new surface sites can create benefits to the territory and the local communities around the sites.

The toolkit builds on three pillars:

1. Architecture concepts and elements,
2. Landscape and

[3] https://www.campadventure.dk/en/skovtaarnet/.

Fig. 2.62 Examples of elements from the architectural toolkit conceived as a basis to further develop architectural guidelines for surface site developments

3. Community

The three building blocks, architecture, landscape, and community (Fig. 2.62)) are the focus of the integration strategies for the surface sites. The strategies aim to balance technical requirements with environmental sustainability and community engagement. The incorporation of architectural innovation, landscape restoration, and public amenities seeks to minimise the ecological and visual footprint while fostering biodiversity and local engagement.

Architecture The architectural design concepts emphasise sustainable and aesthetic integration into the environment. Designers will adopt modern approaches such for instance green roofs, innovative construction techniques, and facade expressions to achieve these goals. These methods reduce the industrial structures' visual dominance. They facilitate a seamless transition between buildings and the surrounding landscape. Designers are encouraged to explore novel materials and construction techniques that align with both environmental and economic objectives. The incorporation of green roofs not only mitigates environmental impacts but also enhances the visual cohesion between built and natural environments. An example for a recent implementation of this concept is the one of Carlo Ratti for the Mutti food processing company in Italy [56] (See Fig. 2.63).

Fig. 2.63 The green roof created from the excavated materials of the construction site allows the building to blend with its natural surroundings. (Agnese Bedini and Melania Della Grave/DSL Studio)

Landscape design The project plans to employ strategies that prioritise ecological restoration and visual harmony. Key components include:

- Nature restoration: Restoration efforts enhance local ecosystems by promoting biodiversity and increasing resilience against environmental changes. Utilisation of natural terrain: By embedding structures into the existing landscape, designers minimise visual disruptions and maintain natural terrain continuity.
- Utilising the terrain: Working with the natural terrain minimises the facilities' visual presence in the surroundings.
- Green buffers: The implementation of vegetative barriers reduces the visual and environmental impact of facilities, supporting local flora and fauna. The landscape design ensures that facilities are integrated subtly into the environment, allowing nature to thrive while masking infrastructural elements from view.
- Uninterrupted landscape: By embedding constructions into the relief and the landscape, nature can flow uninterrupted above, while the facilities can be partially hidden from view.

Community engagement The project is committed to actively involve local communities surrounding the sites by creating shared spaces, educational opportunities, cultural spaces and visit facilities. Depending on the community support, professional and/or leisure services can be foreseen in the designs. Examples of specific actions include, for instance, the establishment of recreational areas such as community gardens, which utilise unused spaces while benefiting local populations. Providing educational platforms and visiting facilities allows the public to learn about the project's scientific objectives and technical achievements. They permit opportunities for direct engagements with scientists and the international engineering community. Leveraging excess energy for community purposes, such as heating public swimming pools, health and relaxation facilities and supporting other leisure activities, are further possibilities that can be taken into consideration. Through these initiatives, the project fosters a sense of inclusion and provides value to surrounding communities beyond its core scientific mission.

The integration strategies for the FCC surface sites reflect a comprehensive approach to addressing environmental, technical, and social dimensions. By combining architectural innovation, ecological restoration, and community-centred design, the project ensures a sustainable and harmonious coexistence with its environment.

Fig. 2.64 Space requirements for a site and landscape integration of experiment site PA in Ferney-Voltaire, France

These strategies not only aim at mitigating potential negative impacts but also provide tangible and concrete actions to enhance local ecosystems and engage the public effectively.

Site PA Experiment Site PA in Ferney-Voltaire (Fig. 2.64) is located in an already urban environment that continues to see further constructions such as a commercial and high-tech innovation quarter, health-care providers, residential buildings and commercial facilities. Located in a crossborder context with the Geneva airport and a border crossing in the immediate vicinity, the remaining open space would be partially occupied by the surface site. Therefore, a good integration and preservation of the view of the Mont Blanc mountain chain need to be ensured. The surroundings of the site can be restored to create added value for an existing habitat and nature corridor. The image below gives an impression of how the site could embed into the open land, exploiting the immediate vicinity of the existing LHC point 8 (not shown) for any constructions and infrastructures that are not necessarily required to be in the immediate proximity of the two shafts.

Site PB Technical site PB in Presinge, Switzerland, is located in an open agricultural landscape away from villages. The area is, however, frequently used for leisure activities by residents, such as walking and running. Together with the protected nature spaces in the immediate vicinity, the context calls for good landscape integration. Conventional industrial buildings are not an option for this location. The architectural toolkit aims to provide guiding principles that need to be applied together with the local stakeholders to yield an acceptable site that provides the technical functionalities required for the science project. Figure 2.65 outlines the total space requirements for the FCC-ee and the FCC-hh phases. The envelope indicated can be kept as small as possible but as large as needed to develop appropriate landscape integration based on an uninterrupted landscape and nature restoration. The aim

Fig. 2.65 Space requirements for a site and landscape integration of experiment site PB in Presinge, Switzerland

is to create additional value by extending the nature preservation site and providing additional habitat to create improved conditions for biodiversity growth and human leisure activities.

Site PD Experiment site PD in Nangy, France is located between the A40 autoroute and the newly developed RD903 multi-lane departmental road that passses right outside the southern end of the site. The surroundings are dominated by the large regional hospital 'CHAL', an industrial zone in the north with a large milk processing facility and a mixed commercial and residential quarter on the opposite side of the multi-lane departmental road. Although the area is large and open, the site is not highly visible, since it would be developed on a slope. The topographic conditions call for a terracing approach from north to south, as shown on Fig. 2.66. Although buildings and equipment for the hadron collider phase do not need to be constructed for the first, lepton collider phase, the site development and landscape integration call for a planned site development of the terraces from the onset. Green spaces will, therefore, dominate the site during the first operation phase. Access to the site from the north is exclusive, so no additional traffic is generated.

Site PF Technical site PF in Éteaux, France is directly located on a national road with heavy traffic. A public works company is established on the opposite side of the road. The area is characterised by an open view towards the Pre-Alp mountains and the slope falling off to a forest and small creek in the south at the A410 autoroute making the site partially visible from the national road. The architectural toolkit provides means to foresee the restoration of nature in this location, thus creating added value despite the consumption of agricultural space.

