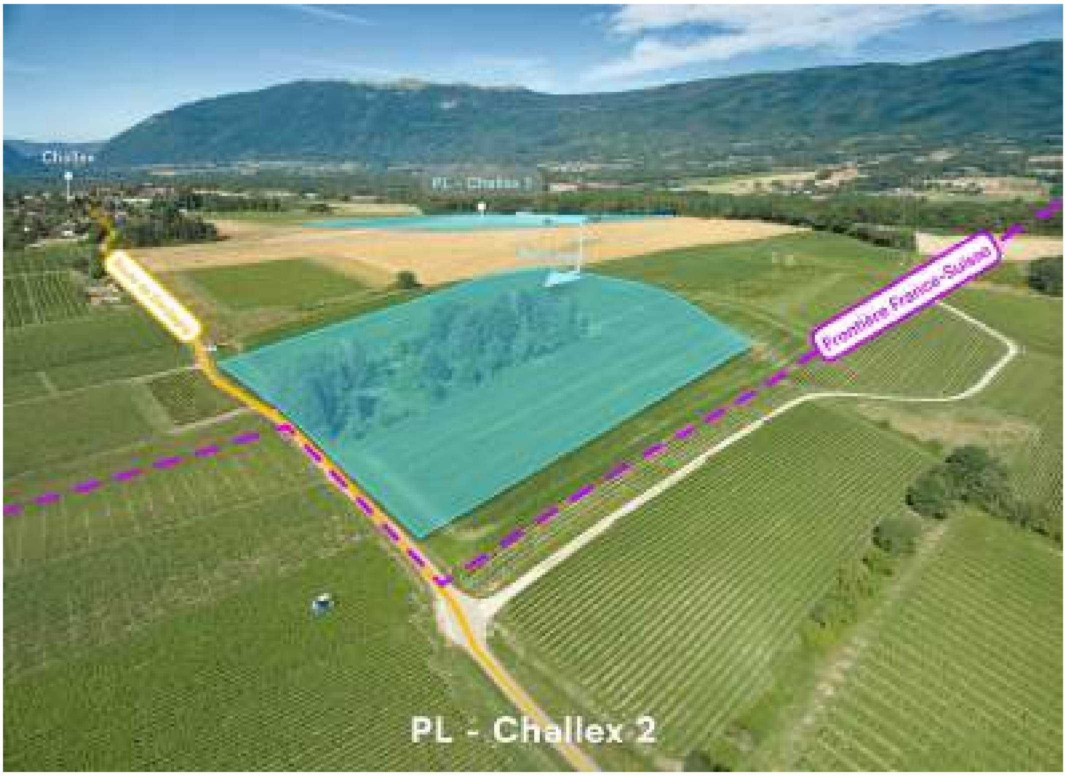


Fig. 2.44 Aerial view of candidate location for surface site PL

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

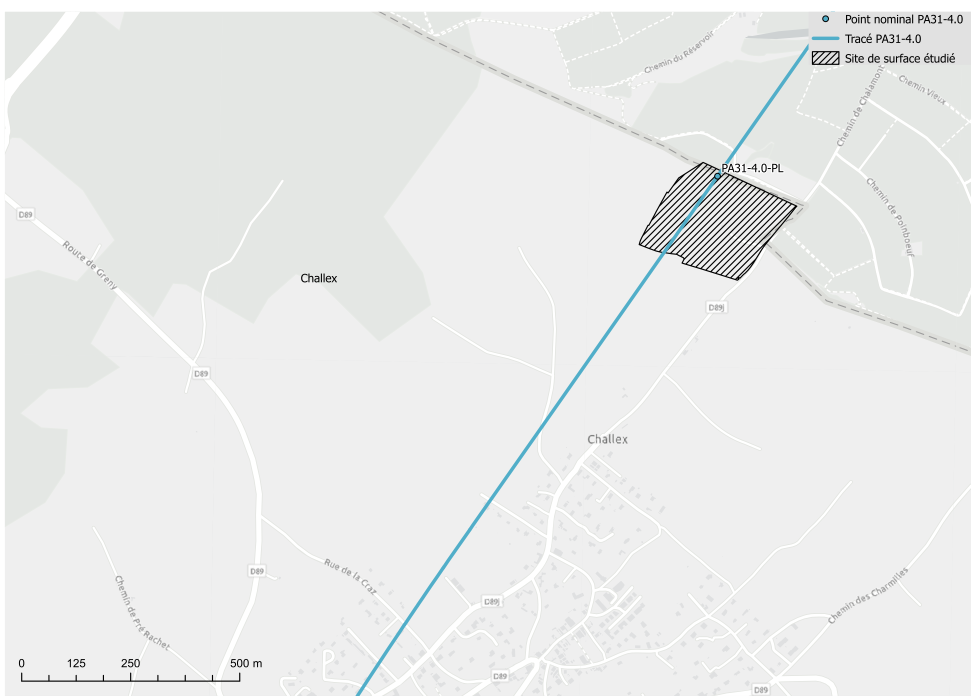


Fig. 2.46 Alternative location for site PL in Challex, Ain, France. The plot is located on the outside of the collider tunnel, which calls for an underground connection tunnel and a more complicated access to the radiofrequency gallery and the collider tunnel for equipment installation and maintenance

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.

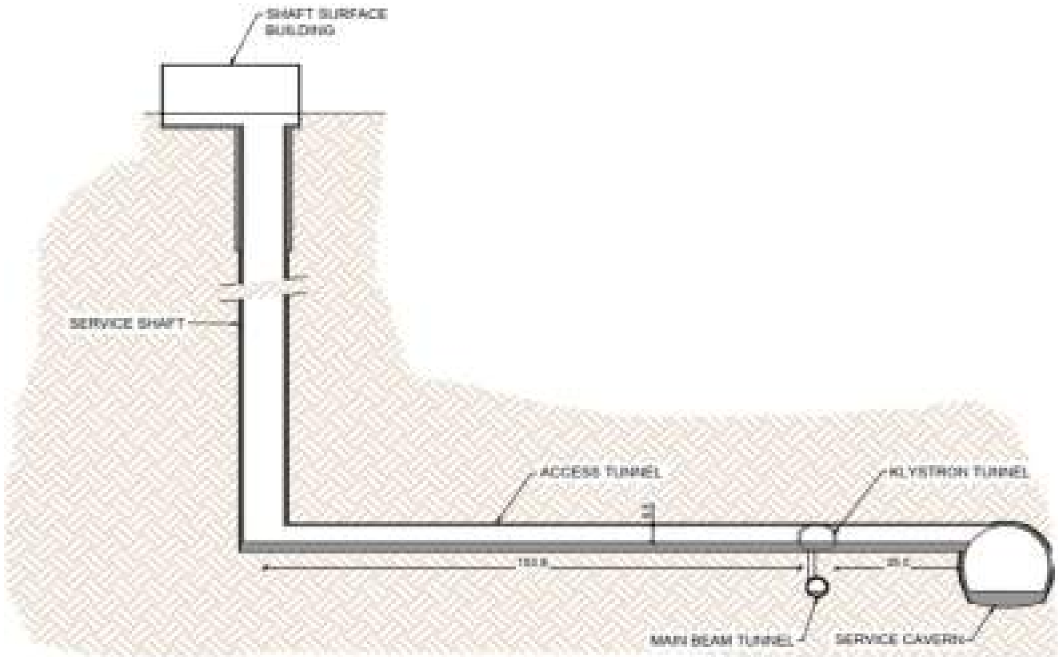


Fig. 2.47 Access to the main tunnel from the exterior via an underground connection. This approach is more complicated and induces additional costs

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.

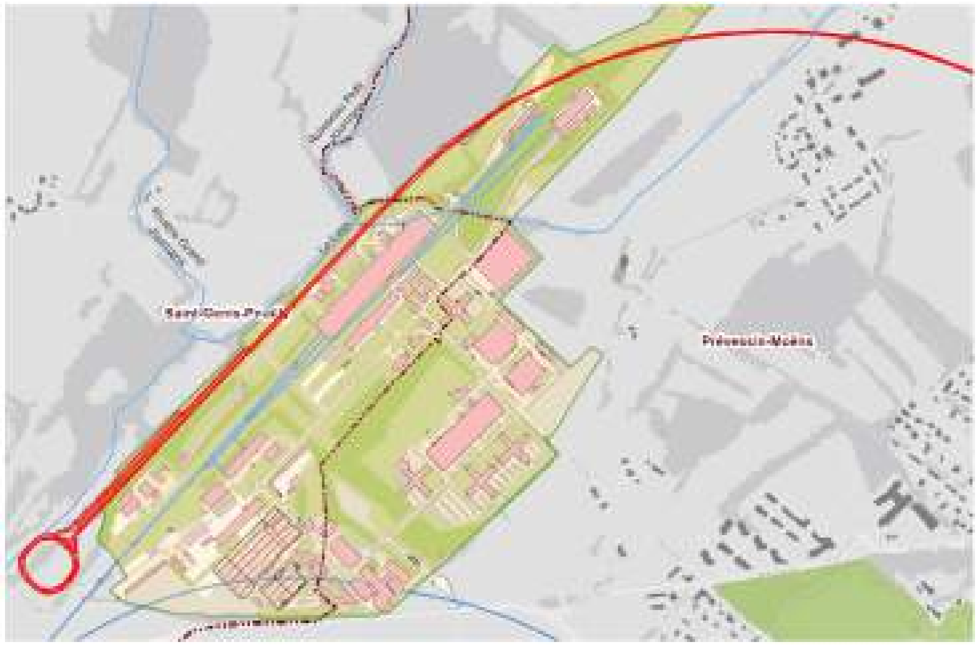


Fig. 2.48 Sketch of the current working hypothesis for a linear-accelerator based injector that has a length of about 1.2 km. A definitive placement remains to be developed in the frame of a design phase, considering environmental, existing experimental facility, territorial development and engineering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

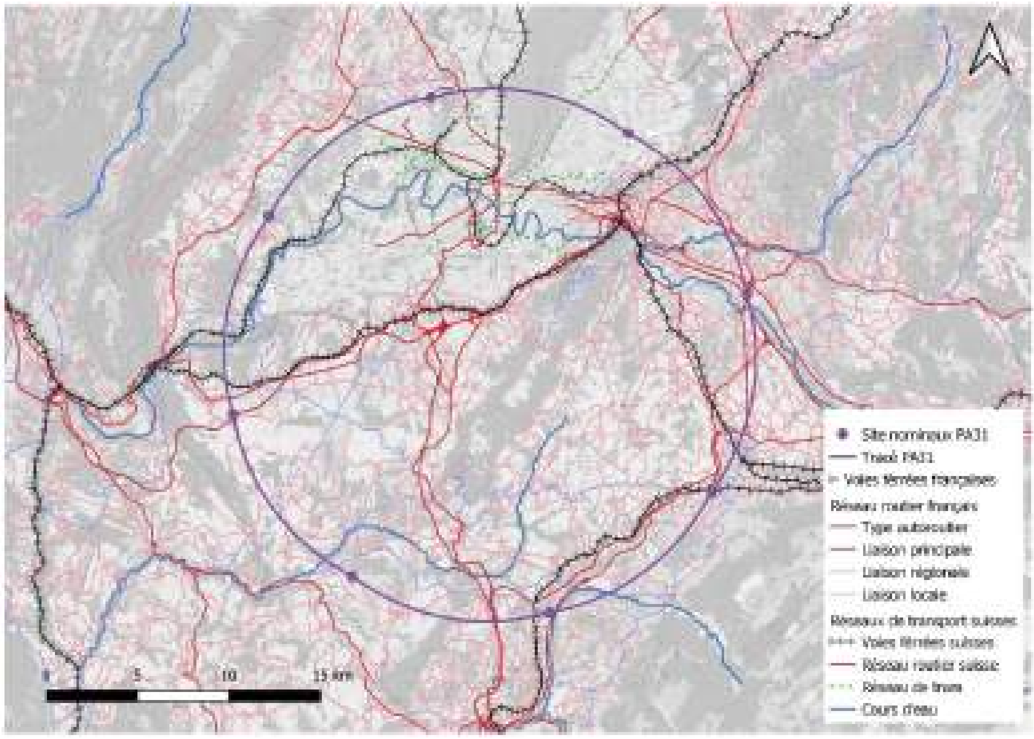


Fig. 2.50 Overview of the road and railway transport network in the perimeter of the reference scenario

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),

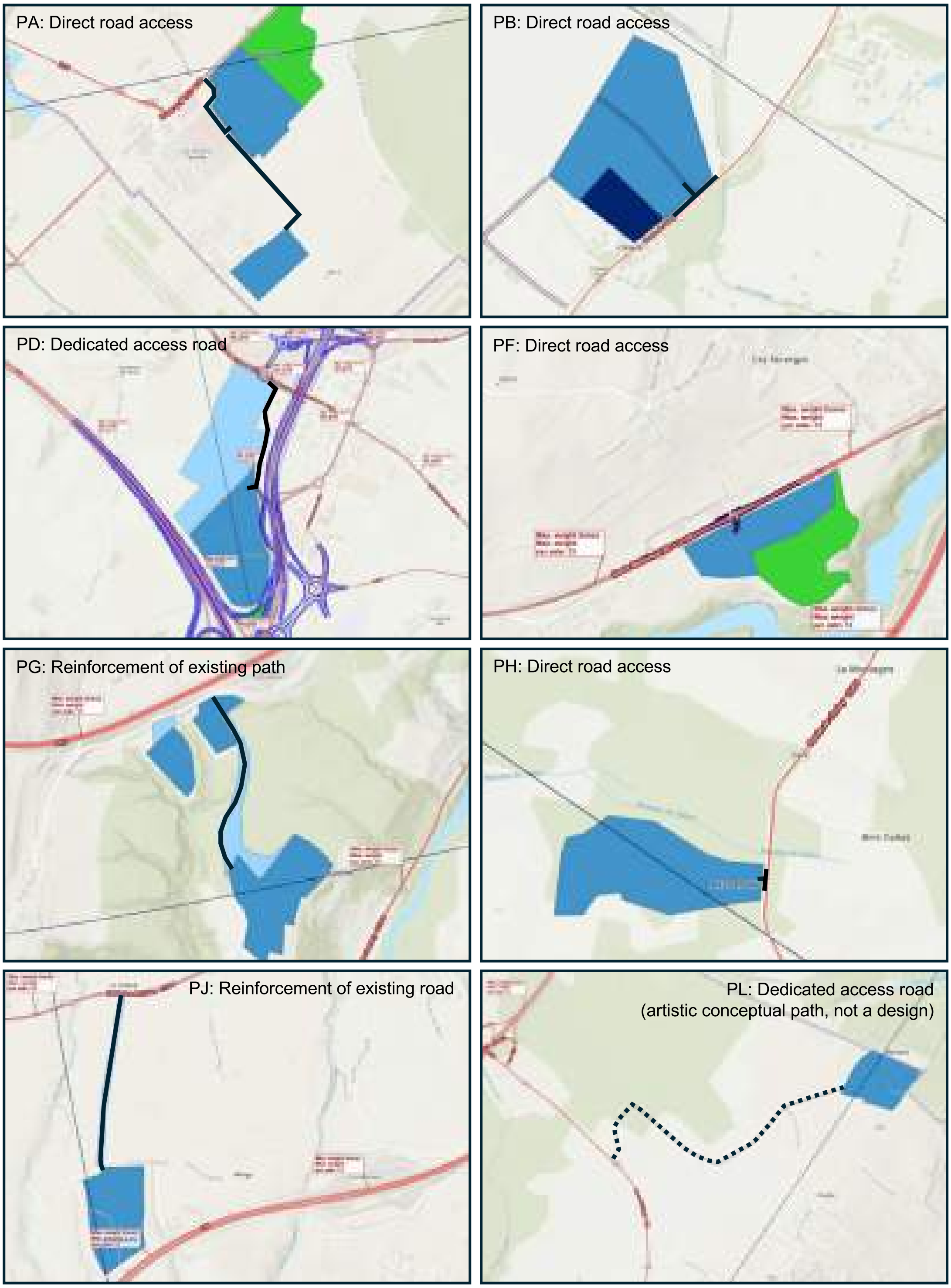


Fig. 2.51 Overview of road access concepts for each individual surface site

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.

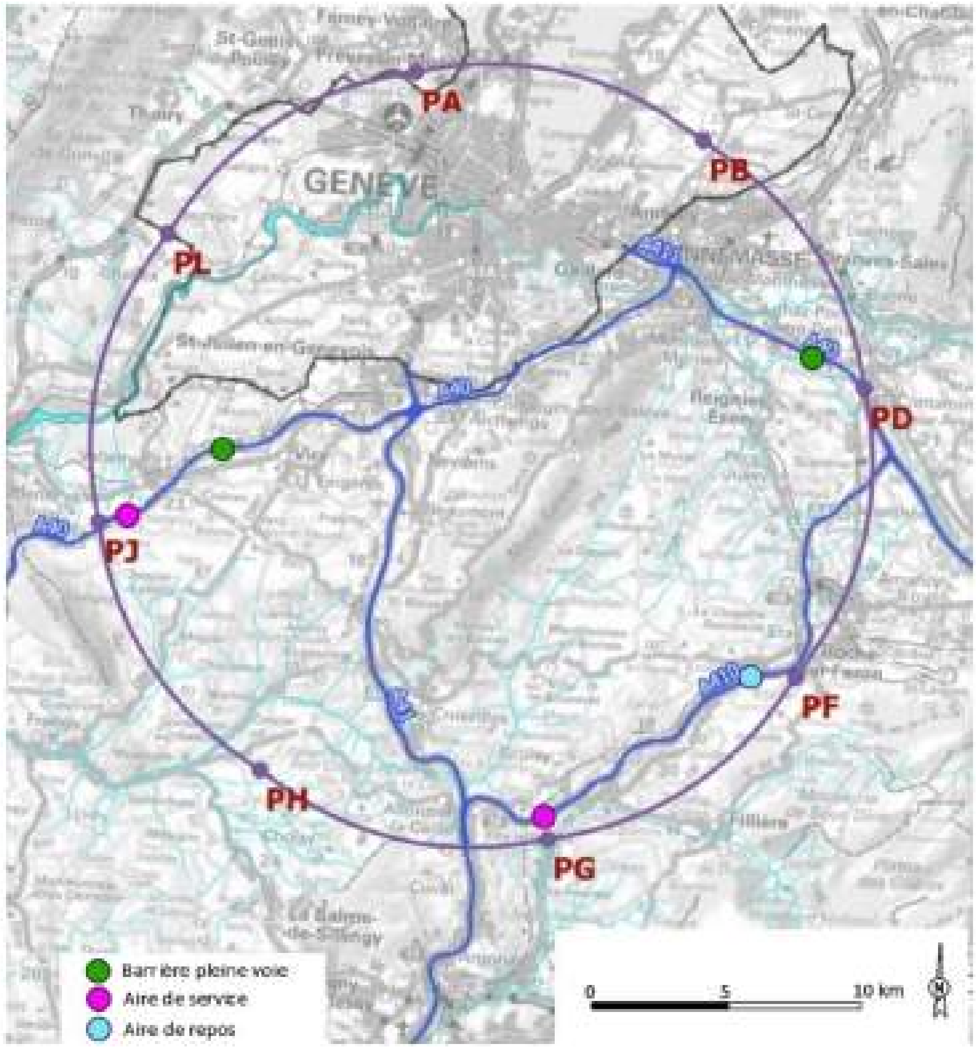


Fig. 2.52 Location of the autoroute connections, which were studied using existing service and rest areas. Blue dots correspond to autoroute rest areas, magenta dots indicate autoroute service stations and green dots indicate toll stations

- 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.

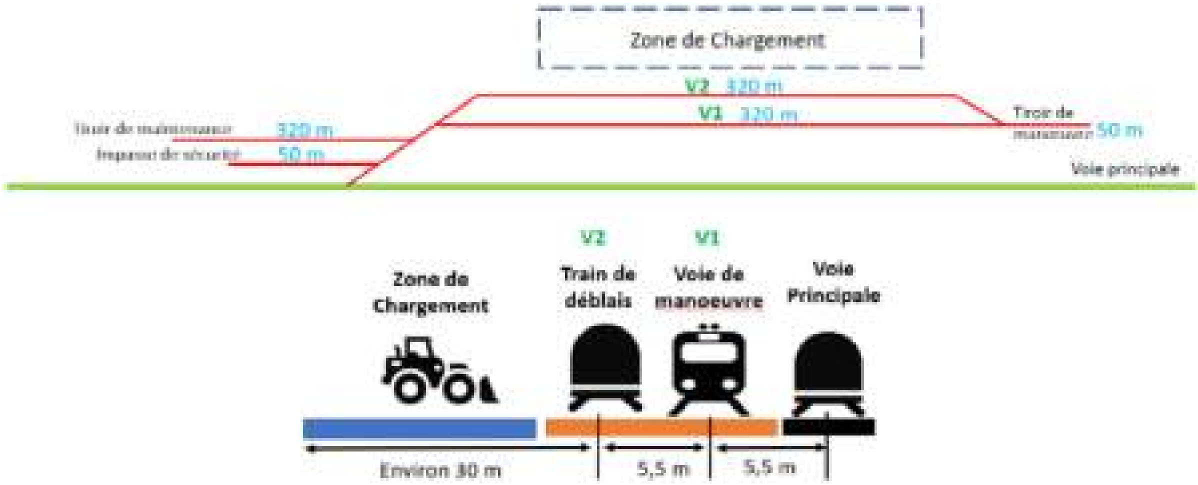


Fig. 2.53 Minimum space requirements of a new railway access for goods transport

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

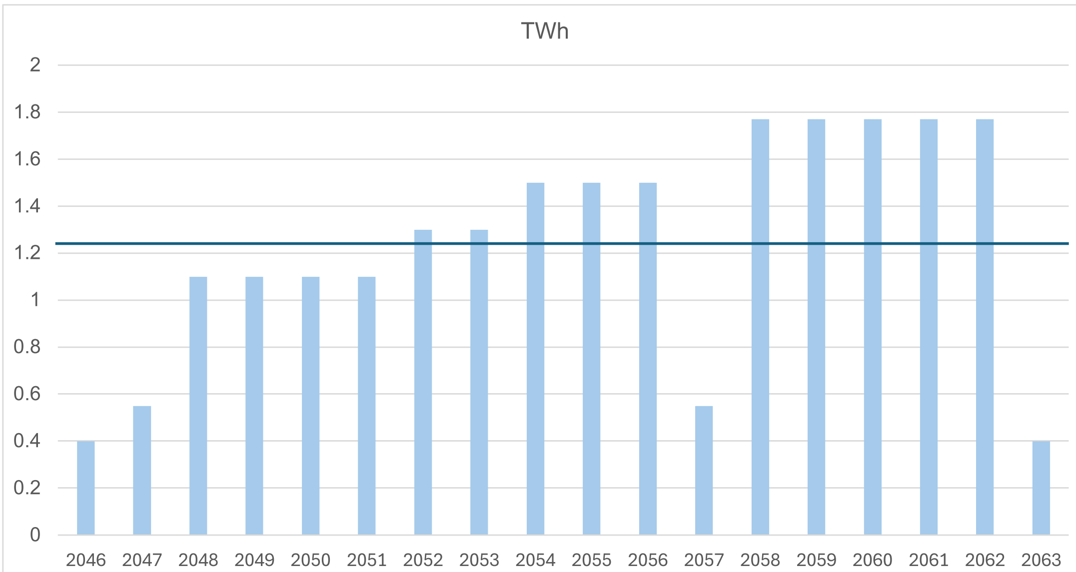


Fig. 2.55 Annual electricity requirements of the collider and its technical infrastructure. The average annual consumption over the programme is indicated by a blue horizontal line

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.

