Tampere University

ANASTASIYA MAGAZINIK

Investigating the Societal Impact of Large Research Infrastructure

A Study on the Compact Linear Collider at CERN

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ACADEMIC DISSERTATION
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Some people say that PhD is like a marathon. When comparing to a sprint, you need to keep your forces and it tests your endurance in a long distance. Sometimes, when you think you no longer have any force to continue, you just need to go further despite anything. It is not an easy period in life, but it is remarkable and challenging. It challenges your stress resistance, consistency, and self-discipline. However, it is a unique opportunity to prove yourself as a manager, researcher, innovator, reviewer, writer, and many other roles. Working as a mechanical engineer for more than 10 years motivated me to discover something else and to widen the range of my engineering knowledge. The academic world opened its door and asked me to come back to student life. However, my engineering experience helped me to find a structure where there seemed to be none. I hope that I managed to represent social science in my research in a structured way.

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ABSTRACT

Research is less and less assessed on scientific impact alone. Governments invest public funds into scientific research with the expectation that economic, medical and other benefits would ensue as the increasingly important contributions of science to society. Research came to be seen as a valuable enterprise itself, given the value of the knowledge generated, even if its application is not immediate. Diverse Big Science centres issue annual impact reports highlighting the positive impacts from the science on society, industry, and technological progress, human excellence, and education. Number of publications, licensing, start-ups, bilateral cooperation agreements, sustainable development goals, related events are used as indicators to measure the impact of a research.

Beside an increased number of literatures on the socio-economic impact assessment, many important meetings and workshops includes an obligatory discussion on the impact. Thus, the European particle physics community repeatedly raised the question on the societal impact during conversations. The community meets to define a strategy for the future developments in fundamental research on physics by evaluating ongoing studies. Thereby in an open symposium in Granada in May 2019, the committee highlighted a pure academic significance of an international collider study and its unclear technical and economic ripple effects for general public. Likewise, the European Strategy update in June 2020 again recommended to emphasise the scientific impact of particle physics, as well as its technological, societal and human capital outcomes. Additionally, the committee underlined an importance of partnership with industry and other research institutes, as these collaborations are key for sustaining scientific and technological progress, helping to drive innovation, and bringing societal benefits.

Despite the raised interest to the topic, there is still no common methodology or tool yet for evaluation of Big Science impacts. The assessment of the costs and benefits of research, development and innovation infrastructures stays extremely difficult and is still discussed as quite subjective and intuitive approach. Causal factors leading to impact remain speculative which creates much uncertainty for effective measures of impact areas.

Thus, this study seeks to obtain data which will help to address the indicated research gaps. There are two primary aims of this dissertation: to identify impact fields and its measures and to explain the relationship between them. The research is built on the Compact Linear Collider (CLIC) study as a large-scale international project at its early development phase. The project still has the 'study' status since CLIC has not been approved for the construction.

The initial data on the CLIC study was collected from the CERN procurement database and presented about 13000 procurement orders, 130 collaboration contracts, 180 collaborators, 930 suppliers, 1800 publications, 296 early career researchers and 54 countries. Then the second generation of the data gathering had more concentrated character and was performed via an online survey distributed among 152 CLIC suppliers. The feedback was received from 74 hi-tech companies.

First, the impacts were assessed from the internal viewpoint using data collected inside the project. Three areas found in earlier research to benefit most were focused on: knowledge formation, technological output, and human capital formation. The particle physics attracts young minds and provide their education and training. Thus, early career researchers benefit via incremental salaries caused by getting first working experience. The scientific community advantages with created knowledge – publications, and its application for their research in terms of citations. Industrial partners profit from increased turnovers and saving in-house resources through the ability to use already existing developments of CLIC. The methodology is heavily built on the previous relevant studies. Opposite to the most part of the preceding studies the assessment was done before the construction phase of a scientific infrastructure and focused only on the past development phase experience. All three impact fields demonstrated as beneficial even already at the study status of the large-scale project. However, the highest benefit/cost ratio belongs to the knowledge output component of profits. The latter is in line with the focal point of this study on the development phase of the CLIC project when the intense procurement has not yet started. The intense procurement and employment belong to construction phase of the project.

Second, the impacts were assessed from the external viewpoint through the data collected through an online survey of CLIC suppliers. The methodology was heavily built on the already existing theories about research – industry collaboration. The benefits for industry were determined as innovation, market expansion, marketing image, economic outcome, R&D improvement and learning on processes and services. The main influencing factors were distinguished from the concerned literature and grouped in three sets such as firm attributes, research infrastructure attributes and relationship attributes. Afterwards the linear regression analysis was conducted to define the relationship between six types of benefits and three sets of explanatory factors. It was found that the industrial partners could benefit from the collaboration even at the earlier phase of the fundamental scientific study through increased knowledge, market expansion, marketing image enhancement, economic outcome, improved research and development, and learnings on internal services and processes. The highest statistical significance and models' fits was demonstrated for knowledge, market expansion, R&D and learning service benefits. The analysis highlighted the importance for companies to participate in scientific events organised by research infrastructures, as well as doing business with other scientific laboratories. On another hand, the Big Science centre can enhance the benefits for industry by simplifying the procurement policy and having well-established communication channels.

Hence, the dissertation contributes to two existing contemporary fields as societal impact assessment of fundamental science and research-industry collaboration evaluation. The research shows that a large-scale international study can already create benefits at a very beginning development phase from internal and external point of view. The developed conceptual model can be used to defend the required public investments in fundamental research and to entice prospective industrial partners. Nevertheless, the study introduces limitations in generalisability of the results and recommends the future research on the missing potential beneficial fields from CLIC and a more detailed analysis of the research-industry collaboration by introducing industrial case studies.

CONTENTS

1 INTRODUCTION

1.1 Background and motivation

Can public money find better applications than fundamental science? There has been increasing interest in societal impact topics in the last years. At the last strategy meeting discussing the next potential particle accelerators, the scientific community recognised 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; and environmental impacts from civil construction and operations (Barrow, 2000).