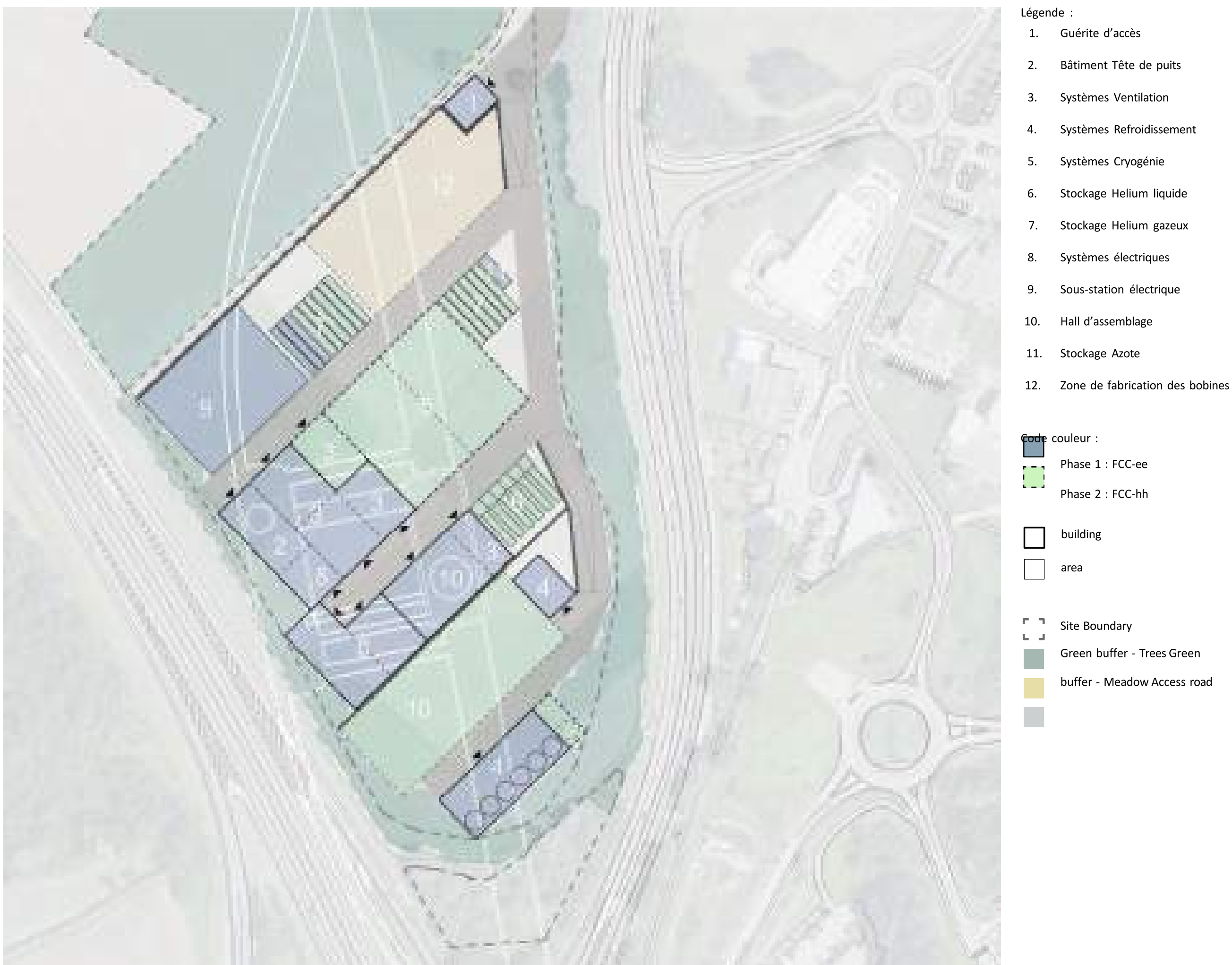


Fig. 2.66 Space requirements for a site and landscape integration of experiment site PD in Nangy, France

Wetlands in the immediate vicinity of the site that are not adequately preserved today can be improved to create habitats and catalyse the lasting growth of biodiversity in this area. Figure 2.67 shows the space requirements for the technical site and the opportunities for the wetland restoration in the west. The restored space is approximately as large as the constructed space.

Site PG Experiment site PG spanning an area across the borders of Groisy and Charvonnex in France is located in a mixed natural environment, a forest, and a pasture used for cattle. Avoiding the forest is not possible, since the main shaft to the experiment cavern cannot be displaced and only little flexibility exists for adjusting the location of the shaft to the service cavern. The habitat and biodiversity constraints generated by the forest call for a reduction of woodland consumption as much as possible. Consequently, a split site location is envisaged that places visually and noise-impacting infrastructures close to the autoroute in the north, facilities that can be displaced to the open plateau outside the forest and keep only strictly needed equipment such as lifts and ventilation close to the shafts. The result is a site that covers a larger area but which impacts nature much less than a monolithic site. The configuration permits the creation of added value through a visiting facility. The first phase dedicated to the lepton collider would keep the spaces largely free of construction and green. Only the second phase, dedicated to the hadron collider, calls for temporary constructions for winding the coil of the detectors and permanent cryogenic refrigeration systems. An area and trees equivalent to the cleared area and trees can be re-created on the site area that is currently open pasture and on clearings in the forest that have been created historically. This means that the site development will eventually aim at an overall neutral balance with respect to habitat and biodiversity preservation and it can create added value through visitor facilities. Figure 2.68 shows the space requirements for constructions at the main site location (right) and the annex close to the autoroute

Fig. 2.67 Space requirements for a site and landscape integration of technical site PF in Éteaux, France

(left). The green spaces for nature restoration and an example of a visitor facility can be seen in the bottom part of the main site.

Site PH Technical site PH in Cercier and Marlioz in France would be entirely located in a woodland on a rather steep slope at the nominal location. In terms of integration, the main technical challenge is the slope that calls for a terracing approach. The site would be entirely hidden in the forest. The technical requirements for hosting all equipment to operate the radiofrequency system require, however, substantial space (Fig. 2.69). The major construction elements are the 400 kV electrical substation, the power converters, and the cryogenic refrigeration system.

Although the location is technically feasible, environmental impact analysis and engagement with local stakeholders following the avoid-reduce-compensate scheme may still call for further reduction of space consumption. In this case, splitting of the site into an electrical part that can be further displaced and elements that need to be close to the shaft (cryogenics, cooling, ventilation) can be re-considered.

From an architectural perspective, the site buildings are less demanding than the others since the site is invisible from the outside.

Site PJ Experiment site PJ in Dingy-en-Vuache and Vulbens in France is located in an agricultural area just south of the A40 autoroute, with existing road access to Vulbens. The existence of a fauna corridor will need to be considered when developing the site integration. The site is not visible from the autoroute or the communes. It is remote from any hamlets or individual houses. The topographic and relief constraints call again for a terracing

Fig. 2.68 Space requirements for a site and landscape integration of experiment site PG in Charvonnex and Groisy, France. The right image concerns the main site around the shafts and the left image depicts the annex close to the autoroute that helps to reduce the impacts on nature, habitat, biodiversity, visibility and noise

approach that makes it necessary to prepare the entire site for both collider phases (ee and hh) from the onset. The terrain provides a good means to integrate the site visually and to foresee a visit facility. The existence of developing soft mobility connections between the communes in the vicinity can also be integrated in the site planning. Most of the surface would be kept as grassland until the second particle collider is installed. Several spaces that would be needed for this phase would also be created already during the first phase, since the terracing approach permits the creation of covered and half-buried volumes that can be used for different purposes at different times. As at other experiment sites, coil winding and detector assembly facilities would only be temporary. These areas would be restored to green fields afterwards (Fig. 2.70).

Site PL Technical site PL in Challex, Ain department, France would be located on an open, flat, agricultural space and the location of two individual houses. Vineyards in the vicinity on Swiss territory exist on slopes that fall steeply off to the Rhône river and to the Allondon river zone. The vicinity of the site location outside the village is used for leisure activities such as walking, hiking, running and visiting the vineyards by local residents and by tourists. Full exploitation of the architecture guidance toolkit for very good integration into the landscape is therefore a primary goal. Since the very even terrain cannot be effectively utilized to integrate the site into the landscape, lowering the site a little to avoid disrupting the landscape can mitigate some of the visibility challenges. Facade expressions, natural construction materials, green facades and roofs, and visibility screens will be essential elements for the site architecture and design. The surface area foreseen for this site (Fig. 2.71) includes an additional green buffer on space that is unusable for agricultural exploitation to be able to ensure that the visibility of the site can be kept low and that the integration can be very well planned and implemented. Such integration also helps improve the habitat value, supporting the thriving of biodiversity and making the area more attractive for leisure activities. Only a small difference between the lepton and the hadron collider phase constructions is planned, ensuring that the site is developed definitely as much as possible from the onset.

