Building CERN's Future Circular Collider—An Estimation of Its Impact on Value Added and Employment

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Abstract This chapter explores the potential economic and employment impacts of constructing the Future Circular Collider (FCC), a next-generation particle accelerator being developed by CERN. The FCC project aims to build upon the existing accelerator complex near Geneva, extending into the Haute-Savoie region and introducing an unparalleled research facility for the global scientific community. By integrating a high-intensity electron-positron collider and a high-energy hadron collider, the FCC is designed to push the boundaries of particle physics throughout the twenty-first century. Beyond its scientific aspirations, the project has the potential to create significant economic value through direct and indirect employment, technology transfer, and innovation spillovers across sectors. The analysis presented in this chapter examines the anticipated impacts on regional and international economies, highlighting the benefits of such a large-scale infrastructure in advancing scientific frontiers while also delivering tangible contributions to society, innovation, and employment growth. Through advanced modelling and projections, the chapter estimates the FCC's potential to act as a catalyst for economic development, further solidifying Europe's leadership in high-energy physics research.

Keywords Future circular collider · CERN · Particle physics · Economic impact · Employment · Research infrastructure · Value-added · Innovation · Technology transfer · Scientific progress · Regional development · High-energy physics · Economic modelling · International collaboration

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1 Introduction

CERN, the European Organization for Nuclear Research, is hosting an international collaboration that develops scenarios for a new circular particle collider-based research infrastructure. The so called "Future Circular Collider" (FCC) would be located in the vicinity of CERN's main sites (Meyrin, canton of Geneva, Switzerland, Prévessin, department Ain, France), connect to the existing particle accelerator complex and extend significantly into the Haute-Savoie department region (see Fig. 1). Hosting subsequently an intensity frontier electron–positron and an energy-frontier hadron particle collider, this research infrastructure has the potential to contribute substantially to the discipline of particle physics and the understanding of nature's workings at the sub-atomic level with a research programme until the end of the twenty-first century.

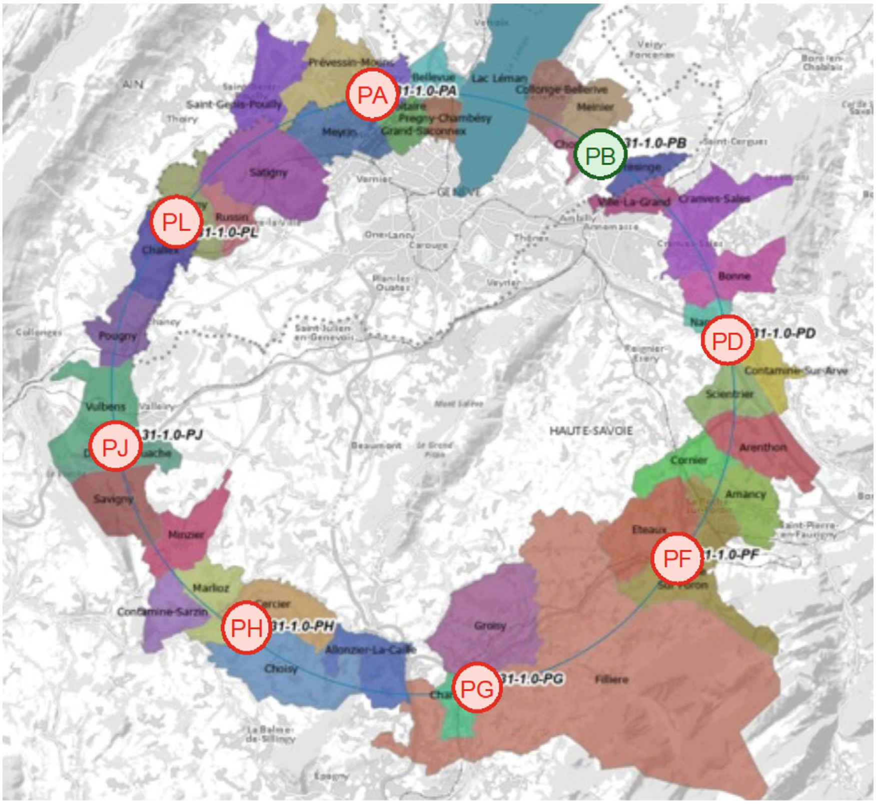


Fig. 1 Working hypothesis for a new future circular collider with a circumference of more than 90 km and eight surface sites that connects to the existing CERN particle accelerator complex. *Source* Placement scenario for the new particle-collider based research infrastructure developed in the frame of the FCCIS H2020 co-funded EU project. *Credits* FCC study/CERN

Such a research infrastructure can also contribute to scientific and technological progress in many areas that will be needed to construct and operate such a facility. This boundary-pushing effect can be felt in unrelated areas as well: the World Wide Web was conceived at CERN around 1990, leading to the take-off of the Internet, until then known as ARPANET, a computer network used primarily by US-American academic institutions.