However, there is still no common mechanism for societal impact evaluation of a large research infrastructure (RI), (Bornmann, 2012; Autio, 2014; Giffoni and Vignetti, 2019; Bornmann and Marx, 2014). Different developed methodological approaches such as econometric studies, surveys, and case studies, do not present the full picture of the impacts of a science endeavour. Assessing basic research outcomes is even more challenging. Building and operating large machines as particle accelerators are extremely costly and require public investments, while the societal benefits are often implicit, unlike those of an applied scientific project. At this point, a societal impact assessment (SIA) can be important for evaluating the negative and positive effects of the project implementation before its funding is approved. Such an assessment would definitely be beneficial for the decision-making process, and for the efficient use of public money. Thus, a SIA of RI is essential for scientists to demonstrate and highlight the source of the economic value expected to be generated for society and the economy, besides the absolute technological or scientific aspects.

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 (European Strategy for Particle Physics Preparatory Group, 2019), 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 (European Strategy Group for Particle Physics Preparatory, 2020). 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.

Furthermore, over the past decade it became a common practice among large RIs to issue socio-economic impact reports distinguishing their prior objectives and evaluating their different impact fields (Dick, 2007; Horwitz & El-kilani, 2016; Ross, 2017; STFC, 2017). The Technopolis group[1] (*Technopolis Group*, 2022) has embarked on a study for Science and Technology Facilities Council (STFC)[2] (*Home - Science and Technology Facilities Council*, 2022) to assess the socio-economic impact of Diamond Light Source (Brown et al., 2021) and ISIS (Simmonds et al., 2016) using surveys, interviews, case studies and desk-based appraisal. There is a widespread practice of involving skilled external experts from related economic fields in the assessment process. An example of this is the massive block of methodology and its practical application to the Large Hadron Collider (LHC)[3] (Evans & Bryant, 2008), the High-Luminosity LHC (HL-LHC) project (Apollinari et al., 2015) and the Future Circular Collider (FCC) (Abada et al., 2019), which were built by the Centre for Industrial Studies CSIL[4] (*HOME - CSIL - Centre for Industrial Studies*, 2022) and Milan University experts. The latter serves as a fundamental base for the next generation of SIA research. Florio's studies and the related research done by his successors are among the first works that presented the net present value of a benefit. Thus, different projects can be compared with this value. The conceptual model developed by the above-mentioned authors has been used fully or partially in other similar studies (Social and Source, 2008; Waaijer, 2011; Simmonds *et al.*, 2016; CERN, 2017; Ross, 2017; Science&Technology Facilities Council, 2017; Notander, 2020). Florio and his

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[1] *Technopolis Group* (no date). Available at: https://www.technopolis-group.com/ (Accessed: 27 January 2022).

[2] *Home - Science and Technology Facilities Council* (no date). Available at: https://stfc.ukri.org/index.cfm (Accessed: 27 January 2022).

[3] The Large Hadron Collider | CERN. Available at: https://home.cern/science/accelerators/large-hadron-collider (Accessed: 20 December 2021).

[4] *HOME - CSIL - Centre for Industrial Studies* (2022). Available at: https://www.csilmilano.com/ (Accessed: 27 January 2022).

collaborators have made a big step forward in applying the CBA methodology to basic scientific infrastructure (Schopper, 2016).

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 (Evans & Bryant, 2008), 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) (Florio & Sirtori, 2016). 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 (Sartori et al., 2014). The developed economic appraisal model was employed afterwards in the appraisal of the National Hadrontherapy Centre for Cancer Treatment (CNAO) in Italy (Battistoni et al., 2016) and for the next generation of LHC, the HL-LHC (Bastianin, 2018). 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 are mainly the ensuing publications, experience gained by the early career researchers, technological spillovers and public outreach. The latest network aiming to fill this gap is RI-PATHS (Reid, 2021), 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)[5] (Aicheler et al., 2012) 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

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

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. Moreover, this study expands the theoretical and practical understanding of how public research can help develop of technology and the impact of such. This study also investigates benefits for industry that stem from collaboration with public Big Science organisations during the development and planning phase of large scientific experiments.

1.2 Research objectives

This dissertation is situated in the two research fields of SIA and research-industry collaboration (RIC). The main goal of this study is to build a theoretical and practical framework for evaluating international-scale projects. Current similar SIA studies offer *post factum* impact results, that is after the construction and commissioning of an RI facility ((Florio, Forte, & Sirtori, 2016); Battistoni *et al.*, 2016; Brown *et al.*, 2021; ESA, 2019; Simmonds *et al.*, 2016; STFC, 2017; Catalano *et al.*, 2020; etc). However, there is an increasing demand to evaluate the impact before decision-making in order to compare diverse large-scale projects with the same mission and required public funding (Giffoni & Vignetti, 2019). Therefore, it is of high importance that the appraisal be done even before a decision is made on the project implementation, construction, and operation. Thus, an earlier appraisal highlights positive and negative impacts for all stakeholders, herein presented as industrial partners, the scientific community and the general public. As a result, public money can be better managed and distributed among scientific projects.

From a policy perspective, if there are good reasons to invest in RIs, there are also arguments for not engaging in such costly investments at a time of tightening budget constraints (Giffoni & Vignetti, 2019). RIs may also pose a problem in terms of an excessive geographical concentration of resources at the expense of territorial cohesion. Accordingly, there is a consensus among most EU and OECD Member States on the need to promote evidence-based strategies for coordinated investments in RIs and to closely link them to impact assessments (OECD, 2019).

There is a common problem with the association of certain measures to certain benefits. This study aims to identify the scale, nature and sustainability of the impacts and benefits for the main actors. The literature review shows benefits from RI and RIC through the procurement for large scientific projects (Florio et al., 2018). However, what if the project is not yet approved for construction? Can benefits be projected in the planning and development phase? Studies on impact assessment emphasise the importance of evaluation at different stages of projects, starting from initiation activities (Barrow, 2000), but earlier studies have neglected this phase. Moreover, the benefits can vary across the lifetime of the project and for different stakeholders. Thus, the intense procurement phase is more beneficial for industrial partners, while the operations phase of the facility stimulates knowledge generation in terms of scientific publications. As such, there is a need to analyse these benefits further from the stakeholders' points of view prior to the implementation of an RI project. Therefore, in this dissertation, impacts are assessed in the early phase of RI projects from internal and external viewpoints. Thus, the first two research questions (RQ) are formulated as follows:

(RQ1) What types of benefits does an international project at the development phase generate from an internal viewpoint?

