SOCIETAL IMPACT OF THE COMPACT LINEAR COLLIDER STUDY

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Abstract

In recent years, there is an increasing interest on societal impact of large scientific projects. At strategy meetings for the next particle accelerator for high energy physics, the scientific community recognizes that it is important to demonstrate, not only the academic significance of the project, but also its potential merits in the context of regional, national, and international development; technological and economic impacts for industries; environmental impacts from civil construction and operation; etc. Starting from existing literature on societal impact assessment and its application to Research Infrastructures, the conceptual model framework for CLIC has been built. The research has been mainly centered around publications as knowledge output, human capital impact through the early carrier researchers and technological impact, representing benefits to business. The results take into consideration the very early stage of the international study and demonstrate already beneficial outcomes for society.

1. INTRODUCTION

The past decade has witnessed an increasing interest on the topic of Societal Impact Assessment (SIA). However, there are still challenges when measuring the impact of a given undertaking. Different methodological approaches such as econometric studies, surveys, case studies, do not create a complete and objective picture of the global impact. Assessing basic research outcomes is even more challenging, since it usually requires large government public funds, while societal benefits are often implicit comparing to an applied science project. The societal impact assessment of research infrastructure becomes essential for scientists in demonstrating and highlighting the source of economic value generated for society, besides its absolute technological or scientific significance.

Moreover, the European particle physics community repeatedly raises the question of societal impact during discussions. The community meets to define a strategy for the future developments in fundamental research on physics by evaluating ongoing studies. In an open symposium in Granada in May 2019 [1], the committee highlighted the purely academic significance of an international collider study and its unclear technical and economic ripple effects for the general public. Likewise, the European Strategy update in June 2020 again recommended emphasizing, besides the scientific impact of particle physics, its technological, societal and human capital outcomes [2]. The committee also underlined the importance of partnership with industry and other research institutes as key to sustaining scientific and technological progress, helping drive innovation and bringing about societal benefits. Furthermore, the particle physics attracts young minds and provides them education and training, which are vital for the functionality of RI and of society at large.

Together with the elevated interest in SIA, the community dedicated to assessing societal impact of RI is expanding. Big Science centres, institutes and laboratories around the world are reuniting their knowledge and experience to build a comprehensive assessment model. The work on the assessment framework for LHC [3], already started in 2015. A conceptual model for the evaluation of social benefits had been proposed in the form of a cost-benefit analysis (CBA) [4]. Such study involved several external and internal CERN experts and was supported by the European Commission in its related guide to Cost-Benefit Analysis of Investment Projects issued in 2014 [5]. The developed economic appraisal model was employed afterwards in the appraisal of the

National Hadrontherapy Centre for Cancer Treatment (CNAO) in Italy [6] and for the next generation of LHC, the HL-LHC [7]. Compared to the socio-economic impacts of cancer treatment infrastructure, those of fundamental discoveries are uncertain since they tend to be practically applied much later. While a major part of the societal impacts of CNAO is its direct health benefits to society, the impacts of an accelerator consists mainly of scientific publications, experience gained by the early career researchers, technological spillovers and public outreach. The latest network aiming to fill this gap is RI-PATHS [8], a European project funded by the EU as a consortium of EFIS, CSIL, ESF, ALBA, DESY, CERN, ELIXIR and Fraunhofer ISI. In 2018, the mentioned laboratories joined forces under the RI-PATHS project funded by EU Horizon 2020 to deliver an impact assessment toolkit specifically addressing RIs.

The present work is relevant to a large-scale study on the Compact Linear Collider (CLIC)[1] [9] and to the scientific context within which a research organisation, CERN, operates. CLIC is an international study for a future 50.1 km long machine to collide electrons and positrons head-on up to several teraelectronvolts (TeV) of energy. Building and operating such a large machine with its corresponding infrastructure is extremely costly. In this study, potential effects on different concerned groups such as society, industry and the scientific community are discussed to prove the required investment needs and to show the importance of possible scientific discoveries. Since CLIC is still at the study phase at this point, a SIA can strengthen the decision-making process in the project implementation phase. The assessment is performed before the project construction and operation to find out at what point the study starts producing benefits.

This study identifies the nature and measures of the impacts, considering the project's particularity and novelty. The framework to be constructed herein can be used by policymakers or other stakeholders of large research laboratories to evaluate the relevance and level of achievement of a project. The applied methodology is established based on the previous studies and describes concerned evaluating fields and proposed methods of appraisal.