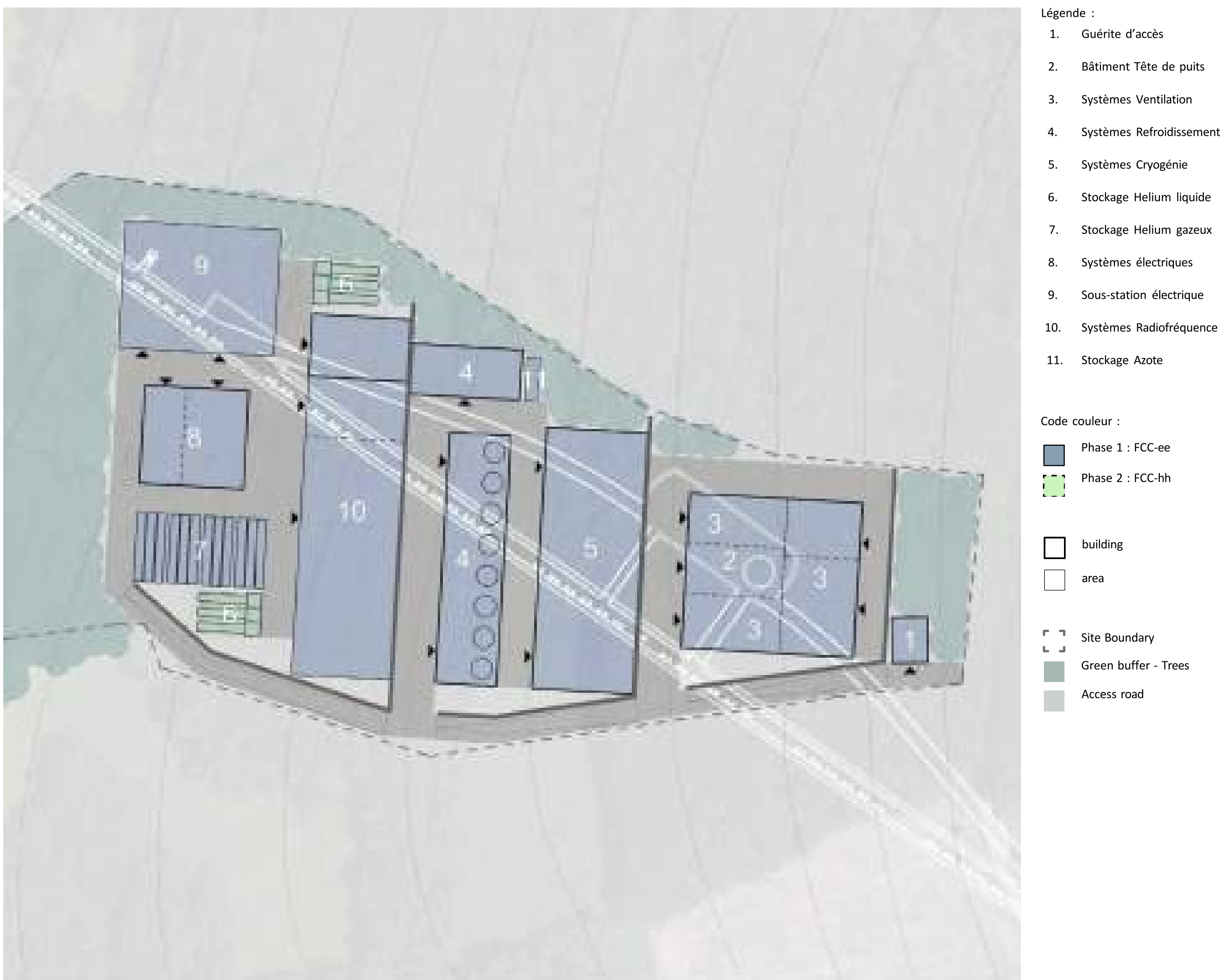


Fig. 2.69 Space requirements for a site integration of technical site PH in Cercier and Marlioz, France

Conclusions Figure 2.72 depicts the results of the application of the architectural toolkit on some of the surface site locations. These works do not represent designs or specific architectural choices for the implementation. They serve as a tool to engage with the local stakeholders to start a dialogue on the needs and constraints in each location. They permit developing architectural concepts and designs as a cooperative effort, federating the scientists and engineers designing the research infrastructure, the architects and landscape planners developing the sites, and the local stakeholders. The engagement first takes the form of collaborative workshops with representatives of the population and interested local stakeholders in each location. This phase also includes common field visits to get a better understanding of what can realistically be envisaged and what is needed both from technical and stakeholder sides. Requirements and constraints from the technical project will be integrated in that activity. Once the boundary conditions are agreed upon and documented, a further, more detailed phase can start in which architect-engineers develop specific scenarios for the sites. The goal is to come to well-balanced and adequately integrated site designs in a subsequent project preparatory phase. The results in the form of design plans, descriptions, and construction prescriptions will be included in the environmental authorisation process in each host state.

It should be noted that the architectural concept and design developments of a public project of this scale with eight new surface sites occupying several ha of space each call for a timely market survey and tendering process for a qualified partner. The availability of such an architectural company must be ensured in terms of minimum personnel and uninterrupted time to work on the project. The entire development process is estimated to span several years.

Fig. 2.70 Space requirements for a site integration of experiment site PJ in Dingy-en-Vuache and Vulbens, France. The architecture toolkit suggests centring the site between existing tree lines to ensure that functional fauna corridors are created. Compared to today, they can lead to an improvement of the habitat conditions

Chapter 3

Environment

3.1 Context

The international, collaborative FCC feasibility study created a basis for the subsequent environmental authorisation processes of the project in the two Host States, aiming at a single permit for the project in each country. The term *project*, in agreement with the national and internationally applicable regulatory frameworks, refers to *any intervention in the natural space including the soil*. It requires three essential parts:

1. An intent to construct that is communicated to authorities.
2. A documented definition of the scope of the project, comprising indirect and induced connected projects.
3. A documentation of the project boundaries and interfaces.

The term *project* is to be understood in a broad sense. It embraces all elements that are required to construct and operate the particle-collider-based research infrastructure. It includes, therefore, (1) the research infrastructure and (2) all territorial enabling developments and elements in France and in Switzerland that are required to construct and operate the research infrastructure.

Fig. 2.71 Space requirements for a site integration of technical site PL in Challex, France

The research infrastructure, in turn, is composed of the subsurface and surface structures, all technical infrastructure, the particle accelerators and the experiment detectors. The territorial development elements include, but may not be limited to: raw and drinking water supply; non-public sewage and water treatment; low, medium and high voltage supplies; access roads; optional autoroute and railway accesses; facilities for waste treatment and management; excavated materials storage; final depot and re-use sites; compensation sites.

Territorial annex projects will need to be considered and developed collaboratively with the Host States. For instance, these may include, but are not limited to, emergency and safety services, as well as temporary housing related to the construction phase, reinforcement of education facilities for workers and project participants (e.g., schools), health services for workers and project participants, district heating networks to supply the waste heat to consumers, water intakes that are shared with public clients, a regional geodetic network. Consequently, the project consists of segments that can ultimately be undertaken by different organisations and may involve multiple actors with distinct responsibilities. Defining the scope, boundaries, and interfaces will therefore be of utmost importance for a construction preparatory phase. This study was limited to the identification of the most relevant project segments and the launch of the process for gathering their requirements and key characteristics.

The term *environment* refers to all elements that surround the project (Fig. 3.1). According to the EU regulation EC 2011/92/EU and the French 'Code de l'environnement', articles L.122-1, R.122-2 and the European Norm EN 14001 Sect. 3.2.1 the environment is to be understood in the largest sense. Specifically, the French *Code de l'environnement* (article L110-1) includes aspects such as the spatial context, natural resources, habitats, noise, odour, sites, landscape, air quality, all living species, biodiversity, soil, geodiversity (subsurface conditions), fauna, flora, climate, social coherence, economy and the well-being of human beings. In Switzerland,

Application of the architectural language elements to the experiment site location PA in Ferney-Voltaire, France

Application of the architectural language elements to the experiment site location PD in Nangy, France

Application of the architectural language elements for the concept of a visitor center at PG in Charvonnex/Groisy, France

Application of the architectural language elements to the technical site location PL in Challex, France

Fig. 2.72 A collection of some artist concepts that result from the application of the architecture toolkit to individual site locations. Landscape integrated designs call for early preparation of the plots, and green buffers will have to be prepared during the subsurface construction phase to be able to screen the sites from the beginning

Fig. 3.1 The environment refers to all elements that surround a project and their interactions with the project and among them. It is to be understood in the largest sense

the *Manuel de l'Étude d'Impact sur l'Environnement* (Manuel EIE) guides environmental impact assessments under the *Ordonnance sur l'étude d'impact sur l'environnement* (OEIE), derived from the *Loi sur la protection de l'environnement* (LPE) at federal level. It covers climate, sites, historical monuments, archaeology, natural dangers, territorial and spatial development, air, noise, vibrations, energy, non-ionising and ionising radiation, subsurface water, surface water, aquatic ecosystems, water management, soil, polluted sites, waste, dangerous substances, dangerous organisms, prevention of major accidents, forests, flora, fauna, biotopes, landscape, light immission, paths for pedestrians and hiking, cross-border effects, as well as cantonal environmental protection regulations as long as they do not disproportionately limit the implementation.

Following the requirement to identify and understand the direct and indirect interactions of the segments and the potential challenges that emerge from them, a variety of topics need to be considered. These include, for instance, but are not limited to the geology, hydrogeology, urbanism, health and safety of people, the well-being of all living species concerned, traffic and mobility, services and infrastructures, natural and cultural heritage, traded goods such as waste of all types, synergies, and conflicts with other planned projects, material goods such as physical items that are privately or publicly owned, technical risks, and many more.

An environmental *aspect* refers to any project element or process that interacts with the environment. Identifying and prioritising these aspects hierarchically is a prerequisite for environmental impact assessment. Several can be identified and quantified early; though eventually, they depend on requirements and design choices. The challenge in large-scale particle collider projects is their iterative, decades-long design process. While subsurface structures and construction are planned first, technical infrastructures follow accelerator and experiment designs, with surface structures finalized later to incorporate advanced techniques and stakeholder-driven landscape integration. This evolving process, guided by a plan-do-act-check cycle, generates a challenge for a timely impact assessment for long-term projects with territorial implications.

An environmental *impact* is any change to the project environment resulting from an identified, relevant environmental aspect. It emerges from the intersection of the environmental sensitivity in a certain location (environmental issues and challenges) and the potential effects of an environmental aspect of a project element (Fig. 3.2). The impacts can, therefore, only be analysed and assessed for a specific, localised project scenario. The impact assessment also requires a certain stability in the designs and a sufficient level of design detail. In practice, the following elements are required for the impact assessment:

1. A specific project scenario (description, location, scope, boundaries, interfaces).
2. Specific construction plans.
3. Specific designs of the technical infrastructures, machine and experiment elements.
4. Descriptions of the construction processes.
5. Detailed operation concepts.
6. Prescribed procedures for operation, including the handling of failure cases and accidents.
7. An analysis of the current (initial) state of the project environment (at least over four seasons).
8. As a result of the initial state analysis, the prioritised issues and challenges of the locations in which the project will be embedded.
9. The descriptions of the goods, products and resources (and their origins) used during all project phases, e.g., a procurement and transport scenario hypothesis.
10. Relevant management concepts for all waste during all project phases.