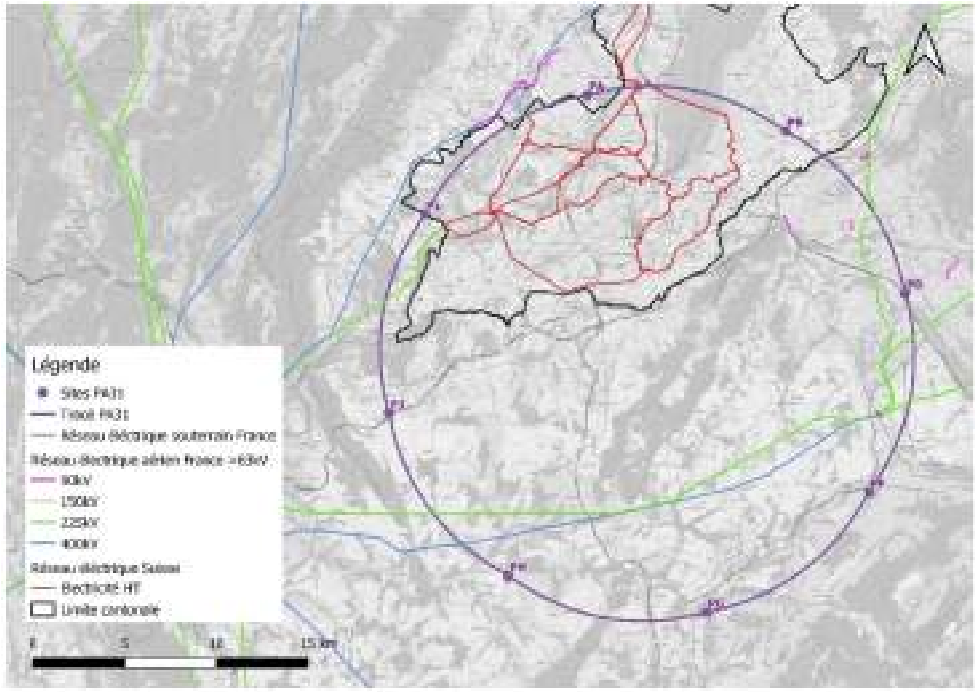


Fig. 2.56 Existing or planned electricity grids in France and Switzerland within the FCC perimeter. Sources: Public layer CAD_ELEMENT_CONDUITE from SITG 2023 for Switzerland (https://sitg.ge.ch/donnees/cad-element-conduite), available for consultation and extraction for free use; for France, Open Data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

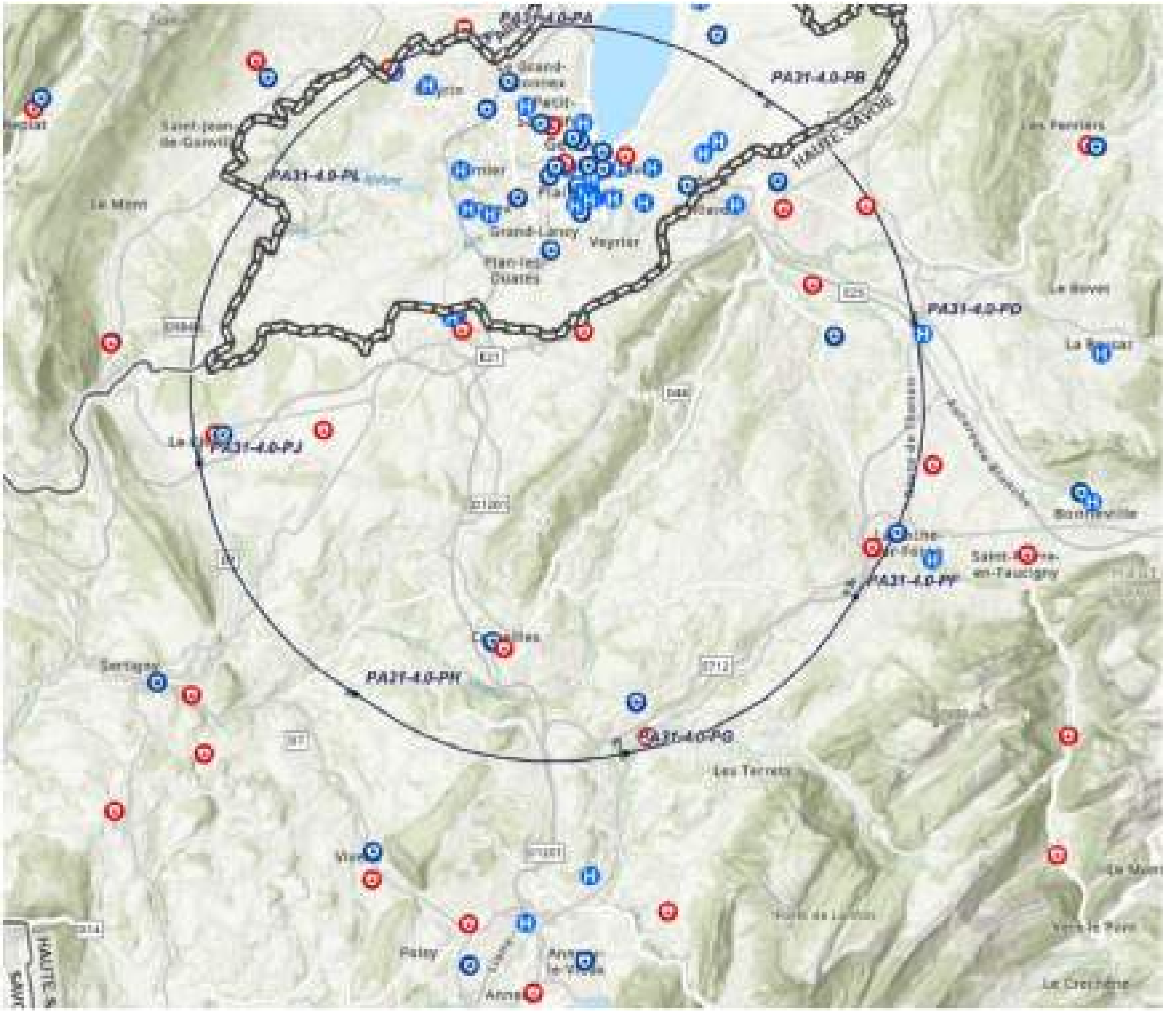


Fig. 2.57 Fire-fighting and emergency services in the perimeter of the reference scenario

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.

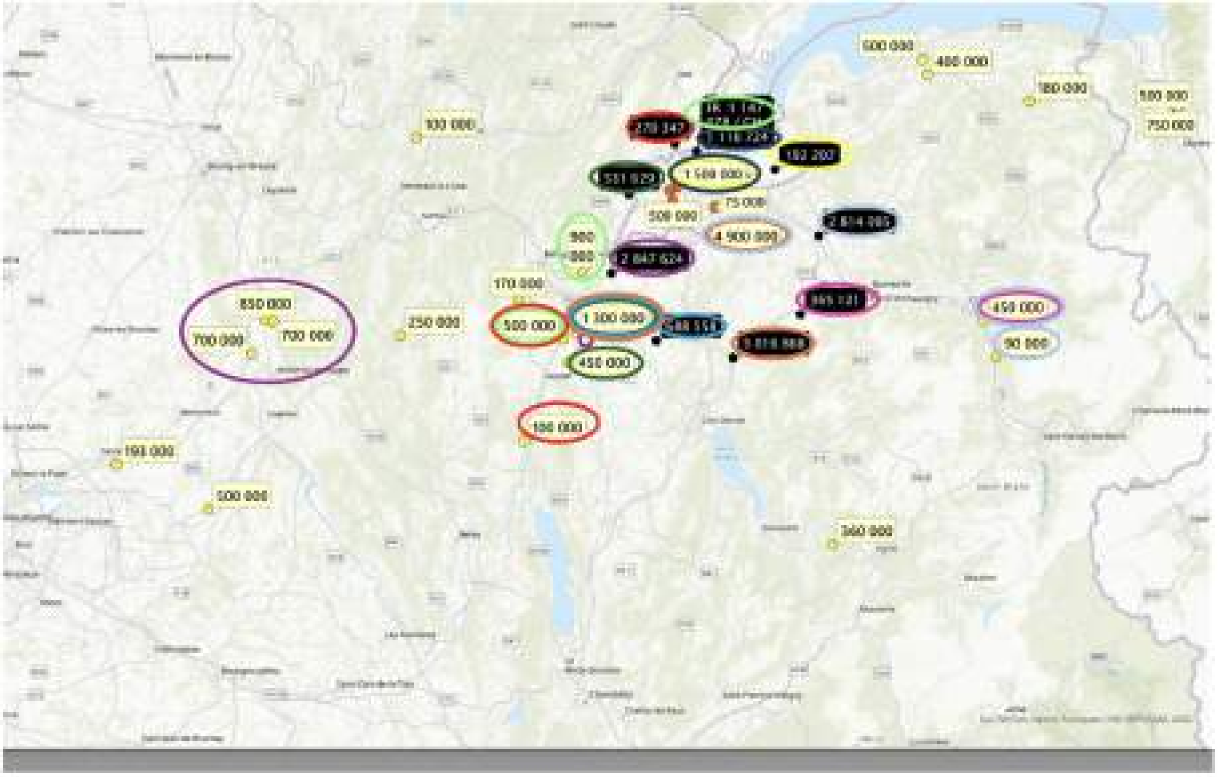


Fig. 2.59 Capacities of quarries that could be re-filled in the vicinity of the project on French territory and in the canton of Geneva in Switzerland. Capacities are indicated in tonnes

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

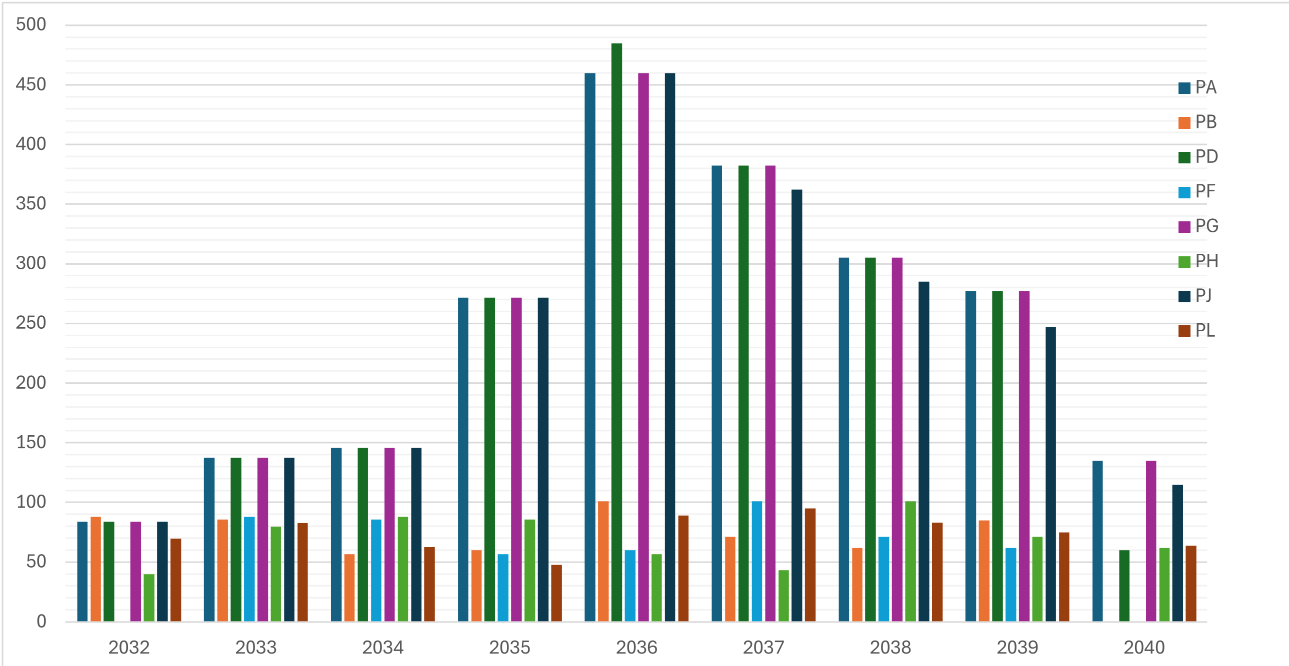


Fig. 2.60 Example scenario of construction workers per construction site and year. A specific personnel and mobility plan has to be developed in the frame of a preparatory phase project when construction activities are defined at a more detailed level

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 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.

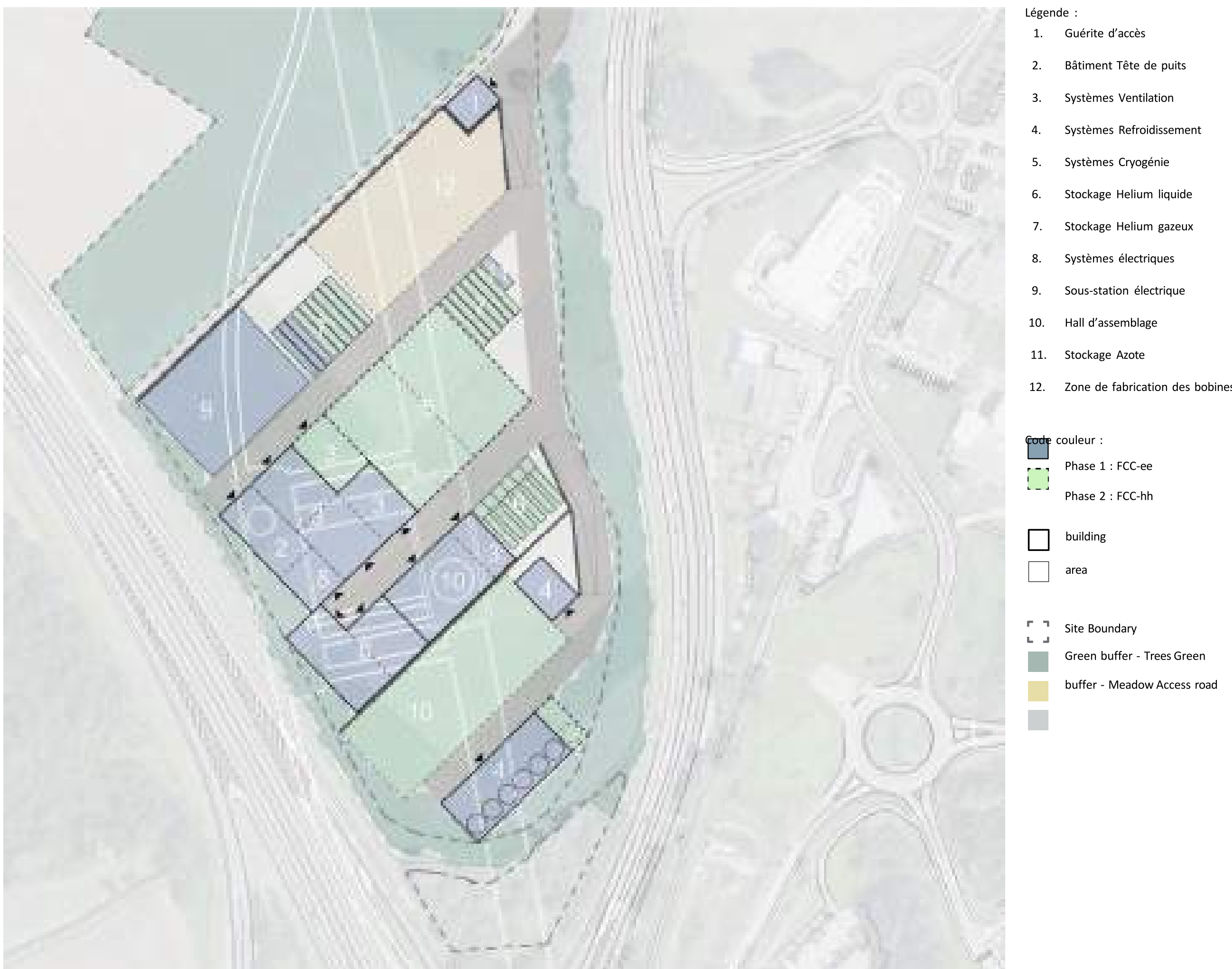


Fig. 2.66 Space requirements for a site and landscape integration of experiment site PD in Nangy, France

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.

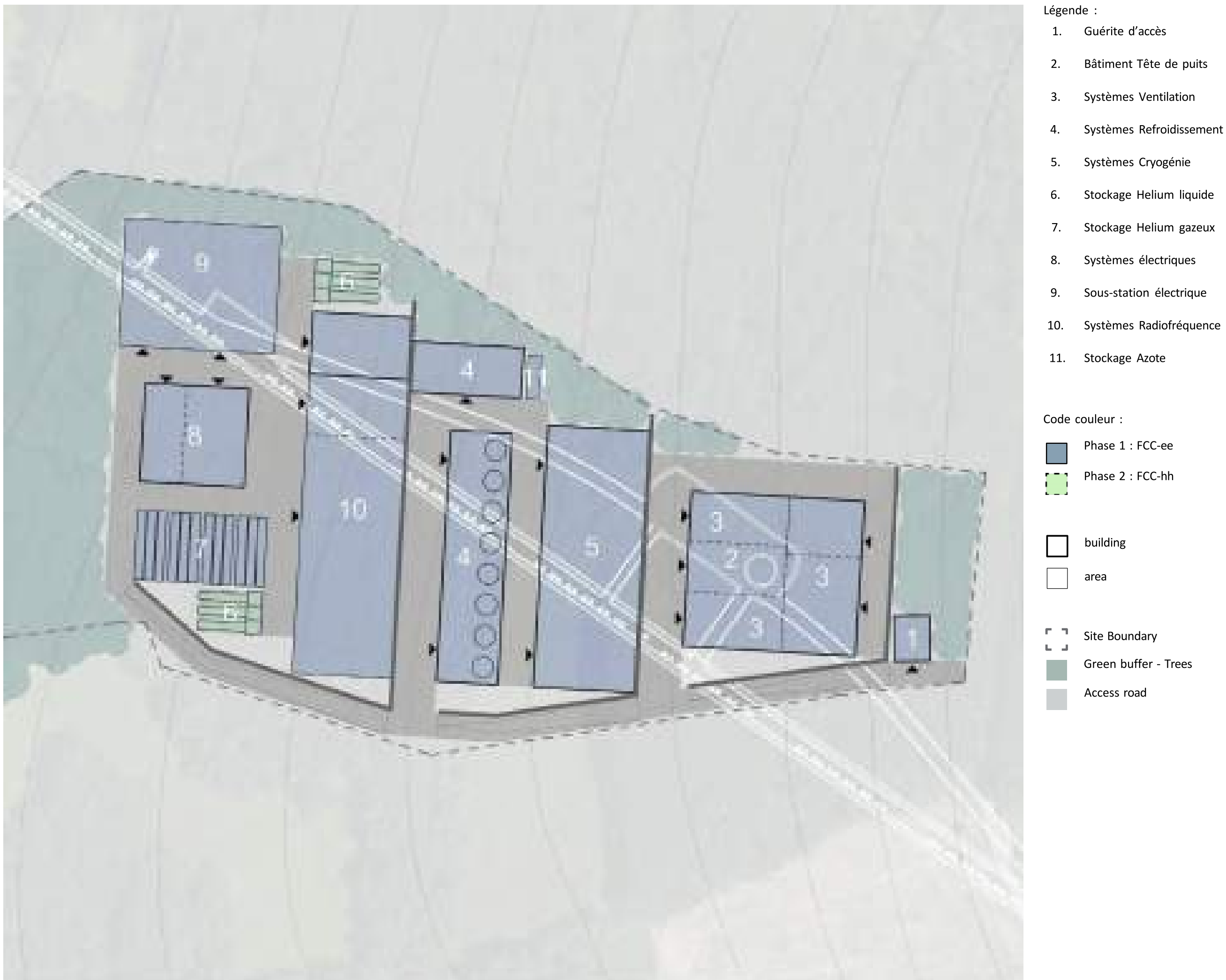


Fig. 2.69 Space requirements for a site integration of technical site PH in Cercier and Marlioz, France

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, water 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

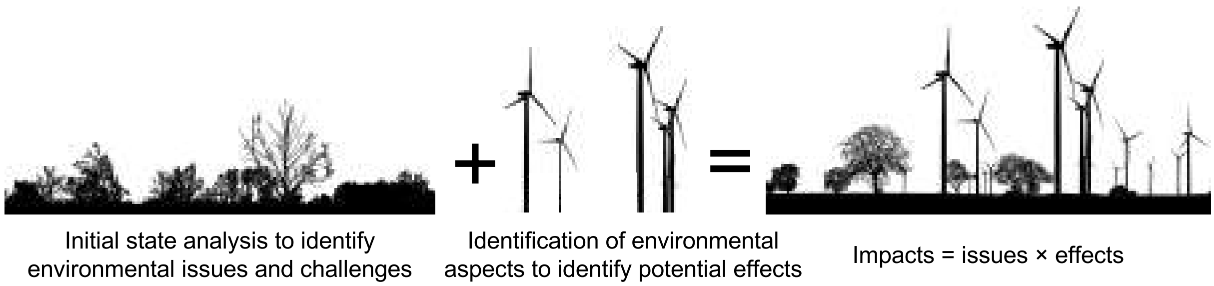


Fig. 3.2 Environmental impacts are a consequence of the environmental sensitivity at a certain location (issues and challenges) and the potential effects of environmental aspects of a project at that location

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 $\sim$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.

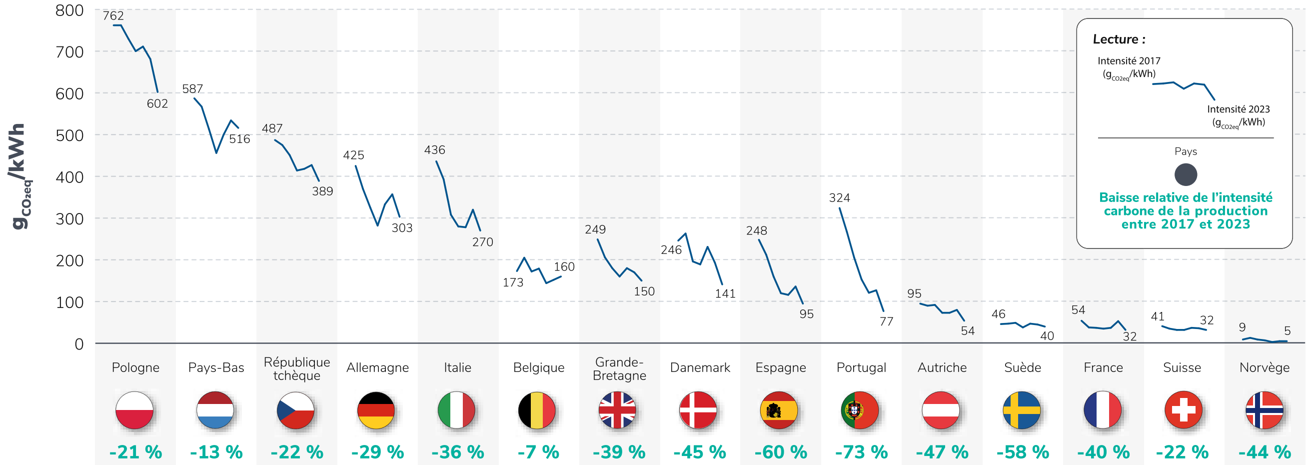


Fig. 3.3 Evolutions of the carbon intensities of national grids in Europe. Source: RTE [67]

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.

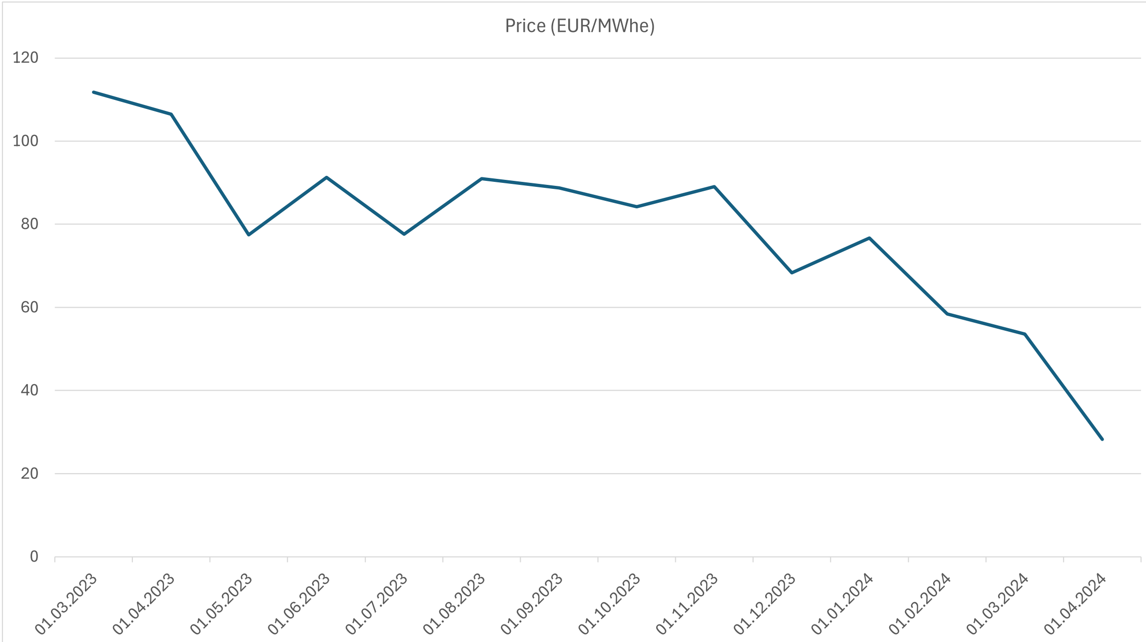
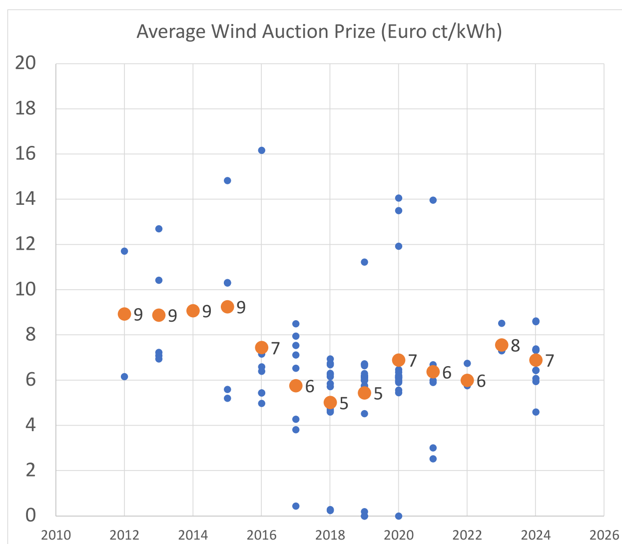


Fig. 3.5 Example of monthly electricity spot price in France between 2023 and 2024 (Source: Ember Energy [72])

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.