Apart from science-changing insights and technological developments, there are more immediate economic benefits likely to arise from this project: the opportunities for firms to contribute to the installation and operation of this machine and the jobs that go along with these opportunities. The purpose of the following chapter is to contribute to an effective and continuously improving open platform to estimate such effects in order to help launch a policy development process to make scientific research infrastructures in Europe more resilient.[1,2]

2 Investment and Costs

The FCC's scientific potential comes with a sizable price tag: In total, investment and operation costs over a 25-year lifetime (10 years of construction followed by 15 years of operation[3]) are estimated at more than 21 bn CHF[4] (in 2019 prices[5]) (Table 1).

These expenditures are linked to tangible economic spill-over effects, even excluding scientific effects[6]: FCC-related CAPEX represents sales opportunities for firms, as does OPEX.[7] Employees engaged in the FCC programme earn wages, which

[1] There will be other incremental benefits from the FCC, from possible advances in fundamental research leading to practical technological progress to individual researchers' career opportunities, in and out of science. However, these aspects do not feature in the present analysis, but are dealt with in a separate segment of the integrating FCC socio-economic impact study. Interim results can for instance be looked at in Bastianin (2021).

[2] For the full report, see Streicher [8].

[3] 15 years of operation (plus 2 years of "scientific research and data processing with already collected data") for a setup with two "experiments".

[4] Investment volumes and operational expense are based on CERN estimates developed between 2019 and 2021, as were all assumptions on structural details for the investment and operation phases.

[5] Cost adjustments based on inflation, GDP and other economic indicator forecasts are not meaningful when capturing the impact generation potentials on large time scales. Therefore, this work chose to report on "current cost and effects" based on actual costs and effects generated today. This helps the reader to get an immediate understanding of the relation between investments and the connected effects. Incremental socio-economic benefits reported on FCC in a comprehensive study uses a social discount rate of 2% to compare the expenses and impacts over a long-time scale, as is best practice in this field of economics.

[6] Consensus among economics researchers exists that a monetary value of the core scientific mission cannot reliably be estimated, since it is unrelated to economic activities and the specific effects of the knowledge increase on economic activities cannot be foreseen.

[7] OPEX = Operational Expenditure; costs that a company incurs for running its day-to-day operations.

Table 1 FCC-related investment and operation cost estimates (CAPEX and OPEX)[8]

		Investment volume [mn CHF]	Annualised volume [mn CHF/a]
FCC-related investment			
Total investment	2031–2050	12,097	605
Core phase	2031–2040	10,709	1071
Upgrade phase	2041–2050	1,388	139
FCC-operation			
FCC OPEX	2041–2055	2,950	199
FCC personnel	2028–2057	5,400	180
Total	2028–2057	21,100	700

Source FCC study preliminary cost estimates (2021). Totals are rounded; 2019 prices

are partially spent on consumption and represent therefore again potential sales for firms. The existing CERN installations are already today a major tourist attraction with up to 170,000 visitors per year before the pandemic. In the run-up to the FCC, visitor facilities will be upgraded and expanded to allow for a total of 300,000 visitors per year, inducing further effects for the regional tourism sector.

For the purpose of the estimation of the economic impacts on employment and value added, the project can be divided into distinct phases (see also Table 2):

- The initial, **core investment phase**, planned to span the decade between 2030 and 2040, when the underground infrastructure and surface technical infrastructures are constructed and the particle collider and the experiments are installed.
- A second **upgrade investment phase**, that is interleaved with the operation period in the subsequent decade, in which the particle collider is periodically updated to reach ever higher collision energies, as specified by the envisaged physics research programme.
- The **operation phase** during which the machine will be used for scientific research starts after 2040 and lasts until approximately 2055. Operating in a baseline scenario with two experiments and a possibility to install four experiments (not covered in this analysis), this period will last for 15 years ("FCC OPEX" in Table 2); however, scientific research personnel will still be active for 2–3 years after the end of particle collider operation to analyse the data gathered in the course of the experiments ("FCC Personnel" in Table 2).
- During the operation phase, the FCC will generate value added directly by virtue of paying wages and through the depreciation of the original investment ("FCC direct" in Table 2).