Assessing the environmental compatibility of the project involves an environmental impact study. It is part of the single environmental authorisation process in each Host State. It concerns the analysis and assessment of the relevant environmental effects of aspects of the project by crossing them with the environmental issues and

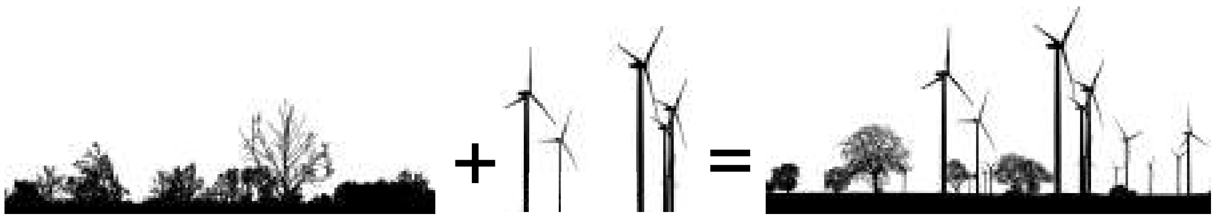


Fig. 3.2 Environmental impacts are a consequence of the environmental sensitivity at a certain location (issues and challenges) and the potential effects of environmental aspects of a project at that location

challenges (also called 'stakes') that have been identified and recorded in the frame of the initial state analysis in project-specific locations. This legally required process concerns the verification of the project's compliance with the regulations. It includes an iterative improvement of the project scenario following the Avoid-Reduce-Compensate scheme that has already been adopted and used during the development of the layout and placement scenario. Public participation is a key element of this process, in line with the Aarhus agreement [57], a UN convention that has been ratified by France in 2002 and Switzerland in 2014 to ensure access to information and public participation in decision-making and access to justice in environmental matters.

3.2 Environmental aspects

3.2.1 Methodology

Identifying and gathering the environmental aspects, i.e., any element of the project that can interact with the environment, is a pre-requisite to be able to plan the environmental impact assessment during a subsequent project preparatory phase. This work started with the availability of technical design concepts in 2024 and will continue after the end of the feasibility study. It permits the establishment of a baseline of potential environmental effects assuming current state-of-the-art technical choices, i.e., without optimisation and not foreseeing technical evolutions and improvements beyond what industrial partners expect that they can deliver today.

The identification of environmental aspects and the assessment of potential environmental effects are conducted systematically using configuration-managed system description sheets. These sheets are jointly developed by environmental engineers and subsystem engineers for all project elements.

However, technical infrastructures located outside the FCC site boundaries — such as access roads, highway connections, potential railway links, public electricity grids, and sewage and water networks — are not included in this approach. These elements are addressed in separate, dedicated environmental impact studies, instead.

Information systematically gathered and compiled in an environmental aspect report [58] serves the following purposes:

- Identify companies suitable to produce environmental impact studies;
- Inform Host State environmental notified bodies about the project scope, contents, and interfaces in order to engage them effectively;
- Inform the public about noteworthy project elements and their environmentally relevant elements;
- Provides a baseline for the project engineers for the implementation of the eco-design approach;
- Guides the environmental impact assessment;

Consequently, all information gathered is documented in French and in a language that permits non-experts to understand the project, the project's technical equipment, and the potential environmental effects linked to those elements.

Depending on the potential environmental effects, the documentation concerns different project segments at system or subsystem levels. Irrespective of the granularity of the element concerned, the following information is gathered and documented:

- Name of the system or subsystem;
- Maturity level of the requirements and designs;
- Linkages and connections to other systems such as a particle accelerator, a technical infrastructure or an experiment;
- A short (around 80 words or one paragraph) non-technical description of the system's purpose: What does the system do and why does it exist;

- A compact (up to one page) functional description of the system: what functions does the system implement, how is it composed and how does it accomplish its purpose;
- The system's capacity and performance including the following information: capacities in different operation modes with a description, number of units deployed, energy needs, resource and raw materials needs, if and how the system transforms energy, types and quantities of emissions together with an estimate of the environmental relevance (including a description of waste production related to the system), known losses and inefficiencies in supplying the intended function, known space requirements. For all system capacities and performance characteristics, an indication of the confidence level and stability of the information is provided.
- Locations at which the system is deployed.

This description is complemented by a structured summary of noteworthy environmental aspects and effects during normal operation, in degraded functioning, or in case of an accident. The following types of aspects are considered:

- Release into water, soil, subsurface, air (including odour);
- Waste production in terms of conventional and radioactive waste;
- Use of electrical and other sources of energy;
- Consumption of raw materials;
- Consumption of natural resources: water, land, natural habitats, aquatic habitats, protected zones, protected subsurface, agricultural space, protected agricultural space and others;
- Use of consumables (chemical products, for example);
- Energy emissions such as non-ionising and ionising radiation, noise, vibration, heat, light or other forms of energy.
- Effects on human environment, material goods and heritage such as traffic and transport ways, landscape, visibility and co-visibility, health, increase of technological risks, agriculture and forestry, constructed spaces, technical infrastructures, demographic development, territorial developments, urbanism, tourism and leisure activities.

The aspects are reported per project phase (construction, installation, operation, maintenance and repair, decommissioning). For each aspect, the likelihood of occurrence is indicated and the potential effect in case it materialises. Its relevance is also indicated in order to be able to create a hierarchy of environmental aspects. Finally, the level of confidence is provided for that piece of information.

The descriptions are complemented with high-level functional diagrams and drawings and references to supplementary information that provide evidence for the source of information and to permit technically interested readers to obtain further information.

3.2.2 Scope

The systematic methodological approach to establishing a first inventory of environmental aspects of the entire project comprises a large variety of project elements with the aim of being as exhaustive as possible given the constraint that the level of requirements and designs at this preliminary stage is still low.

The following topics and elements are included in the inventory and report:

1. Lepton injector: sources, positron production, linear accelerator and transfer lines to the booster.
2. Lepton collider: the collider as a whole and indivisible entity, magnet circuits, magnet power supply, vacuum system, radiofrequency system, beam transfer systems, beam interception equipment. The systems and equipment dealt with are also applicable to the environmental aspects of the booster.
3. Geodetic network and installations.
4. Data communication networks in the entire perimeter of the project, including safety-related communication equipment.
5. Experiments: the research programme and its duration up to the end of the century, a generic detector and a working assumption for its subdetectors, the technical infrastructure systems required to operate the detector, the data acquisition and online computing infrastructure.
6. Technical infrastructures: ventilation systems, compressed air production, connections to the French national high capacity electricity grid for operation, local electricity distribution networks primarily intended for construction, short-term energy buffering systems to ensure the stability of the electricity supply, emergency energy supply, general communication networks, cryogenic refrigeration system, cryogen storage, drinking water supply, raw water supply, water cooling systems, demineralised water production, chilled water production, cooling tower water management, underground water drainage recovery and evacuation, management of used water, clear water management (including rainwater), and personal safety systems.
7. Hadron collider: the research programme, the injectors, the collider, the experiments and the technical infrastructures at a high level, with a baseline of today's technologies.

8. Subsurface structures with a focus on the construction: shafts, transfer line tunnels, caverns, accesses, elevators, and subsurface transport systems.
9. Surface sites with a focus on the construction: Site locations and functions, each individual net site (PA, PB, PD, PF, PG, PH, PJ, PL), the re-use of LHC point 8 for site PA, the Prévessin and Meyrin sites at a high level.
10. Territorial developments in France: electricity supply for the construction, electricity supply for operation, drinking water, sewage, used water treatment, options for additional supply of cooling water, access roads, access to autoroutes, options for railway accesses, emergency services, communication network needs, needs concerning the management of excavated materials, requirements for the supply of waste heat, local transport needs for the construction, installation, and operation phases.
11. Territorial developments in Switzerland: electricity supply for construction, electricity supply for operation, drinking water, sewage, used water treatment, raw water supply for cooling, site access, options for railway access, emergency services, communication network needs, needs concerning the management of excavated materials, requirements for the supply of waste heat, local transport needs for the construction, installation, and operation phases.
12. Construction phase: a dedicated description of the environmental aspects linked to the subsurface construction activities and the development of the surface sites, a preliminary schedule, descriptions of the construction sites, preparation of the sites before construction starts, management of the construction sites, management of the personnel engaged in the construction, the supply of construction materials, resources required for the construction, shaft and cavern construction processes, tunnel construction processes, surface site civil structure construction approach, principles for the management of the excavated materials, site restoration after construction.
13. Installation phase: Installation of technical infrastructures, particle accelerators, the detectors, supply of the cryogens, transition of the technical infrastructures, the detectors, and the accelerators into operation.