The paper introduces the methodology and the valuation of human capital formation, technological impact, and knowledge formation. The document also discusses the future study to be done to complete the societal impact assessment of CLIC.

2. METHODOLOGY

The guide to CBA [5] issued by the European commission (EC) presents an economic appraisal tool. After definition of the objectives, technical feasibility, and environmental sustainability, if a project requires financial support (FNPV < 0), an economic analysis has to be performed. The economic net present value (ENPV) for a funded RI (FRI) is calculated as the difference between the discounted total social benefits and the economic costs plus a non-use value term.

$$ENPV_{FRI} = \underbrace{[S + T + H + Str + C]}_{\textbf{MEASURABLE BENEFITS}} - \underbrace{[K + L_S + L_O + O + E]}_{\textbf{ECONOMIC COST}} + \overbrace{B_n}^{\textbf{NON-USE VALUE}} , \quad (1)$$

The terms of this equation are evaluated based on earlier approaches found in literature and are specific to a RI. The detailed description of the measures is discussed in details in the subchapters 2.1 and 2.2 of the present paper. A value of ENPV < 0 indicates that the society is better without the project while ENPV > 0 means the society benefits from the project. Also, according to the EU guide, the ENPV uses accounting prices instead of imperfect market prices, and includes any social and environmental externalities, as in the following equation:

$$NPV = value/(1 + r)^t, \quad (2)$$

where $\boldsymbol{r}$ is the discount rate, and $\boldsymbol{t}$ is the time frame of the project.

Fig. 1 shows a finalised methodological CLIC appraisal model. The framework combines EIA [10] with collaboration network assessment, partially emphasising CBA as a well-defined tool that can be used for comparative purposes. The methodology describes all possible evaluating fields and proposed methods for their

[1] Home | CLIC - Compact LInear Collider (no date). Available at: https://clic.cern/ (Accessed: 21 December 2021).

appraisal. The calculation is performed for technological, human capital and knowledge outputs. However, hereinafter, the measurable benefits and costs are discussed for the full SIA model.

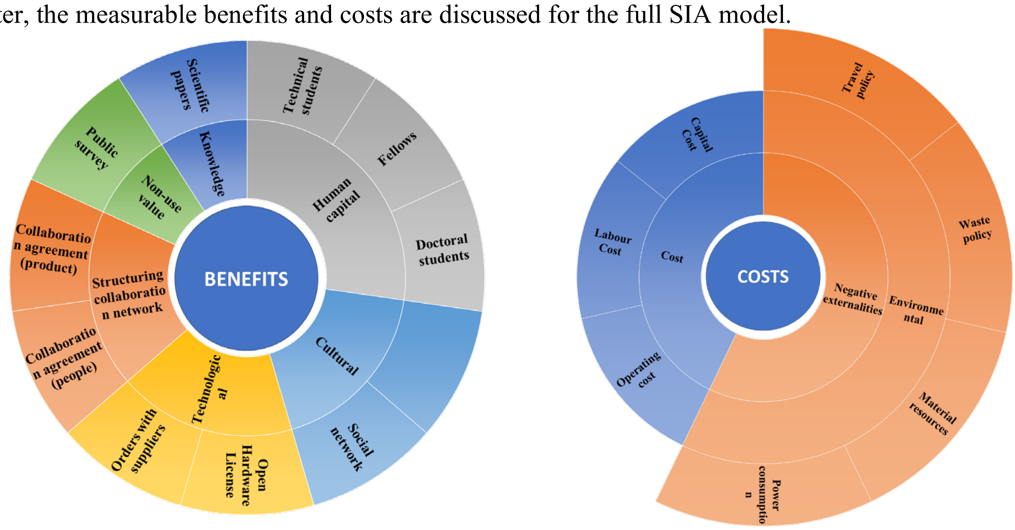

FIG. 1. Benefits and costs for the SIA.

2.1. Measurable benefits

Knowledge outputs (S) are new knowledge created based on produced scientific publications. The aggregate value is determined based on the number of papers and their citations and considering their production time. The indicators are scientific papers, including CLIC notes, publications, and proceedings.

Technological outputs (T) are benefits generated for industrial partners through CERN procurement activities. The value is calculated based on the cumulative value of procurement orders adjudicated to a company, the incremental profits gained through additional sales to third parties and the technology and knowledge acquired "for free" from Open Hardware use. The indicators are procurement orders, suppliers' general information from ORBIS[2] and the Open Hardware Repository[3].