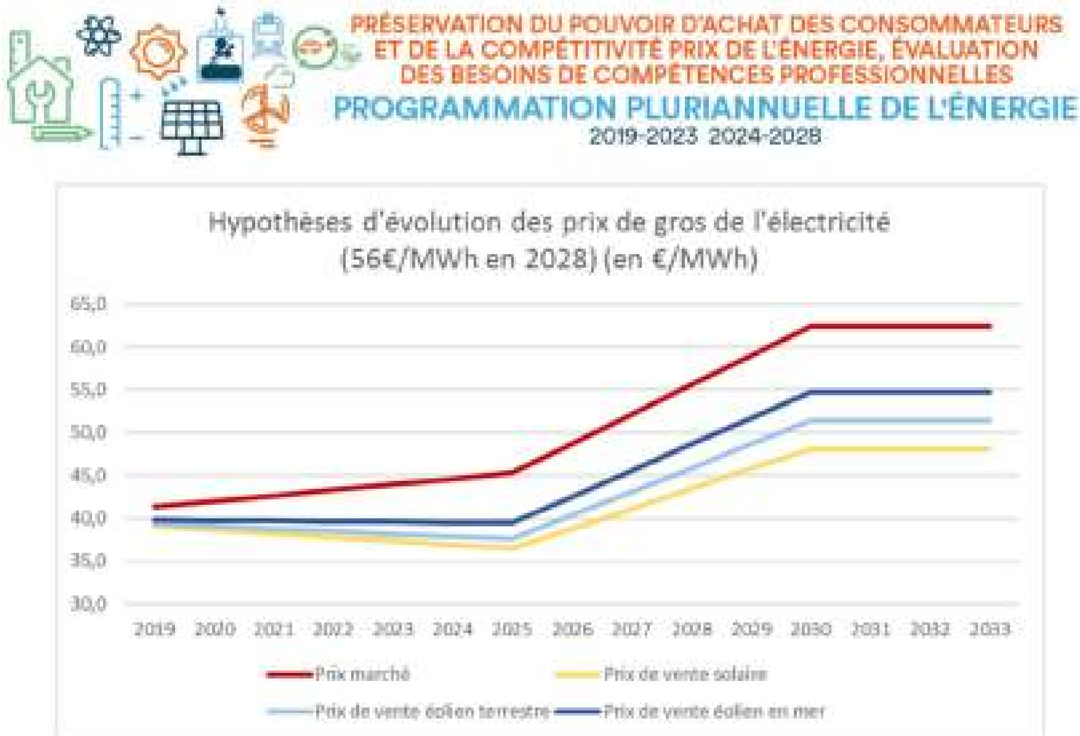


Fig. 3.7 Stated electricity market price targets for 2030 published by the French government in the pluri-annual energy programme [65])

The subsequent project preparatory phase must include the preparation of the power purchasing strategy and a plan for the construction phase. This will serve as a learning experience to develop and negotiate the power purchasing agreement portfolio for the operation phase, which is assumed to start after 2045.

3.2.6 Waste heat use

Almost all of the energy used to operate the technical infrastructures and subsystems of a particle accelerator is eventually converted into heat. Energy used to operate accelerator magnets, amplify radiofrequency energy, absorb synchrotron radiation, air management systems, operate electronics and data processing equipment is almost entirely converted into low-grade heat, typically below 45°C. Temperatures above 50°C, but still below 70°C, can rarely be reached, for instance, when cooling cryogenic refrigeration system equipment and electrical transformers and substations. This heat is typically dissipated in the ambient air via water-cooling and free-to-air cooling systems and is thus lost. Given the amount of heat that particle-accelerator based research infrastructures generate, there is an interest to explore ways to recover that heat and convert it into a valuable resource. The use of the heat for other purposes inside and outside the project boundaries has the following socio-economic benefit potentials:

- Reduction of electrical energy consumption and associated costs due to reduced cooling system operation requirements.
- Reduction of raw water consumption and associated costs due to reduced cooling system operation requirements.
- Increased cooling system lifetime and reduction of associated maintenance and repair costs due to lower operational load on equipment.
- Reduction of heat-generation-related carbon emissions due to the avoidance of dedicated heat production.
- Lower heat costs for consumers.
- Opportunities for creating new economic activities in the vicinity of the heat source.

However, heat recovery and supply also require additional efforts and costs:

- Additional components to recover the heat.
- A dedicated network to transport the heat to where it is needed.
- Potential additional components to raise the temperature of low-grade heat supplied for specific needs.

- Short-term and long-term heat storage systems to ensure supply stability and provide heat when needed.
- The need to refurbish existing buildings and the need for new buildings that are equipped with heating and cooling that function with the low-grade heat.
- The need for a heat supply operator if the heat is used outside the research infrastructure boundaries.

A technical-economic study has been carried out by an expert engineering company to create an inventory of the heat sources in the research infrastructure, to confirm the technical and financial feasibility and, most importantly, to draw up a detailed cartography of the heat demand within the surface sites perimeters. The study also included an assessment of how far heat recovery and supply is technically feasible and economically viable [73–75].

The information gathered was also integrated in the comprehensive, wider socio-economic impact analysis, estimating the contribution to the net present value of the project and subsequently reporting on the overall net benefit. This approach ensures that an informed decision-making process is implemented. If the system is put in place, it is strongly advised that the heat supply is continuously monitored to report on the efficiency of the approach and to be able to further optimise the waste heat recovery and supply process.

Whilst retrofitting heat recovery and supply to existing cooling systems is technically possible, it can be more costly than planning the concept from the onset. Depending on the existing equipment, infrastructures and environment around the particle accelerator facility, retrofitting may be less efficient since the operating temperature of the equipment supplying the heat may not be matched to the consumer needs e.g., magnet water cooling circuit temperatures too low, lack of data centre rack cooling infrastructure, mismatch of the waste heat characteristics with existing district heating networks or missing low-temperature district heating networks and finally lack of space and missing agreements with consumers. It is, however, preferred over no heat recovery. Therefore, from the outset, the FCC project has adopted an eco-design approach that integrates heat recovery and supply into the research infrastructure while embedding it within its broader socio-economic and environmental context.

Waste-heat recovery and supply are already implemented at CERN in the frame of the LHC project. One installation supplies waste heat from the cryogenic refrigeration system at LHC Pt8 in Ferney-Voltaire. A district heating network developed by the company Dalkia for the municipality, supported by the state, the region, and the French environmental organisation ADEME, connects to this surface site. The surface site PA in Ferney-Voltaire is envisaged as an immediate extension of this LHC site, leveraging not only the existing district heating network but also opening a window of opportunity to connect to structured heating networks [76] on the nearby Swiss territory that also supplies Geneva airport and major industrial and commercial facilities as well as residential buildings in the vicinity of the surface site. The second example is the newly constructed data centre at the CERN Prévessin site. Its recovered waste heat will largely cover CERN's campus heating needs. A third example is the heat recovery project at the CERN LHC surface site point 1 (ATLAS experiment) that will supply heat to the CERN Meyrin campus.

The following are examples of equipment that can serve as a starting point for the study of the functionality of integrating heat recovery and supply.

- Normal conducting magnets (recovery of cooling water at temperatures between 25-45°C).
- Normal conducting radiofrequency cavities (cooling water temperature between 25-45°C).
- Synchrotron radiation absorbers (cooling water temperature between 25-45°C).
- Rack mounted electronics (water cooled with a δT of 20 K and a temperature range between 27-49°C on the outer circuit with a temperature range between 39-60°C on the rack cooling circuit).
- Radiofrequency amplifiers of different types e.g., solid state, klystrons, IOTs with a cooling water circuit temperature range between 25-35°C with high stability and low-temperature fluctuation constraint – depending on the case, as tight as 0.1°C. By design, the maximum water temperature at the klystron's collector may be allowed to reach 63°C, but so far, applications operating in this regime are not known.
- Cryogenic refrigeration plants for superconducting components (e.g., magnets, radiofrequency cavities) with equipment cooling circuit water temperatures in the range of 50°C (e.g., compressors) to 75°C (e.g., oil separator).
- Power electronics and converters (temperature range of circuits between 30-60°C for directly water-cooled IGBT systems, for example).
- Electrical transformer stations with water cooling-based systems in the range of 20-70°C (e.g., oil-based transformers).
- Data centres [77] (recovery of 15-20°C air, 40-50°C heat from the CRAHs and 50-60°C from liquid cooling systems).
- Ventilation and air management systems (e.g., heat from motors and air-to-air transfer) from 25 up to about 40°C.

The initial equipment and heat load analysis will inform the designers which components are the ones that produce most of the heat and with which characteristics (stability, temperature). This permits the creation of a hierarchy of heat-producing components that can guide the development of the heat recovery and supply concept.

A multi-criteria analysis with different weights for the individual aspects is a suitable approach for this first step. The analysis process should at least include the following non-exhaustive list of aspects:

- Operational temperature requirements and constraints from the equipment components to be cooled and their temperature variation tolerances.
- Temperatures of the heat recovery potential for the different equipment to be cooled.
- Variability and stability of the heat generation (hourly, daily, weekly, monthly).
- Climatic and weather conditions in the environment of the research infrastructure (for instance, a particle accelerator facility and a data centre operated in the north of Europe permit the use of different heat recovery and supply technologies than in a southern European region).
- Use cases for the recovered heat inside the research infrastructure (e.g., pre-warming of water, offices, workshops, assembly halls, guest houses).
- Demand of industrial heat consumers outside the research infrastructure (e.g., food production and processing industries, offices, hotels, airports, shopping malls, theatres, cinemas, congress centres).
- Demand for heating public spaces and institutions (e.g., schools and universities, hospitals, prisons, train stations)
- Demand for heating of private spaces (e.g., apartment buildings and individual houses).
- Demand for hot water production (the required temperature is above 55°C for sanitary reasons and therefore priming with water boilers and heat pumps may be needed on an individual basis).
- Distances between heat production and consumers (note that distances up to 10 km are feasible with modern pipe technology for low-grade district heating systems in the 50°C range).
- Gap analysis concerning the need for heat buffering (e.g., capacity, space, duration, technology, investment costs, operation costs).
- Investment costs for heat recovery, buffering and supply.
- Operation costs for heat recovery, buffering and supply.
- Capital and operation expenditures outside the system boundary (e.g., district heating network operation host, private heat pumps and priming equipment).
- Public co-financing possibilities.
- Duration and observation period envisaged for the heat recovery and supply.
- Baseline for avoiding fossil energy sources for heating and the avoidance of primary energy for heating. Only the energy for stepping up the temperature for specific end-use cases needs to be considered.
- Definition of the interface between the heat recovery and supply system that is part of the research infrastructure and the segment that is outside the responsibility of the research infrastructure.
- Conditions of the heat supply operator which provides the infrastructure up to the consumer and that supplies the heat with guarantees or with contractual conditions that require the consumer to generate or obtain the gap between supplied and required heat.
- The proposed heat supply technology (e.g., direct, indirect via a loop, indirect via heating the soil or other approaches).

Based on technical designs in the subsequent development phase, all data need to be collected and the most promising heat sources that qualify for a heat recovery case have to be identified. The viable heat consumers have to be confirmed in the frame of a territorial co-development activity. Eventually, the following non-exhaustive list of aspects to tune the heat recovery and supply scenario should be considered:

- Increase of the heat supplied by relaxing the equipment cooling requirements (e.g., water-based magnet cooling up to 50°C, increase of ambient air temperature inside the facility up to 40°C and possibly beyond).
- Validation that mission-critical systems remain within their required operation margins (e.g., increasing the cooling water temperature of klystrons or relaxing their temperature stability may lead to unacceptable performance or render operation unfeasible).
- Total amount of CO_2 emission reduction potential as a result of avoidance of fossil fuel and any primary energy, based on a credible estimate for the energy required to prime the heat for the end-use applications.
- Optimisation of the heat supply by adjusting the operation schedule and introducing the possibility of reacting dynamically to heat needs.
- Adaptation of the particle accelerator operation schedule to the actual societal heat demand to increase the overall socio-economic performance.
- The potentially different energy costs for the research infrastructure operator when adjusting the operation schedule of the particle accelerator or when introducing the capability to dynamically react to both electricity supply and heat demand constraints.
- Additional societal and economic benefits that can be generated by creating new heat consumers in the vicinity of the supplied heat (e.g., food processing industries, agricultural producers, biogas production, thermal baths and recreational installations).

Table 3.1 Waste heat supply potential according to local demand, supply scenario and operation mode

Mode	Minimum supply potential	Adaptation of operation schedule to demand	Adaptation to demand and redistribution between sites
Z	223 GWh/year	308 GWh/year	414 GWh/year
WW	239 GWh/year	339 GWh/year	471 GWh/year
HZ	256 GWh/year	371 GWh/year	529 GWh/year
L.S.	60 GWh/year	60 GWh/year	60 GWh/year
$t\bar{t}$	296 GWh/year	441 GWh/year	710 GWh/year

Table 3.2 One scenario outlining the potential for avoiding carbon emissions by supplying waste heat based on an average of 165 t avoided CO_2 per GWh of heat supplied

Mode	Years	Heat supplied/year	Heat supplied	CO_2 avoided/year	CO_2 avoided
Z	4	308 GWh/year	1232 GWh	50,820 tCO_2/year	203,280 tCO_2
WW	2	339 GWh/year	678 GWh	55,935 tCO_2/year	111,870 tCO_2
HZ	3	371 GWh/year	1113 GWh	61,215 tCO_2/year	183,645 tCO_2
L.S.	1	60 GWh/year	60 GWh	9900 tCO_2/year	9900 tCO_2
$t\bar{t}$	5	441 GWh/year	2205 GWh	72,765 CO_2/year	363,825 CO_2
Total			**5288 GWh**		**872,520 tCO_2**
Operation Scope 2 emissions (for comparison, 20,350 GWh at 25 tCO_2/GWh)					**508,750 tCO_2**

- Introduction of temporary heat buffers (daily, weekly, monthly).
- Availability of specific public co-financing facilities and loans with specific conditions.
- Optimisation of the interface between research infrastructure, operator and heat consumers.

The recovered heat will not be consumed at all times and the consumption pattern will change. Therefore, care must be taken not to under-dimension the cooling, ventilation and evaporation systems for the research infrastructure. If the heat is not consumed or cannot be delivered, it must be possible to cool all components reliably to ensure operation for scientific research purposes.

The techno-economic analysis permitted establishing the demand-based waste-heat supply scenarios based on the three different assumptions shown in Table 3.1.

Based on this scenario, the potential of avoiding carbon emissions in the region by substituting conventionally created heat with waste heat that is largely produced from renewable energy sources can be estimated. Table 3.2 shows the estimates of carbon emissions avoided, based on the following assumptions: an average market-based carbon footprint of 25 tCO_2/GWh of electricity supplied to the FCC. A weighted average of about 190 tCO_2 per GWh of conventional heat produced that can be substituted with waste heat.[6] The resulting net carbon footprint avoided by supplying waste heat is 190-25 = 165 tCO_2/GWh. Comparing the avoidable carbon emissions by supplying waste heat with the range of total Scope 2 related carbon emissions of the collider operation between 305,000 and 509,000 tCO_2 shows that the supply of waste heat can be partially substitute conventional heat sources at the same level, thus generating substantial positive environmental externalities that are made visible in the comprehensive socio-economic impact assessment.

The 'minimum' scenario is based on the hypothesis that the particle collider starts operating in March and ends at the latest in November. Figure 3.8 shows as an example the weekly overview of the cumulative heat demand around a perimeter of 5 km around each surface site.

Figure 3.9 shows the heat demand and supply during the Z mode throughout the year, with a schedule that is better adapted to the heat demand.

Figure 3.10 shows the site PA in Ferney-Voltaire as an example for the heat demand study that permitted the development of the concept for the heat supply.

Several industrial and public heat consumers were identified in the vicinity of several surface sites. They include, for example, a hospital, a school, cheese production facilities, an airport, commercial zones and public housing. Such heat consumers are preferred over supply to individual houses that are more difficult to connect. Public,

[6]Regional heat production mix: 36% electricity at 147 gCO_2/kWh, 34% gas at 227 gCO_2/kWh, 16% oil at 324 gCO_2/kWh, 11% wood at 30 gCO_2/kWh, 0.3% heat at 49 gCO_2/kWh leads to a total footprint of 186.7 gCO_2/kWh = 186.7 tCO_2/GWh.

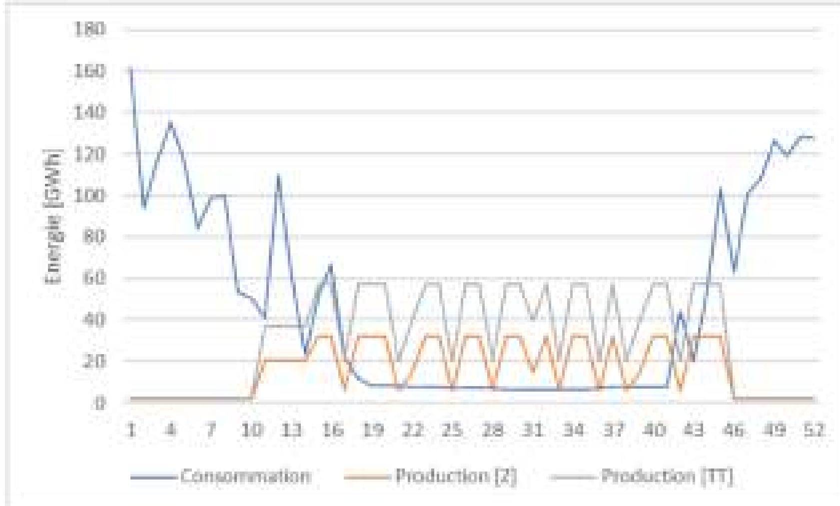


Fig. 3.8 Weekly heat demand and supply for an example schedule of the Z operation mode

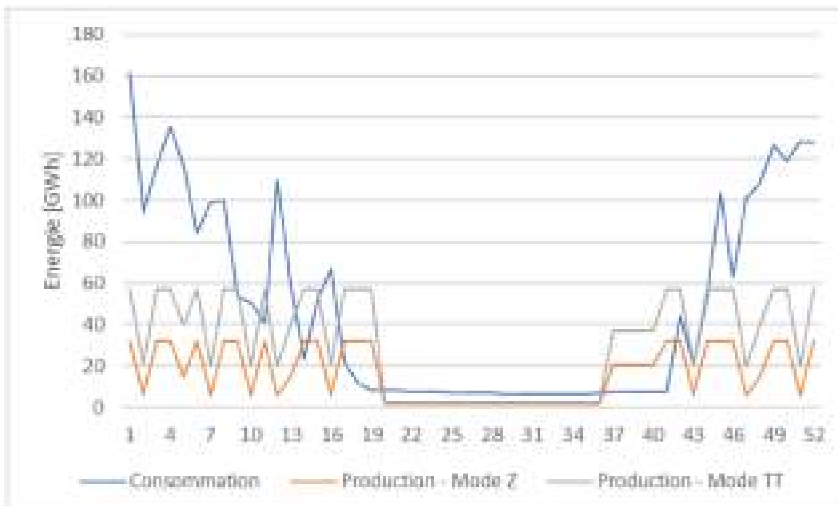


Fig. 3.9 Weekly heat demand and supply for an adapted schedule of the Z operation mode

industrial and commercial consumers typically have a higher and more stable heat demand. Site PD in Nangy (see Fig. 3.11) is one example where significant amounts of heat in the 10 GWh/year range can be supplied in the close vicinity of the surface site.

The techno-economical study revealed that waste heat supply is challenging at site PH (Cercier and Marlioz) and would be modest at sites PL (Challex) and site PB (Presinge). Therefore, a redistribution of the heat from PH to PG, from PL to PA and between PB and PD could be considered to improve the yield.

Table 3.3 gives an overview of the potential total waste heat demand that exists today in the perimeters studied around each site. Waste heat is best re-used with the creation of new consumers, such as healthcare facilities, thermal baths, greenhouses, industrial facilities, and residential buildings that are connected to the new network from the outset.

The supply of residual heat (or waste heat) from the FCC creates windfalls in three ways:

1. Balance the non-avoidable and non-reducible residual carbon footprint of electrical energy: supplying the FCC with electricity (the working hypothesis is based on using electricity partly from renewable sources) would represent an average carbon footprint of around 40,000 tCO_2(eq)/year. The yearly supply potential from residual waste heat is around 320 GWh of energy per year. The total maximum residual heat capacity is around 1600 GWh per year. Consequently the supply of waste heat can substitute for the carbon footprint of the electrical energy consumed, provided that this heat supply can be implemented and that the demand can be satisfied via a heat distribution infrastructure. The technical-economic study [73–75] showed that 220 GWh to 300 GWh of heat could be consumed within a radius of approximately 5 km around the surface sites. However, to increase the efficacy of waste heat supply, the particle collider operation schedule needs to adapt within acceptable limits to the heat needs.

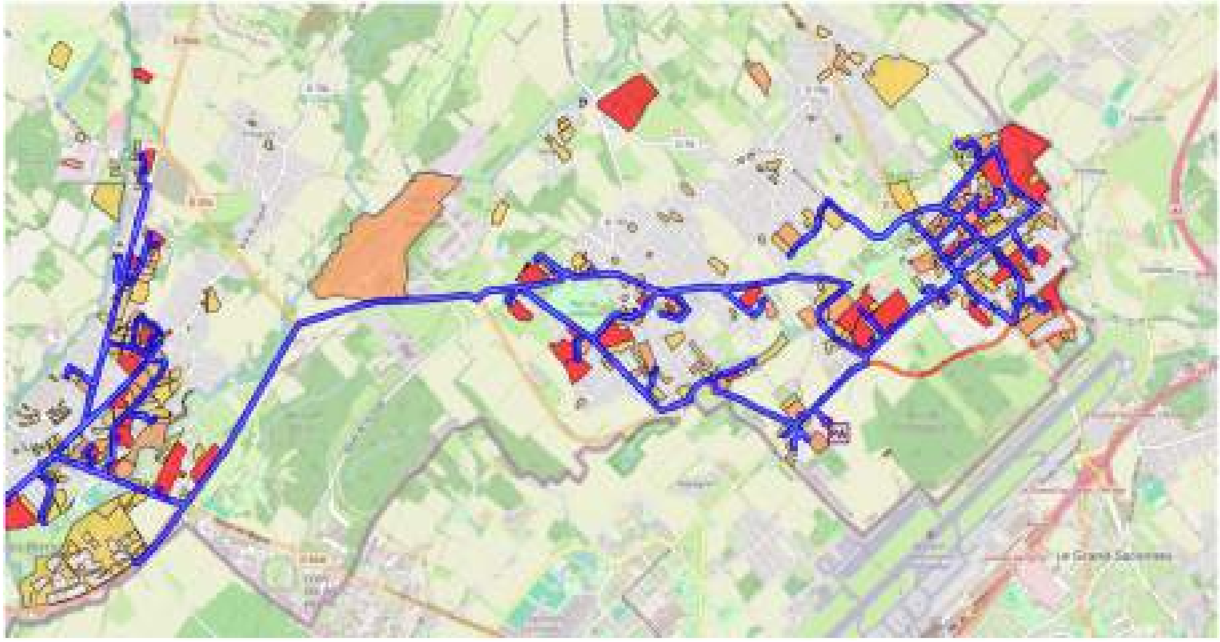


Fig. 3.10 Example from the heat demand study at site PA in Ferney-Voltaire, within a perimeter of ∼5 km around the site

Table 3.3 Overview of the total potential waste heat demand that exists today in the perimeters studied around each site

Site	Potential	Demand	Consumers
PA	High	200 GWh/year	Schools, commercial zones, residential
PA Extended	High	1700 GWh/year	Extension to Switzerland: airport, commercial and industrial activities, residential, hospitals
PB	Medium	30 - 200 GWh/year	School, greenhouses, penitentiary, hospital, commercial activities, housing
PB Extended	High	> 200 GWh/year	Commercial and residential demands in nearby France, sector Annemasse
PD	Low	14 GWh/year	Hospital, industrial
PD Extended	Medium	50 GWh/year	Schools, healthcare, residential
PF	Medium	60 GWh/year	Sector La Roche-sur-Foron: industrial expo center, schools
PG	Low	16 GWh/year	Schools, residential
PG Extended	Medium	35 GWh/year	Schools, residential
PG Annecy	High	860 GWh/year	Annecy at distance of 7 km: Industrial, commercial, residential
PH	Very low	14 GWh/year	At 8 km distance: Retirement home, residential
PJ	Low	20 GWh/year	Schools, commercial, residential
PL	Low	30 GWh/year	Spread over 5 km: school, commercial, residential

2. Reduction of the carbon footprint of heating and cooling in the region: the supply of energy by a heating network using a high proportion of renewable energies (including residual heat) avoids the need for other sources of heat. Based on the minimum reuse hypothesis (220 - 300 GWh/year), the production of 27,500 to 38,500 tCO_2(eq) could be avoided each year. Reasonable adaptation of the operating schedule throughout the year would be required to make this approach an effective lever.
3. Increasing the purchasing power of the local population: The organisation operating the FCC is not a profit-making organisation. Energy can, therefore, be supplied by network operators at very competitive prices. According to the French multi-annual energy programme (PPE), waste-to-energy plants (which recover waste heat) sell this heat at a very competitive price, between 10 and €25/MWh. As a result, the heat supplied can