3.2.3 Status and conclusions

The establishment of the comprehensive environmental aspects report [58] is currently in progress. It is an iterative work that advances with the gathering of requirements and suitable technologies to establish a baseline and credible outlooks for future technologies and approaches.

The civil engineering construction phase (underground structures and surface sites), the technical infrastructure systems, and the lepton collider systems are described according to the currently established baseline, along with the corresponding preliminary confidence and detail level. This preliminary analysis will evolve as more detailed construction details and plans become available.

Requirements for materials and resources that form the basis for an iteration of the environmental aspects analysis must be understood to be approximate and linked to certain uncertainties. In particular, only a high-level description of a generic experiment detector is available today as a baseline for further studies. This description is based on current state-of-the-art technologies for detectors, typical detector technical infrastructures and data acquisition and processing. The subsequent design phase must at least include individual descriptions of four specific experiment detectors with more tangible and technical design assumptions based on a reasonable technological outlook for the coming years.

Conducting an environmental impact assessment requires detailed plans. If technical designs for particle accelerators, experiment detectors, and their associated infrastructures are unavailable, voluntary commitments on performance characteristics must be established.

The lepton injector and its systems and the installation phase, including commissioning, are currently under pre-study. Descriptions are, therefore, not included at this stage. The territorial developments in France and Switzerland have not yet been precisely defined. However, the minimum needs are known and have been included. It should be noted that some adjustments of site locations may still be required, depending on the progress of the dialogue with local stakeholders in the vicinity of such sites.

At this stage, the main environmental aspects discussed in this chapter are linked to the construction activities: the territorial development of some 50 ha of land spread over eight new surface sites, the generation of ∼6 million m^3 (in situ) of excavated materials and the nuisances that are linked to any construction activity (e.g., noise, vibrations, dust, artificial light pollution, additional traffic).

Consequently, the study anticipated a life-cycle analysis of the construction activities to gain a better understanding of other potential environmental effects on climate and the depletion of natural resources [59]. Contrary to conventional subsurface constructions, the creation of civil engineering structures for a research infrastructure is less impactful. The LCA was based on actual available low-carbon footprint products backed by EN 15804 certified Environmental Product Declarations (EPDs) and construction processes that foster short supply chains and construction prescriptions that consider responsible use of resources. The resulting estimated carbon footprint covering the A1 to A5 lifecycle phases concerning the construction phase is about 0.53 million tCO2(eq). This value can be compared to CERN's current carbon footprint of 0.36 million tCO2(eq) in 2022, covering Scope 1, 2 and 3 emissions. It must be noted that for carbon accounting the emissions must be distributed over the potentially contributing countries; consequently, the resulting annual impact per capita is about 0.11 kg, limited to the construction period. For comparison, the Paris Agreement defines a carbon budget of 2000 kg per capita per year. The effects are mainly induced by two types of construction materials: ready-made concrete and steel. Design optimisations and technological progress will permit further lowering the footprint. An update of the lifecycle analysis can be carried out during the technical design phase to quantitatively report on the reduction effects. A dedicated environmental impact assessment will consider the directly related construction effects and their management. The planning of the construction process will have to include an environmental impact management plan that describes the responsible use of resources (e.g., water), the management of the construction activity-related waste production and the management of the construction-related traffic.

Concerning the management of the excavated materials, the initial inventory of locations to permit refilling quarries and deposit of non-reusable materials revealed the technical and managerial feasibility of the construction. However, in an effort to increase the reuse, a dedicated multi-year study has been launched in 2024 on CERN terrain with excavated molasse materials from the HL-LHC construction to develop quality-managed processes to transform the molasse into reusable materials. The pathways include rewilding projects (e.g., restoration of wasteland and preparation of the lower soil layers for new agricultural areas with fertile topsoil), the creation of raised hedges, the stabilisation of roadsides, the treatment of rural and forest paths, the creation of parks and mini forests and the improvement of poor agricultural soil. Further applications, such as the production of insulation materials and non-structural construction materials, are being developed with industrial partners. The goal is to limit the pure deposit of non-reusable materials to 30%. It is important to recognize that, at this stage, no definite statements about the re-use fraction can be provided due to the need to get an understanding of the excavated material's characteristics with dedicated subsurface investigations. However, FCC collaboration is actively investing in research and development of different innovative solutions to maximise material reuse and minimise environmental impact.

Although the additional traffic induced by the construction activities is limited with respect to the existing road traffic (between 2 and 15 transports per hour at the 8 sites during working hours, representing an addition of 0.15 to 1.8% of the total traffic, depending on the site) in the immediate vicinity of the construction sites, care will have to be taken to develop a solid plan of the transport activities. This will include the preference to transport excavated materials to the nearest major transport axe by conveyor belts and to optimise the supply of materials from the transport axes to the sites (e.g., conveyor belts and optimised logistics). The goal is to avoid transit through residential neighbourhoods and small roads as much as possible. The transport concept is part of the construction planning, the associated authorisation process, and the subsequent requirements that are to be included in the tendering procedures.

The artificialisation[4] of land and the linked loss of habitat and biodiversity has been quantified and included in the socio-economic impact study. This effect is intended to be largely mitigated with rewilding projects around the sites and the re-creation of agricultural spaces. The environmental impact assessment will need to develop these measures in detail.

During construction and exploitation, noise is a topic that can lead to notable effects in a few locations where residential houses are within a perimeter of between 100 and 300 m around the sites. The effects have been quantified and are included in the socio-economic impact study. The environmental impact assessment will have to include the development of adequate protection measures following the avoid-reduce and compensate approach. So far, the potential effects revealed are limited to less than 10 households in total for the entire project.

The effects of ionising radiation have also been quantified and have been found to be insignificant (actual annual dose in the vicinity of surface sites below 0.01 mSv/year well within the natural background radiation of about 0.8 mSv/year). This is because, based on CERN's multi-decade experience of operation, the scientific research installations generate additional ionising radiation far below the permitted thresholds with no health effects. Nevertheless, the applicable socio-economic quantification methods have been used to cost the effects and report them. The environmental impact assessment will need to include all the required monitoring and protection measures to ensure that the potential effects are maintained at an insignificant level.

Noteworthy effects are expected to be primarily indirect, arising from the supply of raw and construction materials, as well as off-site emissions. These include Scope 2 emissions, which result from the electricity, heating, or cooling purchased to power project-related operations, and Scope 3 emissions, which encompass the broader environmental impact across the value chain, such as the production and transportation of materials, construction activities, and waste management. To address both aspects linked to the construction of the facility and the scientific instruments and their operation, a procurement plan that includes the environmental aspects will have to be developed and implemented. A first analysis carried out with experts in the domain of energy procurement

[4]May be defined as: the transformation of a soil of agricultural, natural or forestry character by management actions, which may result in its total or partial waterproofing.

revealed that a large coverage of supply from renewable energy sources keeps the indirect emissions low. Privileging electrified construction methods on a time horizon of 10 years can be foreseen. Entering operation on a 2050-time horizon, in turn, offers the possibility for substantial energy supply coverage from renewable energy sources. Supply of waste heat, in particular when the research infrastructure operation is adapted to the local and seasonal needs, can largely help to reduce the carbon footprint by replacing conventional, fossil heat sources. The supply of raw and construction materials for the infrastructures and instruments will need to be well-planned and included in the procurement and in-kind supply requirements. The market is currently evolving fast in Europe towards fostering recycled materials (e.g., steel) and low-carbon production (e.g., concrete). The application and requirement of European Norms such as product comparison based on EPD (Environmental Product Declarations) are needed to ensure a low environmental footprint. Further lifecycle analysis for technical infrastructures, particle accelerator components and experiment detectors are needed in the subsequent design phase to develop these requirements. Gases that are harmful to the environment will need to be avoided if they have not already been taken off the market.

The surface sites lead to noteworthy environmental effects that are mainly linked to visibility. These must be addressed in the design phase through the engagement of the public who is directly affected or concerned in cooperation with architects who have experience in landscape integration of industrial and functional buildings. Preliminary studies have been carried out, and they confirm the existence of suitable approaches and technologies today.

Each site presents unique requirements and constraints that must be carefully considered. A key challenge for the integrated project is the evolving definition of the space required to accommodate technical equipment for the lepton collider, along with the long-term needs for a potential future hadron collider. In locations where seamless landscape integration is a priority, constraints will play a determining role in decision-making. A balance must be struck between minimising the site footprint for efficient land use and ensuring that the infrastructure can accommodate both the initial and potential second collider phases.