Human capital (H) represents training and educational benefits for early-career researchers (ECRs). The value is calculated based on the salary earned over the entire work career after leaving the project, considering a career length of 35-40 years. The indicators are the number of ECRs, such as technical and doctoral students and fellows.

Cultural output (C) is a factor represented by general cultural activities, such as conferences, events, and visits of the facility, based on the time spent in travelling, travel cost, length of stay, means of transport, areas of origin and number of website visitors, among others. The cultural impact of the CLIC study can be represented and calculated by the following indicators: (1) number of guided tours for students and other visitors of the test facilities such as the showroom, CTF3 [11] and the test module lab [12]; (2) number of public events, such as CERN Open Days [13], focusing on the CLIC representation stands; and (3) social networks. The last one can be evaluated by number of visits to the official CLIC webpage [14], and number of mentions of CLIC in social networks such as Facebook, LinkedIn and Instagram through related posts and tags. The value can be calculated by estimating the travel cost and the time spent in creating a post or a tag. The indicators are activities in social networks, public events and guided tours.

Structuring collaboration (Str) is the value assigned to the formation of scientific collaborative networks. The formation of collaboration network creates benefits at different geographical levels. Universities profit from the common R&D programs in terms of support and scientific inputs from large RIs. Large RIs are good platforms for knowledge dissemination, technology development and concept testing, for which small institutes largely benefit. Moreover, the collaboration network creates additional advantages for industrial partners that have already proven their ability to provide high-quality products or services to other collaboration partners. In the framework of this study, information on different types of collaboration agreements is collected, which forms an

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[2] https://www.bvdinfo.com

[3] "Open Hardware Xband components - All Documents." https://espace.cern.ch/project-clic-xband-production/_layouts/15/start.aspx#/Open Hardware Xband components/Forms/AllItems.aspx (accessed Aug. 10, 2021).

overall picture of the universities and institutes involved. CLIC has around 130 collaboration contracts with 180 universities and institutes. The indicators are the number of collaboration agreements and related procurement activities, publications and ECRs related to CLIC. This can be however claimed as a second-tier impact field, and CLIC's correlated share of the impact has to be established.

2.2. Economic costs

The cost estimation is presented in the CLIC project implementation plan (PiP) [15].

Capital cost (K) differs according to the considered stage of the project.

Labour cost (L) defines the cost of the employment need for the construction and operation of the accelerator. The CLIC PiP specifies 11500 FTE-years of explicit labour. Based on the LHC results, 40% scientific and engineering personnel (L_S) and 60% other staff (L_O) are required.

Operating cost (O) represents the ongoing expenses for running a scientific experiment and already built infrastructure.

Negative externalities (E) have been reviewed earlier in the CLIC EIA [16]. Moreover, some estimations of power and energy consumption are reported in the CLIC PiP [15]. The indicators are travel policies, material resources, waste policies and power consumption.

Non-use value (B_n) is a non-use value of a scientific discovery [10], that is, scientific knowledge as a public good, based on the questionnaire for university students as representative future taxpayers, which includes a question about willingness to pay for LHC research activities (a fixed lump sum). A non-use value is created for non-direct users of the scientific discoveries. The impact is mentioned in the CBA for the EIA and SIA. In the case of the LHC [4], the calculation is done based on the results of the survey of non-users, which includes an item on willingness to pay for scientific discoveries. The projection of the mentioned study can be implemented in the CLIC case, since the nature and purpose of those two large infrastructures the LHC project and CLIC study are similar carrying fundamental character. The indicator is the value of willingness to pay provided by non-users via a public survey.

Since the status of CLIC is still that of a study and the infrastructure does not yet exist, its SIA is based on the past. Thus, the cultural impact and non-user impact can be neglected in the initial appraisal step. This study assesses three out of six impact areas: human capital formation, technological impact and knowledge benefits. The earlier studies [17], [18] have mentioned the three categories as the biggest benefits areas. However, structuring collaboration, non-use value and cultural impact are suggested for further appraisal to build a complete picture of the societal impact of CLIC.

Thus, the economic cost for the SIA of the early stage of the CLIC study has only two components: labour and capital cost. The operations cost is related to the operation of the existing infrastructure, of which there is none yet in the case of CLIC. The final comparison between costs and benefits is possible only when all the assessment fields have been measured. Therefore, it is discussed in the framework of further study.