CAPEX = Capital Expenditure; purchases of significant goods or services that will be used to improve a company's performance in the future.

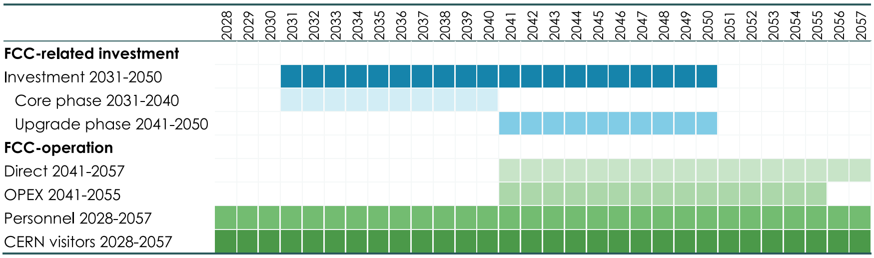
[8] See Footnote 4.

Table 2 Summary of economic effects and linkages related to FCC construction and operation, annualised over FCC-related construction and operation 2028–57[9]

	Investment / consumption period	Investment / consumption volume	annualised invest./cons. volume	Average annual Value added effects [Mio. CHF]			Sum total	Avergae annual employment effects [persons]			Sum total
				Direct	Indirect	induced		Direct	Indirect	induced	
Investment related											
Total Investments (I + U)	2031–2050	12,097	403	179	206	86	471	2600	3400	1700	7700
Initial Investments	2031–2040	10,709	357	160	184	75	418	2400	3000	1500	6900
Upgrade Investments	2041–2050	1388	46	19	22	11	53	200	400	200	800
Operation related											
Direct FCC	2041–2057	0	0	255	0	0	255	5700	0	0	5700
OPEX	2041–2055	2956	99	40	50	27	116	400	700	500	1700
Living-related for resident personnel	2028–2057	9180	306	149	106	368	623	1600	1600	5200	8400
Visitors	2028–2057	3900	130	46	67	61	174	700	1000	800	2500
Total	2028–2057	28,133	938	669	429	541	1384	11,000	6700	8200	26,000

Source Own calculations with ADAGIO based on CERN data

[9] In all tables, results on value added are rounded to the nearest 50 if value > 500 and to the nearest 10 if 20 < value ≤ 500 and to 1 if value ≤ 20. Values on employment are rounded to one decimal. Sums are rounded independently, rounding errors are not compensated.



Source: CERN.

Fig. 2 Schedule of the FCC-ee project for the purpose of economic analysis of the employment sector. *Source* CERN

- During those phases and including partially the "design phase" that is assumed to start around 2028 when the first project-related, relevant investments take place, between 4000 and 11,000 persons will work for the project, not all of them on-site. The induced **consumer spending** of the resident FCC personnel will contribute to the economy of the region and beyond.
- A visitor facilities development programme that is already starting with the inauguration of the "Science Gateway" at the CERN headquarters in 2023, will permit gradually to increase the annual **visitor numbers** from the current 150,000 to around 300,000. A survey by CERN (see [5]) showed that visitors typically stay for an average of 4 nights spending around 1000 CHF per person, thus significantly contributing to the local economies of the western part of Switzerland in the Auvergne-Rhône-Alpes region in France

Figure 2 depicts the different phases used for the economic analysis of the employment sector in chronological form.

Those outlays—spending on FCC investment and operation as well as visitors' expenditures—are in turn associated with opportunities for firms in terms of turnover and employment. Further impact pathways exist and could be evaluated, subject to resource availability for such studies.

3 Model and Method

The method of choice to estimate value added and employment associated with some investment project is Input–Output Analysis (e.g., [7]). IO analysis is based on Input–Output tables, which split up the total economy into economic sectors (corresponding to commodities, i.e. goods and services) and compile the flows of intermediate inputs and outputs (one firm's inputs are another firm's output) between these sectors from statistical sources like surveys, tax records, or trade data. In the case of multiregional IO tables, these flows additionally distinguish between sectors in different regions, thus following the flows between sectors in different regions—the global value chains.