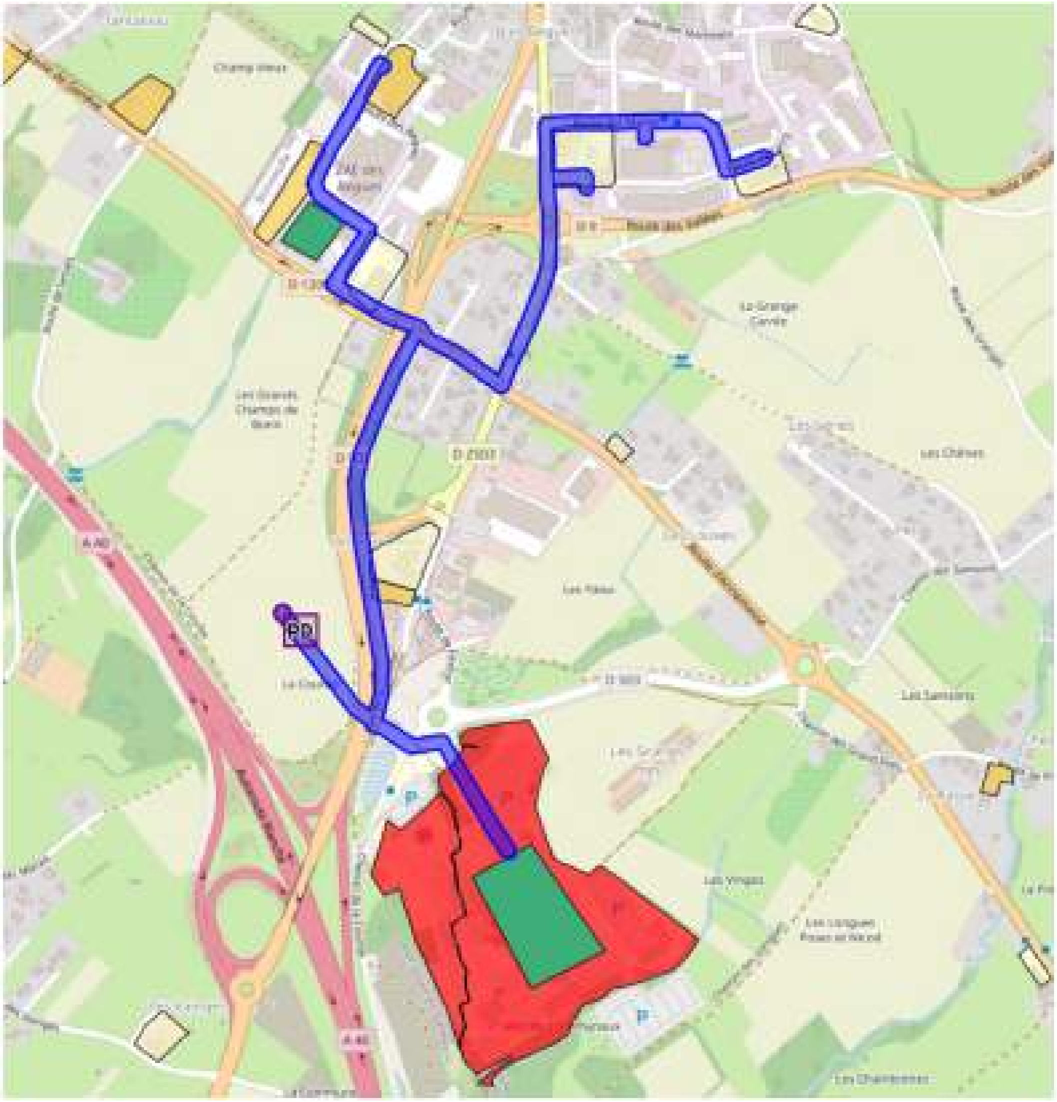


Fig. 3.11 Example from the heat demand study at site PD in Nangy, concerning a nearby hospital (south), a cheese producer (north) and a mixed industrial/residential zone (north-east)

then be the preferred choice for heating, hot water, and cooling. In the Anergie network (Ferney-Voltaire), the price of waste heat supplied by CERN equipment is even lower. According to a study by AMORCE and ADEME, the average selling price for networks supplied mainly by renewable and recovered energies ("EnR&R") was €78.2 /MWh, incl. tax, in 2020 (these prices do not take into account the initial investment costs of the networks). According to the waste heat supply study carried out for this project by the engineering firm Ginger BURGEAP, the average price was at the same level more recently. Based on this model, the potential savings are currently estimated at €50/MWh compared with gas heating and €140/MWh compared with electricity, using energy prices of 1st November 2023 as a reference.

4. Limiting water consumption: reusing residual heat would also reduce the need for cooling water. The potentials are described in Sect. 3.2.9.

3.2.7 Construction related carbon footprint

As the global focus on combating climate change intensifies, reducing greenhouse gas (GHG) emissions has become a top priority. Infrastructures—spanning transport, construction, and scientific instruments — play a critical role in this transition. Carbon budget analysis, as part of a more comprehensive Lifecycle Analysis (LCA) (see Fig. 3.12), has emerged as an essential tool for measuring and managing these emissions effectively.

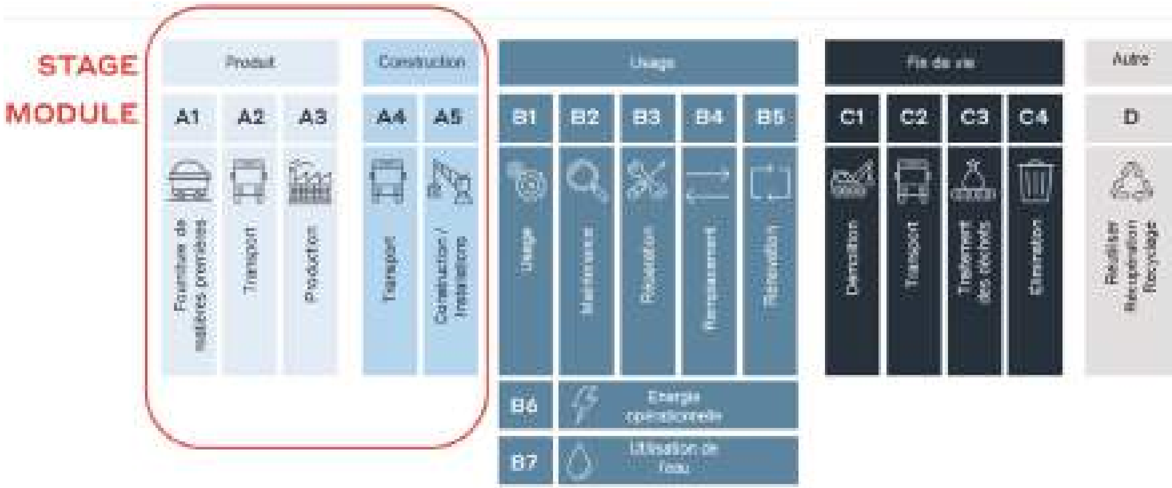


Fig. 3.12 Stages considered for the LCA of the infrastructure construction

A comprehensive lifecycle analysis (LCA) conforming to the applicable ISO standards and European Norms, EN 14040 and EN 14044, has been carried out [59]. For the construction sector, the EN 17472 norm has been followed. In addition to the use of generic databases, a specific procurement scenario has been analysed, based on currently available Environmental Product Declarations (EPD) conforming to the European Norm, EN 15804+2, and the French 'Fiche de Déclaration Environnementale et Sanitaire' (FDES).

The goal of the work was firstly to identify the key drivers for quantitatively estimated environmental impacts of the construction and, secondly, to establish a credible reference scenario for the carbon budget as a baseline for further designs and optimisations. It is important to note that a generic LCA cannot provide adequate indications for the carbon footprint, but is limited to the capability of identifying drivers. A specific and geo-localised project scenario with a particular sourcing scenario is necessary to be able to report absolute and credible estimates. The methodology adopted comprised the following steps:

1. Identification of components: a detailed inventory of materials was compiled based on the bill of quantities for the subsurface construction, the 4 experiment sites and the technical sites. The products concerned are used throughout the infrastructure's lifecycle.
2. EPDs acquisition: EPDs were sourced for each material and product identified, ensuring compliance with EN 15804+A2, the foundation of EN 17472. The materials were selected based on expert knowledge of the local environment and state-of-the-art products. The availability of the products was confirmed by the suppliers.
3. Software Tool: A certified tool compatible with French and Swiss Environmental Product Declaration, One Click LCA, was chosen, ensuring robust and accurate calculations.
4. Data Entry: data was imported into the tool and project-specific data was entered, including material quantities and lifecycle phases, transportation for excavated and construction material.
5. Calculations: the tool was used to estimate the carbon budget, drawing on EPDs' data to evaluate GHG emissions for each lifecycle phase.
6. Result Analysis: the results were analysed to pinpoint major emission sources, comparing them against benchmarks and reduction targets.
7. Guidance: the results were used to sensitise engineers and scientists to include a carbon budget as a further input to the subsequent design phase and to ensure that requirements are well formulated and justified so that the infrastructure corresponds to what is required, thus limiting the environmental impacts.

The analysis provided a breakdown of GHG emissions and additional quantitative potential environmental impacts across the various lifecycle phases, products and materials. The key emission sources are reinforced steel (14%), precast concrete (49%) and concrete (23%). This highlights opportunities for emission reduction by designing the infrastructure with carbon reduction in mind, making careful material selection, optimising the construction process and making energy efficiency improvements. The most effective environmental impact management approach is a combination of the establishment of technical requirements for the infrastructures with rationales for the requirement, design of the infrastructure based on the requirements with carbon reduction in mind, careful material selection in agreement with the requirements, construction process optimisation, and energy efficiency improvements. The GHG impacts of the initial and benchmark scenarios are given in Table 3.4.

The 526,188 tCO_2(eq) carbon footprint of the construction over a period of 10 years can be compared to CERN's current annual carbon footprint (184,173 tCO_2(eq) [78]. Thus, the construction corresponds to about

Table 3.4 Reference carbon footprint of the FCC infrastructure construction for a period of 10 years based on specific sourcing and procurement scenarios with EPDs

Item	Carbon footprint
Subsurface	477,388 tCO_2(eq)
4 technical sites	17,600 tCO_2(eq)
4 experiment sites	31,200 tCO_2(eq)
Total	526,188 tCO_2(eq)

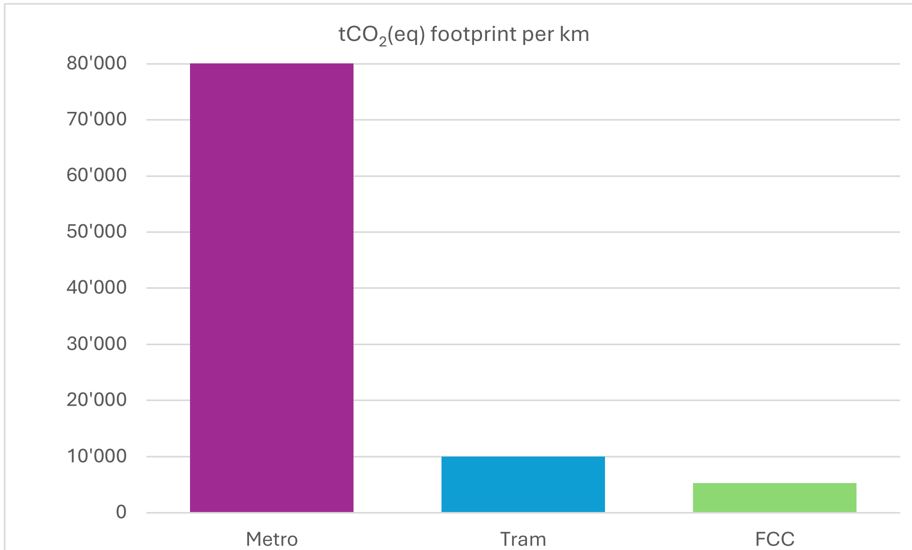


Fig. 3.13 The construction-related carbon footprint per km of the FCC tunnel compared to typical public transport linear structures [59]

3 years of CERN's annual footprint or about 30% of CERN's annual carbon footprint per construction year. The FCC construction carbon footprint can also be compared to that of the Olympic Games in Paris which had an estimated carbon budget of 1,580,000 tCO_2(eq) [79].

With respect to conventional construction projects, the carbon footprint of a research infrastructure is significantly lower (see Fig. 3.13) than a small-scale metro line or a tramway line. For instance, the construction of the U5 Metro line in Berlin, Germany had a carbon footprint of 98,000 tCO_2(eq) per km [80]. On average, per km of underground transport line construction, the carbon footprint is 80,000 tCO_2(eq). The construction of a tram line has a carbon footprint between, 7600 and 10,850 tCO_2(eq) per km.

Based on the analysis, a number of recommendations were developed with the help of the expert company that carried out the LCA.

Although CERN's annual carbon footprint will gradually be reduced, in line with the established environmental goals, national climate protection plans and IPCC recommendations, it would be advisable to limit adding construction-related climate impacts to the operation-related carbon budget. Hence, while the construction of a new facility ramps up, it would be prudent to reduce the activities related to other carbon-intense activities. With respect to the construction, the following strategies can help to reduce the potential impacts further:

- Implementation of a thorough systems engineering methodology to develop well-justified and fully documented technical requirements for both subsurface and surface structural elements. These requirements will represent the absolute minimum necessary to accomplish the scientific research programme effectively (for example, determining the precise dimensions and volumes of structures that meet the essential technical and physical requirements).
- Integration of an eco-design in the comprehensive systems engineering process with carbon reduction in mind that matches the established requirements (e.g., appropriate sizing of the caverns, shafts, alcoves).
- Structural modification of the scenario by reducing the inner line thickness of subsurface structures by at least 5 cm, leading to a reduction of 16% for precast concrete and rebar steel.
- Material substitution, considering low-impact materials which meet the established requirements and working with industrial partners to innovate and produce locally wherever possible.
- Construction process optimisation to minimise emissions.
- Reuse of excavated materials, for instance, in concrete production.

With respect to the initial baseline scenario, the reduction of the circumference to about 91 km and the suppression of 4 shafts have led to a significant reduction of the construction-related carbon footprint during the scenario development phase. Furthermore, the carbon footprint must be seen in the context of establishing an infrastructure that serves a worldwide community of about 15,000 scientists for two subsequent particle colliders until the end of the century. Although according to international norms the quantities reported by the LCA must be entirely accounted for the first project phase only (FCC-ee), it can be seen as an investment that benefits the second phase, the high-energy hadron collider phase (FCC-hh).

3.2.8 Operation related carbon footprint

Detectors While the carbon footprint of today's scientific research facilities, such as the LHC and its experiments, is largely caused by gases used in the detectors, this contribution will be only marginally relevant for the FCC era: gases with significant climate effects are already being banned, and the list of such products is growing rapidly.

Today's working gases will largely be unavailable by the year 2050 when the first collider enters its operation phase. The performance and long-term operation of gaseous detectors rely primarily on the use of the optimal gas mixture, which is the active medium where the primary ionisation happens in the detector. Several gaseous detector technologies make use of gas mixtures containing expensive or greenhouse gases, which have specific properties that allow optimal detector performance and avoid ageing effects. The GHGs most in use are the $C_2H_2F_4$ (known as R134a, GWP of 1430) and SF_6 (GWP of 23,900) for the Resistive Plate Chambers, the C_4F_{10} (GWP of 8860) for Cherenkov detectors and the CF_4 (GWP of 7390) for wire chambers, Cherenkov detectors and micro pattern gaseous detectors (MPGDs). These gases are necessary to mitigate ageing phenomena, to act as a Cherenkov radiator and to contain charge development (thanks to their electronegative properties) or to improve time resolution.

The detector volumes range from a few m^3 to hundreds of m^3 making the use of gas recirculation systems compulsory to reduce operational costs and GHG emissions. Even with the implementation of these systems, in some cases, emissions can be present mostly due to detector requirements or the presence of leaks. Residual leaks are mainly due to failures of plastic pipes and connectors that break due to built-in fragility and mechanical stress. These leaks are not accessible during run periods and, in some cases, during regular technical stops. Big leak search and repair campaigns usually take place during long shutdown periods, but leaks typically keep developing.

To reduce emissions, today's strategy [81] is based on three lines of action:

- **Gas Recirculation.** The gas mixture is taken at the output of the detectors, purified and sent back to the detectors. It is technically possible to recycle 100% of the gas mixture.
- **Gas Recuperation.** The gas mixture is sent to a recuperation plant where the GHG is extracted, stored and re-used. This system is always used in combination with a gas recirculation system to allow a further GHG reduction.
- **Alternative gases.** Search for alternative gas mixtures suitable for particle detectors that do not contain or have limited use of GHGs.

The substitution of fluorinated gases (F-gases) is fundamental because of the implementation in Europe of the F-gas regulation that will render such substances unavailable by 2050. Also in 2023 the European Chemicals Agency (ECHA) released a proposal regarding restriction on PFAS, i.e., per- and polyfluoroalkyl substances, which contain at least one fully fluorinated methyl (CF_3-) or methylene (-CF_2-) carbon atom (without any H/Cl/Br/I attached to it). The proposal covers over 10,000 different PFAS, which are considered environmental pollutants with links to harmful health effects. Most of the so-called 'eco-friendly' gases belong to the PFAS family.

In addition, devices and circuits using gases either for cooling or for particle detection purposes must be designed to be leak-tight and use a re-circulation principle.

Scope 2 The principal cause of carbon footprint will be the use of electrical energy.

The same approach will be used for the optimisation of all other resource use, such as electrical energy. The adoption of the hierarchical 'Avoid-Reduce-Compensate' principle guides the iterative planning, implementation, checking and taking action cycle that leads to continuous optimisation.

A comprehensive technical requirements gathering process has to be established to document and scrutinise where and when electrical energy is needed. Following a baseline scenario, the eco-design approach helps to conceive designs and choose products that lead to reduced energy consumption. A review of the operation model that will be guided by overall sustainability goals integrating economic, ecological and societal aspects will guide the development of different scenarios. Some measures require another iteration of the eco-design cycle by introducing new requirements that foster sustainability, such as the integration of waste-heat recovery and supply functionality. It permits, for instance, substituting fossil energy used inside and outside the project, but it comes with constraints such as additional investment and operation costs, the necessity to buffer energy, the need to dynamically adapt operation, requirements on financial and ecological accounting and the requirement to establish administrative

Table 3.5 Examples of some official electrical energy carbon footprint sources

Country	Source	Energy	Carbon footprint gCO_2/kWh tCO_2/GWh	Year
France	Ademe Base Empreinte	Offshore wind	15.6	2023
France	Ademe Base Empreinte	Unqualified energy mix	52.0	2022
Germany	Umweltbundesamt (UBA)[a]	Unqualified energy mix	380.0	2023
Italy	ISPRA	Unqualified energy mix	257.2	2022
Switzerland	BAFU/OFEV[b]	Unqualified energy mix	54.7	2018
Switzerland	BAFU/OFEV	Renewable energy mix	15.7	2018

[a]https://www.umweltbundesamt.de/publikationen/entwicklung-der-spezifischen-treibhausgas-10.

[b]https://www.bafu.admin.ch/bafu/de/home/themen/klima/fragen-antworten.html.

and commercial frameworks for successful implementation. All relevant ESG parameters need to be taken into consideration, and it is therefore recommended that experienced companies be employed for the overall energy optimisation of the infrastructures.

Official national values for the selected base year of the sustainability analysis must be used to determine the carbon footprint of the electricity consumed during the design and planning phases. Consequently, the carbon footprint depends on the technology (offshore wind, onshore wind, photovoltaic, hydro, nuclear) and the geographical location of the energy production. Even if all electricity is transported and supplied to the FCC by the French electricity grid, operated by RTE, this does not mean that the electrical energy needs to be sourced solely from French territory. Studies carried out with experts in the domain [51] showed that a comprehensive portfolio of energy supply contracts or power purchasing agreements (PPA) would be best established with sufficient lead time (order of 10 years). It must be able to respond to the evolving needs of the commissioning and operation phases. In order to foster the use of renewable energy sources and exploit the waste heat supply functionality, the particle collider would need to adapt to the energy supply contract conditions that eventually are determined by commercial conditions on the one hand and by the availability of renewable energy capacities on the other.

Depending on the country of origin, the carbon intensity of electricity is made available from different sources. Table 3.5 provides an illustration.

Once a specific energy supply contract is active, emission accounting will be carried out using supplier-provided emission information. For instance, a typical consumer-oriented electricity contract based entirely on renewable energy sources (62% hydro, 31% wind and 7% PV, 100% are certified to be of renewable energy sources) in France today has an actual carbon footprint of 34 $kgCO_2$(eq)/MWh [82]. This value is higher than the ADEME indicated emission factor for renewable energy sources to be used for the planning and design phases since the consumption of electricity in the frame of a live contract includes all emissions along the value chain and not only the production-related emissions. In addition, renewable energy that is potentially sourced from physical PPAs is not accounted for in the carbon footprint.

Different assumptions were taken to estimate the Scope 2 carbon footprint related to the operation. One assumption is based on today's energy mix, including nuclear energy and renewable energy sources with a varying contribution of up to 75% and a carbon footprint of 24 gCO_2/kWh. This configuration leads to an average annual indirect carbon footprint of about 500,000 tCO_2 or approximately 35,000 tCO_2 per year depending on the renewable PPA and energy supply contract portfolio.[7]

For an optimistic reference estimate, it was assumed that an energy mix based on a portfolio of physical and non-physical PPAs and energy supply contracts on the 2050 time horizon, entirely sourced from French territory via the national grid operated by RTE (see Table 3.6). Based on this mix, the total carbon footprint of about 300,000 tCO_2(eq) was estimated[8] for the entire scientific research period over 15 years. This corresponds to an annual average of about 20,500 tCO_2(eq). Using a pessimistic estimate of 25 tCO_2(eq)/GWh leads to a carbon footprint of 522,500 tCO_2(eq) of an annual average of about 34,800 tCO_2(eq).

The residual carbon footprint can in principle also be offset by the supply of waste heat. Depending on the amount of waste heat re-used, this opens an opportunity to evolve towards net-zero operation scenario after 2050. Such a scenario requires the careful development of energy supply contracts and/or long-term PPAs and the creation of district heating and industrial heat supply networks, with an adaptation of the accelerator operation to the energy supply and the heat demand. Introducing temporary heat buffering will help achieve the goal.

[7]20,900 GWh * 24 tCO_2(eq)/Gwh = 501,600 tCO_2(eq).

[8]20,900 GWh * 14.74 tCO_2(eq)/GWh = 308,066 tCO_2(eq).

Table 3.6 Lowest carbon footprint energy mix assumption used for the estimate of the carbon footprint for operation on a 2050 time horizon. The carbon intensity figures were obtained from the Ademe Base Empreinte database, 2023

Energy Source	Contribution	Carbon intensity
Nuclear	10%	3.7 $gCO_2(eq)/kWh$
Offshore wind	55%	15.6 $gCO_2(eq)/kWh$
Onshore wind	10%	14.1 $gCO_2(eq)/kWh$
Photovoltaic	15%	25.2 $gCO_2(eq)/kWh$
Hydro power	10%	6.0 $gCO_2(eq)/kWh$
Total	100%	**14.74 $gCO_2(eq)/kWh$**

Table 3.7 Overview of the raw water needs for cooling for each operation mode, waste water re-use potentials for sites PD, PF, PG and the residual treated water that can be made publicly available

Mode	Years	Initial FCC water need	Waste water used at PD, PF, PG	Residual water needs	Treated waste water available to society
Z	4	1,604,861 m^3/year	560,304 m^3/year	1,044,557 m^3/year	2,049,792 m^3/year
WW	2	1,928,943 m^3/year	619,017 m^3/year	1,309,927 m^3/year	1,991,080 m^3/year
ZH	3	2,165,458 m^3/year	705,173 m^3/year	1,460,285 m^3/year	1,904,924 m^3/year
L.S.	1	163,817 m^3/year	78,840 m^3/year	977 m^3/year	2,531,256 m^3/year
$t\bar{t}$	5	3,077,591 m^3/year	897,334 m^3/year	2,180,258 m^3/year	1,712,763 m^3/year

3.2.9 Water use and saving

Drinking water from the existing local distribution networks will only be used for drinking and sanitary purposes. All raw water required for industrial cooling systems will be sourced from CERN's existing water supply (SIG) in Switzerland, which sources the water from Lake Geneva.

From a quantitative point 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 consumption in 2022. The availability of a supply representing twice the total needs was confirmed by SIG in 2023.

During the subsequent design phase, it will be necessary to verify aspects relating to the sharing of water with the other local stakeholders who use the same water sources, particularly with regard to related catchment areas which currently experience chronic deficits (Pays de Gex, La Roche-sur-Foron and possibly the Usses). Numerous synergies can be considered with local authorities in the vicinity of surface sites in terms of the reuse of residual heat and released water.

Therefore, a study has been launched recently to determine the feasibility and the conditions to also source water from a water treatment station near the site PD in Nangy (STEP SRB in Scientrier, see Table 3.7). Initial results are promising, requiring, however, a reduction of the non-soluble content in the water and an effective treatment of bacteria. A demonstration will be required for such an installation. If considered viable, it can lead to substantial raw water reduction and can help supply treated water for other industrial purposes when the particle accelerator does not require it.

The preliminary analysis has been carried out based on the water supplied to the treatment plant during a typical year and an assumption of a treatment capacity of up to 400 m^3/hour. Although a water treatment plant has, in principle, the capacity to provide more water than is needed for the cooling of the particle collider, it is prudent to assume that the water is mixed with ordinary raw water, that the treated water is not always compliant with the needs, and that the treatment is not always fully efficient or available. Figure 3.14 gives an impression of the typical annual operation of the water treatment plant in Scientrier close to site PD and how wastewater recovery would map to the collider cooling needs for the Z mode as an example.