2.3. Technological output

The technological outputs or benefits to firms-suppliers resulting from CERN contracts were already discussed in the earliest study [19] and are presented herein as increased turnover and cost savings:

$$Benefits = Incremental\ Turnover + Cost\ Savings, \tag{3}$$

Moreover, a utility/sales ratio was calculated based on the interviews with related companies [19]. Thus, the corrected utility ratio, equal to 85% of the net utility, is in between 1.4 and 4.2, depending on the various industrial categories. The overall corrected utility/sales ratio reached to 3.0, which is used in the current evaluation of the benefits to business.

$$Utility = Sales \times corrected\,\frac{utility}{sales}\,ratio, \tag{4}$$

Earnings Before Interest, Taxes, Depreciation, and Amortization (EBITDA) is one of the indicators of the financial results of a company and one of the means of comparison of companies' financial effectiveness. Investors use this indicator as an indicator of the expected return of their investment. EBITDA is also used to calculate the profitability ratio – EBITDA margin, which measures how much earnings a firm is generating before interest, taxes, depreciation, and amortisation:

$$EBITDA\,margin = \frac{EBITDA}{total\ revenue}\,, \tag{5}$$

In other words, the EBITDA margin measures a company's operating profit as a percentage of its revenue and it is used in earlier similar empirical studies [6], [20-22]. EBITDA allows evaluation of the true performance of the company not excluding expenses. The incremental turnover in a company attributed to its relationship with an RI can be computed as follow:

$$Incremental\ turnover = EBITDA \times Utility\ ratio \times sales\ from\ an\ RI\,, \tag{6}$$

where the sales are equal to the total value of the procurement orders received from CLIC.

The EBITDA margin for CLIC suppliers was extracted from the study's sample via the ORBIS database maintained by the Bureau van Dijk. Based on the survey replies, the final companies' sample comprised 71 firms from 16 countries. The ORBIS database presented information on 69 companies from the sample. Still, some firms' datasheets were not completed, and it was not possible to define the EBITDA margin for 26 companies. Thus, the rest of the sample shows the average EBITDA margin of about 10.4%, with a standard deviation of 7.2%. For benchmarking analysis, the EBITDA margins applied in previous empirical studies are as follows: for LHC, 13.1% [21] and for CNAO, 7% [6].

Moreover, based on the data collected from the survey, the companies indicated an increase in their clients that led to a revenue increase. The companies further showed a wide variation in results, with an average value of 11.1% and a standard deviation of 21.2%. The total volume of external CLIC procurement from 2009 to 2020 associated with selected firms is 28.06 MCHF. The resulting mean value of the corresponding benefits considering the utility ratio is 8.754 MCHF with the standard deviation of 6.06 MCHF (see Table 1).

TABLE 1. TECHNOLOGICAL BENEFITS

Category	Value (MCHF)	Benefits/cost ratio
Incremental turnover		
EBITDA	8.754	0.99
EBITDA (LHC value)	11.03	1.07
Increase in clients (self-estimation from the industrial survey)	9.34	1.01
Cost savings		
Per one download per ten components (see Table 2)	19.1	Incorporated in the above calculation

Another factor of the technological benefit is the cost savings from the use of existing CERN developments and the reduction of the production cost. This part can be presented from several aspects: (1) the use of an existing design to prevent expenses on the research and development work of a company and (2) improvement of product quality and service. For example, the software developed to analyse the LHC experimental data, which was made available for free [21]. The benefit was calculated by multiplying the number of downloads and establishing the price of an equivalent commercial tool.

Open Hardware is one of the knowledge transfer models used at CERN [22] to govern the use, copying, modification and distribution of hardware design documentation, as well as the manufacture and distribution of products [23]. This model has been remarkably successful and is now also being adopted for other types of hardware. This protected dissemination is the only viable option when a private partner needs to take considerable financial and strategic risks in order to adopt and further develop a technology to reach a competitive new market. Opening access to already established concepts helps external collaborators to save resources from developing a product from scratch. Consequently, sticking to the mentioned approach, CLIC's technological benefits are proportional to the avoided cost of the purchase or development of technology from scratch, and the cost of an alternative design or engineering solution for CLIC components. At the end of 2020, after almost two years of use of OHL, 39 users from 18 laboratories and companies were identified as current users of the directory (see Table 2).