(RQ2) What types of benefits does an international project at the development phase generate from an external viewpoint?

The external viewpoint covers the industrial perspectives. Furthermore, by knowing the factors that influence the created benefits of the collaboration, certain types of outcomes can be emphasised. Levy et al. (2009) and Klimczak et al. (2017) distinguished and discussed the role of the companies' size and geographical location in RIC. Meyer-Krahmer and Schmoch (1998) argued about differences in knowledge transfer depending on the technological field of a company. Salmi and Torkkeli (2009) examined the most important factors facilitating and impeding knowledge transfer in academy-industry research collaborations in terms of nature of knowledge being transferred and communication theory. Florio et al. (2018) proved the critical dependence of the impact on suppliers' performance, including learning and innovation outcomes on its firm size and status as a high-tech supplier. There is also a need to evaluate the timescale problem when emphasising impacts only in the short term, ignoring potential long-term (Bornmann, 2013). Thus, the aim of the study is to find the influencing factors of impacts and their role in large RI and industry collaboration. Therefore, the final two research questions are as follows:

(RQ3) What factors influence RIC outcomes?

(RQ4) How do the identified influencing factors enhance or diminish the benefits from RIC?

Answering these questions should advance the fields of SIA and RIC and offer insights into the evaluation of the societal impacts of fundamental science projects already at the development phase, as well as insights into effective project management and the maintenance of stable partnerships between RIs and industrial partners.

From the managerial viewpoint, the results of this dissertation should help with the following: first, the evaluation by policymakers or RI managers, the relevance and level of achievement of a project; and second, the establishment of strategic and sustainable relationships with industrial firms that are among the essential partners in achieving the main goals of an RI. Understanding the key influencing factors of RIC can improve stakeholders' satisfaction, market share and profit and can increase industries' interest in and motivation to do business with Big Science.

1.3 Scope and limitations

The objectives of this dissertation are to assess the societal impacts of a large-scale international project on direct and indirect users at its early development stage and to analyse the benefits of RIC from industry perspectives. To achieve the latter, the direction and magnitude of the explanatory factors of the benefits for industry from its partnership with the Big Science centre are also determined. This study is delimited in two ways: by the developed theoretical framework and by the data and methods of analysis. Hereafter, the main limitations of this study are outlined.

First, the theoretical framework of this study is heavily built on university-industry collaboration since there is still a lack of research on Big Science RIs. Even though Big Science is becoming more and more popular in defining large RIs and their facilities, the theoretical component is still missing and is poorly covered in the existing research. RI are facilities that provide resources and services for research communities to conduct research and foster innovation while universities an institution of higher learning providing facilities for teaching and research and authorized to grant academic degrees. Both institutions have one of the aims to conduct researches. Therefore, considering the motivation of this study, the tools for evaluating university-industry collaboration were taken as the basic pillars of the constructed theoretical framework. The corresponding literature is analysed to distinguish the influencing factors and the possible benefits for industries.

Second, there are limitations to the data and methods used in this study. One limitation is that a qualitative approach is mostly used herein. While the values of the impacts are quantified, they are highly dependent on interpretation, and the methods of assigning measures to evaluation of certain impact fields are strongly based on previous similar studies that had difficulty in attributing benefits and costs to a project under assessment (Schopper, 2016). Another limitation of this study pertains to the time scale of the data gathering. The current research uses data estimated from past experience, that is, from the early research and development (R&D) and prototype development stage of the still ongoing CLIC study. Therefore, the results of that study must be extrapolated to forecast the future benefits and impacts of the project. Furthermore, the research is focused on only one part of the CLIC project—the accelerator[6]—due to time and resource limits. The detectors and physics part[7] of the CLIC collaboration is not considered. The later has massive data to be analysed.

Another limitation of this study is in its methodology. Following the existing literature that investigated RIC and its influencing factors, this study also assumes a linear relationship between the variables, using linear regression as the method of analysis. This limitation must be considered for the generalisation and applicability of the main findings of this study, since the linear relation was imposed and can skew the relationship between the dependent and independent variables.

Thus, the mentioned limitations are structured and considered for the scope of the study to assess the problems and biases.

1.4 Dissertation structure

The dissertation has five chapters. The first chapter introduces the background and motivation of the study and the corresponding research objectives as well as limitations.

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[6] "Home | CLIC Accelerator Activities." https://clic-study.web.cern.ch/ (accessed Dec. 07, 2020).

[7] "Home | CLIC Detector and Physics." https://clicdp.web.cern.ch/ (accessed Mar. 03, 2021).

The second chapter summarises the theoretical background and the relevant literature based on the two main research topics: SIA and RIC. The first part of the literature review focuses on impact assessment and existing evaluation methods, and the second part discusses partnerships between industry and RIs and the factors that influence such partnerships.

The third chapter describes the methodology used in this study, from the strategy to the chosen methods as well as the data model and the data gathering.

The fourth chapter presents and discuss the results of the study. The results are divided into two parts. The first part introduces the results of the SIA from the internal perspective of the CLIC project, and the second part describes the results of the industrial survey conducted and the impacts from the external perspective of the CLIC company-suppliers.

The fifth chapter summarises the results of the presented work; their validity and reliability as well as their limitations; the scientific and managerial contributions of the study; and suggestions for future research.

2 THEORETICAL BACKGROUND

The theoretical background is built on two literature structures. The first theory was collected from the existing SIA approaches and methodology; the second theory was constructed on RIC; and the influencing factors were evaluated based on their impact on the effectiveness of the RIC and the motivation of the partners.