The consumption of agricultural space and forest not only leads to a reduction of habitat and biodiversity but also has tangible economic impacts. The loss of income (direct, upstream and downstream) has been analysed and quantified and is included in the socio-economic study. Compensation proposals need to be developed. While in Switzerland, only a one-to-one compensation of the space is acceptable, in France, collective compensation measures can also be jointly developed with affected stakeholders during the environmental impact evaluation phase. The direct compensation for the loss of protected agricultural space involves the transfer of the high-quality topsoil to locations with either poorer soil quality or wasteland that will need to be refurbished. The loss of forests limited to France can for example be partially compensated through re-forestation in the vicinity of the surface sites and at specific locations. The notified bodies will be consulted for recommendations and validation for compensatory measures.

Water consumption remains within current levels, as the requirements for the FCC-ee are similar to CERN's current needs. Recognising the importance of responsible resource management, efforts will be made to limit water use. The FCC-ee replaces the Large Hadron Collider's water demand. Considering the continuous depletion of water resources, protection of water resources and reduction of water consumption are part of the eco-design goals. Therefore, studies are underway to understand if and how treated wastewater can be used for cooling purposes. The initial results confirm, in principle, its technical and financial feasibility. Local effects may remain with respect to water needed during the construction phase. The subsequent environmental impact study must therefore include a water sourcing and management plan to ensure that there are no noteworthy local impacts due to the construction activities which affect the population and the existing economic activities.

The construction and operation of the research infrastructure entail generating significant amounts of conventional waste. The subsequent environmental impact study will detail the types and quantities. The effect stems mainly from procured goods and therefore to manage this issue, waste avoidance and management must be included in the procurement process. Since the operation of a new research infrastructure replaces the operation of CERN's current flagship project and the number of persons involved is expected to be stable over time, the daily waste production is not expected to grow. Continuous efforts to reduce waste generation, fostering reuse first and recycling in line with the Host State regulations is expected to lead to a continuation of the waste reduction already engaged today.

Finally, the aim to keep environmental impacts within acceptable limits calls for an adaptive operation concept. Considering climate change effects and the need to generate environmental benefits to balance negative externalities requires the inclusion of external constraints into the operation. For instance, the optimisation of the waste heat supply may call for a shift of operation into colder seasons. The operation of the particle accelerators could be linked to the availability of abundant renewable energy via online notifications received by a link with the energy supplier. The operation may also need to include consideration of the changes in secondary circuit cooling water temperatures due to the long-term evolution of the climate. The presence of personnel also means having to consider seasonally changing working conditions. For instance, it can be more sustainable to work during colder seasons than in hotter ones since heating can be achieved by waste-heat recovery, but cooling requires additional energy.

The preliminary inventory and analysis of environmental aspects have led the environment consortium, composed of a number of companies, to develop a first version of an environmental strategy that is described in Sect. 3.2.4. The guidelines that this strategy includes are iteratively provided to the designers of the facility and are included in new procurement actions relating to studies and technical designs. In this way, a culture of integrating the environmental impact into the design process is gradually being established. This eco-design approach is expected to play a fundamental role in the subsequent design, construction, and operation of the FCC.

3.2.4 Environmental strategy

Purpose and scope The purpose of the strategic vision [29] for the environment, eco-design, and sustainable development for the project is to define and set guidelines in order to:

- Set out the project owner's ambitions in relation to the environment, eco-design and sustainable development.
- Steer and design the project to consider and integrate environmental aspects.
- Embed the project in an overarching sustainable development approach based on the three sustainability pillars: environmental, social and economic.
- Establish a cross-disciplinary framework for the project, as well as for the international partners and collaborators, that can be applied to all phases of the project's development and operation.

The strategic vision applies to all phases of the project's development: planning, design, construction, operation, maintenance, and future development. It, therefore, concerns the construction of the infrastructure, the particle accelerators, and the experiments that will be carried out there. From a geographical point of view, the strategic vision is transnational in scope and incorporates the national and specific regulations applicable at every stage of the project.

Organisation and steering The environmental strategy and its organisation and steering are based on the principles [60] already being followed at CERN as the project host. The strategy also incorporates the recommendations issued in the context of the environmental standards that serve as guidelines [19, 61], including the recommendations relating to the key issues to be addressed. CERN's main objectives for the period 2021–2025 [62] and beyond place the environment at the top of the agenda. This 2E+SD (Environment, eco-design and Sustainable Development) strategic vision reflects a strong commitment to design a new project that encompasses local and regional developments. To date, CERN's environmental objectives have been focused on existing activities. An evolution is needed to meet the environmental challenges of building and then operating a new large-scale research infrastructure while taking into account the protection and development of the region. The project needs to be conceived considering the environment in which it will be embedded from the outset. To develop a scenario for a project, the project owner should set up an appropriate structure that is responsible for the integration of the 2E+SD strategy. This structure will make it possible for the strategy and its implementation to be steered independently of the entities responsible for the study, design, and implementation. It must report directly to the project management and have clearly identified reference people in all the entities involved in the various phases of the project. It will help to define the project management procedures and will set requirements for the operational management (organisational issues) and/or for the steering.

Collective and individual responsibilities The project management team develops the strategy, communicates it clearly, and ensures all international collaborators adhere to it. They establish an organisational structure and implement all necessary measures to achieve the objectives outlined in the 2E+SD strategic vision. To accomplish this, the following actions will be taken:

Short term (2024-2030)

- Understand the environmental and regulatory context in which the research infrastructure project and its related projects unfold.
- Draw up an 'Environment, eco-design and Sustainable Development' roadmap to structure the way in which the environment is taken into account throughout the project and to identify and involve all stakeholders.
- Set targets to be reached and continuous improvement objectives that are applicable to all stakeholders and to all phases of the project based on the UN's Sustainable Development Goals.
- Engage in a systematic process of avoiding, minimising and offsetting the project's impacts through follow-up and improvement measures.
- Monitor regulatory and technical developments to anticipate changes in the fields of the environment, eco-design and sustainable development.
- Integrate environmental and sustainable development objectives into all activities relating to the project, in particular during the project design phase.

Medium term (2030-2040+)

- Steer the integration of environmental and sustainable development objectives into the construction of infrastructure, technical equipment (particle accelerators, scientific experiments and all the technical infrastructure needed to operate them) and territorial development projects.
- Develop partnerships with local stakeholders planned during the previous period (2024–2030).
- Update the strategic vision and adapt it to changing circumstances based on environmental monitoring.

Long term (2040+)

- Continue to integrate the sustainability enablers, in particular solutions with the lowest energy consumption and greenhouse gas emissions, provided that they are compatible with the scientific operation of the project and are economically viable.

All those involved in project-related activities actively contribute to the implementation of the 2E+SD strategy through exemplary conduct and by keeping in mind the associated objectives and adopting best market practices on the basis of assessment of emerging technologies.

At every stage of the project, while pursuing the aim of achieving its scientific objectives, everyone must actively seek out information enabling them to minimise the project's impact on the environment and must fulfil the environment, eco-design, and sustainable development responsibilities entrusted to them.

Decisions to adopt measures must be based on a cost–benefit assessment of the various options, including lifecycle analysis where appropriate.

It is understood that actions to avoid and reduce impacts must be technically feasible, economically viable, and compatible with the need to deliver sustained scientific excellence on a global scale and with the scientific goals of the new research infrastructure.

Priority environmental themes Among the many environmental aspects, the following eight topics have been assigned a priority for the subsequent design phase:

Water

- Limit water consumption, avoid sensitive periods and do not consume water from sensitive sites.
- Monitor and control the quality of released water and how it is managed.
- Optimise water use, recycling and reuse.

Waste

- Channel all waste to appropriate sorting facilities.
- Repurpose to avoid and reduce final waste.
- Use recycled and organic materials where possible.

Energy

- Limit consumption and increase system efficiency.
- Favour renewable energy sources.
- Recover and store energy; supply residual heat.

Ionising radiation

- Apply the standards and the agreement of CERN with the two Host States [63].
- Study solutions to reduce and limit the generation of ionising radiation.
- Identify and quantify local risks.

Biodiversity

- Identify and preserve sensitive sites.
- Identify local protected and heritage species.
- Take appropriate environmental offsetting measures.

Emissions

- Quantify emissions, including in terms of carbon footprint.
- Develop recovery and management systems.
- Monitor and control the quality of emissions and what happens to them.

Placement

- Avoid sites that are sensitive or are subject to strong constraints.
- Reduce surface areas and optimise the site layout.
- Blend the infrastructure and activities into the environment.

Societal dimensions

- Limit activities to necessary locations and periods.
- Limit disruption and preserve the comfort of local residents.
- Plan the creation of added value for society as part of the project.