Assuming that the research and development time was from 12 to 24 weeks (3 to 6 months); depending on the complexity of the component, including of the RF and the mechanical design, and of the involvement of scientists and engineers; and the average rate of 51 CHF/h and a 40-h work week, the avoided cost is between 24,480 and 48,960 CHF per component. The calculated cost does not include the proof of concept by producing and testing prototypes. Even with this preliminary price the maximum benefits reach 1.9 MCHF (Table 2).

TABLE 2. OPEN HARDWARE X BAND COMPONENTS COST SAVING

Users	Development time	Salary rate	Development price (CHF)	Cost Savings per one download per one component (CHF)	Cost Savings per one download per all presented in OHL component (CHF)
39	12-24 weeks	51 CHF/h	24,480-48,960	954,720-1,909,440	9,547,200-19,094,400

The calculation was done based on the assumption that only a single component was downloaded, while the OHL users are usually interested in the design of multiple components. Currently, the X-band OHL has 10 components under license.

The calculation of the technological outcome combines the calculation of the economic benefits based on the EBITDA with that of the use of the already created conceptual design via the CERN OHL. Thus, the final ratio was calculated as the sum of the two mentioned parts to the total volume of CLIC's external procurement from 2009 to 2020 associated with selected firms. The final ratio demonstrated that the benefit is almost equal to cost, the value is between 0.99 and 1.07. While the previous studies based on the CBA demonstrated the technological outcome as one of the biggest share of overall benefits from the project [6], [21]. The low benefit/cost ratio in the present study is explained by the evaluation at very early phase of the CLIC study, while the construction has not been started. The latter is in line with [21], who discussed a large investment peak during construction involving civil engineering and technical hardware, where suppliers play an essential role. Hence, the most beneficial from companies' perspectives is the construction phase of a RI.

2.4. Human capital output

One of the assessment fields is the human capital formation benefits to ECRs. This is an important output for society, since an RI provides a place for young researchers to work and study and invest in their education by offering them student grants and not less important, a place for first work experience. Thus, ECRs gain important skills and, a kick-off experience with a well-known international organisation, which is worth including in their CV. Moreover, as has already been demonstrated in similar projects, the human capital represents the largest element of the total benefits of the project: for LHC, from 1993 to 2025, around 33% of the total contribution of the main stakeholders [21], and for the next HL-LHC, up to 2038, the benefits raised up to 40% [7]. Both estimations are based on the premium salary expectations, derived from [24]. The latter demonstrated from their analysis of a survey that an extra training in and RI results in valuable skills with 'a price tag' on their learning experience from 5% to 12% compared to what they could expected without their career at CERN.

The beneficiaries of human capital formation in the CLIC study over the period 2009-2019 included three ECR categories: 67 technical students, 106 doctoral students and 63 post-doctoral students or fellows, for a total of 236. The economic benefit can be estimated as an increase in the salary of each person, which depends on several factors combined, such the current employment of a person, the country of work, and the number of years of professional experience. The NPV of the human capital benefit, considering the discount rate of 3%, recommended by the EU's Guide to Cost-Benefit Analysis of Investment Projects [5], is:

$$\sum(Number\ of\ students) \times (Incremental\ salary) \times \begin{pmatrix} discounting\ effect \\ over\ 35\ or\ 40\ years \end{pmatrix} = Human\ capital\ benefit, \quad (7)$$

Human capital benefit is represented by the incremental salary earned over the entire work career after leaving the project and considering the career length, depending on the initial status at CERN: from 35 years for fellows to 40 years for students. The salary premium was calculated based on the data collected from two sources, allowing the benchmarking of the results: (1) $\Delta\ salary_i$ from payscale.com[4], where $\Delta\ salary_i$ is the difference in salaries between skilled and average specialists per profession: engineers, researchers and managers; and (2) percentage premium from the LHC study [17]– of 11.8% (see Table 3). The benefit to cost ratio was between 4.3 and 10 for students and between 0.9 and 1.2 for fellows. The latter is explained by the fact that the funding amount for fellows is higher. Moreover, the salaries are at the Swiss level, which makes them high and difficult to exceed afterwards.

[4] "Payscale - Salary Comparison, Salary Survey, Search Wages." https://www.payscale.com/ (accessed Dec. 18, 2021).