By recording the flows of intermediate products between sectors (as well as the employment associated with these flows), the method takes into account the total production process beyond the **direct** purchase of the final investment item from a contractor, including all **indirect** effects at the level of this contractor's suppliers and their suppliers.[10] Thus, IO analysis highlights the entire global value chain set into motion when an investment good is purchased. In addition, IO analysis can also be used to estimate the **induced** effects that are linked to the consumption and investment connected to the wages and profits generated in the course of this production process, resulting in the simulation of a "Keynesian economic multiplier".[11] This economic cycle brings about a widening of the economic effects, both in sectoral and regional terms (purchases of intermediate products from other sectors as well as other regions).

To estimate these effects, we use ADAGIO, a multiregional IO model developed at WIFO.[12]

ADAGIO—A Global Dynamic Input-Output Model

ADAGIO is an Input-Output model, distinguishing 43 countries (the EU 27 plus 16 of the major economies) and 64 sectors and commodities. At its core, it is a full representation of the flows of goods and services between these 64 sectors in the 43 countries (plus the Rest-of-the-World), tracing out the "global value chains" connected to any (idealized) commodity that is produced or consumed in the model countries. This allows ADAGIO to simulate the effects on output, value added and employment of some "demand shock", new demand that for example arises from the FCC project.

To make use of this model, we first convert the investment plan into demand for model-compatible investment commodities.[13] The main beneficiaries in terms of sales are construction (with almost 40% of the investment volume), electronic, electrical and mechanical equipment (with more than 40%). As in this explanatory stage of the project, the individual contractors cannot be known, we must make assumptions about where these commodities are sourced: For a broad regional structure of the origins of the FCC parts and inputs, we make a "fair share" assumption which reflects member countries' contributions to the CERN budget to determine the total

[10] IO analysis allows to follow—in a statistical way—the, say, metal components of a machine via the production of its metal products and the production of the metal itself all the way back to the mining of the iron ore and coal.

[11] Induced effects constitute **multiplier effects**: by working via value added, they amplify the initial direct and indirect effects.

[12] FOR technical details of FIDELIO, ADAGIO's predecessor which was developed for and with the EU's Institute for Prodpective Technology Studies IPTS, see Kratena et al. [6]

[13] FOR details on this as well as all details on all the other calculations, assumptions and results, see Streicher [8]

amount for the contracts awarded to the firms of each member state (allowing for some deliveries from non-members of crucial components which cannot be sourced from member states). Additionally, assumptions about which goods and services are purchased from each member are based on each country's economic and technological strengths and specialization. In economic terms, this specialization is reflected in a country's export structure—if its firms are especially competitive at producing some specific commodity, then it should lead to this commodity having an above-average share in the country's total exports. Thus, if France has a relative advantage in, say, machinery, apparent from an above-average share of machines in its exports, then we assume that France also has an above-average share of machines supplied for the FCC. In this way we ensure that FCC investment goods are sourced from the member states where they are produced most efficiently. However, one must consider that the distribution of specialisation is evolving. Evidence from previous studies on the LHC project also showed that a project of the FCC scale can induce an acceleration of technology development in a country [4] and thus also influence the evolution of regional specialization.[14] A careful analysis of the needs and a policy development together with participating nations and industrial partners is therefore required during a project preparatory phase.

In the regional dimension, expenditures by resident staff and visitors are easier to pinpoint: apart from mobility-related services (e.g. spending on non-regional transport), almost all purchases take place in the region on both sides of the Swiss-French border. Figure 3 shows today's distribution of the persons who participate in CERN's projects and operation activities. As ADAGIO operates at the national level only, we assume a 50:50 split of visitor expenditures between France and Switzerland as well as a 75:25 split of living expenditures by resident personnel between France and Switzerland [1].

Having specified the procurements in the regional as well as the sectoral dimension, we can use ADAGIO to estimate the global effects on production, value added and employment that are linked to the construction and operation of the FCC under the assumption of today's economic performance and specializations of nations.

[14] A systematic monitoring system of key economic variables of contractors (turnover, employment, export share, R&D expenditures, etc.) before, during and after their involvement with the FCC would allow for the analysis of such specialisation at the level of individual firms, thus helping to better understand such knowledge-driven developments.