Specific guidelines As a result of the development of the strategic vision, the following specific guidelines have been formulated. They are to be integrated in the subsequent design phases by all infrastructure and equipment developers.

Water

- Avoid using drinking water for non-sanitary purposes.
- Avoid extracting groundwater.
- From the planning stage onwards, preserve the quality and quantity of groundwater.
- Do not create interaction between layers of groundwater or mix their waters.
- Put rainwater collection systems in place for purposes that do not require drinking water.
- Limit evaporation by using closed circuits and, where possible, dry systems.
- Optimise water use, in particular by recycling and reusing it.
- Minimise direct extraction from watercourses.
- Ensure that water released into the natural environment is of a quality at least equivalent to that of the water quality of the environment.
- Develop synergies for sharing water and reusing waste water for the benefit of other consumers, subject to technical and regulatory feasibility.
- Evaluate the use of waste water for industrial processes.

Waste

- Where possible, choose materials with a low impact on the environment (e.g., recycled, organic).
- Include a requirement in tendering processes for companies to avoid packaging and to remove their waste.
- Channel all waste to the appropriate sorting facility.
- Repurpose excavated materials, if possible, locally.
- Avoid single-use and limited-use equipment and containers.
- Share space and equipment.

Energy

- Take the Host States' energy and climate goals into account when planning, building and operating future facilities.
- Limit energy consumption to the quantities and durations required.
- Recover and reuse as much energy as possible in the research infrastructure.
- Take energy recovery measures.
- Limit the use of fossil fuels.
- Plan for the timely implementation of energy supply contracts or power purchasing agreements for the supply of renewable energies.
- Plan to recover, store and supply energy, including waste heat, first for use within the project, with the possibility of subsequently making it available outside the project.
- Avoid unnecessary consumption (e.g., by operating systems only where and when necessary, avoiding systems that run in standby mode and assessing the possibility of switching systems off).
- Increase the temperature of the cooling water and ambient air in areas requiring air handling.
- Limit the areas in which air handling is required and the duration thereof.
- Avoid unnecessary lighting and operation of machinery.
- Optimise schedules by striking a balance between different criteria, in particular by gearing consumption towards periods when cheap renewable energy is available and by making the best possible use of recovered waste heat.
- Optimise and pool means of transport (e.g., conveyors, trains, electric vehicles) and commuting between sites.
- Adapt IT and data processing systems to requirements.
- Design and construct buildings with ambitious energy performance targets.

Ionising radiation

- Limit activities that produce ionising radiation.
- Locate hazardous activities in non-sensitive areas.
- Identify, quantify and control all radioactive emissions and immission in the environment and waste.
- Keep track of the locally applicable regulations.
- Draw up risk management protocols.

Biodiversity

- Identify local biodiversity issues to avoid destroying sensitive sites, habitats and ecological corridors. Where avoidance is not possible, reduce and compensate.
- Limit indirect impacts that disturb the environment (e.g., noise, light, vibration).
- Contain unavoidable impacts (e.g., lighting intensity and colour, operating periods).
- Plan measures to preserve flora and fauna and where not possible, develop mitigation measures to address residual impacts.
- Enhance biodiversity on and around the sites.
- Plant only local species and avoid planting any undesirable ornamental species.

Emissions

- Take into account the climate goals set by Switzerland and France in line with the IPCC recommendations.
- Identify all sources of emissions.
- Treat emissions and immissions in the environment before release.
- Determine the carbon footprint of emissions and immissions in the environment.
- Keep all activities on a virtuous emission pathway.
- Monitor and measure activities that are likely to pollute the air, soil and water.
- Avoid gases that have a significant greenhouse effect (e.g., SF_6) and use alternatives.
- Opt for electricity and hydrogen (fuel cells) from renewable sources for the powering of machinery and the transport of equipment.
- Encourage soft mobility and electric transport.
- Remain below the thresholds in force for the immission of suspended dust (PM10) and nitrogen dioxide (NO_2) around the perimeter of the future extensions.
- Identify and limit greenhouse gas emissions in the life cycle of the research infrastructure, taking into account the scientific objectives, technical feasibility and economic sustainability, including during equipment construction and procurement activities.

Placement

- Avoid locations that present major concerns.
- Reduce the footprint of surface sites to the absolute minimum, compliant with the requirements.
- Optimise the use of space by increasing the density of sites and buildings.
- Ensure that the infrastructure blends well into the landscape, the local environment and the urban setting.
- Avoid ground sealing and manage rainwater.
- Incorporate islands of freshness.
- Limit the impact of activities within the site.
- Plan for the resilience of the sites.

Societal dimensions

- Identify local sensitivities and issues.
- Limit noise, odour and light pollution for local residents.
- Integrate activities into the economic and social environment and develop synergies with local services, such as the fire brigades and other emergency and security services.
- As far as is compatible with the project plan, limit disturbance during rest periods (nights, weekends).
- Minimise road traffic and put in place alternatives (e.g., pooled transport, public transport, rail transport, conveyors).
- Provide parking spaces and loading and unloading areas during the construction phase, based on requirements identified and quantified in advance.

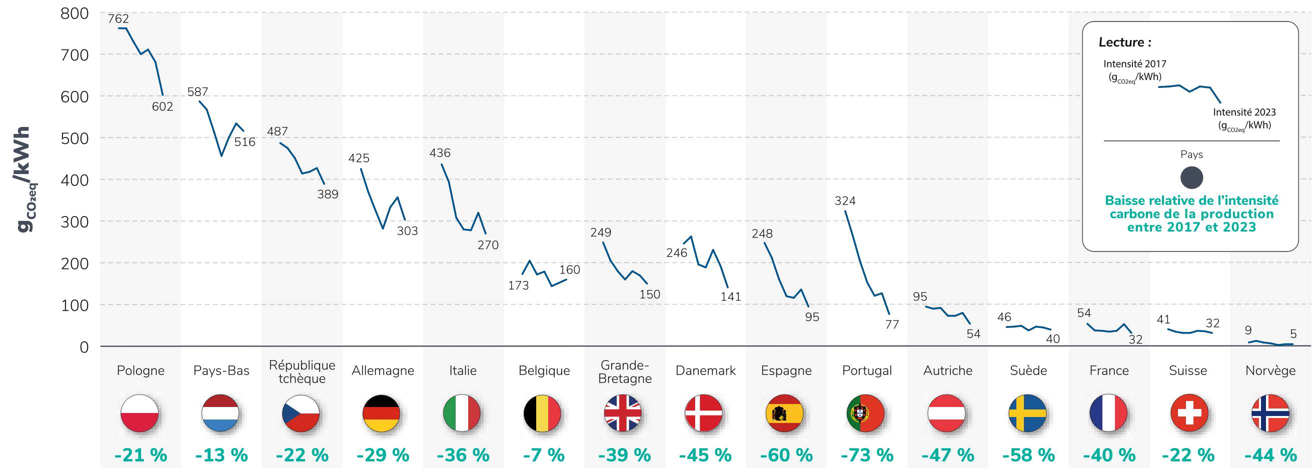


Fig. 3.3 Evolutions of the carbon intensities of national grids in Europe. Source: RTE [67]

Raw materials

- Analyse the lifecycle of materials and infrastructure to anticipate the end of their life.
- Favour the use of low-carbon construction materials (e.g., low-carbon concrete), where feasible.
- Favour the use of recycled materials (e.g., steel, copper), where feasible.
- Prioritise local sourcing and regional production.
- Favour organic resources (e.g., wood), where feasible.

3.2.5 Energy use

The project is committed to promoting and continuously increasing the use of renewable energy sources [64]. Fossil fuel-based energy will generally be avoided, and where its use is unavoidable, it will be minimised as much as reasonably possible. The internal heating of the particle accelerator infrastructure will reuse waste heat and renewable energy sources whenever feasible and economically viable in the long term. The use of fossil energy sources for backup electricity supply should be avoided. Instead, hydrogen to power a fuel-cell based system can be a valid alternative in addition to the short-term electricity supply via battery-based energy storage systems (BESS).

Studies carried out with external consultants to understand how far renewable energy sources can be leveraged, show that a strategy based on sourcing the majority of electricity from renewable energy sources at the national level can satisfy the project needs [50]. Continuous increase of renewable energy sources and cross-border electricity transfer capacities pledged by the French government [65] support the validity of this concept [66]. In line with other European countries, the French electricity grid has experienced a continuous reduction of its carbon intensity [67] and is today amongst the countries with the lowest location-based electricity carbon intensity (Fig. 3.3, Sweden, France, Switzerland, and Norway). The long-term planning [68] published in early 2025 confirms the feasibility of the supply of the required energy from the grid and via renewable energy sources.