TABLE 3. HUMAN CAPITAL BENEFITS

Category	Value (MCHF)	Benefits/cost ratio
Technical students		
Payscale.com	Over 40 years:142141 CHF Per year: 3554 CHF	6.3
11.8%	Over 40 years: 224621 CHF Per year: 5615 CHF	10
Doctoral students		
Payscale.com	Over 40 years: 223227 CHF Per year: 5580 CHF	4.3
11.8%	Over 40 years: 224621 CHF Per year: 5615 CHF	4.3
Fellows		
Payscale.com	Over 35 years: 165641 CHF Per year: 4441 CHF	0.9
11.8%	Over 35 years: 208805 CHF Per year: 5220 CHF	1.2

2.5. Knowledge output

For the evaluation of the knowledge outputs or benefits of FRIs to scientists the bibliometric techniques applied in several studies [25-28] were used. One of the well-established approaches for evaluating the fundamental science knowledge outputs of large-scale infrastructure was presented in [4] and has been implemented in a health care project (CNAO) [6] and in HL-LHC [7]. The cited studies, compared to other bibliometric studies, went beyond merely evaluating the topics, the number of publications per year and the number of co-authored publications. The studies were aimed at forecasting and monetising the outputs and calculating the ENPV.

There are two important quantities in the calculation of the social value of publications: (1) the marginal cost of an article produced by scientists working in an RI and (2) the total discounted value of the publications. The following important parameters are considered in the calculation [21]: (1) the average annual salary of scientists, (2) the amount of time devoted to research activities, (3) the number of papers produced per year per scientist, (4) the number of citations in L1, (5) the number of references in L1, (6) the amount of time for downloading, reading and understanding the publication and (7) the amount of time needed to decide whether to cite the publication. The last two are assumed to be one hour. According to [21], the social value of scientific outputs is the cost of the publication L0 multiplied by the degree of influence of that piece of knowledge on the scientific community. The latter considers the number of references (n) in each citing paper L1 and is equal to $\sum_{t=0}^{\tau} 1/n_t$.

The calculation of the scientific outputs of CLIC in its early stage reflects the methods used in the aforementioned studies and follows a simplified evaluation path. Publications linked to CLIC were collected from two sources: the CERN Document Service [27] and the Inspire database [28].

The current benefits were estimated based on the number of publications authored by CLIC researchers (L0) and the number of citations by other articles (L1). Moreover, the direct benefits were deemed as the value of the citations of the L1 to L0 papers, as the original cost of producing the publications (Xc) is the cost of the RI. The benefits are considered to be the use of already existing knowledge for future research, which is represented by the citations as well as the references. Assuming that the cost of a citation is

$$X_C = \frac{X}{AV\_REF} \quad , \tag{8}$$

where X is the cost of a single CLIC publication and AV_REF is the average number of references per paper, the benefit is equal to

$$S = Xc \times L1, \tag{9}$$

where S is the knowledge benefit and L1 is the global number of citations of L0. The ratio of the benefits to the costs is computed by the following formula:

$$Ratio = \frac{Benefits}{Costs} = \frac{L1}{AV\_REF}. \tag{10}$$

An earlier research [29] evaluated 41 research journals in different fields. In the physical science field, the number of references was generally between 20 and 50. The authors presented a formula for the references: 14.4+2.2L, depending on the length of the paper (L). Another benchmarking study for CNAO [6] considered the average number of 30 for the references. The sample from the CLIC database indicates an average number of 14.122 references.

Finally, Table 4 shows the parameters for the calculation of the scientific output of CLIC. In the final calculation of the ratio, the cost of the initial publication was considered not important. However, the cost of the paper will depend on the distribution of the authors (fellows, PhD students and senior scientists), since it is directly connected to the time spent for the research and for writing the paper. Moreover, based on the qualifications, the average salary is quite diverse. The calculation based on the abovementioned parameters reached the benefit/cost ratio of 73 to 196.