2.1 Societal Impact Assessment

Societal impact assessment is defined as the process of recognising the future consequences of a current or proposed action which are related to individuals, organisations, and social macro-systems. SIA has gradually unfolded into a type of policy-oriented social research that is applied in all sectors of society (Becker, 2001). Giffoni and Vignetti (2019) claimed, however, that there is still no common understanding and definition of an impact. In literature terms, *social* and *societal* are often mixed. Bornmann (2013) classified societal impact as a higher category than social impact. Both cases, involve a complex evaluation model of impact on different fields. Hereinafter, Bornmann's definition is used, and societal impact is presented through an overall model of evaluation of concerned areas.

The literature review demonstrates that studies on SIA most often cover the following key topics, which mainly repeat the variables discussed by Barrow (2000) that are presented in Figure 1: (1) mission of RI, (2) mission of SIA, (3) conceptual orientation or types of benefits, (4) impact groups, (5) appraisal approaches, (6) time frame and (7) project scale. However, it was quite rare for a study to report on all variables simultaneously.

The further theoretical discussion is organised according to the related studies that encompassed the mentioned variables.

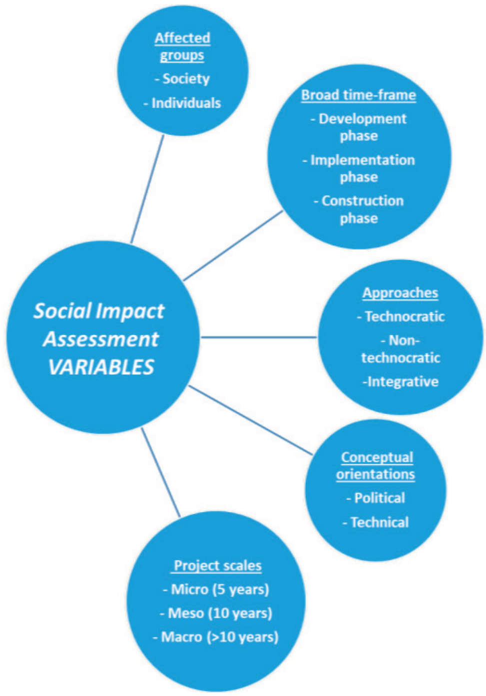

Figure 1. Variables for Societal Impact Assessment (following Barrow, 2000).

2.1.1 Mission of Research Infrastructure

Research Infrastructure is an organisational structure dedicated to facilitate or conduct research, provide scientific equipment, data or services for use in basic or applied research (OECD, 2019). Understanding the mission of an RI, including the main features of the proposed development project, program or policy is one of the essential tasks of the SIA (Barrow, 2000). According to the OECD (2019), the mission of an RI defines its strategic purposes and activities, the services and products its provides and its key users. These must all be considered in the impact assessment.

The European Commission (EC, 2013) defines RI missions as the conduct of research and the fostering of innovations in the relevant field. Autio (2014) categorises the missions of big-science facilities as research-oriented, service-oriented, fundamental research-oriented and solutions-oriented. Autio claimed that many big-science facilities demonstrate elements of each orientation and emphasise certain missions along the life span of the RI. In contrast, the OECD (OECD, 2019) describes the objectives of an RI more specifically into the following standard objectives and adding one objective on social responsibility:

- Be a country- or world- leading scientific RI and a science-enabling facility;
- Be an innovation-enabling facility;
- Become integrated into a regional cluster or regional strategies or become a hub for facilitating regional collaborations;
- Promote education outreach and knowledge transfer;
- Provide scientific support to public policies;
- Provide high-quality scientific data and associated services;
- Assume responsibility towards society.

One of the last frameworks developed under the EU Horizon 2020 program was that of RI-PATHS (Reid, 2021). RI-PATHS is the project of a consortium of universities and laboratories that united to develop a framework for SIA. The project has developed an impact assessment toolkit (*EFIS RI-PATHS*, 2020) to demonstrate the societal impacts of international study projects and to highlight the following self-identified main missions of scientific projects or RIs: to enable science, solve problems and assume their responsibility towards society.

However, the discussion of these missions also covers astronomy projects as examples of big science in the context of the European Southern Observatory (ESO), particularly for the Very Large Telescope (VLT) project (Fernandes et al., 2014). The mission of astronomy projects is not only to implement fundamental science projects but also to generate knowledge. The mission of research in galactic and extragalactic astronomy is not oriented towards immediate industrial application. However, astronomy RIs have to conduct applied research in optics, electronics, data processing and other areas to build and operate the scientific instruments needed to pursue their original mission.

Nilsen and Anelli (2016) focused on knowledge and technology transfer as an important part of the mission of most research organisations. Schopper (2016a) pointed out that the unique mission of CERN is to promote science and bring nations together.

According to Giffoni and Vignetti (2019), RIs have different scopes, target agents and impacts. However, the basic role of RIs has not changed: to stimulate relevant innovation and to advance science.

Miller (1992) concluded that the scientific impacts can be compared within the laboratories with comparable primary tasks and research outputs. Thus, the part of the theoretical background that will be applied in this study is built on the comparative analysis of similar research entities such as LHC (Florio et al., 2015), FCC (Catalano, 2018), and ITER (Puliga et al., 2018).

2.1.2 Mission of Societal Impact Assessment

Martin (1996) identified the following main reasons for conducting basic research assessments such as: (1) growing costs of the scientific instrumentation; (2) constraints on spending on research; (3) to convince a funder to fund the research; and (4) to assure stakeholders that public money is being spent well.

Societal impact assessment aims to review the societal effects of infrastructure projects and other development interventions. It originated from the environmental impact assessment (EIA) model. Environmental assessment (EA) is the assessment of the environmental consequences (positive and negative) of a plan, policy, program, or actual projects prior to the decision to move forward with the proposed action (Becker, 2001). The link between EIA and SIA is discussed in the guidelines and principles for societal impact assessment by the Interorganizational Committee on Guidelines and Principles for Social Impact Assessment from U.S. Department of Commerce (1994).