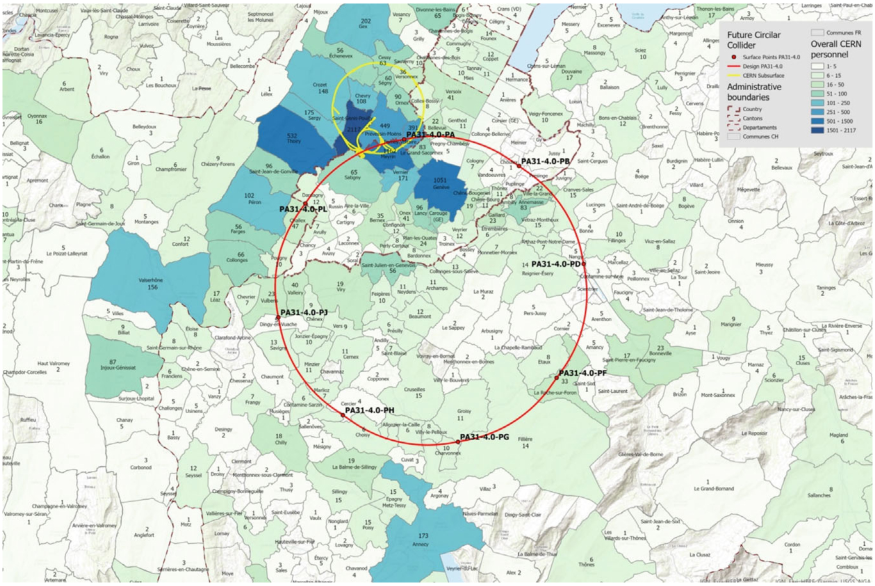


Fig. 3 Places of residence of current CERN employees, resident users, resident contractors. The yellow structures indicate CERN's current particle accelerator complex. The red ring indicates the perimeter of the FCC. It is likely that today's distribution of residents (two third in France and one third in Switzerland) experiences a shift towards the Haute-Savoie region (three quarters in France and one quarter in Switzerland). *Credit* FCC Study/CERN

4 Results

Table 2 reports the average annual effects over the project's 30-year period for the investment as well as the operating phases.

Over the 30 years of FCC construction and operation, about 28 bn CHF of expenses (on average about 940 mio CHF per year) are estimated to occur. Thereof, about 21 bn CHF relate to the construction and operation. The average annual spending of 940 mio CHF is connected with an estimated 1, 4 bn CHF of world-wide value added, filling 26,000 jobs. This means that in addition to about 6000 directly project-related science, engineering, administration, and management jobs, more than 20,000 jobs are secured to provide the goods and services for the construction and operation of the FCC, as well as for the goods and services that are consumed by FCC personnel and visitors. Most of the job opportunities (and value added) are generated during construction; Fig. 4 shows, how the estimated number of jobs linked to the construction and operation of the FCC develops over the whole period. It is important to note that the economic analysis cannot pinpoint the national location of these jobs; rather it is based on the above-mentioned assumptions on the distribution of direct contracts between the CERN member states. For any more accurate estimation, an organisation model and project structure need to be drawn up that permit analysing

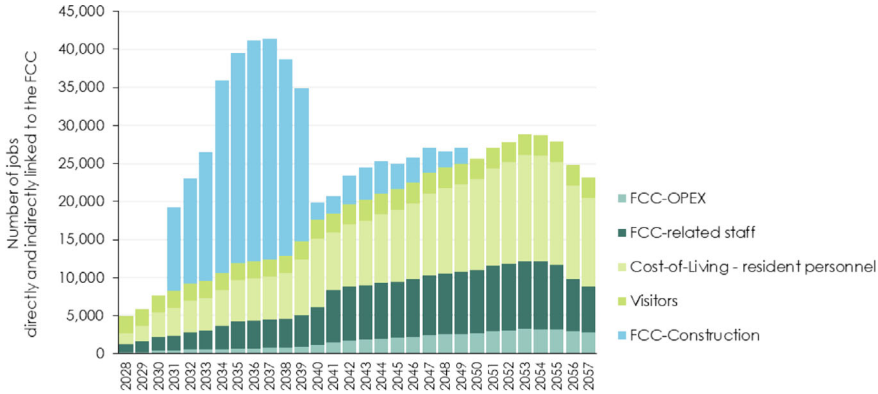


Fig. 4 Summary of annual employment effects related to FCC construction and operation (world total). *Source* Own calculations with ADAGIO based on CERN data

the effects and locations of employment related value-added in detail (e.g. wages, taxes, insurances).