It should be noted that ultimately the feasibility of this approach and the actual capacities depend on the technical designs and the possibility of implementing the concept in cooperation with the national, regional and local stakeholders in France.

Furthermore, water reduction can be achieved with the recovery and supply of waste heat, since less heat needs to be dissipated with evaporation towers. The reduction potential estimated in the dedicated engineering study was approximately 1.6 m^3 of water per MWh of waste heat supplied. Table 3.8 outlines the potential amount of cooling water savings for each operation mode and for one of three different waste heat supply scenarios:

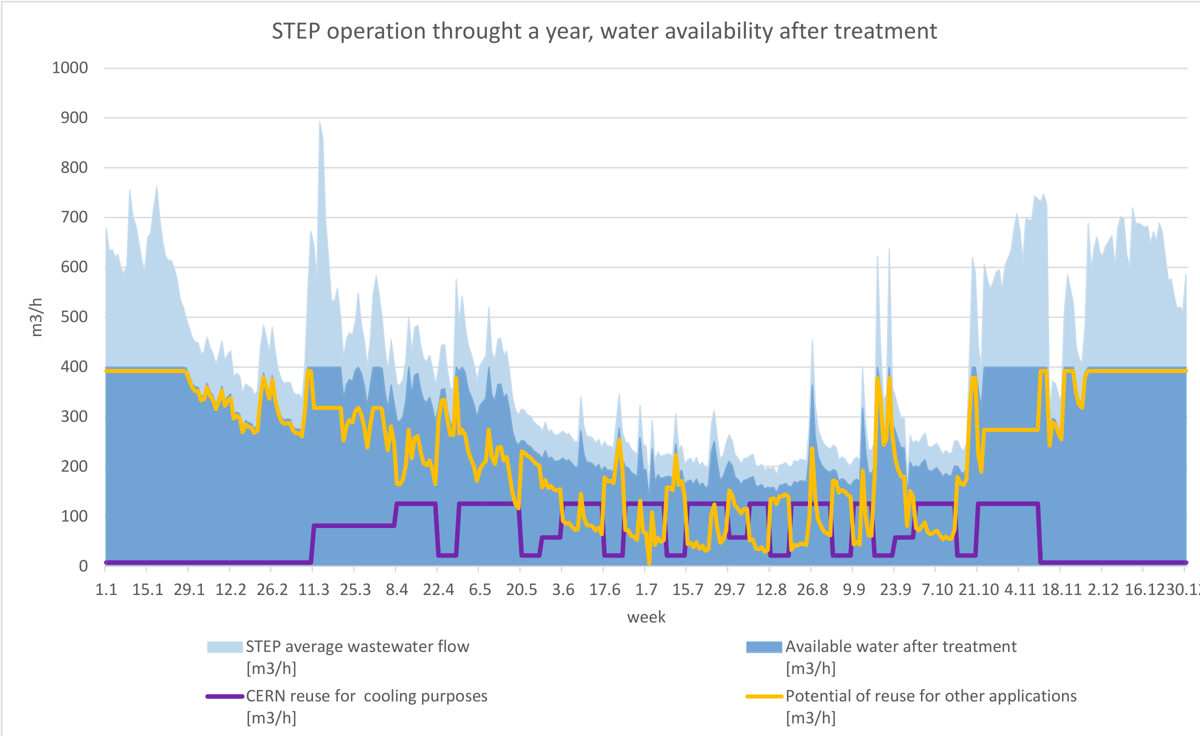


Fig. 3.14 Operation of the STEP in Scientrier throughout a typical year, matching with FCC Z mode water cooling needs and the capacities made available by water treatment to the FCC and society

Table 3.8 Water saving potential related to waste heat supply (scenario 2, adapting the collider operation to seasonal demand)

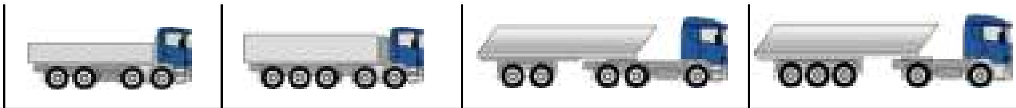
Mode	Years	Heat supplied	Water saved
Z	4	308 GWh/year	477,000 m^3/year
WW	2	339 GWh/year	523,000 m^3/year
HZ	3	371 GWh/year	571,000 m^3/year
L.S.	1	60 GWh/year	96,000 m^3/year
$t\bar{t}$	5	441 GWh/year	678,000 m^3/year
Total		**5288 GWh**	**8,155,200 m^3**

Scenario 1: the heat is distributed in a 5 km radius with no adaptation of the schedule. This means that the FCC would be operated from April to September, when the heating needs are low.
Scenario 2: the heat is distributed in a 5 km radius with an adapted schedule. This means that the FCC would be operated from October to March, when the heating needs are high.
Scenario 3: the heat is distributed in a 5 km radius with an adapted schedule and distribution. This means that the infrastructure would operate from October to March, when heating demand is highest, and the heat would be distributed to areas where there is higher demand than in scenario 2.

The water savings also translate into a modest reduction of operating cost of about 6 million CHF. Whilst this is not a noteworthy financial sustainability contribution, together with some annual electricity savings of 4 GWh per year, in total about 60 GWh which is worth another 5 million CHF, financially and economically compensating the additional effort to operate the waste heat recovery system.

3.2.10 Induced road traffic

To estimate the additional traffic induced by the construction activities, a traffic analysis has been carried out using up-to-date traffic data in approximately 5 km wide perimeters around the surface site locations and comparing different standard trucks used for construction (Fig. 3.15). Based on this traffic analysis (Fig. 3.16) and the



Axles	4	5	3 + 2	2 + 3
Total weight (t)	32	40	40	40
Capacity (m^3)	12	17	24	24
Capacity (t)	18	24	24	25

Fig. 3.15 Capacities of different standard trucks used to analyse the construction site induced additional road traffic

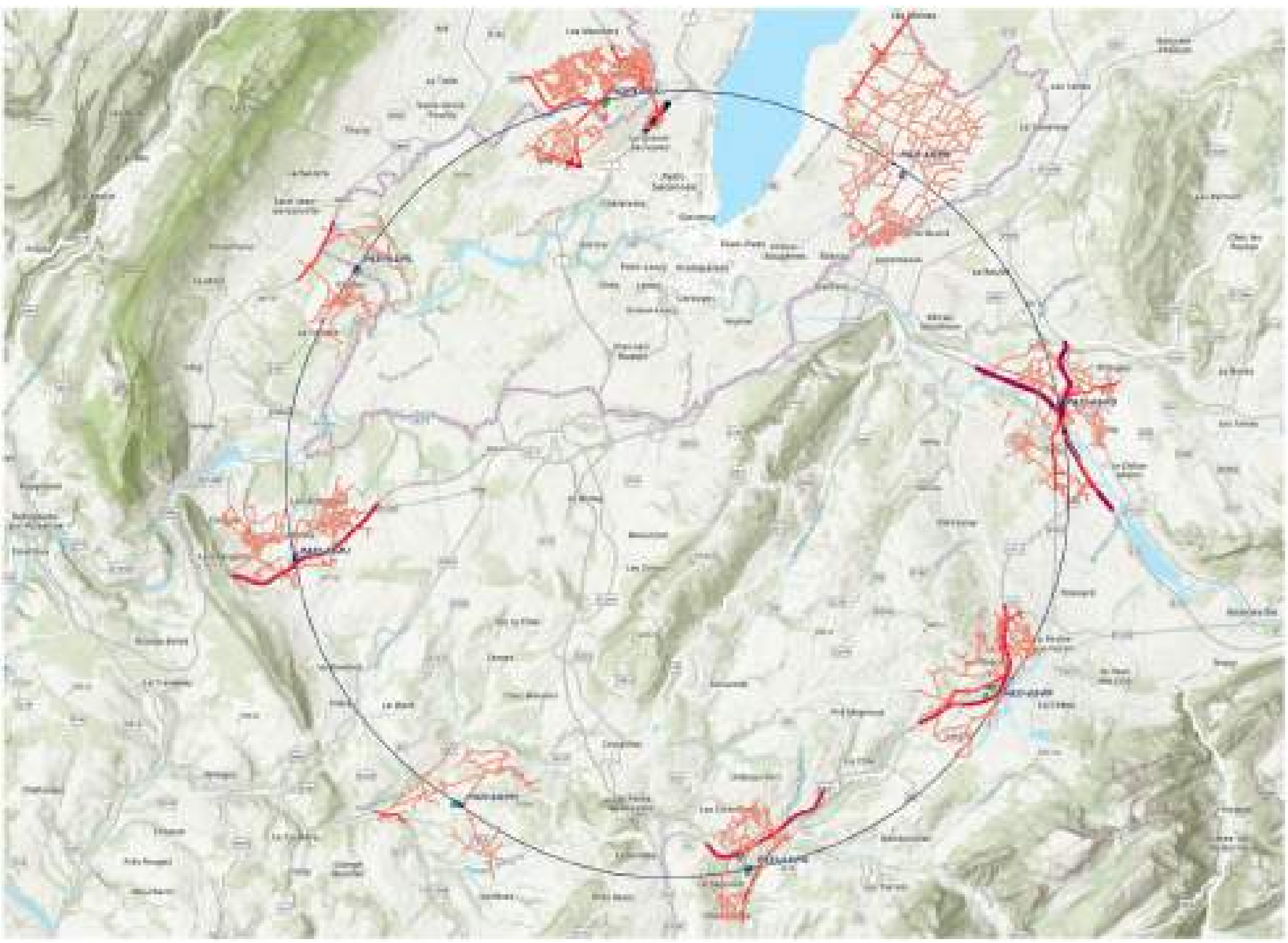


Fig. 3.16 Perimeters of the traffic studies for each construction site. The bolder lines indicate the traffic recorded on major transport routes

assumption of a worst-case scenario in which all materials need to be transported by trucks on roads, it can be shown that the additional traffic induced by the project, distributed over nine construction sites and more than eight years is only marginal (Table 3.9). Traffic is assumed to be limited to working days and regular working hours, avoiding morning and evening peak hours.

The subsequent project design will emphasise reducing road-based transport requirements. The traffic can be further reduced by using larger trucks (2+3 axles or 3+2 axles). Conveyor belts are the preferred means to bring excavated materials to major road and rail transport networks so that no local traffic is induced. Where possible,

Table 3.9 Worst case scenario during the construction period for excavated material transport using trucks only. The traffic can vary with different excavation scenarios, leading to less traffic at PL and PB and more traffic at PA

Site	Traffic per day	Additional 5-axle trucks per day	Additional traffic in percent	Additional 5-axle trucks per hour
PA	7803	46	0.5%	4
PB	5918	37	0.6%	3
PD	20,475	93	0.4%	8
PF	11,331	12	0.1%	1
PG	13,681	100	0.7%	8
PH	1709	23	1.3%	2
PJ	13,954	95	0.7%	8
PL	3380	46	1.4%	4
Injector	7803	9	0.1%	1

Table 3.10 Number of people on-site during various different activity periods

Site	Installation 5 years	Operation 10 months per year	Maintenance 2 months per year	Shutdown every few years
PA, PD, PG, PJ	200 - 300 people	15 to 20 people	100 people	200 - 300 people
PB, PD, PH, PL	100 people	0 to 10 people	15 - 30 people	Up to 100 people

construction materials are brought in via autoroutes to site connections or via major roads to avoid passing through residential areas.

The traffic for the five years of installation of the particle accelerator equipment is small. It ranges between 9 and 18 trucks per site and day, i.e., between 1 and 2 trucks per working hour. No traffic is foreseen during the night and non-working days. The limitation to traffic during the installation is due to the limited capacity of transferring equipment through the access shafts. The handling speed between surface and underground and in the constrained underground environment determines the amount of equipment that can be brought in. Between about 200 and 300 people per day are expected to be present on experiment sites and about 100 people on technical sites (see Table 3.10). This leads to daily work-related traffic of about 100 to 200 cars. This traffic can be significantly reduced by organising the work and providing the possibility of carpools and bus transport.

During operational periods, technical sites are expected to have minimal personnel presence, based on system requirements, resulting in minimal traffic impact. For experiment sites, the highest projected staffing scenario involves small teams of up to 20 people working across three shifts. Transportation should be organized to limit daily vehicle movement to several dozen cars entering and exiting each site. However, visitor traffic at sites PA, PD, PG, and PJ may be substantially higher.

3.2.11 Environmental monitoring

An environmental monitoring system will be put in place once the new research infrastructure is completely constructed. Such a system will help track compliance with the initially set goals and support safe operation. Such a system typically comprises the following functionalities:

- Clear water monitoring: Measurement stations for effluent water integrate continuous monitoring of temperature, pH, hydrocarbons, foam, turbidity, conductivity and flow rate. Alarms are triggered based on threshold and trend conditions. Where a surface site is equipped with water retention facilities, additional monitors will be installed to activate retention when needed.
- Sewage water monitoring: Measurement stations integrate continuous monitoring of temperature, pH, conductivity and flow rate for water released into the public sewage network. Periodic sampling is also implemented.
- Process water sampling: Such stations serve periodic sampling of residual effluents from the processes such as for instance water recycling and treatment.
- Air quality monitoring: Such stations continuously monitor the air, including oxides (nitrogen oxides and ozone) that may be byproducts of the synchrotron operation. Those systems are coupled to air recycling functions. Continuous comparison with the existing background air conditions will be implemented.
- Noise monitoring: Such stations measure and record continuously the noise levels at the surface site locations and in sensitive areas in the vicinity.

- Meteorological monitoring: These stations are equipped with anemometers and pluviometers for assessment of hazards due to potentially radioactive substances and fumes in case of fire. Cooperation with the national metereological services will be considered for data exchange.
- Radiological monitoring: Monitoring of radiological parameters during and after the operation to provide evidence for compliance with the dose constraints and limits. The system comprises equipment for on-site monitoring for the safety of workers and on and off-site monitoring for the environment.

In addition to the stationary environmental monitoring facilities, additional portable devices will be used for periodic in-field monitoring. Samples such as water, soil and plants will be analysed regularly by environmental laboratories.

3.3 Current state of the environment

3.3.1 Methodology

The current state of the environment in the perimeter of the reference implementation scenario and at the surface site candidates has been analysed following the national regulations in the two Host States, France and Switzerland. The resulting single, integrated report [30], complemented by interactive maps, audio, image and video materials as well as by an Environmental Information System based on the ESRI geographical information system, is an essential preparation work for the subsequent environmental authorisation process that has to include an environmental impact assessment in a transnational context. This work has been carried out between 2023 and 2025 with a consortium of expert companies. The following section gives a glimpse of the scope of the work carried out and provides the basic conclusions. The initial state of the environment is only valid for a limited period of time since the environment is constantly evolving. Therefore, further complementary studies (e.g., hydrogeological investigations, further studies on fauna and flora, more comprehensive environmental measurements) and studies for potential alternative site locations have to be engaged during a subsequent environmental impact assessment phase.

3.3.2 Air and climate

Climate The climatic conditions and their foreseeable evolution have to be considered for a long-term programme like the FCC that will extend until the end of the century. The environmental state analysis includes the collection of climate data from bibliographical sources and climate observation facilities in Geneva (Switzerland) and Annecy (France). Despite the limited distance of about 30 km between the extreme sites of the FCC, the climatic conditions are notably different. The north is characterised by a subcontinental climate with hot summers, but moderate weather conditions due to the protective effects of the mountains and the moderating effect of Lake Geneva water mass. The south experiences a mountain continental climate with greater weather and temperature differences between the summer and winter seasons. Winds are rather constant in all areas. The climate evolution shows a sustained and evolving temperature anomaly between +1.7° and +2.5°C compared to the pre-industrial period. The number of frosty days has decreased significantly by 20% since 1950. Precipitation is highly variable, without noteworthy changes over the time period. Extreme heat conditions during summer periods are expected to evolve further until the end of the century. They are typically accompanied by dry periods with effects on the soil and the amount of precipitation is expected to decrease. Rain is expected to intensify during the wet periods.

Lake temperatures have risen in recent years due to climate change. Since 1980, the surface water in most lakes has warmed by about 0.4°C per decade. The warming of the deep water is more variable and mostly ranges between 0.0 and 0.2°C per decade in the deep lakes. A further increase in the temperature of the surface water layer down to 1 m deep is expected in all Swiss lakes: for a scenario without climate change mitigation of between 3 and 4°C in most lakes towards the end of the century. The water temperature at depths where raw water intake occurs will only slightly increase.

The evolution of climatic conditions is, however, not expected to lead to noteworthy effects on the particle collider, for instance the water cooling systems. Nevertheless, the FCC must account for climate evolution in its design and the development of an operational concept. In the presence of an average envisaged temperature increase of around 4°C until the end of the century, these steps concern in particular, the adoption of operation to conditions that permit efficient work (e.g., avoiding periods that are too hot) and increasing the benefits of waste-heat reuse project, both internally and in the region (e.g., shift operation to a colder season).

Air The air condition within the perimeter of the FCC is generally good, and the air quality is improving constantly. The main cause of air pollution is road traffic, mainly diesel-powered trucks. Fine dust particles have their origin mainly in the agricultural sector and industry, in particular construction and quarries. All typical air pollutants

Fig. 3.17 Air quality measurements carried out using monitoring equipment to assess atmospheric pollutants in the vicinity of the surface site

have been studied to document baselines, and air quality measurements have been carried out to establish references in the vicinity of the surface site. These references serve as valuable input for the development of the construction process and the design of the infrastructures in order to be able to properly and adequately ensure the protection of the air quality and meet the EU zero pollution vision for 2050. If it is decided to go ahead with the project, continuous air monitoring (using devices like that shown in Figs. 3.17 and 3.18) has to be implemented at the surface sites to monitor the evolution and to be able to control the impacts on the air quality during the construction and operation phases.

Climate protection plans France has reduced its emissions by 27% with respect to 1990, in line with an average reduction of the emissions in Europe by about 31%. The per capita footprint in 2022 was about 6.5 tCO2(eq) per year [83], a value that is below the European Union average of 8 metric tons per capita. While the energy and industry sectors were able to reduce their footprints considerably, the transport sector did not yet see the same improvements. Emissions due to transport even slightly increased. This situation is also reflected at a regional scale, with the transport sector remaining the main producer of greenhouse gas emissions. France has adopted the 2015 Paris Agreement, aiming for a reduction of the net emissions by 55% with respect to 1990 by the year 2030 and climate effect neutrality by 2050. Locally, the climate protection goals can differ. For instance, for the Pays de Gex around CERN today, the goals established are −66% by 2050 with respect to the year 2015. For 'Grand Annecy' the goals are −55% by 2030 and −87% by 2050.

In Switzerland, greenhouse gas emissions have decreased continuously since 2010. Transport, agriculture, and industry remain the main emission contributors. As of 2025, two laws are in place that impose requirements: the law on CO_2 and the law on climate and innovation. The established goals are a reduction of 60% of the greenhouse gas emissions by 2030 with respect to 1990. The long-term goal for the country is to achieve net carbon neutrality by 2050. Also, at the cantonal level, an operational climate protection plan is in place. It prescribes goals and 41 specific measures to be implemented by 2030. The emission reduction objectives are in line with values established at the federal level.

Summary and conclusions The planning, construction and operation of a future research infrastructure at CERN takes into account the plans and regulatory requirements that have been established at the national levels to achieve the goals of the Paris Agreement. Aspects related to energy and greenhouse gas emissions are considered according to the current policies established by CERN, aiming at keeping the energy required for its activity as low as possible, ensuring that the established research programme goals can be achieved. This includes continuous improvement of its energy efficiency, recovering and supplying waste heat and reducing greenhouse gas emissions. CERN is committed to demonstrating that appropriate measures are taken with respect to energy and greenhouse gas emissions during all phases of a future research infrastructure, in line with the plans and regulatory requirements established by the Host States.

Fig. 3.18 Air quality measurements conducted to assess atmospheric pollutants in the vicinity of the surface site

At the end of 2019, CERN established a target for the reduction of its direct CO_2 emissions by 28% with respect to 2018 (baseline year) by the end of the Large Hadron Collider Operation Run 3 (around 2026). This target has been highlighted since September 2020 in the CERN public environment reports that are published biennially. Recently, CERN has adopted a target for the reduction of its direct CO_2 emissions by 50% with respect to the baseline year 2018 for the year 2030 [84]. Indirect emissions related to electricity consumption and other emission categories, such as those related to procurement, are also reported and published. Associated reduction targets are under investigation.

If a new research infrastructure is approved and included in CERN's overall environmental performance management, emission reduction plans and goals, including the new research infrastructure, will be set with respect to the corresponding updated envelope of policies.

The integration of a new research infrastructure into CERN's environment will generate additional emissions that the organisation will strive to minimise within the established goals to be achieved for the scientific research performance. A rigorous eco-design approach applied to the construction activities, the technical infrastructures, the particle accelerators, and the detectors will be introduced at the level of the organisation and will be required from the entire international collaboration contributing to the project, ensuring that in-kind contributions will comply with the relevant environmental rules and regulations.

The proposed particle collider will not operate concurrently with the Large Hadron Collider. Therefore, the emissions generated by the operation of the new collider and its experiments will replace those linked to the LHC operation. The new collider and its experiments will technologically be significantly more advanced, and the eco-design will make it a research infrastructure with lower emissions than the LHC today.

Together with continued efforts to technologically upgrade other CERN research facilities and activities, effective support of the Host States efforts to meet their climate protection goals remains achievable.

In the context of the environmental authorisation process, a climate protection plan integrating the new project is expected to be included as part of the environmental impact assessment.

3.3.3 Water

Context The situation of surface and subsurface water within the perimeter of the scenario has been analysed based on bibliographical data, databases, maps, and reports. The legal frameworks in France and Switzerland are very different with respect to this topic, which makes the comparison and integration of data challenging. Whilst in France, the European Union definitions and directives are applied, different water protection frameworks exist in Switzerland at federal and cantonal levels. For this reason, the current state of the water has to be looked at separately for each of the two countries. In addition, subsurface water tables have to be distinguished from surface water. However, both water masses, subsurface and surface, extend across the national borders and lead to

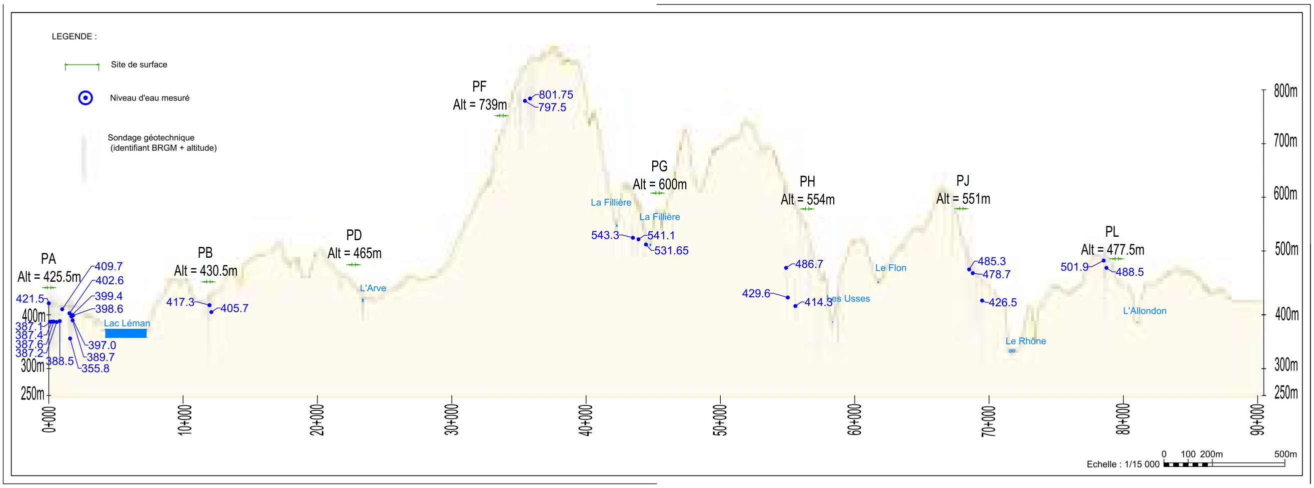


Fig. 3.19 Overview of surface and subsurface water bodies in the scenario perimeter. In this conceptual drawing, the subsurface structures are assumed to be at an elevation of 250 m. The uncertainty of the water table heights is indicated in grey. The surface site locations and elevations are indicated

cross-border aspects with respect to subsequent analysis of potential environmental aspects: effects and impacts that will need to be considered during a project preparatory phase.

Subsurface

France Concerning subsurface water, five distinct relevant water masses have been identified. FRDG517 extends from Gex across the Geneva basin to the Grande Côte de Bonmont and the Usses sector. FRDG208 lies below the FRDG517, extending from the Jura to the lake and towards the Usses sector in a calcareous geology. FRDG231 is located north of the Genevois zone in France, partially under the FRDG517, partially limited like a river between the Rhône and Divonne-les-Bains, touching the Swiss border at the height of Versoix. FRDG511 is located in the Savoie alpine region, south of FRDG517. FRDG364, corresponding to the Arve valley, passes at about 100 m of the site PD in Nangy.

With respect to the European legislation, a goal has been set to maintain the so-called 'good state' level quality attained in 2015 of all water masses. The standard needs to be maintained both in qualitative and quantitative terms.