Interest in SIA is growing partly because policymakers and lead managers of private and public organisations have started to speak loudly about the advantages and disadvantages of different scientific projects, technologies and techniques to society. For example, the European Strategy meeting held in May 2020 about the post-LHC accelerator era requested the considered projects to provide and complete the technical documentation and to study the social impact (European Strategy Group for Particle Physics Preparatory, 2020). Therefore, one of the missions of SIA is to highlight all the positive and negative impacts of the subject of the assessment to society. It can also be used for project evaluation. SIA acts as a tool for comparing different large projects that require large investments and time. Thus, the role of SIA is to *advice* and *inform* about likely risks, benefits, and development options available. Moreover, like EIA, it must flag potentially dangerous and irreversible impacts (Wildavsky, 2018). SIA has the potential to warn about what is needed sufficiently in advance for effective arrangements to be made (Barrow, 2000).

Nowadays, the societal impact of different projects, studies and enterprises is a very popular topic and research area. To illustrate this, the benefit-to-cost ratio of LHC was calculated as 1.2, which reveals that for every 1 CHF spent on the construction of the large accelerator, there is a benefit of 1.2 CHF (Florio et al., 2015). Thus, timely appraisal of a large project can constitute an essential phase before its implementation and can play an important role in the decision-making on its construction.

2.1.3 Conceptual orientation or types of benefits

In 1996, Martin (1996) described the multi-dimensional nature and outputs of basic research categorised as scientific, educational, technological, and cultural. The assessment model of Becker (2001) covers the following impacts (1) Environmental Impact Assessment (EIA), (2) technological impact, (3) economic impact, (4) social impact and (5) strategic impact. Bornmann (2013) identified the following main areas of evaluation of project returns: (1) social, (2) cultural, (3) environmental and (4) economic. The authors of the ASIPRA approach (Joly et al., 2015) added to Bornmann's classification health and political impacts. Thus, for an RI assessment, they focused on (1) economic, (2) environmental, (3) social, (4) health and (5) political benefits. Barrow further added hazard and risk assessment, project program and policy evaluation, social soundness analysis, future studies and monitoring (Barrow, 2000). The Technopolis group has proposed a guidance document to disentangle and characterise the concrete benefits of RI investments for different stakeholders and to build a schematic impact assessment framework that can be used in evaluations to trace the core impact pathways (Reid et al., 2015). The report distinguishes the following impact fields: the economy, human resource capacity, innovation, scientific activity, and society. The earlier mentioned recent EU-funded project RI-PATHS (Reid, 2021) is the latest project to develop a modular impact assessment framework that represents all major impact pathways of RIs— enabling science, problem-solving and science and society—and discusses major impact areas: human resources, the economy and innovation, society, and policy. Figure 2 presents different impact studies and related evaluation fields. All the mentioned researchers conducted an economic impact appraisal, a major part of which introduced EIA. Otherwise, the impact areas differ in the title but can have comparable natures and could have been assessed using similar methods and measures for its estimate.

Figure 2. Assessment fields of societal impact

Salter and Martin (2001) categorised the benefits of basic research as follows: (1) increasing the stock of useful knowledge; (2) training skilled graduates; (3) creating new scientific instrumentation and methodologies; (4) forming networks and stimulating social interactions; (5) increasing the capacity for scientific and technological problem-solving; and (6) creating new firms.

Another study aimed to measure the benefits of fusion R&D programs in Korea (Choi et al., 2017) by estimating the technological benefits (i.e., how companies expand their business), human capital (i.e., job creation), and economic benefits (i.e., estimated sales increase).

2.1.4 Impact groups

Another variable in SIA is the impact group (Barrow, 2000; Scaringella & Chanaron, 2016). How does a project affect an individual or the entire society? Does it have different impacts on the public (current users and end-users), academy (scientists, engineers and directors of laboratories) and industry (managers and workers)? The studies on SIA were usually orientated toward certain stakeholders. Florio et al., 2020 investigated in detail the benefits for the following social groups: early-career researchers, scientists, industry, and the general public. The authors further defined the benefits for two classes: for direct and indirect users and for non-users. Many other studies investigated the impacts on only one type of stakeholder.

A large part of the literature on SIA encompassed the relationship between RI and industry. The theoretical background on RIC is examined in detail later in this chapter. Big science centres can benefit industry as sources of knowledge by being unique hi-tech customers, goal setters, motivators, funders, facilitators, references and others (Autio et al., 2004). Companies highlight market and personnel benefits, while RIs emphasise technological and organisational benefits (Fernandes et al., 2014). The increasing challenges of Big Science demand the merging of the public, private and academic sectors into a single collaboration—public-private academic partnerships (Anderson et al., 2012). The authors present the potential benefits for each party from the collaboration simultaneously highlighting the importance of the explanation and consideration of the goals and motivations of each partner to achieve a state in which all the partners are mutually accountable and mutually benefitting.

2.1.5 Time frame

Studies on impact assessment have described the importance of project evaluation in different time scales, that is, from both short- and long-term perspectives (Barrow, 2000). Likewise, it is significant to consider every single phase of a project such as its initiation, construction, stable operations, adjustment, closedown, replacement, or recycling phases. Each phase is characterised by a certain structure, activities, and outcomes. In the initiation phase, especially for start-ups or prototypes, the financial requirement is higher than in the stable operations phase. As mentioned at the start of this chapter, any project has initiation, construction, stable operations, ongoing management, adjustment, closedown, replacement and rehabilitation phases. Researchers propose to conduct the SIA for each of these phases (Becker, 2001). Thus, at any phase, actions can be launched to mitigate or eliminate a problem.

Moreover, the potential impacts of big-science facilities evolve during their life cycle, with different impact mechanisms dominating in different phases. To maximise the integrated impacts over time, it is important to understand how this potential changes along the life cycle and what the key impact drivers are in each stage (Autio, 2014). Benefits could also be created for different users at different stages. For example, Reid et al. (2015) classified construction and operational phases of RIs and identified different impacts for each phase. The construction phase has economic impacts and impacts on innovation, and the operational phase has the same impacts from the first phase as well as impacts on human resource capacity and scientific impacts.