Under the current national specialization assumption, the countries that benefit most from the CAPEX and OPEX spending are Germany, United Kingdom, France, Italy, the USA and Spain. This is not surprising as we assumed in a first analysis that direct contracts are proportional to a country's contribution to the CERN budget and these countries are the biggest contributors.[15] Immediately after these countries, however, China would profit most from an FCC project, although it is not a member of CERN, and therefore only a very small share of the direct contracts was considered to be awarded to firms from this country. This discrepancy between China's share in the initial investment and in the induced value-added highlights its prominent role in the global value chain. In contrast, the major share of the economic effects of spending by resident personnel as well as visitors remains in France and Switzerland, the host countries.

5 Discussion

In this report, we covered some aspects that go beyond the narrowly defined purpose of a value-added analysis for the FCC construction and operation; these include for instance the touristic aspects, but also the induced effects from the cost-of-living expenditures of FCC personnel. However, this is certainly not exhaustive, and a multitude of additional effects and developments with links to the FCC remain to be identified (and estimated), whose economic potential however could not be explored

[15] For the USA, which is not an official member of CERN, the effect can be traced to the assumption of a contribution to the experimental research operation programme.

here.[16] Some examples for which dedicated economic impact studies could be carried out and for which socio-economic strategies and policies could be developed include, but are not limited to:

- Global co-operation on a technologically advanced project like the FCC creates a special environment in which personal and institutional networks can thrive, laying the foundation for future collaborations on scientific or commercial endeavors. While the overall value-added figures of an FCC project would not significantly differ from a conventional infrastructure investment project (e.g. a train or road tunnel, a bridge), a scientific research infrastructures represents an investment choice that leads to sustained returns over its entire lifecycle (and probably beyond) with strategic development opportunities that strengthen the economic competitiveness and cohesion of the participating nations in (among others) high-tech co-developed products and services, increased markets and competitiveness of participating companies, development of underdeveloped sectors in a country to increase specialisation and most importantly, the sustained development of highly qualified and academic workforce, which are known to be key drivers of the economic development.
- FCC contracts with their exacting specifications on size and quality push the limits for many suppliers, even for those that would not be counted as "high tech"; For many suppliers, this also pays off commercially by improving their (future) profit potential.[17]
- However, concentration on the direct returns from such a project—even if those can be sizable, as this analysis has shown—is somewhat short-sighted: The participation of specialised regions on the one side and the development of key specialisations on the other side outweigh individual national short-term returns on annual membership fees. The academia-industry-third sector co-development approach is by far more relevant for scientific research infrastructure developments. It has been confirmed very recently that the key ingredient for industrial spillover effects is the relationship between the research infrastructure and the contracted company [2].[18] This overarching appraisal approach leads to governance and control over key technologies for the communities of participating nations, by increasing their share in global value chain effects (while at the same time strengthening their resilience towards detrimental exposure to the same global value chains). Acting as a group, they have stronger hand in setting the conditions for global participation and creating strategic advantages through a common market. As outlined above, the sustained training of early-stage career professionals in an international

[16] Some of them were dealt with in other reports on the FCC, such as the impact on science as well as individual careers within and outside science or the impact of technological challenges on suppliers to the FCC.

[17] Gutleber et al. (2021) conclude in Chapter 4.3. that "1 Euro spent for LHC procurement generates on average 15.3 Euro of additional revenues and 2 euro of additional profits for the supplier" (or even 20 resp 3.11 Euro in the case of a high-tech procurement contract).

[18] As a matter of fact, the EIB uses the "Internal Economic Return Rate" (IERR) as the key parameter to judge if an investment is not acceptable, fair, good, very good or excellent [9].

and mobility-oriented ecosystem is a key investment multiplier that works across generations.