Water-bearing layers exist in relation to these water masses. All apart from in the implementation perimeter are 'free', i.e., there are no water-tight layers towards the surface. None of the hydrogeological entities is characterised by an aquifer.

Because of the need to maintain the quality levels and the potential interactions between water masses, particular protection measures are in place that will need to be observed with respect to subsurface works.

Switzerland In Switzerland, various types of water-bearing layers are distinguishable based on their water capacity and depth. Deep layers can also exist in the molasse layer which is preferred for tunnel construction. Today, four water-bearing layers are identified in the canton of Geneva, and two of them are used for providing drinking water: Allondon and Genevois. Montfleury and Rhône are currently being studied in terms of capacities and quality with respect to serving as a drinking water supply. The deep layers are today not mapped and therefore dedicated subsurface investigations are required for a future particle collider project. A multitude of shallow and temporary layers that are between 2 and 10 m below the surface is spread over the entire canton. They need to be analysed where shafts and surface sites are planned. One of them is at a distance of about 140 m from site PB in Presinge at a depth of 2 m. No potential mutual effects could be determined.

Another water-bearing layer is at about 90 m from site PA in France. The Montfleury layer at a depth of about 45 m is located 800 m south of the main site. One shallow layer is directly at the surface site location PL in Challex in France. It spans the border, and no information is available on this layer. Sites PL and PA require particular analysis to take these layers into account for the choice of the shaft location and the shaft construction technique. All three sites, PL, PA and PB, need to consider the potential water layers in the vicinity of their surface site and consider cross-border aspects.

Surface

France Four main surface water bodies are within a radius of 1 km of the surface sites. Three of them are in good state (FRDR11960, FRDR559, FRDR537) and one has moderate quality (FRDR555c) with a goal to achieve good quality by 2033. The site PF in Éteaux is located in the vicinity of a stream (50 to 100 m). Also, site PH is in the vicinity of a small creek (30 m). Other sites such as PD (600 m from the Arve) and PG (300 m from the Fillière) are further from rivers.

Switzerland Lake Geneva in Switzerland is the most important water body at the surface. It is 4 km from the PA and PB sites. Site PB is located in the vicinity of a small stream (30 m).

Summary The projection from the line of the implementation scenario to the subsurface intersects with the geographical location of numerous subsurface water bodies. However, the tunnel will be located significantly below them (see Fig. 3.19). No intake from any subsurface water-bearing layer is expected for the construction and operation of the project. Water for drinking will be consumed from connections to the existing drinking water network. Raw water for cooling purposes will be taken from the existing water supply network for CERN in Switzerland, which takes water from Lake Geneva. Drinking water protection zones are largely avoided for the entire project so that any potential adverse effects can be excluded.

The majority of subsurface layers are not located under a watertight layer. Thus, they are potentially subject to pollution. Also molasse layers may include water-bearing volumes. Therefore, dedicated hydrogeological investigations will be carried out to optimise the location of the shafts to avoid potential adverse effects with water-bearing layers in PA (Ferney-Voltaire, France) at a distance of 35 m from a drilling ban zone (sector B in Switzerland) and PL (Challex, France). Particular attention will be devoted to avoid affecting nearby creeks and the biodiversity around sites PB (Presinge, Switzerland) and PH (Cercier and Marlioz, France). PH is, in addition, in an area with chronic lack of water and therefore subsurface works such as the creation of a shaft will have adequate protection measures in their design in case there is a risk of affecting any water bearing layers.

Concerning the release of water into the environment and particularly into nearby creeks, the design of the infrastructure will include filtering and cleaning before release. Connections to wastewater networks will ensure that all other water is released via the existing water treatment infrastructure at all times, ensuring compliance with the legal and regulatory frameworks in the two Host States.

3.3.4 Subsurface

Relief The FCC perimeter is constrained by noteworthy mountains (see Fig. 3.20). The Jura is located north and west of Lake Geneva with peaks of 1720 m. The south-east is characterised by the Bornes plateau evolving into the pre-alps that lead to Mont Blanc which has an elevation of 4806 m. The west is constrained by the Vuache mountain reaching 1112 m. The Salève (1379 m) is located in the centre of the FCC circular alignment. The Aravis mountain range is located just south of sites PD, PF and PG. Mont Sion (78t m) is located between the Vuache range and the Saléve. In the south, the tunnel crosses under the Mandallaz range (923 m), also called Balme, that is part of the pre-Alps. The Massif du Chablais is northeast of Lake Geneva and east of the PB and PD sites. Despite the presence of the numerous mountain chains and peaks, all surface sites are located on lower ground in flat areas at between 400 and 700 m elevation.

Topography Site PA is located at an elevation of approximately 425 m in an open area with a very slight slope of about 2 to 5%. Site PB is at an elevation of about 430 m on an even and open area. There are hills only a few kilometres to the north. Site PD at an elevation of approximately 460 m is located on a slope of about 5% towards the north. The zone is hilly in all directions, but the terrain is cut by major transport routes (A40 autoroute, D903 departmental road). The absence of bushes and hedges makes the terrain visible. Site PF reaches elevations of between 730 and 745 m on a slope of about 7% from west to east. This makes the area very visible towards the mountains and from the RD1203 road. However, it is not visible from the A410 autoroute. Site PG is separated from the A410 autoroute in the north by a forest on a slight slope of 5% in north-south and west-east directions at about 600 m elevation. At the southern boundary, the slope starts to become steep – from 25% to 40% towards the RD1203,:Annecy road. this area is avoided. Site PH is located on a slope of 10 to 20% at an elevation of between 517 and 591 m, falling off from the RD203 road. The entire area is located in a forest that covers the zone towards the Usses Valley in the west. The topography imposes a terracing approach for the site. The PJ site is located on a wide and long slope of 6% at an elevation of between 496 and 532 m that falls off from the A40 autoroute to the Rhône valley. This location also requires terracing. Tree lines that break the even space and slope exist in the vicinity. The PL site is located at 500 m elevation on a rather flat area. The absence of noteworthy trees or hedges in the vicinity makes the terrain highly visible. The land falls off steeply towards the Rhône valley on the opposite side of the nearby pathway towards Switzerland.

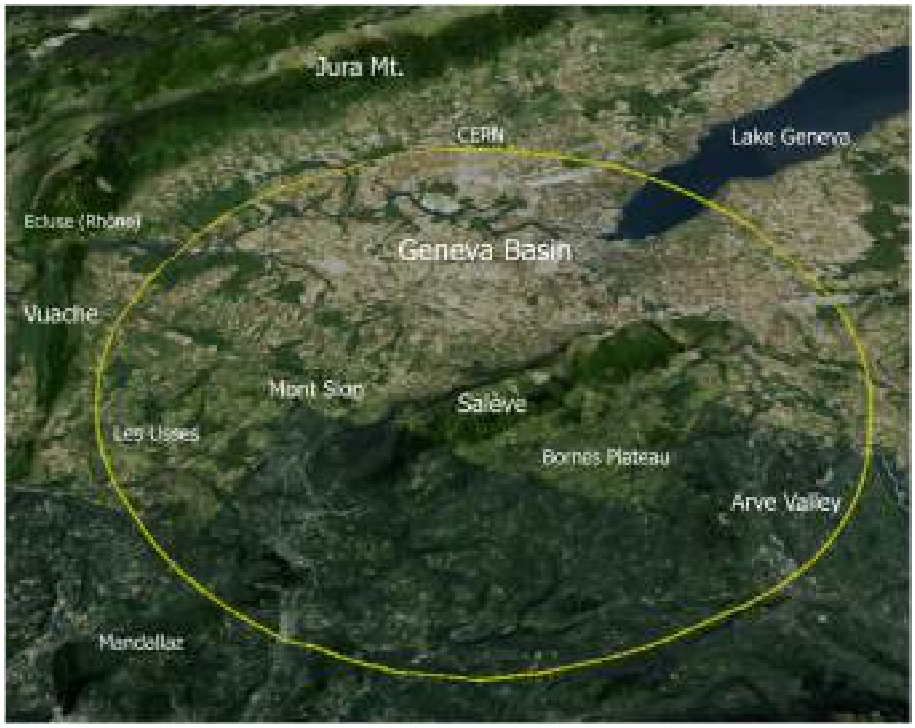


Fig. 3.20 Relief in the area of the FCC reference scenario

Geology The geology is covered in greater detail in the sections on civil engineering since it determines the placement of the subsurface works. Here, a general overview (as shown in Fig. 3.21) provides the context. The geological landscape of the Genève Basin spans between the Jura Mountains in the northwest and the Prealps in the southeast, with a Tertiary molasse basin overlaying Cretaceous formations. Shaped by Quaternary glaciations, the basin features deep valleys and sedimentary deposits up to 400 m thick, especially in the Grand-Lac, with Holocene sediments varying by river currents. The Rhône Delta sees Holocene sediments exceeding 100 m in thickness. The basin's geology includes three main units: Jura sedimentary rocks in the northwest, central Tertiary sandstone (molasse), and thrusted molasse with Prealpine units in the southeast.

The Ain department is located on two very different geographical and geological domains with, to the west, the large plains of Bresse and Dombes the western plains of Bresse and Dombes, a tectonic rift filled with Tertiary deposits, and to the east, Jura mountains, marking the southwestern edge of the Swiss molasse plain. In addition, the department is covered by three large geological units, Bresse and Dombes including Côtière and part of the Val de Saône; Bugey and the southern part of Revermont and finally the Pays de Gex. The Pays de Gex, where the PA and PL sites are located, features mountainous limestone formations (Middle and Upper Jurassic, Lower Cretaceous) with karst systems, bordered by faults and glacial deposits. Similarly, the surface sites PD, PF, PG, PH, PJ in Haute-Savoie in France and PB in Switzerland are part of the molasse basin and showcase diverse geological features from crystalline Alpine massifs to sedimentary molasse basins like the Plateau des Bornes. These molasse deposits, formed from Alpine erosion during the Oligocene to Miocene, vary in thickness and are tectonically influenced by Alpine uplift. The geological formations of the different surface sites are presented in Table 3.11.

Soil Field soil investigations were carried out in July 2023 for site PD and in April 2024 for the sites PA, PB, PF, PG, PH, PJ and PL. The primary objective was to analyse the pedological characteristics of the soil of these sites to determine their suitability for agricultural activities and other potential uses.

The work consisted in the identification and description of existing vegetation and crops, as well as the assessment of factors impacting agricultural productivity, such as accessibility, topography, non-cultivable areas, wet zones, and irrigation infrastructure. Soil samples were collected using hand augers (see Figs. 3.22 and 3.23) up to a depth of 120 cm to examine soil layers, coarse elements, and traces of waterlogging. The number of samples per site was determined based on plot size and soil diversity in order to ensure adequate representation. A total of 48 samples were collected across the eight sites.

The PA site is dominated by deep loamy soils (neoluvisols) with a low content of coarse elements, although areas near roads feature shallower and rockier soil.

At the PB site, the surface horizon consists of clay-loamy soils with low amounts of coarse elements, but signs of pseudo-gleying appear in deeper layers.

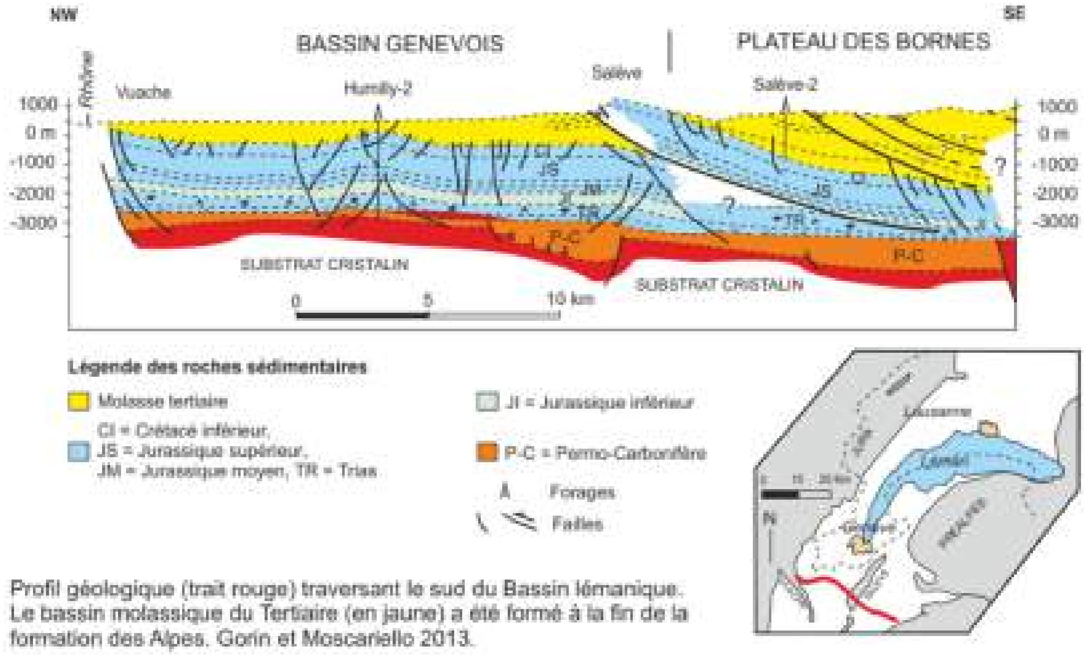


Fig. 3.21 Geological profile of the Geneva Basin, illustrating stratigraphic units, tectonic features, and sedimentary formations shaping the region

Table 3.11 Geological formations present at surface sites

Site	Deposits	Composition of materials
PA	Würmian glacio-lacustrine	Layered clays and silts
PB	Morainic	Clays, silts, and sands
PD	Glacio-lacustrine	Clays and silts
PF	Würmian to post-Würmian morainic	Silts, sands, pebbles, gravels, with localised presence of clays
PG	Würmian morainic	Clays, sands, pebbles, stones, and boulders
PH	Würmian to post-Würmian morainic	Clays, sands, pebbles, stones, and boulders
PJ	Würmian to post-Würmian morainic (or colluvium)	Silts, sands, pebbles, gravels, with localised presence of clays
PL	Würmian morainic	Pebbles, gravels, sands, and limestone with localised presence of clays

PD site is characterised by deep loamy soils, healthy and well-drained, with low, coarse elements throughout the soil profile and limited hydromorphy. The soil is highly suitable for agriculture due to its deep, fertile, and easily mechanisable soils.

At the PF site, the surface layer consists of loamy neoluvisols with low rocky content, while clay accumulation begins at around 70 cm depth. These parameters are suitable for permanent grasslands.

The surveys carried out at the PG site and its annexes show that the present soil does not match the soil recorded in the French GIS-Sol database. The soil of PG main site is deep, homogeneous, and range from clayey to clay-loamy textures, with low amounts of coarse elements and temporary hydromorphy traces. Annex sites have lighter, powdery soils, moderately deep with a clay-loamy texture.

The PH site is covered by deep Brunisol-type soils with Redoxisol characteristics, where strong hydromorphic features are already apparent near the surface, indicating limited drainage. The survey confirms that the permanent grassland at a small part of the PH surface site corresponds to the soil cover listed in the database.

PJ site is characterised by deep argilo-limoneux soils with minor coarse elements. Moderate hydromorphy is visible near the surface, with traces of altered limestone beyond 70 cm. The area is suitable for both permanent and temporary grasslands.

Fig. 3.22 The auger boring method used to obtain soil samples from different depths

Fig. 3.23 Soil sample obtained by using auger boring method

PL site at the border with Switzerland is predominated by calcosols with areas of colluviosols in southern regions. Soils vary from superficial to deep, with coarse elements more common in superficial areas. Hydromorphic features are less pronounced, and soils are generally suitable for agriculture.

Overall, most surface sites have deep soils with limited coarse elements, ensuring good agricultural potential, although hydromorphic tendencies and limited drainage at certain locations limits their agricultural use. Additional laboratory analyses of the soil are currently being conducted to assess its quality in terms of the presence of various mineral elements and their availability to plants, and potential contaminants.

Summary Concerning relief and topography only, site PH in Cercier and Marlioz exhibits significant issues due to the slope in the forest. PJ in Dingy-en-Vuache and Vulbens is also located on a slope, but it is in an open area and significantly less steep with good access. Sites PA, PB and PL on very open and flat areas call for particular integration with respect to visibility and co-visibility. Site PD and PF do not exhibit any particular challenges, although good landscape integration is advisable to reduce visibility and to blend into the terrain. Care needs to be taken at site PG to stay clear of the steep slope towards the Annecy road.

The geological context of the study area highlights the diversity of formations across the Geneva Basin and the Ain and Haute-Savoie departments. The basin features sedimentary deposits influenced by quaternary glaciations,

Fig. 3.24 Fiery Clearwing Moth *(Pyropteron chrysidiformis)* feeding on a plant

with thick holocene sediments in the Rhône Delta and Grand-Lac. The sites span different geological units: Pays de Gex (limestone formations with karst systems) and molasse basins (formed by Alpine erosion), showcasing a variety of materials, including glacio-lacustrine clays, morainic sands, gravels, and silts. These variations underline the region's complex geological history, which is crucial for subsurface work placement and excavated material management.

The pedological surveys confirmed diverse soil characteristics, ranging from deep, fertile, and well-drained loamy soils to hydromorphic and clayey profiles with drainage limitations. Sites such as PD and PL are highly suitable for agriculture due to their deep, fertile, and easily mechanisable soils. PA, PB, PF, and PJ show varying degrees of hydromorphy, particularly in deeper layers, making them more suitable for grasslands or selective agricultural practices. PH and PG present significant hydromorphic constraints, with PH showing pronounced surface water retention issues due to its altered limestone subsurface. Variations in texture, depth, and coarse element content reflect the influence of local geology and historical land use.

3.3.5 Biodiversity

Biodiversity refers to the diversity of species, ecosystems, habitats and ecological processes. It includes both natural and human-modified environments, which together create the conditions for the existence and functioning of various organisms. A variety of species in the natural spaces are not locally confined. They extend across fauna corridors and ecologically coherent zones that comprise the terrestrial and aquatic species, namely plants, insects, mammals, amphibians and reptiles, which are considered as an integrated whole.

To assess potential impacts on biodiversity, the current situation was analysed for all candidate surface site locations, first using bibliographical information. This includes, for example, the study of protection zones at regional, national and international levels, inventories of natural heritage, ecological corridors and their continuations. Then, field investigations were carried out by numerous experts over a time frame of more than one year, covering the four seasons. Various photographs from these field investigations are shown in Figs. 3.24 to 3.32. The investigations served not only to confirm and complement the existing bibliographic information but also as necessary input to establish a baseline for the avoid-reduce-compensation approach, the optimisation of the sites and the subsequent environmental impact assessment. The investigations were not restricted to the area within the perimeters of the surface site locations. They were extended to a perimeter of up to several hundred metres larger, depending on the topography, but the extension was investigated in less detail. An extended perimeter covering up to 5 km was analysed at a high level with the help of existing databases and cartographic materials.

Site PA in Ferney-Voltaire is in the vicinity of nature protection and humid zones as well as forests that serve as cross-border corridors for animals. Amphibian breeding zones are noted in the enlarged perimeter on the Swiss side. The forests also serve as retreat areas for migrating birds. There are nature protection and wetland zones, including amphibian reproduction zones, in the vicinity of the PB site in Presinge. There is a protection zone for migrating birds at some distance. For site PD in the Arve area there is a nature protection zone in the vicinity. Nature protection zones and ecological corridors have been identified in the vicinity of site PF in Éteaux. Several nature protection zones also exist in the vicinity of site PG in Groisy and Charvonnex. Further away, there is a biotope protection zone. Nature protection zones also exist in the vicinity of site PH in Cercier and Marlioz. At some distance, there is a biotope protection zone. Rare species are found in the immediate vicinity of the site and partially at the limit of the site, mainly close to a creek that passes at the site boundary to the north. There are

Fig. 3.25 Bocage hay meadow photographed during the field investigations

nature protection zones in the vicinity of site PJ in Dingy-en-Vuache and Vulbens. There are nature protection zones and cross-border ecological corridors, linking forest spaces and the Allondon zone with the Rhône river zone in the immediate vicinity of site PL in Challex. Strict bird protection zones on the Swiss side of the border extend into the forest on the French side. There, biotope protection zones are known.

None of the sites is directly affected by a nature protection restriction, a national park or international biodiversity protection regulations (e.g., Natura 2000, RAMSAR, UNESCO or national parks).

Natural habitats In the context of environmental analysis, a habitat refers to the natural environment or ecosystem where a particular species, community, or group of living organisms lives, grows, and thrives. It includes the physical, chemical, and biological components that support life, such as soil, water, air, terrain, other plants and animals and the interaction among all those components. The studies carried out comprised establishing an inventory of the existing habits at the surface sites, investigating the perimeters around them, and evaluating their characteristics and qualities. This work helped to determine the sensitivity levels associated with the larger zones concerned by the surface sites in order to apply the avoid-reduce-compensate scheme for further optimisation of the project scenario.

Site PA in Ferney-Voltaire, France is predominantly a peri-urban, open agricultural habitat of about 70 ha that is also closely linked to Geneva airport, agricultural spaces in Switzerland and forest spaces between Switzerland and France. Its mainly formed by prairie, bushes, trees, monocultures and artificial habitats (paths, roads, industrial and commercial buildings). The groves in the vicinity of the site exhibit high sensitivity. Overall, the sensitivity on the site is average to low, often only partially fulfilling the requirements of a habitat.

The site PB in Presinge, Switzerland, is also an open agricultural space dominated by monocultures with some nearby woodlands and isolated hedges. Only a thin strip in the close vicinity of the nearby creek exhibits a moderate to average habitat quality.

Site PD in Nangy, France is located in a rural context, constrained at the side by an autoroute and a departmental road and one side is bordered by a hamlet. Some isolated bushes and trees can be found in the vicinity. The habitat quality is very low to low. Only in a small patch at the southern end at the surface site border, the bushes represent a high value in this much-constrained space.

Site PF in Éteaux, France is in a mixed agricultural and prairie zone. Woodland starts to appear at the borders. The north is limited by a heavily used national road. The enlarged investigation zone includes a wetland. At the location of the surface site the habitat quality is low to average. The neighbouring wetlands and forest lands have a strong sensitivity.

Site PG in Groisy and Charvonnex in France is located in a mixed environment consisting of prairie, woodland, grassland and rural/forest paths. The enlarged space close to the autoroute is dominated by artificialised spaces such as retention basins, temporary inert waste buffering, roads, paths and constructed areas. The zone can, in general, be characterised as predominantly a forest habitat. On average, the whole zone studied exhibits a low to average level of habitat quality. Where areas can be considered wetlands, both inside and outside woodlands, the habitat quality can be considered average. Two forest areas that are outside the site perimeter, but in the immediate vicinity, have been identified to have a high sensitivity due to the quality of the trees.

Site PH in Cercier and Marlioz in France is almost entirely located in a woodland. There exist some cleared spots that host prairies and grassland. Overall, the habitat quality is low and where monocultures exist, it is very low. A zone exists that can be considered a wetland due to its characteristics south of the site. Its effects extend to a 0.4 ha large part of the site, making this area a high-quality habitat zone.

Site PJ in Dingy-en-Vuache and Vulbens in France is located in an open rural, agricultural space that is limited at two sides by treelines, a temporary creek, by an autoroute in the north and a rural path and further agricultural

Fig. 3.26 Wetland observed during the field investigations

areas in the south. The extended study perimeter also includes zones that can be characterised as humid. The habitat quality is heterogeneous, ranging from very low to high. The space occupied by the surface site can be split in two halves: an area of low and an area of high habitat quality. The half that is closer to the autoroute exhibits the higher value.

Site PL in Challex in France is located in a rural context. The site and the larger study perimeter spanning 100 ha include agricultural fields, wasteland, bushes, and trees around houses that are on the surface site. The herbaceous spaces carry characteristics of wetlands. The agricultural constructed spaces with trees and gardens currently have a low to very low habitat quality. The humid prairies in the vicinity, but not on the surface site, have an average habitat quality.

Wetlands Wetlands provide numerous services for ecosystems, particularly in terms of regulation, water storage, and conservation of biodiversity. In the context of this study, investigations were carried out on the presence of wetlands in areas potentially affected by the surface sites. The study of wetlands is important environmentally and also a regulatory requirement under French law. This study aims to assist in decision-making for the location of sites and their optimisation according to the avoid-reduce-compensate approach. In France, in the case of the destruction of a wetland, the regulations impose compensatory measures with a ratio that can reach 1.5 to 2 times the wetland area impacted. Measures can include the improvement of partially degraded wetland functions and monitoring over a defined period to evaluate their effectiveness.

The study of wetlands was carried out in the same way for Swiss and French territories to obtain comparable and coherent data. In Switzerland, only wetlands listed in the federal inventories of low marshes, riparian zones, OROEM, RAMSAR sites, and amphibian breeding sites are potentially protected. In the absence of a direct equivalent of wetlands in Swiss legislation, this study was inspired by the definition of wetlands given in French legislation. According to Article L211-1 of the French Environment Code [85], *"Wetlands are understood as areas, used or not, usually flooded or saturated with freshwater, saltwater, or brackish water, permanently or temporarily; vegetation, when present, is dominated by hygrophilous plants for at least part of the year"*. Article R211-108 of the Environment Code specifies that: *"The criteria to be retained for the definition of wetlands [...] relate to the soil morphology linked to the prolonged presence of water of natural origin and the possible presence of hygrophilous plants. These are defined based on lists established by biogeographical regions. In the absence of hygrophilous vegetation, the morphology of the soils is enough to define a wetland."* Thus, French legislation defines wetlands based on floristic and/or pedological criteria.