The studies permit expecting that by 2035 the energy needs relating to the construction activities can be entirely satisfied by renewable energy sources. Implementing the approach via the local electricity supplies requires, however, that dedicated renewable energy supply contracts with certificates of origin are settled. This in turn calls for a sufficiently exhaustive analysis of the energy needs at the construction sites over the construction years and a reliable construction planning that is sufficiently stable (planning security).

To prepare the energy supply for the operation phase, up to ten years of preparatory time may be required. This time frame serves well for defining the energy needs and consumption patterns, the invariant energy needs, the development of concepts and techniques that permit adapting the research infrastructure to supply possibilities in terms of changing availability and price. Furthermore, it allows time to develop the portfolio of power purchasing agreements in terms of functions and capacities, the contractual conditions and the tender processes. Eventually, the portfolio will lead to a mix of energy production technologies that match the needs of the research infrastructure, the ability of suppliers to grant flexibility, the carbon footprint, and general contract-related conditions. While the studies with external consultants show that on the time scale of 2035 covering more than 1 TWh with renewable energy in the region is feasible at the 60% level, significantly higher coverage will be feasible in the 2050 time frame.

Fig. 3.4 Evolution of the levelized cost of electricity (LCOE, Source: Lazard's Levelized Cost of Energy Version 17.0)

It is worth keeping in mind that the supply and consumption of energy from renewable sources do not rely on a physical connection between the producer and the consumer. In an interconnected electricity grid, electrons are fungible, i.e., indistinguishable and interchangeable. Therefore, any volume of purchased energy from renewable sources is accounted in the financial, societal and environmental accounting scheme that determines the sustainability level of the project. It is not relevant where the energy has been physically produced and when it has been produced in the frame of a power purchasing agreement. It is, therefore, important to distinguish the carbon footprint of the power grid (location-based carbon footprint of consumption) from the certificate of electricity origin carbon footprint of a project (market-based carbon footprint of consumption). Renewable energy certificates and guarantees of origin that are part of power purchasing agreements play a crucial role in the carbon accounting of a project. The Greenhouse Gas Protocol Scope 2 Guidance explicitly states the requirement to report both figures [69]. To achieve good financial performance, a more detailed forecast of the volumes required over an operating year and the possibility to adapt to the availability of renewable energy and its changing rewards are desirable. Consequently, a portfolio of renewable energy power purchasing agreements must be developed with adequate preparation time. The portfolio will evolve during the operation phase since the energy consumption needs to evolve according to different operation phases.

By 2023, the so-called levelized electricity costs (LCOE)[5] of all renewable energy sources are below the production costs of electricity production from fossil fuels [70] (Fig. 3.4). Seasonal fluctuations in the daily electricity prices are a result of a complex interplay of production capacity (supply), demand and non-technical factors. With respect to the pre-pandemic, electricity price evolution remains volatile. The production location can be different from the consumption location in the interconnected grid. Therefore, no general statement can be given, and the observation of large-volume electricity prices over multiple seasons did not permit an unambiguous seasonal cost variation pattern to be derived (Fig. 3.5). In particular, the production costs of electricity from renewable energy sources are diverse: while wind power is 10% cheaper in winter and 20% cheaper in spring than in summer, the situation for production from photo-voltaic sources is, in general, the inverse. In continental climate zones, a quasi-equilibrium of supply and demand exists [71].

So far, it has not been possible to identify a significant difference in the cost of energy from renewable energy sources between seasons.

To achieve good coverage with low-carbon electricity sources, off-site energy storage could be foreseen in the power purchasing strategy. For example, hybrid PPAs are rapidly entering the market and, by the 2040 to 2050 period, will be an integral part of large-volume power purchasing. Missing volumes of renewable energy sources can be complemented with nuclear energy, which has a higher LCOE than renewable energy sources but is characterised by a very low carbon footprint.

By way of comparison, medium-sized offshore wind farms with a capacity of 600 MW, such as Kriegers Flak (Denmark) or Dunkerque, produce around 2.5 TWh of electricity per year at a cost of 44 euro/MWh at 2021 prices.

[5]LCOE (Levelized Cost of Energy) is a metric used to assess the cost of generating electricity from different energy sources over their lifetime. It represents the per-unit cost (e.g., USD/MWh) of building and operating a power plant, considering all costs and revenues.

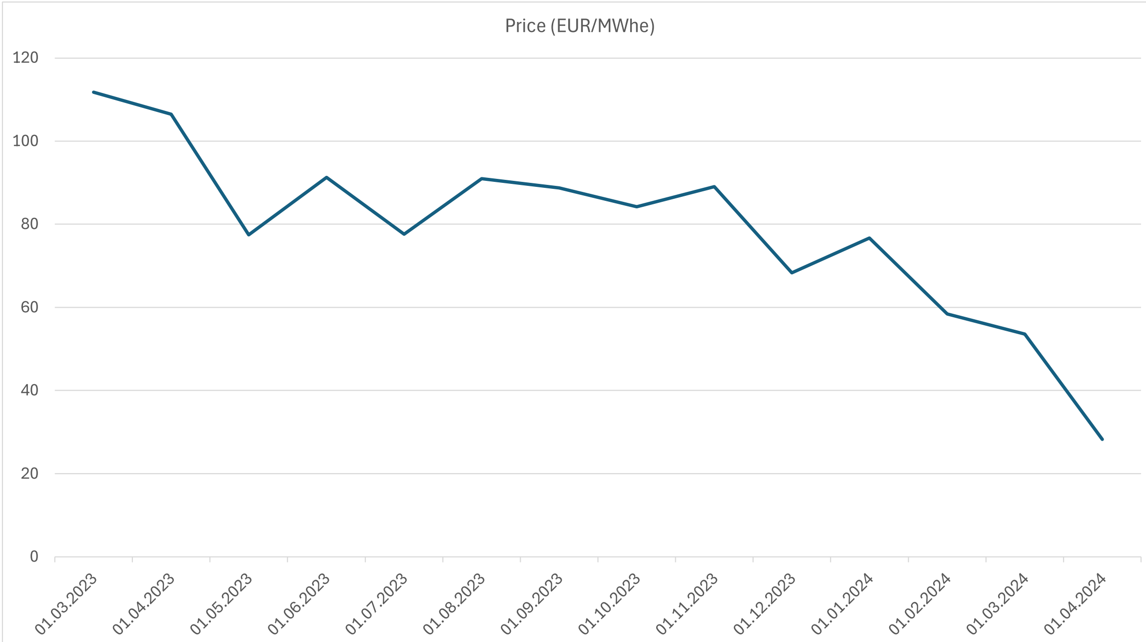
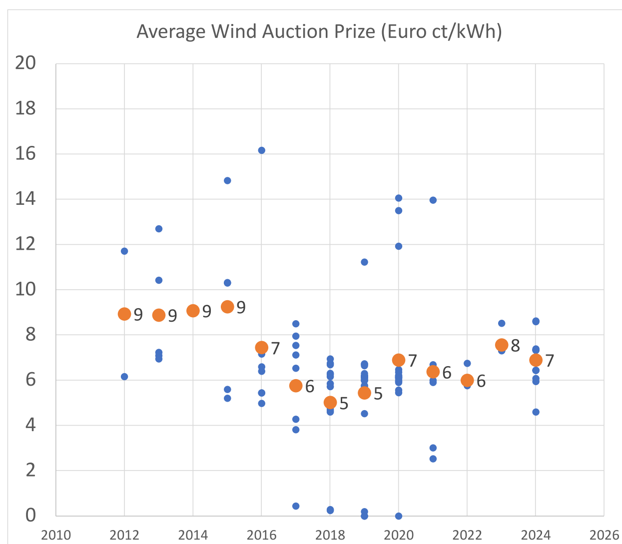


Fig. 3.5 Example of monthly electricity spot price in France between 2023 and 2024 (Source: Ember Energy [72])

Fig. 3.6 Historic contract market prices of electricity from wind power in Europe in cents/kWh up to the end of 2024 (Source: graph derived from public European wind auctions)



Due to periods of economic crisis that caused an energy price increase between 2020 and 2023, the auction prices for offshore renewable wind energy in France are decreasing again. In France, auction prices for renewable wind power sources are currently, on average, 69 euro/MWh. These auction prices are a suitable indicator for setting the electricity price to be assumed for the annual energy costs in the overall sustainability assessment. Based on today's prices (Fig. 3.6) and environmental performances of energy production, an average price range of 70 to 80 euro/MWh and a market-based carbon intensity of 15 to 25 $gCO_2(eq)$/kWh of electricity is very conservatively assumed today.

This value is significantly higher than the price goal of 56 euro/MWh in 2030 in France, communicated in the public multi-annual energy planning of the government [65] (Fig. 3.7).

To maximise waste heat supply potential while maintaining reasonably-sized heat buffering systems, operational flexibility and shifting operations to cooler seasons are preferred. Given the regional climate patterns, working conditions are generally more favorable in autumn and spring compared to summer.