The broad literature review demonstrated that many projects were assessed after the construction phase and after the experiment was commissioned and run (Battistoni et al., 2016; Florio, Forte, & Sirtori, 2016). Special focus was put on the fundamental science laboratories because of the particularity of the CLIC study, and because it is a fundamental science project.

In most cases, some positive impacts are hidden, and it is important to open them up to the main stakeholders and to explain them. Not all benefits are hidden, though; some advantages to society of the application of fundamental science discoveries to daily life can be seen. The developed technologies are used in diverse applications such as in information technology (IT; e.g., WWW, and touch screens) and medicine (e.g., radiography, proton therapy for cancer treatment, three-dimensional printed implants and others). Fundamental science pushes or even pull technology to reach the desirable and demanded level of service provision to an RI. Very often, the technologies required by RIs are cutting-edge.

2.1.6 Appraisal approaches

The impacts of basic research have been studied increasingly since the 1990s (Salter & Martin, 2001). The impacts of basic science projects are more difficult to assess than those of science projects that lead to direct applications. Especially, the benefits of fundamental science projects are less obvious and direct than those of applied science projects (e.g., drugs and IT). Pure scientific quality does not tell anything about the societal and economic values of a project. Public resources are no longer sufficient for funding the growing scientific research and choosing where to distribute the limited resources is difficult without tools for assessing the impacts. Politicians and other decision makers are struggling to evaluate the benefits of supporting science projects. Therefore, it is essential to have ways to fairly measure the impacts of science projects on society (Bornmann, 2012). Measuring the societal impact of big science projects has been demonstrated using different methods.

First, some researchers have conducted critical reviews of literature and identified main appraisal approaches in several categories. Salter and Martin (2001) divided the methods into case studies, econometrics and surveys. Giffoni and Vignetti (2019) grouped the most common methodologies for assessing the socioeconomic perspective into three macro-categories: economic, mixed-methods based on multi-partial indicators, and theory-based according to the causation literature approaches.

Thereby, a great variety of assessment models has been identified, explained by multiple combinations of different assessment fields and variables. For instance, the societal impacts of an organisation or a project can be calculated based on different project characteristics, such as territorial agglomeration and territorial innovation using the Territorial Innovation Model (TIM) (Scaringella & Chanaron, 2016); financial returns using CBA (Sartori et al., 2014); the final project benefits using the End-user Approach (Lyall et al., 2004); direct and indirect benefits using the BETA Approach (Bach & Wolff, 2017); and general characteristics through independent peer reviews using DELPHI Approach (Rowe & Wright, 2001). Among the criteria for choosing one or another method are the availability and authenticity of assessment data. Data are collected via desk research, online research, case studies, ex-post evaluation or surveys (industrial, scientific and peer) and others.

The TIM and End-user approaches do not include all assessment fields described in the models. The BETA Approach can only be used to complement other evaluation models. The DELPHI Approach is based on peer surveys, and the data quality highly depends on their knowledge. Thus, these methods are not sound enough to be used separately, while their combination can yield an evaluation model with all kinds of assessment categories and variables. Interactions between research organisations and end-users have been evaluated by combining a range of qualitative and quantitative tools: interviews, focus groups discussions, questionnaire surveys, desk research, documentary analysis and stakeholder analysis (Lyall et al., 2004). The authors note that while this combined approach might lead to criticism about the consistency and reproducibility of the results, the method is flexible and helpful and can draw meaningful conclusions.

The mentioned BETA approach measures the economic impact of publicly funded R&D programs (Rowe & Wright, 2001). The evaluation focuses on the effects of the different forms of learning experienced in the performance of R&D activities. The BETA approach was developed theoretically based on innovation economics and knowledge management literature. Specifically, the approach was derived from the evolutionary theory of innovation and the resource-based view of the firm. In the BETA-EvaRIO method, impacts are assessed by measuring changes in the capacity of the actor. This capacity increase is linked to a potential for future impact: when the capacity gain is harnessed by the actor, it leads to an economic effect which is directly measurable in most.

Another comprehensive theory-based approach to assessing the societal impacts of a research organisation was studied for the ASIRPA (Socio-Economic Analysis of the Impacts of Public Agricultural Research) project (Joly et al., 2015). The project was launched by the French National Agricultural Research Institute in 2011.

The latest study of Florio et al. 2015 showed that every CHF results in 1.2 CHF. The authors distinguished assessment categories and attempted to monetise them by calculating a net present value (NPV) (Florio & Sirtori, 2016) and presenting the ratio of costs to benefits. Thus, the method is called Cost-Benefit Analysis (CBA). The study by Florio et al. covers the benefits generated from the LHC. The CBA approach is one of the most complete analytical tools for evaluating societal impact attributed to RIs. Compared to other studies, the CBA of LHC presents a more extensive map of the outputs of the project. Even so, the methodology can still be argued and extended. This kind of study can have large uncertainties and difficulties in expressing benefits in monetary terms (Schopper, 2016). Moreover, the study can be extended by incorporating the cost of the preventive actions for the negative externalities, such as environment change because of the construction and operation of such large RI. The impacts can also include societal services and community impacts, which have positive and negative consequences.

Funding by private investors and public sectors drive different expectations about the returns. The former is motivated by financial returns, whereas the decision of the latter is formed by more complex objectives, specifically, a knowledge return to boost technological and scientific progress. Likewise, the government can reinforce its decision-making process by calculating the societal return of a given investment in an RI project. This requires calculating the value to society produced by the construction and operation of the RI, even if the financial revenue is negative. Scientific discoveries often have implicit indirect benefits to society. The time for applying scientific findings to quotidian life varies from a year to decades. Two of the most famous examples of ubiquitous technologies developed at CERN demonstrate how the organisation creates tangible benefits for society, without which life nowadays cannot be imagined: the touch-screen, launched on March 1972, and the World Wide Web, launched on March 1989 (Berners-Lee, 1989). The touchscreen already existed but was difficult to implement mechanically. The proposal for the capacitive touch screen came in March 1972 (Beck & Stumpe, 1973); its CERN application appeared four years later; and the commercial solution became available in 1977 (*CERN becomes one of the touch-screen pioneers | timeline.web.cern.ch*, 2022).