The delineation of wetlands on surfaces concerned by the potential site locations was based on departmental/cantonal, Swiss, and French inventories, floristic criteria, and pedological inventories. Government inventories of the departments of Ain and Haute-Savoie allowed a first delineation of the known wetlands currently present on surface sites. Inventories of flora allowing a second delineation of wetlands were carried out during the flowering period in spring 2023 and by an expert company to identify and delimit the types of habitats potentially present on the immediate and extended perimeters around each site. These inventories also highlighted 'pro parte' surfaces, i.e., surfaces where the habitat identified was not systematically or entirely characteristic of wetlands. Finally, pedological inventories were conducted by another expert company in 2023 and 2024. These inventories identified soils characteristic of wetlands for surfaces where the presence of wetland characteristics was eventually determined to be actually present or not in 2024 using shallow subsurface investigations (12 to 90 cm deep).

At the border of site PA in Ferney-Voltaire, two wetlands are known with a total size of 6.3 ha. The site does not directly impact the zone. The concept for the site has a rewilding project to improve the quality of this area and to make it a permanent and protected natural habitat with recreational characteristics. There are zones that are comparable to the French definition of wetlands in the vicinity of site PB in Presinge. None of these is in the immediate perimeter of the site, and the site will not impact any of these protection zones. The conceptual plan for the surface site includes the integration of one part of the nearby creek's area to rewild the space used for agricultural purposes today and to make it a fully protected habitat.

Three wetlands zones can be found in the extended perimeter of site PD in Nangy, separated from the site by an autoroute. The site does not affect any of these wetlands. A number of wetland zones can be found in the immediate vicinity of site PF in Éteaux. The field investigations revealed that the zone is larger than registered in the regional inventory. The site does not impact these zones. However, the conceptual plan for the site concept includes the creation of a green buffer that includes one of the zones currently used for agricultural purposes to rewild it and to make it a protected habitat. There are also several wetland zones in the forest in the vicinity of site PG in Charvonnex and Groisy. The shape of the site has been adapted to avoid potential negative effects on these zones. A wetland zone exists in the forest at the northern border of site PH in Cercier and Marlioz and cuts through the site towards the south. Out of 16 ha about 0.8 ha are in the perimeter of the currently indicated site boundary. Consequently, the site will be further optimised during a subsequent design phase to either exclude significant effects on the wetland zone or to develop appropriate compensatory measures where the effect cannot be avoided. For example, a nearby area of land which has very poor biodiversity and habitat value has been identified and it can serve as an optional space in case the surface site equipment does not fit within the reduced surface site geometry.

The vicinity of site PJ, in particular close to the autoroute, is characterised by extended wetland zones, covering 13.6 ha. 1.6 ha are on an agriculturally exploited area of the surface site. The subsequent site design phase will take in account the presence of this zone to establish avoidance and reduction measures, including the possibility of creating an annex further in the north on land that is not affected. Compensation measures may have to be developed for the part that cannot be entirely avoided. Wetland zones also exist at some distance from site PL in Challex, in the forest. The site does not affect them.

Summing up, none of the sites is directly affected by wetland induced constraints. The restoration of an ecological compensation zone in the immediate vicinity of site PA provides an opportunity to increase the value of the zone and thus compensate for the loss of space by fostering the development of a natural habitat and the increase of biodiversity opportunities. Sites PH and PJ deserve particular attention during the further development of surface site designs due to zones that have characteristics of wetlands entering partially the site perimeters. Care also needs to be taken during the optimisation of the perimeter of site PG to ensure the avoidance of potential wetland-like areas outside the site limits.

Flora On-site field visits were conducted in 2023 to validate bibliographic data and inventory the species present at the surface sites. These investigations aimed to confirm the presence of remarkable flora and invasive species and provide insights into local ecological contexts. "Remarkable flora" refers to plants that are notable or extraordinary due to their unique characteristics, ecological importance, rarity, or cultural significance. These plants often stand out because of their striking appearance, unusual adaptations, or the critical roles they play in their ecosystems. The term can apply to native, endemic, or even cultivated plants. Invasive plants are non-native species that are introduced to a particular ecosystem, where they spread rapidly and often outcompete native plants. These plants typically lack natural predators, diseases, or other controls in their new environment, allowing them to thrive unchecked. As a result, they can disrupt local ecosystems, reduce biodiversity, and cause environmental and economic harm.

For this study, remarkable species are those with legal protection status (national, regional, or departmental) in one of the two Host States and those listed as "near-threatened" (NT) and those that appear in regional and national red lists.

Special attention was given to invasive species, since soil that hosts invasive species must not be simply transferred to land compensation areas in order to avoid spreading of such species. Risk levels established at regional and national criteria were considered to determine the sensitivity of areas with respect to invasive species.

Fig. 3.27 Military orchid *(Orchis Militaris)* observed during field investigations, providing valuable data on local wildlife presence and ecosystem dynamics

Fig. 3.28 Glutinous sage *(Salvia glutinosa)* observed during field investigations, providing valuable data on local wildlife presence and ecosystem dynamics

The habitats and floral compositions in the study area of site PA in Ferney-Voltaire, France are dominated by the agricultural space. During the field inventory, no remarkable species were observed. However, the municipal species list for Ferney-Voltaire identifies 3 noteworthy species that could in principle be encountered in the enlarged study area around the site. Complementary studies will be required during a project preparatory phase to confirm or exclude the presence in all areas that would potentially be affected by the surface site. Several species of invasive plants were observed in the PA study area that need to be considered when developing agricultural space compensation plans.

The habitats and composition in the Presinge study area in Switzerland concerning site PB are mainly agricultural. Woodland exists at a further distance and close to the Nant de Paradis creek, plants typical of wetlands (wetlands, riverside vegetation) are found. During the field visits, two remarkable species, protected at the cantonal and national level, were observed. Apart from these exceptions, no other important species listed in the bibliography were recorded. Several invasive species exist in the surroundings, and there are even some exotic ones. The agricultural space is free from remarkable and invasive species.

Fig. 3.29 Common toad *(Bufo bufo)* observed during field investigations, providing valuable data on local wildlife presence and ecosystem dynamics

Applying the municipal catalogue of remarkable species for site PD in Nangy, France does not lead to any significant sensitivity of the site. During the field inventory, no noteworthy species were found. However, several invasive species were observed that may negatively affect agricultural cultivation. Therefore, it remains to be studied if the soil can be transported for compensation purposes as is or if particular measures to eliminate those species will be required.

No remarkable species were recorded during the field inventory of the site PF in Éteaux in France. Three noteworthy species listed in the bibliography may, in principle, occur in the enlarged study area including wet meadows and wooded areas, outside of the surface site perimeter.

The municipal species catalogue of Groisy and Charvonnex applicable to site PG in France mentions three remarkable species that could be present in the study area. None of them were identified during the field inventory and no other remarkable species from the bibliography were observed either. A few invasive species have been recorded in the study area and topsoil that is removed should be cleared of those species.

The list of flora species of the communes of Cercier and Marlioz applicable to site PH in France includes a considerable number of remarkable species, but none of them is present in the study area, and no remarkable species were observed during the field visit.

None of the remarkable species listed in the bibliography for Dingy-en-Vuache and Vulbens for site PJ in France occur in the study area and no remarkable species were observed during the field visits. Some remarkable species listed in the communal lists could, however, be potentially present in the area that exhibit sufficient characteristics to support those species. They concern mainly humid zones at the edges of the surface site candidate perimeter.

For site PL in Challex, France, four species are highlighted as noteworthy in the bibliography. Tow out of them may potentially occur in the area of the PL site. However, none of them were observed during the field visits. On the contrary, two invasive species were inventoried in the study area, which should be taken into account in the case of reuse of agricultural topsoil.

Summing up, no particular sensitivity of any surface site candidate could be established with respect to remarkable flora. However, some sites will require attention with respect to the treatment of invasive species before the topsoil can be re-used for compensation measures. The PB surface site design requires attention due to two remarkable species observed during the field visit and the large number of potentially present species listed in the bibliography in the larger area. This site is, therefore, still considered to have a strong sensitivity at its edges. No outstanding flora species were inventoried at the PA, PG, PH, PJ, PL and PF sites, but these areas require complementary studies during a preparatory project phase to confirm the state and to plan for the construction site activities. So in general, additional field visits are required to reliably assess the environmental impacts. The sensitivity of site PF is also considered strong due to potential remarkable flora at the very edges of the site. Attention will need to be paid to invasive species present in several locations, and this will need to be taken into account when considering the reuse of agricultural soil in other locations.

Fauna

Amphibians For some groups of amphibians, identification down to the species level cannot be carried out without genetic analysis due to the strong hybridisation within these groups. However, an inventory based on bibliographical data and field investigations was established not only on the sites, but also for the perimeters in the vicinity of the site. Investigations were done during the day and the night for several months. Amphibians are frequently found in the vicinity of water spaces, creeks, rivers, and wetland zones.

Amphibians were observed in the vicinity of site PA in Ferney-Voltaire across the French and Swiss territories. Some of them are considered endangered in Switzerland. No amphibians are present on the surface site location. In

Fig. 3.30 Reed warbler *(Acrocephalus scirpaceus)* observed during field investigations, providing valuable data on local wildlife presence and ecosystem dynamics

the immediate vicinity of site PB in Presinge the bibliographic inventory was confirmed by the field investigations and the issue[9] is big, and therefore the river zone will be entirely avoided by the project. The integration of a rewilding project in the site will help to raise the protection level of that zone further. The area is currently partially used as agricultural space. Site PD in Nangy and its vicinity have a low stake concerning amphibians. Although the site PF in Éteaux is not directly concerned, the immediate vicinity revealed species with a high stake. At site PG in Charvonnex and Groisy several amphibians are confirmed in the vicinity and few on the site. The stake concerning amphibians is also high in the vicinity of site PF. On the site, no issues could be identified. Some amphibians were observed in the vicinity of site PJ, but the site did not reveal particular issues. Some amphibians were observed in the larger area around site PL in Challex, including Switzerland. Some of them are listed as endangered and protected. The site does not host amphibians.

Summing up, the zones in the vicinity of sites PA and PD feature a few habitats that would give them a high value. For sites PF and PJ, the availability of habitats also seems relatively limited, but the forest/hedge environment and the presence of streams give them a higher value. The vicinity of site PB, meanwhile, has the particularity of being partly located on an amphibian reproduction site, that increases its value level, despite the lack of direct observation of high-valued species. The sites PG, PH, and PL have high values due to a high density of aquatic habitats and the observation of a large number of high-value species in their vicinities.

Birds Ornithological surveys were conducted using sound recorders and visually with binoculars and cameras. The survey period spanned 2023 and 2024. An inventory was carried out for the 8 surface site locations over several seasons. Five ornithologists took part in the surveys. The inventories were conducted under suitable weather conditions (no rain and little/no wind). Field observations were recorded on-site using computer equipment. Observation intensity varied depending on the seasons. Increased observation intensity was applied to the spring inventories due to the sensitive period for breeding birds. A matrix was established using European guidelines for endangered species that is only applicable to the French territory. For Switzerland, the cantonal and federal protection lists were used to analyse the risks.

Birds find living space in the vicinity of site PA in Ferney-Voltaire, mainly in trees, bushes, and hedges. Some noteworthy species have been found in the vicinity. Birds are also prevalent in the vicinity of the agricultural space in site PB in Presinge and next to the small creeks and rivers. Protected and endangered species were found in the extended zone around the site. Areas and trees in the vicinity of site PD in Nangy provide protection spaces for birds. Some noteworthy species have been found on the surface site location. The surface site PF in Éteaux today includes several bushes that serve birds to find food and rest during the migration. Some noteworthy species have been found on the site. The forest on site PG in Charvonnex and Groisy provides living space for a variety of birds, and the bushes around serve as a retreat and reproduction space. Some noteworthy species have been found in the vicinity of the site. Also the forest on site PH in Cercier and Marlioz provides space for birds. Some heritage species were found on the site. Site PJ is surrounded by bushes and hedges that serve birds as living and reproduction space and for rest during migration. Some heritage species were found on the site and in the immediate vicinity. Also the hedges nearby site PL provide protection for birds and noteworthy species were found there.

[9]Environmental issues mentioned here and in the following sections may also be referred to as 'stakes' - an alternative translation of the French 'enjeux'.

Fig. 3.31 European kestrel *(Falco tinnunculus)* observed during field investigations, providing valuable data on local wildlife presence and ecosystem dynamics

Fig. 3.32 Red fox *(Vulpes vulpes)* observed during field investigations, providing valuable data on local wildlife presence and ecosystem dynamics

A full database of species observed was established, and it has been integrated into a project-wide geographical information system. The bird observations have limited validity and must be continued if a decision to advance with a project design is taken.

In summary, the sites PD, PL, and PJ in France, as well as PB in Switzerland and their surroundings, contain hedgerows and open areas that support nesting species of high conservation value. The sites PF, PG, and PH in France feature hedges and forests adjacent to extensive pastures, which are crucial habitats for uncommon species throughout the year. Site PA in France consists primarily of conventional agricultural land that becomes waterlogged in winter, serving as an important stopover site for waders.

To mitigate the environmental impact, dedicated measures will be implemented during the design phase to recreate bird nesting and living areas comparable to those lost, either within the green buffers of the sites or in their immediate vicinity. These efforts will be integrated into rewilding projects associated with the development.

Mammals Data on terrestrial mammals was collected during all naturalist assessments of other groups on the surface sites. Therefore, data on terrestrial mammals were collected both day and night at all surface sites throughout four seasons. Terrestrial mammal species were recorded visually or through indicators such as tracks, faeces, burrows, etc. The particular attention given to weather conditions for other groups was also applied during the assessments of terrestrial mammals. All observations were geolocalised and recorded in the project-wide geographical information system.

The PA site in Ferney-Voltaire has been the subject of infrequent observations of terrestrial mammals during naturalist investigations. They include the European roe deer, wild boar, European badger, European hare, brown rat, and greater white-toothed shrew. In the wider surrounding bibliographic data also revealed the presence of species of medium concern, such as for instance the hedgehog and beaver.

In the vicinity of site PB in Presinge, two species with a high conservation priority in Switzerland were observed: the beaver and the hare. Other species with a low priority that were encountered are the roe deer, badger and fox.

Fig. 3.33 Bat detectors used to detect the presence of bats by converting their echolocation ultrasound signals

Bibliographic data also provided information about species with a very high priority: the harvest mouse, polecat, weasel, wolf and the dormouse. Two species with a medium priority are the hedgehog and the stoat. However, these species were not observed.

The observations on site PD in Nangy of medium importance are the beaver and hedgehog. A species with lower importance, the fox was also observed. Bibliographic data also reports on the wildcat, the polecat, the black rat, but they were not observed.

Several observations have been recorded at the PF site at Éteaux: the hedgehog, with medium importance, and the fox and the badger, with very low importance. Bibliographic data details the presence of four species of medium conservation concern, including the Alpine Ibex, European beaver, European rabbit and the wildcat.

Observations at the PG site in Charvonnex and Groisy ranging from very low to low importance are: European roe deer, fox, squirrel, wild boar, European hare, chamois. In the surroundings, the bibliography also reports species with high importance: European otter, polecat. The following species with medium importance are reported: hedgehog and wildcat. However, these species were not observed.

At the PH site in Cercier and Marlioz the presence of species with medium importance such as the beaver and the squirrel were recorded. Species of lower importance concern the red deer, roe deer, wild boar and fox. The bibliography also mentions the presence of species with very high concern such as the grey wolf, otter and medium concern such as the wildcat and the hedgehog. These species were, however, not confirmed.

At the PJ site in Dingy-en-Vuache and Vulbens several observations of mammals with medium importance were made, such as the European beaver and the wildcat. Species with lower importance are the squirrel and with even lower importance the red deer, roe deer, hare, wild boar, badger, fox and the greater white-toothed shrew. The bibliography also mentions the presence of the lynx and the otter with very high importance and the rabbit with medium importance, but they were not observed.

Observations on site PL in Challex with a very low importance include the badger, fox, roe deer and hare. The analysis of the bibliography highlights four species with medium concern: wildcat, beaver, rabbit, and hedgehog. The polecat is cited with high importance and the lynx with very high importance. These species have, however, not been observed.

Summing up the bibliographic and field investigations of mammals carried out on all surface site candidates and in extended perimeter around the sites shows that overall a strong sensitivity exists for all sites although on none of the sites direct observations of relevant species were confirmed. The reason is that mammals were observed in the vicinities and extended surroundings of the sites and they can traverse the sites today, but they will face limitations during construction periods and when the sites are constructed. However, no protected or endangered species would be affected directly by the surface sites. A subsequent preparatory project phase needs to consider the mammals in the surroundings of the site in the design of the construction sites and the surface sites. Ecological corridors need to be considered and preserved. Where possible, green buffers and sites that can be traversed by mammals can preserve their current behaviour. Embedding the presence of animals in general in the concepts of surface sites can also help to improve their habitats and eventually even support the increase of biodiversity and conditions for them.

Chiropters Chiropters (bats) are mammals. The name chiroptera comes from the Greek words cheir (hand) and pteron (wing), meaning ‘hand-wing’. This reflects the unique structure of their wings, where elongated fingers are covered by a thin membrane of skin that allows them to fly. Chiropters are in the focus of environmental studies due to their ecological importance, vulnerability to habitat changes, and the legal protections they enjoy in France and Switzerland through national laws, as well as in the frame of the EU habitats directive, the ‘EUROBATS’ agreement, the 'Bern Convention' and 'Natura 2000 site'. Violating protections of bats in France can result in significant penalties consisting of high fines and prison sentences.

This study comprised dedicated field investigations applying different techniques which included echolocation detectors (see Fig. 3.33),to establish an inventory of bats on and in the vicinity of candidate surface site locations to permit developing avoidance, reduction, compensation, and accompanying measures during a subsequent project design and preparatory phase.

Bibliographic analysis could unfortunately not be carried out since it requires a detailed description of the areas to be investigated, and the surface site locations were not sufficiently defined at the time of making such inquiries for data, which are time-consuming processes with different data owners. Therefore, indirect (e.g., passive and active acoustic searches with ultrasound detectors and microphones, search for traces) searches were immediately carried out at the larger candidate surface site zones.

On site PA in Ferney-Voltaire, France, the existence of an ecological corridor renders the passing of chiropters likely in a band at the southern end of the surface site and outside that zone. 12 species were recorded in the larger area around the surface site location, in particular in the neighbouring woodlands and groves. There were no sightings on the site itself, probably due to it being an open space currently subject to light pollution during nighttime.

On site PB in Presinge, Switzerland, the zones at the borders of the surface site towards the Nant de Paradis creek represent an area of interest for chiropters for hunting. The same applies for individual bushes, the Seymaz zone and woodlands in the vicinity and garden areas in the Avenir hamlet. 2 species have been observed at houses that would be removed for the construction of the site and 18 species were found in the larger area. 7 of them have a preservation status. This makes the area sensitive and calls for measures to preserve the habitats and avoid and reduce light pollution as far as reasonably possible.

On site PD in Nangy, France, the larger zone is of interest for Chiropters for hunting where bushes, trees and houses exist. 3 species were observed on the site and 8 in the extended investigation area. They have protection status. As with site PB, the larger area is sensitive and calls for measures to preserve the habitats and avoid and reduce additional light pollution as far as reasonably possible.

On site PF in Éteaux, France, the neighbouring areas are of interest for chiropters, in particular zones with hedges and woodland. This concerns for instance the boundaries of the surface site, houses and gardens along the national road and the wetland zones. 13 species were observed on the larger area and some of them on the site close to trees. 3 enjoy a protection status. The larger area represents an interest for this species and calls for measures to preserve the habitats and avoid and reduce additional light pollution as far as reasonably possible.

On site PG in Groisy and Charvonnex, France, the woodland is of interest for chiropters. It extends to the autoroute zone in the north. 18 species have been observed in the larger area and 13 species were found in some locations on the surface site, primarily in the forest. 8 enjoy a protection status. The strong presence of chiropters in the forest calls for a minimisation of the impact on those zones during the design phase and envisages compensation and accompanying measures.

On site PH in Cercier and Marlioz, France, chiropters find hunting areas and a corridor in and between the woodlands. 13 species have been observed within the site perimeter in the woodland. 5 species enjoy a very high protection status and two are highly protected. The density and diversity diminishes as one approaches the road on the eastern side of the site. These findings call for further optimisation of the site, reduction, compensation and accompanying measures in the subsequent phase.

On site PJ in Dingy-en-Vuache and Vulbens, France, the woodlands at the creeks and the hedges at the limits of the surface site are interesting spaces for chiropters. Ten species were found on the border of the site and 16 in the larger area around the site. Some enjoy a particular protection status. The density and diversity are higher around hedges and trees close to the motorway. This location will need some attention during the subsequent site design with respect to avoidance, reduction, compensation and accompanying. Artificial light pollution is one issue to be considered in this area.

On site PL in Challex, France, chiropters find suitable locations in the woods, hedges, hamlets and individual houses, their gardens and the nearby vineyards. Two species with medium to low protection status were recorded at the houses that would have to be removed to construct the surface site.

Summing up, the stakes with respect to chiropters directly on the surface sites are low in PA, PB, PD and PL. PJ has no particular sensitivity on the entire site, but a small sector that is close to the woodlands requires particular attention. The stakes are average for PF, high for PG and very high for PH. The limitations of impacts on chiropters, the preservation and, where possible, the improvement of their habitats have to be included in the eco-design approach to be implemented in the subsequent phase.

Reptiles Field investigations on the candidate surface site locations focused on identifying reptile populations (like the wall lizard shown in Fig. 3.34) in environments that are known to be favourable habitats for them. They include for example semi-open areas, forest boundary zones, cavities and stone or woodpiles as well as constructed areas. These inventories were carried out during the reptile's primary activity periods from May to June and from

Fig. 3.34 Common wall lizard *(Podarcis muralis)* observed during field investigations, providing valuable data on local wildlife presence and ecosystem dynamics

September to October. Each observation was geolocated. No intrusive methods were used to avoid disturbance to the species. Several methodological limitations, an unfavourable rainy spring and an exceptionally hot summer as well as access limitations set limits on the quality and reliability of the results. This concerns mainly the data for snakes that are more difficult to observe than other reptiles. For a preparatory phase project and a comprehensive environmental impact assessment, the initial state of reptiles has to be updated with complementary studies.

The natural habitats investigated for reptiles varied across the sites, leading to different levels of suitability for living spaces and ecological corridors.

At site PA in Ferney-Voltaire, France, the forest edges and wood strips were identified as high-value habitats. Isolated trees and cultivated areas had a lower interest. Only one species with a low conservation value, the common wall lizard, was observed on the annex site south of LHC point 8. Bibliographic data do not indicate the presence of species with high stakes.

At site PB in Presinge, Switzerland, the zones with vegetation at the nearby creek Nant de Paradis, gardens in the Avenir hamlet and small woods in the vicinity are of interest to reptiles, but not the surface site location. Only a single species was found in the larger area around the site. No species were found on the perimeter of the site.

At site PD in Nangy, France, interesting locations for reptiles are at the southern end of the site in the hedges and the borders of the autoroute, but not the surface site. Three species were found in the larger area around the site and at the extreme edge in the south, outside the site.

At site PF in Éteaux, France, the hedges at the border of the surface site are of interest for reptiles. Only a single species was found in the larger environment around the site. No observations could be confirmed on the site or in the immediate vicinity.

At site PG in Groisy and Charvonnex, France, the forest zone and the limits of the woodlands are of interest for reptiles. Also, areas close to the highway can be relevant spots. 2 species were found in the larger area around the site, but no observations could be confirmed on the site directly.

At site PH in Cercier and Marlioz, France, the entire forest occupied by the surface site location is of interest for reptiles. 2 species were found in the area around the site, sometimes entering the perimeter of the site. However, no clear pattern of presence or movement could be determined that would permit drawing sound conclusions on the permanent presence of reptiles on the site.

At site PJ in Dingy-en-Vuache and Vulbens in France, areas in the vicinity of the creeks, bushes, groves and trees including the zone close to the motorway are of interest for reptiles. 7 species were found in the larger area around the site, leading also to the conclusion that at the edges of the site, species could be present.

At site PL in Challex, France, gardens, bushes, and trees are of interest for reptiles but not the majority of the surface site. Only one species could be found at a distance of the site, close to the forest in the north. No observations on the site could be confirmed.

Summing up, only very low sensitivity with respect to reptiles exists for sites PA, PB, PD and PL. In the vicinity of PF some care needs to be taken to preserve the living spaces of reptiles. For PG and PH sensitivity may exist in some parts of the forest and the project design needs to respect this condition. An update of the initial state with complementary field investigations is required to optimise the integration of the surface site, applying avoidance and reduction measures. The architectural designs of the surface site constructions should integrate concepts that favour the creation of habitats and thus help to increase the presence of reptiles.

Insects Bibliographic research and field investigations of the sites and their vicinities by specialised companies were used to identify the issues with respect to insects. Field investigations were carried out for several months

Fig. 3.35 Butterfly black-veined white *(Aporia crataegi)* observed during field investigations, providing valuable data on local wildlife presence and ecosystem dynamics

Fig. 3.36 Golden-ringed dragonfly *(Cordulegaster boltonii)* observed during field investigations, providing valuable data on local wildlife presence and ecosystem dynamics

during good weather conditions, low wind and during both day and night identifying insects like those in Fig. 3.35, Fig. 3.36 and Fig. 3.37.