TABLE 4. LIST OF PARAMETERS FOR THE MONETIZATION OF CLIC ARTICLES

Parameters	
Average annual salary of a researcher (CHF)	Y
Average number of authors per paper	5.9
Yearly productivity	2
Share time for research	60%
Average references per paper [6]	30
Average references per paper [30]	14.4+2.2L=37.8
Average references per paper (the study's sample)	14.122
The cost of the paper	X
Number of cited papers	798
Global number of citations	2768
Average citation	3.48875
Value per citation	X/Av_REF
Benefits	X/Av_REF*2768
Benefits/cost ratio	2768/Av_REF
Results	
Average references per paper [6]	92.3
Average references per paper [30]	73.2
Average references per paper (the study's sample)	196

The results of this study are significant in at least one major respect. They demonstrate the benefits of CLIC to insiders in the science community who had cited CLIC publications in their research. Therefore, the created knowledge is implicated in other research lines. However, the results of this evaluation are not monetised. Further work is required to establish the NPV of the knowledge outcome of CLIC at the development phase of the study. In a future investigation, it may be possible to extend the data from this study by gathering information on the subsequent flows of papers produced by other scientists, including the number of references they contain, and the value of the citations of each paper. Such data will allow for calculation of the value of the publications authored by CLIC researchers and the value of subsequent papers.

3. DISCUSSION

From the current evaluation the highest benefit/cost ratio was seen in the knowledge output components of the CLIC SIA. This can be explained by the focus of this study on the development phase of the CLIC project when intense procurement has not yet started. The intense procurement and employment will take place in the construction and operation phases of the project. Nevertheless, the SIA of CLIC can be completed only by presenting the complete picture and calculating the rest of the impact fields such as the cultural impact, non-use value and network formation, and by eliminating the related costs and the negative externalities presented by the environmental impacts.

The design phase of a RI facilities can be very long and new facilities sometimes developed in the same location as that of previous infrastructures and experiments [21], what is the case for LHC, constructed at the place of the Large Electron-Positron Collider [31]. The costs incurred before the start of the appraisal period, such as costs for feasibility studies undertaken at an earlier date or construction costs already sustained for a previous project, are sunk costs and excluded from the investment costs in an ex-ante project analysis [21]. However, in some cases, a consolidated financial analysis across different funding or management bodies may be helpful. Thus, this study offered the results of the assessment exercise with the real example on the early development phase of the CLIC study to the earlier literature. The benefits were calculated based on the past experience and provided the direct impact from the early phase of the project. Moreover, the developed framework includes a series of suggested crucial measures as assessment of structuring collaborative network as benefit and negative externalities as a cost part of the model.

CBA presented as a reliable empirical methodology for a systematic comparison of positive and negative socio-economic impacts of an investment in RI and there was an increasing consensus that it provided guidance on how to trace the potential of a RI to generate specific societal impacts thanks to the identification of all the expected beneficiaries of the projects. Since a major part of the SIA in this study was built on the pillars of CBA, the chosen approach was assumed to be reliable. However, the casual chains of events from costs/inputs to benefits/output were not among the output of the model, for which additional tools, such as qualitative approaches based on causation theories could be used as a complement [32]. The SIA approach was based on a theory that was well implemented by other scientific laboratories. The theoretical framework supported the results and the expected impacts. The conceptual model allowed for replicability of this study and can be generalised for other RIs.

The validity of this study was assured by capturing most of the effects expected by an RI. The latter was ensured by addressing all expected impacts of RI and ability to measure them. Moreover, the measures used in the study were based on the previous related studies [6-7], [20-22], [24]. However, this study calculated only a part of the possible range of the expected impacts of a RI. Therefore, the validity of this study can be improved by calculating all expected effects presented in the full SIA model.

The SIA of CLIC, this study had several important limitations. The methodology was limited by the strong construction of the theoretical background on Florio's cost-benefit conceptual model. Three appraised fields were distinguished as the most beneficial in Florio's earlier study on LHC, and the same indicators were mostly used in this study. There are some conceptual uncertainties in monetising the benefits from basic science using the econometric approach [33]. The results of the SIA of RIs can be useful for evaluating educational or technology transfer outcomes, but the overall conclusion, if used to assess a project, needs a detailed discussion [33-34]. Moreover, the methodology can introduce a bias to a positive impact and underestimate other possible measures.

Some criticisms of the model can be introduced [35]. Because of its methodology, the spent money always creates benefits. In the most cases, publications get citations, ECRs have a first experience, and companies' EBITDA grows. These are also related to the size of the project, because assessing large projects includes more actors, which means a positive average effect is more probable even if some of the effects are negative. This is true for publications, since not all of them are cited; for companies, since not all of them have a positive yearly balance; and for ECRs, as some of them have their first experience in their home countries, where sometimes, it is quite difficult to beat Swiss salaries. The next steps are to forecast the benefits for the future and to compare such benefits with the costs as was done in the previous topical studies [6], [21].

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