The literature also discussed some causality problems as obstacles in SIA and therefore, some criticisms for identifying all possible fields and their measures, as they are not an exact science. A researcher ought to be accurate when defining impacts and finding an appropriate measure for each category. After that, a mathematical and statistical model can be used. However, researchers need to avoid possible bias towards negative or positive impacts because of their possible subjectivity and the interpretation of the data with respect to a category. Therefore, Bornmann (2012) recommended using several experts or even an assessment group to avoid such bias. Once the possible assessment fields are defined, the data have to be collected. Typically, big data are concerned, which have to be mined from different sources and which come with the unavoidable risk of missing data. The RI-PATHS toolkit describes tools for data collection and even proposes approaches to data analysis depending on the concerned impact area. The program recommends embedding the assessment framework into the RI management system as well as into the strategy of the interdisciplinary research team. Furthermore, the appraisal shall be implemented in the long term and shall be done periodically. The same obstacles were identified by Bornmann (2012). The author highlighted a timescale problem as ignoring the potential long-term impact and mentioned the causality problem of which impact to use for which cause. Apart from these, Bornmann underlined the attribution dilemma as to what should be attributed to research and what should be attributed to other inputs, as well as the internationality problem, that is emanating from the international nature of R&D and innovation, which makes attribution virtually impossible. Contrary, however, to the author's insistence that research on societal impacts is still in its early stages, the RI-PATHS program and the increasing interest in the topic have proven that the situation in 2012 is changing.

To conclude, impact assessment is a complex undertaking with many variables. Researchers choose an appraisal approach based on fields of application, accessible data and studied effects. A well-established SIA model should have a preventive character by incorporating risk analysis, mitigation of negative impacts, enhancement of positive impacts and design of the most effective strategy. Stakeholders expect information and assistance on dangerous and irreversible impacts and benefits to support decision-making.

2.2 Research-Industry collaboration

Nowadays, universities, research laboratories, and industries have close connections. The borderline between scientific and commercial ventures is becoming more and more transparent. Several studies have assessed the motivations and factors of RIC and the overall collaboration between industry and research organisations (Autio et al., 1996; Soh & Subramanian, 2014; Tijssen et al., 2009; Huang & Chen, 2017; Bruneel, D'Este and Salter, 2010; Siegel et al., 2003; Skute et al., 2017; Santoro & Chakrabarti, 2002). In addition to the traditionally noted technological and status advantages of RIC, the motives of industry for partnering with big science vendors include increased problem-solving competence, product quality discoveries, and scientific learning processes (Andersen & Åberg, 2017). The motives of companies for entering big science markets are classified by market, beneficial, network, diversification, educational and radical (challenging existing technological frontiers) strategies. Moreover, companies can benefit by leveraging RI's past performance through a formal technology transfer process, by joining ongoing projects that align with their current business goals or by participating in the initiation of projects with long-term goals and significant technology challenges (Hameri, 1997). Together, according to Torkkeli and Tuominen (2002) technology presented both a great possibility and a threat to companies at the same time. Since a company can waste its competitive advantage by investing in wrong alternatives at the wrong time or by investing too much in the right ones.

Researchers widely cover various interaction channels and intensities, as well as enhancing and diminishing factors of collaboration (D'Este and Patel, 2007; Abramo et al., 2009; Yamaguchi et al., 2018). University researchers frequently interact with industry through consultancies, contract research, joint research or training. CERN interacts with its partners for knowledge and technology transfer via licensing, research collaborations, open source software, open hardware, spin-off and start-up companies (Nilsen & Anelli, 2016). Nonetheless, Meyer-Krahmer and Schmoch (1998), emphasised collaborative research and informal contacts, that is informal discussions, as most essential. They claimed that depending on the interaction typology, collaborative research implies a *bi-directional* knowledge flow, while contract research mostly has a *one-directional* orientation. The authors further highlighted a non-uniform interaction in different technological fields: —university-industry relations are closer in application-oriented fields than in science-based fields. D'Este and Patel (2007) demonstrated a higher level of interaction in the engineering disciplines than in mathematics and physics. One explanation for this is the more intense knowledge transfer in the former. A higher number of interactions occur in medicine and chemistry, whereas the industrial, information, and engineering sectors show the highest percentage of co-authored articles, according to Abramo *et al.* (2009). Temel et al., (2013) also studied the importance of collaboration in innovation propensity of firms taking into consideration specific Turkish context. The authors found via a logistic regression analysis that cooperation had a positive and significant influence together with doing on a permanent basis intramural R&D on the propensity to develop and commercialise novelties.

Salter and Martin (2001) claimed that it is difficult to develop a simple model for benefits assessment because basic research and innovation do not interact in a systematic way. Thus, earlier research has attempted to provide policymakers, industrialists and academics with a framework for promoting and establishing systematic balanced interaction between Big Science and industry. Autio *et al.* (1996) identified the following motivating dimensions for the partners in Big Science-public and industry interplay: educational, political, financial, epistemic (knowledge creation), strategic and technological. Financial motivation is associated with short-term goal setting, while technological motivation is associated with longer-term goal setting. The authors considered such motivations for the interplay between public, industry, and academic institutions. All partners have proper direct and indirect or non-monetary benefits from the interaction. Well-designed industrial policies of Big Science centres result in their increasing attractiveness to companies and national policymakers.

Besides emphasising factors and motivations, previous studies have evaluated possible collaboration barriers due to cultural, institutional, and operational differences (Rohrbeck & Arnold, 2011). The collaborating parties have divergent missions and goals (cultural), different natures of work (institutional), and a lack of knowledge about the partner and its processes (operational) (Debackere et al., 1988). Knowledge of the abovementioned is essential for the creation of a mutually shared mission and goals, with a beneficial environment of trust and transparency. Besides, previous experience of collaborative research increases the trust level for both academic and industrial actors (Bruneel et al., 2010).