Despite the highly urbanised environment, a strong population of insects was observed in the surroundings of site PA in Ferney-Voltaire due to the favourable living and breeding spaces. The site itself, an agricultural area is not subject to a strong presence of insects and thus, therefore, has only a very low sensitivity. The vicinity of the border between France and Switzerland towards the Geneva airport may require the consideration of a cross-border impact since some species observed in this zone outside the site perimeter are protected in Switzerland. Complementary field investigations are required during a project preparatory phase to reveal any such potential case.

The surroundings of site PB in Presinge feature an important population of insects, mainly those relating to aquatic habitats. Some species observed in this area outside the site perimeter enjoy particular protection status in Switzerland. The site itself is an agricultural space with low stakes apart from the areas that are close to the nearby creek.

The surroundings of site PD in Nangy are characterised by a few insect species. The site is an agricultural space and has low stakes with respect to insects. No species with protection status were observed. The extended surroundings of site PF in Éteaux are attractive for insects. However, on the site and in the immediate vicinity, no relevant species were identified, and the sensitivity is low.

The forest at and around site PG in Charvonnex and Groisy is moderately attractive for insects, as are the surrounding hedges. The site itself does not show particular issues with respect to insects. Also, the woodland spaces did not reveal the presence of relevant insects.

The forest spaces at and around site PH in Cercier and Marlioz provide, in principle, a favourable habitat for insects. However, only little presence of insects was revealed within the candidate site perimeter. Due to some observations at the border of the site, the site has a medium level sensitivity.

Fig. 3.37 Italian locust *(Calliptamus italicus)* observed during field investigations, providing valuable data on local wildlife presence and ecosystem dynamics

Fig. 3.38 Stream photographed during the field investigations

Site PJ in Dingy-en-Vuache and Vulbens, in principle, offers favourable conditions due to the trees and hedges around it. The stakes are high in the extended surroundings, but they are low on the site itself.

The hedges and bushes around site PL in Challex also, in principle, provide a favourable habitat for insects. However, the site shows only low-level issues with respect to insects, though a presence cannot be entirely excluded. Some species are protected in the nearby Swiss territory. A preparatory project phase will have to make complementary field investigations to consider potential cross-border impacts.

Summing up, none of the surface site candidates exhibits particular sensitivity with respect to insect presence. The surroundings of site PB present a habitat with high sensitivity. The wider surroundings of site PF present, in principle, some sensitivity. For sites PG and PH, despite being woodland, the favourable habitat for insects turns out to be less favourable than expected. The presence of some relevant species in the surroundings raises the sensitivity of the areas that are in the vicinity of the site. There were observations of some species with medium sensitivity in the surroundings of site PJ, suggesting that they might also be present on the site.

Aquatic Fauna in the aquatic context has been analysed based on cartographic and orthophoto information. Systematic investigations and water analysis for all aquatic aspects were not carried out at this stage. They are planned to be done if a design phase is launched. However, nearby surface water, like the stream in Fig. 3.38, in

Fig. 3.39 Trees in the woodland photographed during the field investigations

the vicinity of sites PF, PG, PH and PJ was analysed. The stake concerning macroinvertebrates is often high in the extended surroundings around surface sites. Aquatic benthic macroinvertebrates are insects in their nymph and larval stages, snails, worms, crayfish, and clams that spend at least part of their lives in water. Fireflies are another important species that are sometimes encountered in the wider perimeters of the sites.

Although the site PA and its immediate surroundings are not subject to aquatic fauna presence, the wider environment is known to be a habitat for vulnerable and endangered species. Protected and endangered species are close to site PB, although the site does not affect their habitats. Sites PD and PF and their surroundings are not concerned by aquatic fauna. The vicinity of site PG is characterised by important aquatic habitats with vulnerable and endangered species that the project will avoid and aim not to affect. The site perimeter has already been adjusted as a result of various stakes identified during the initial state analysis. Although site PH lies in the forest and close to a creek the presence of noteworthy aquatic species is low and the site itself is not affected. Sites PJ and PL and their surroundings also have no issues with respect to aquatic fauna.

Summing up, the PJ site does not present any observations of benthic macroinvertebrates. The wider surroundings of the PD, PF, and PL sites show a few habitats favourable to the development of benthic macroinvertebrates, but only a few taxa are present. Also, the PH site does not present any taxa with significance; however, the habitats are varied and the taxonomic diversity is high near the site, although with very low significance. The PG site hosts taxa with 'medium' significance, but the habitats are varied and taxonomic diversity is high near the site border. The wider PA site surroundings are subject to an observation with 'high' significance, but the habitats are poor and have little interest for the benthic macrofauna. The PB wider site surroundings have several observations of taxa with 'very high' significance. No surface site has any relation with fish although some sites (PB, PF, PG, PH, PJ) are in the vicinity of small creeks.

Forest During this study, expert companies and forest evaluation consultants have made a comprehensive and detailed forest quality and value analysis. This included the potential loss of biodiversity, habitat and economic income over a sustained period of several decades. The results are also integrated into the comprehensive, wider socio-economic assessment. The French 'Indice de biodiversité potentielle' (IBP) methodology was applied [86, 87]. The project will not affect any existing forest spaces in Switzerland. Forests like the woodland shown in Fig. 3.39 are in the vicinities of sites PA, PB, PD, PF, PG, PJ and PL. Only sites PG and PH will require clearings.

The forest that would be affected by site PG has quite a diverse character. The xeric woodlands located in the southeast mainly consist of small-diameter oak woods, showing a strong to weak stake depending on the area. The ravine woodlands in the west feature a composition of large and very large trees rich in dendro-microhabitats, potentially hosting a rich and diverse biodiversity. The central area of the forest presents a character more easily exploitable for forest owners. This leads to more or less diverse stands depending on the plots. The presence of large dead wood is less important overall. The challenge in terms of biodiversity varies from strong to weak depending on the age of the trees. Consequently, the surface site has been adapted to reduce the affected forest as much as possible and to select an area for the access shaft locations that has a lower quality than the surroundings. In total about 2.4 ha of forest may be affected by the surface site development.

The forest at PH features relatively young woodlands resulting from agricultural abandonment, thereby having few dendro-microhabitats. The woodlands located on the northern fringe of the site are the oldest and there is presence of a temporary watercourse. Medium wood is less conducive to supporting forest biodiversity than large and very large wood. In total, up to 10 ha of forest may be affected in the communes of Cercier and Marlioz. Further surface site designs are needed to determine the exact surface requirements, taking into consideration all the environmental issues that have been identified.

Summary Detailed data are included in specific paragraphs of the biodiversity section. To the east of the PA are wetlands that serve as a migratory stopover for bird species, and to the south, near LHCb Pt8, is a forest of ecological value due to the presence of bats and insects. Some agricultural patches near the site with isolated trees also play a valuable role for birds. The PA surface sites have low ecological stakes, however the future construction must carefully consider the surrounding elements to maintain the key habitats and species.

The PB surface site presents low to moderate ecological stakes, however the presence of diverse bird species, aquatic insects and protected plants along the Nant du Paradis stream highlights the ecological value of the site's nearby areas. The future construction must take into account the ecological sensitivity of these places to ensure the preservation of biodiversity and habitats.

The site PD is entirely covered by agricultural land which represents low-level stakes. Small areas of high ecological importance are located further north of the site. These include hedges and old trees that provide habitat for birds and bats of low or moderate concern. Future construction in this area has to take into consideration small fauna species that might be present on or crossing the site.

The PF site is used as an agricultural meadow and presents moderate ecological states. However, the site is located within the ecological corridor for wildlife movement, near the wetland area and forest with the stream providing habitats for a range of species, including birds, bats, and amphibians. The site layout must be carefully planned to avoid disrupting the sensitive ecosystems and ensure good functionality of the fauna corridor.

The main PG surface site is partly in a forest area, which represents high stakes, and partly in pasture land with low stakes. The annex site to the north, located near the highway, shows low ecological stakes. The main constraint rPG site is the valuable forests that hosts fauna and flora species, therefore the effort has to be put into limiting deforestation and maintaining the current habitats.

The PH surface site is located in the forest with small clearings and wetland area. Part of the PF surface site shows very high stakes, mainly in the north, due to the presence of bird species, including those of high conservation concern, bat species with their ecological corridor as well as small fauna. Stakes of strong character, with parts of medium and low are located in the southwestern part of the site. Limiting the use of areas with high stakes will be necessary to preserve its biodiversity and ecological value.

Most of the PJ surface site presents low stakes, excluding an inventoried small wetland and hedgerow that are considered as strong stake. The current layout of the site already foresees the space for an ecological corridor and grassy meadows in order to maintain connectivity between natural areas for wildlife and to keep areas for birds to hunt.

The major part of the PL surface site is located on the agricultural land presenting low stakes. Some hedges within the site and in the vicinity of the site play an important role for bird species and must be preserved whenever possible.

To ensure responsible development of the areas, site construction must be carefully planned to minimise habitat disturbance, maintain ecological corridors, and preserve biodiversity. By integrating these considerations into project design plans at the early stage, it is possible to balance infrastructure needs with the preservation of local biodiversity and ecological integrity.

3.3.6 Ecological functionality

In France, the ecological network, known as the 'Trame verte et bleue' (Green and Blue Framework), is a component of the national and regional planning framework. It integrates terrestrial and aquatic ecological continuity. This network comprises biodiversity reservoirs, ecological corridors, permeable terrestrial and aquatic spaces, and large agricultural areas. These elements collectively support species movement, lifecycle completion, and biodiversity preservation. In Switzerland, the ecological network identifies essential zones for nature and their connections. The REN's (Réseau écologique national) framework includes nodal zones (vital habitats for species lifecycle completion), extension zones (lower-quality or smaller zones), continua (interconnected areas such as forests and wetlands), and development zones (partial habitats). The network also features ecological corridors linking key areas.

The difference in both countries lies in implementation and structure. In France, the ecological network emphasises integrating green and blue corridors at a national scale under regional governance. In contrast, Switzerland's REN adopts a more localised approach, focusing on specific ecological zones and their physical connectivity. Additionally, the French framework includes significant agricultural spaces and functions of water bodies while the Swiss REN categorises its zones with a greater focus on inter-zonal ecological dynamics.

The site PA and nearby area are permeable agricultural spaces that represent only limited interest in terms of ecological functionality. A regionally important ecological corridor was identified south of the surface site. Wetlands in the vicinity of the surface site contribute to the ecological functionality in the context of the blue network. According to the local urban development plan, three isolated trees located to the east of the main surface site and trees to the south-east are considered a landscape element to be preserved. The layout and design of the surface site constructions will need to ensure that the ecological continuity is maintained.

Site PB is located on large agricultural land with some extensive areas and a continuum of dry grasslands. However, these areas which are conducive to biodiversity are not located within the surface site. There are two locally important movement corridors for large fauna, one of which passes west to the surface site without crossing it and the other through the eastern part of the surface site area, near the hedgerows, which should be taken into account in the design phase. The PB surface site lies in the immediate vicinity of the blue continuum, which follows the hedgerow line to the north-east. However, the location of the site does not directly interrupt the functionality of this network.

The area of PD surface site is located on the permeable relay agricultural land. South of the PD surface, under RD903, a secondary corridor of medium fauna that is to be considered in the design phase was identified. The surface site does not encroach on any element related to wetlands or water areas and therefore does not affect the functionality of the region's blue network. According to the Nangy local urban plan, no element of biodiversity reservoirs or ecological corridors is present in the study area.

The PF surface site is located within permeable agricultural spaces and a forest ecological corridor connecting the areas located to the north-west and south-west of the site. It is a remote area used by large fauna. The surface site is close to two wetland areas of the blue network, the functionality of which has not yet been analysed. This aspect must be taken into account in the design phase of the surface site. It will also be necessary to ensure the functionality of ecological corridors and large fauna movement routes between the forest areas to the north and south of the site surface, as required by the Éteaux commune's local urban plan.

To the north of the PG surface site, across the highway, there are two forested corridors, while to the south there is a linear corridor, also forested. The PG area with its annex is located in permeable spaces, partly on agricultural and forest land, however the PG surface area is not located in any ecological corridor and no biodiversity reservoir has been inventoried. The surface site does not concern any element of the blue network. According to the Groisy local urban plan, the surface site and the possible access road are located on classified forested areas - Espaces Boisés Classés - which results in preservation or appropriate reforestation in the case of felling, depending on the agreed compensation method, therefore construction in the forested area will be limited to the minimum necessary.

The PH surface site is concerned only with permeable relay spaces and does not cross any ecological corridors or biodiversity reservoirs. The surface site's proximity to the Tabassé stream, which joins the Usses watercourse, is one of the main elements of the blue network of the area. During the field visits, the wetland was inventoried on the perimeter of the surface site, but it does not seem to represent a major functional role in the blue structure. The local urban development plan of Val des Usses and Cercier also mentions a sector of ecological interest related to the watercourse to the north, which will be taken into account when designing the layout of the infrastructure.

The PJ surface site is located on agricultural land with permeable relay spaces, as well as an ecological corridor connecting forested biodiversity reservoirs between the north and the south, which connects with another ecological corridor in the further part. There are two small streams, west and east of the PJ site, and a wetland has been inventoried on the site itself, but its functionality has not yet been analysed. In accordance with the local urban plans of two municipalities concerned, the surface site is located between wooded area ensuring the ecological continuity, and contains two lines of protected hedges. The preservation of ecological continuity and the ecological corridor will be taken into account during the design phase.

The PL surface site is located on the relay permeable spaces and agricultural spaces. A regional wetland from departmental inventories and a corridor for the movement of large fauna are located to the north of the site, however, these structures do not cross the site. According to the local urban plan of the municipality of Challex, small hedges that are within the surface site perimeter and in close vicinity are considered natural structures and are to be preserved for ecological reasons.

In summary, the PA site includes a regional ecological corridor with wetlands and hedges that need preservation to maintain ecological continuity. The PB site is near two fauna movement corridors and the blue network along the eastern side. Though the site does not directly impact the blue structure, the surface site layout has to take it into consideration. The PD site consists of agricultural spaces with a secondary fauna corridor in the south, near the RD903 but does not encroach on wetlands or biodiversity reservoirs. The PF site is located near two wetlands and within an ecological corridor, which will have to be taken into account in the design phase. Part of the PG site includes a classified forest area, and wood cutting should be minimised. The design of the site will have to ensure that the functionality of nearby ecological corridor and biodiversity reservoir is maintained. The PH site is close to the stream, and a larger watercourse is to be considered during the layout design. It also has some wetlands present but these play a minor functional role. The PJ site lies in a large ecological corridor, including an area of wetlands and hedgerows of ecological value. Lastly, the PL site consists of agricultural land with hedges that need preservation, while a regional wetland and fauna corridor further to the north remains unaffected. Overall, ecological continuity and protected elements must be carefully considered during the design phase to ensure their functionality.

3.3.7 Urbanism

The urbanism aspects comprise all local and regional policies and plans for territorial developments. All land plots are subject to such plans, and they are regularly reviewed and updated at the municipality level and at the local and regional public administration levels.

Table 3.12 Summary of urbanism issues

Topic	Extended perimeter around site	Description of stakes
Strong urbanism stakes	PA, PB, PD, PF, PG, PH, PJ, PL	Nature and agriculture protection zones, humid zones.
Other urbanism stakes	PA, PB, PD, PF, PG, PJ, PL	Protected or valuable architecture in the vicinity, sport facilities, agriculture, roads, highways.
Public utility servitude	PB, PF, PH	Pipelines, electricity lines and protection buffers around those infrastructures.
Urban environment and applicable regulations	PA, PB, PD, PG, PF, PJ, PL	Co-visibility, requirement for integration in the urban context, topographic constraints.

Table 3.13 Summary of urbanism topics by site

Site	Stakes	Urbanism topics
PA	High	Protected agriculture zone, gas pipeline at the site border
PB	High	Protected agriculture zone (SDA), ecological corridor, landscape integration
PD	Low	Agricultural space, road development project
PF	Low	Agricultural space
PG	Low	Agricultural space, nature zone (forest)
PH	High	Agricultural space, nature zone (forest), pipeline at the northern site limit
PJ	High	Agricultural zone, wetland zone, protected agricultural space, ecological corridor
PL	Medium	Protected agricultural zone, nature protection zone

The urban aspects of the perimeters of the surface sites, enlarged and extended zones of several kilometres around the surface sites have been analysed based on the relevant regional and local urban plans in France and in Switzerland. In addition, field visits permitted the publicly available information to be complemented and enriched with the up-to-date situation. This survey permits all regulatory constraints with respect to the territorial development to be compiled and anticipating the planned evolution of the territory from an environmental point of view, considering all of the applicable laws and regulations. The relevant documents and associated geographical information systems and maps comprise PLU, PLUi, PLUIh, PADD, SCoT in France and PDCn and PDCm of the canton in Geneva in Switzerland.

Table 3.12 shows that all extended or enlarged perimeters around the surface sites are subject to strong or other urbanistic and territorial development issues. These issues have to be taken into account during the detailed project plan development.

Table 3.13 shows that half of the sites are directly affected by urban constraints that need to be considered during the site design development and that require particular attention during the project authorisation process.

3.3.8 Mobility

Data about the public transport infrastructures and road traffic as well as soft mobility and multi-modal mobility within the perimeter of the project have been collected and analysed. Figure 3.40 presents a schematic representation of the travel flows in Grand Genève.

Public transport The PA Site is well served by the Geneva public transport system (TPG) which operates across the Swiss/French border and serves the entire zone. The bus connection is direct, and there is a tramway connection within a reasonable distance. Site PB in Switzerland is also served by the TPG network with a bus station in the immediate vicinity and a tramway connection at a reasonable distance. The PD Site in France is well served by regional French bus lines, including a park+ride facility connecting to Geneva. The presence of the large hospital (CHAL) ensures that the connections are maintained and potentially further developed. The location of site PF is poorly served by public transport. However, 2 km away, La Roche-sur-Foron train station is an important multi-modal transport pole including a connection to Geneva via the Léman Express. The PG site is not served by public transport. However, the Groisy train station is 2 km away and provides regular connections to Annecy and Geneva via the Léman Express line. The PH site is not served by public transport and no public transport exists in the vicinity. Site PJ is not served by public transport, but 2 km away, a Swiss TPG bus line connects to Vulbens

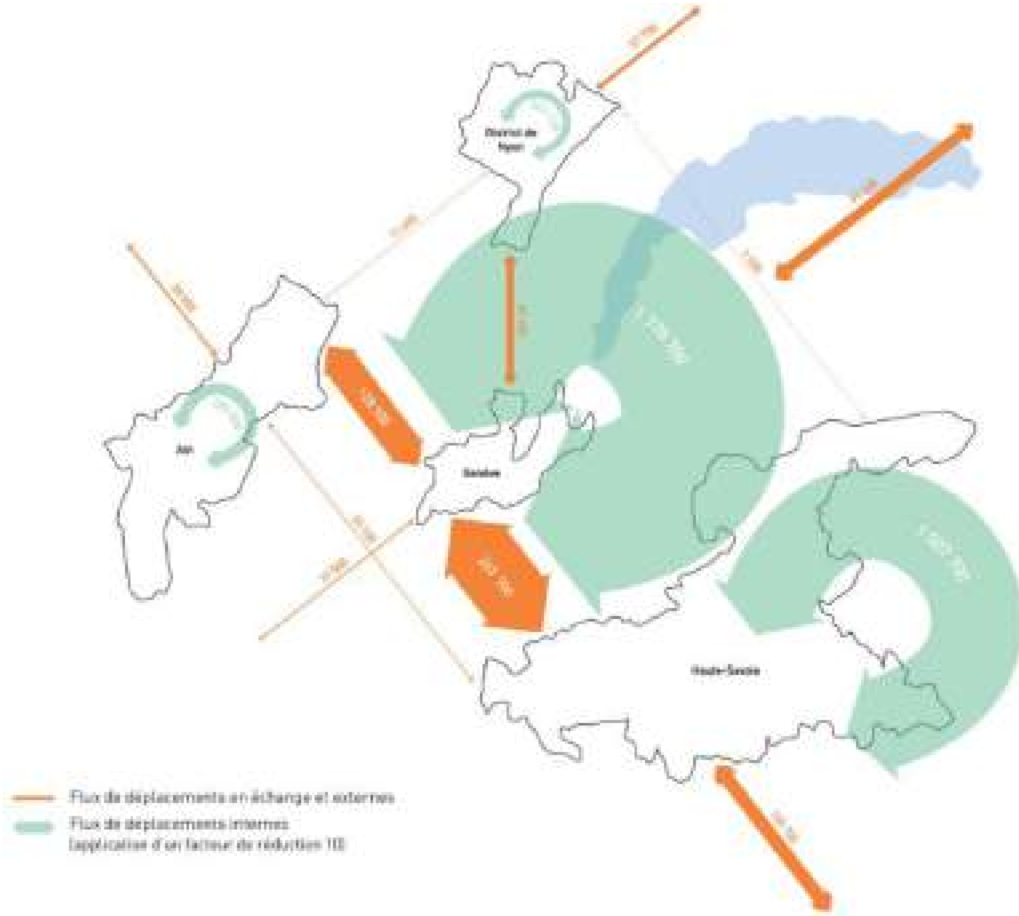


Fig. 3.40 Daily travel flows (all modes combined) in Grand Geneve (Source Grand-Genève [88], based on MRMT – EDGT 2015 - 2016) Although Geneva remains a central hub, the analysis of flows reveals a more multipolar organisation, with a majority of internal travel within the large territories (Geneva, French Geneva, Nyon district)

and in Valleiry, there is a train station on the line between Bellegarde and Evian via Annemasse. Although there are Swiss TPG bus stops in Challex in the vicinity of site PL, the frequency is modest. Better connections exist in nearby Dardagny in Switzerland. At a distance of 4 km in La Pleine, there are very good connections to bus and train lines.

Summing up, the experiment sites PA and PD are well served by public transport and the experiment sites PG and PJ are reasonably connected at some distance. The technical sites PB, PF, PH and PL are not well served by public transport. An analysis of the demand from these sites would be required if further development of the public transport system is considered in relation to the FCC project. It could be in the mutual interest of the project and the local stakeholders to develop public transport around the PG and PJ experiment sites at least.

Road network The experiment sites PA, PD, PG and PJ are in the immediate vicinity of major roads and would profit from direct access to the autoroute infrastructure for construction and installation purposes. This would eliminate any potential residual local traffic challenges around the sites during these phases. The PA site is also well-connected to the CERN Prévessin and Meyrin sites via a major departmental road. In addition, the PL technical site is in the vicinity of a major departmental road and is also well-connected to the existing CERN sites. The PB Site is directly on a good road, but the traffic situation through Geneva and to nearby Annemasse in France is challenging. Technical site PF is also well-connected via a major departmental road. Although site PH is directly located on a departmental road, it is isolated and is distant from major transport routes. The closest autoroute access is at a distance of 10 km in Allonzier-la-Caille. Installation of bulky equipment at this site needs to be carefully studied, developed and planned.

Other transport modes The study also included the analysis of dedicated bicycle tracks in France and Switzerland. Dedicated lanes and tracks have recently been constructed in the vicinity of site PA and these are expected to

Fig. 3.41 Current and potential future extension of the Leman Express

be further developed. These spans the Franco-Swiss border. A dedicated bicycle track is also being constructed directly at the PB site. Sites PD and PF are not equipped for soft mobility. No dedicated bicycle lanes exist around site PG, but the road to Groisy is well-adapted for cyclists. Site PH has no soft mobility infrastructures. The surroundings of site PJ are being developed with a view to strengthening soft mobility, aiming to link the nearby municipalities Vulbens and Valleiry. The creation of access to site PJ also permits the connection of Dingy-en-Vuache to this system. PL is not particularly equipped for soft mobility. Although walking and biking are easy in the commune, there are no dedicated links to other municipalities in France and Switzerland.

Foreseeable evolution The Grand Genève area is developing a multi-modal transport plan that aims to improve further the transport infrastructure across the Franco/Swiss border. The continued housing development and demographic evolution of about +1.2% per year in the neighbouring French departments of Ain and Haute-Savoie, which is unrelated to CERN's activities, calls for such developments. There are about 1.2 million journeys today within the perimeter of the project, but about 4.2 million per day are expected by 2040. As will be described later, the activities relating to the construction, installation, and operation of the project are insignificant compared to the existing and future mobility in the region.

The extension of the Swiss railway system continues to increase its daily train capacity, mainly due to the Léman Express lines (see Fig. 3.41). This also includes an improvement of the services to the Arve valley (La Roche-sur-Forton), Groisy and Annecy for completion in 2030. In the longer term, developments are planned for increasing the service to La Plaine and beyond to Bellegarde. Autoroute extension projects in Switzerland have been planned, but were recently put on hold. A project to connect both sides of Lake Geneva sides by a tunnel under the lake has been studied, but any potential implementation before 2050 is unlikely and therefore the project is not included in specific plans. In France, an autoroute is planned to connect the A40 (Arve valley) to the A412(Thônon) via a wide departmental road (RD903) connecting to the A40 in Nangy. Bus line developments between major agglomerations and the hospital next to the PD site are likely.

Project induced traffic Project induced traffic refers to the following types:

1. Workers commuting to and from the construction sites during an approximately ten-year-long construction phase.