- Given the dimensions of the subsurface structures housing the FCC, innovative solutions to manage the excavated material must be developed and brought to market to avoid disposal and negative effects connected to such a process. This approach has positive impact potentials on an entire industry sector that is today still largely relying on disposal and thermic truck transport with significant nuisances and carbon footprint. Typically, many conventional infrastructure projects have a low overall project budget compared to the investment needs for developing and bringing to market circular-economy technologies. Therefore, the innovation processes as well as the evolution of the legal and regulatory frameworks are still slow. The FCC is sufficiently large and long lasting to make a difference in this sector. Recently established cooperation with the "Metro Lausanne" (Switzerland), the Lyon-Turin Tunnel (TELT), the SAFER[19] of the region Auvergne-Rhône-Alpes and leading companies in the field demonstrate the necessity and validity of this impact pathway.
- The FCC can trigger the development of more efficient electrical distribution systems, refrigeration systems, heat recovery, supply and storage systems, with benefits for the whole economy and society. The supply of low-grade (40 to 45 degrees Celsius) waste heat for heating, aqua cultures and aquaponics, thermal applications, biogas production and as a baseline for food and chemical industries is an intriguing case with significant economic value-added potentials. Recently in 2023, CERN cooperation partners Ginger Burgeap (France) and NTNU (Norway) started to analyse the market potentials and develop solutions around CO2 as a transport medium for heat networks and storage systems. Regionally, a project like the FCC can act as an infrastructure development catalyser, since its size and duration are large enough to justify the works from which the environment in which the project is embedded will benefit.
- As in the past (e.g. with the World Wide Web), FCC-related work is likely to advance the state-of-the-art in software applications, from business information systems to general software libraries. Examples that have already been analysed are digital libraries (the CERN-operated Zenodo, which is based on Invenio), collaborative tools (Indico) and particle-matter interaction modeling tools that find application in life-sciences and space technologies.
- Part of the up to 11,000 people would contribute to the regional economy through their consumption spending. With the installation of four instead of two experiments, the effect would even be more pronounced. However, the project would also be an important economic player in the region beyond these induced effects. With respect to the current impacts that CERN generates, the FCC's perimeter of economic effects would be enlarged.

At a general level, the results presented in this report show that the "costs" that a scientific research infrastructure development project like the FCC entails are directly

[19] Link to the SAFER in France.

connected with "economic impacts", in terms of supply opportunities for firms and employment opportunities for scientists and non-scientists alike. By concentrating on a core set of transmission mechanisms only, these results constitute a lower bound for the expected economic effects. Numerous drivers and effects were not included at this initial stage in the analysis. Therefore, even though the narrow economic linkages of the construction and operation of the FCC are not larger than would be expected for a conventional infrastructure project of this size, the potential for spillovers into quite unrelated areas of technology and business are certainly much more pronounced—for example, only few projects would have the FCC's touristic attractiveness, not to mention its technological Open Innovation potentials.

It is important to highlight that the economic effects of large-scale scientific research infrastructures are sustained over long periods of time and are not limited to individual nations, but rather for communities and for a group of participating nations that acts collaboratively as a "whole". The focus on the involvement of persons at the early stages of their careers leads to impactful societal and economic development if the eco-system foresees an effective transfer of these trained people into the "ecosystem" of participating nations, supporting mobility. Marie-Curie actions at CERN and within the framework of CERN managed projects have given evidence for these effects with the quantitative evidence for a lifetime salary premium for those people with respect to their peers who are not exposed to a comparable experience [3]. However, a dedicated and targeted international early career programme would be needed to assure the appropriate competence transfer from science to industry, ideally involving directly the private and third-sector partners. Such a system would have a natural place in the framework of a EU research programme, but, however, does not yet exist. The effort of proposing and running numerous individual small training projects is high and does not yield the same effects as a single, uniform programme that targets research infrastructures such as the FCC and comparable organisations (e.g. ESO, SKA).

By estimating the regional structure of the effects linked to the construction and operation of the FCC, the analysis has also shown that the connection between contributions to a CERN project, direct contracts and indirect benefits is not always clear-cut. For example, the USA and China, which are not CERN member states and who therefore do not contribute annually to its budget, are estimated to have sizable economic benefits due to their prominent roles in global value chains. This finding could form a basis for negotiations between CERN and such countries on intensifying and formalizing mutually beneficial collaborations in the future. The direct, indirect and induced economic effects based on the analysis of the internationally recognized and widely used Input–Output method could also inform the definition of adequate annual contributions to a project like the FCC.

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