The literature review exposes a greater tendency to base the research either on survey data or bibliometric analysis derived from questionnaire metrics or co-author publications. Furthermore, the previous studies on RIC can be classified based on one or several of the following research perspectives: (1) benefits from RIC, (2) firms' attributes, (3) RI attributes and (4) relationship attributes. The further discussion in the next section is based on the mentioned research perspectives, from which the hypotheses are formulated.

2.2.1 Benefits from research-industry collaboration

There are two main actors in RIC: industry and RI. Each follows its own goals and motivations (Autio et al., 1996) to gain commercial and technical benefits. Later studies have discussed a wider range of outcomes from RIC. A similar study performed for the LHC (Florio et al., 2018) demonstrated direct outcomes in performance enhancement and intermediate outcomes in learning, innovation and market penetration.

Learning and innovation benefits appear to be shaped by the quality of the supplier's relationship with the research organisation (Autio et al., 2003). The study revealed significant marketing reference benefits from CERN, with technological learning, development of new products or services and starting new R&D and/or business units. Technologically challenging projects are also important for CERN to increase the motivation and knowledge acquisition by its staff. Finally, it has been hypothesised that becoming a CERN supplier induces more intensive effort in R&D and knowledge creation, which improves productivity and profitability, especially of high-tech suppliers (Castelnovo et al., 2018). The study found that the order value and its innovative level shape the relationship between CERN and its suppliers.

The study of ITER investigated industrial participation (Puliga et al., 2018) and found that it allows firms to (1) improve their financial performance, (2) enhance their brand image, (3) extend their network of collaborations, (4) improve their internal processes, (5) acquire new standards, (6) have a new company vision, (7) involve new people and (8) invest in local and regional territories. The study provides policymakers, managers, and researchers inferences and tools for managing companies' involvement in Big Science projects. The tool indicates incentives to be offered to small and medium enterprises to enhance knowledge propagation and business continuity.

2.2.2 Firms' attributes

RIC literature has considered the following main attributes of firms that influence their benefits from RIC; their size, ownership status, industrial sector and geographical location (Levy et al., 2009). The geographical location of a firm is one of the first determinants of its ability to collaborate (Calvert & Patel, 2003). In the *geographical proximity effect* (Knoben & Oerlemans, 2006), the capability of a firm to collaborate decreases with its increasing distance. Thus, the universities most active in collaborations are located in more industrially developed regions (Tijssen et al., 2009). Earlier research also confirmed the dependence of RIC on the size and status of firms (Levy et al., 2009). Independent large firms, or their subsidiaries, collaborate more often than small ones. The latest studies have demonstrated that large groups have a higher tendency to cooperate with research universities than small independent companies (Levy et al., 2009; Mohnen & Hoareau, 2003). Similarly, small and medium technological enterprises refer less effectively collaborate with institutions (Klimczak et al., 2017). However, according to Goel et al. (2017), universities have more problems launching collaborations with large firms than with small ones.

The firm's size and its application field influence companies' motivations for and benefits from RIC. Large industrial firms profit from the collaboration via knowledge transfer and research support in non-core-technology areas, whereas smaller firms focus more on problem-solving in core-technology areas through technology transfer and cooperative research relationships (Santoro & Chakrabarti, 2002). However, Motohashi (2005) proved that small firms achieve higher productivity through university-industry collaborative activities than large firms.

As for the age of companies, Soh and Subramanian (2014) found different results from participation in R&D-related RIC between young and old firms. The younger firms benefited more from their relationship with universities than older firms did because of different knowledge bases, organisational structures, and routines involved in knowledge-related activities.

2.2.3 Research infrastructure attributes

RI attributes are summarised characteristics by which an RI can influence RIC, such as procurement policy, communication and scientific events.

Earlier studies have shown that procurement activities have an influence on innovation by restricting interaction (Åberg & Bengtson, 2015). CERN has its own procurement policy, with proper regulations and a different governance system for contractual relations (Åberg & Bengtson, 2015). Companies with different sizes can participate and work with CERN. However, additional rules on awarding contracts could create barriers to industries.

The expansion of scientific knowledge requires technological breakthroughs that go beyond industrial innovation and better technological returns from fundamental research. To achieve these breakthroughs, active partners are needed in an innovative transformation process to turn scientific ambitions into commercial products. Some industrial companies pursuing an active R&D strategy have realised that product innovation is not the only motive for engaging in a large scientific collaboration (Hameri, 1997).

Nevertheless, the big science market is still relatively specific and sometimes difficult for long-term collaboration. Moreover, the market can be characterised by a bureaucratic procurement process because of the severe financial and political pressures that RIs face. The bureaucratic and politically charged procurement function at CERN has some effects that hinder the motivation and innovation of companies (Vuola & Hameri, 2006). The best offer does not always win, early participation does not guarantee contracts, and succession is rarely taken for granted. The first hypothesis is formed as follows:

H1. The benefits of RIC to industry are influenced negatively by the procurement policies of RIs.

Still, CERN procurement rules can lead to some difficulties in choosing the technically best supplier because of the bureaucracy of the process (Åberg & Bengtson, 2015). Sometimes, a company struggles to report its approach and technical solution to CERN. Moreover, additional suggestions or improvements cannot be communicated because the firm must always cost-effectively fulfil the technical requirements. Furthermore, long-term productive cooperation with an industrial partner is difficult to guarantee since the decision is made based on the tender process. However, CERN grants some exceptions in cases where the supplier has already proven the quality of its product or service, and its ability to meet deadlines as well as where it is one of the very few providers of the product or service. Nevertheless, a well-established communication system becomes essential at this point. In large scientific projects, the industrial partner must make sure that the people involved really understand what they are supposed to do and with what resources, determine and clarify who is the customer of the project, strictly control the project process and use all available information and know-how, including on new financial sources of basic and applied research and development (Hameri, 1997). Lack of communication is a hindering factor encountered in RIC (Kaymaz & Yasin Eryiğit, 2011). On the other hand, some of the factors that prevent industry from tapping the potential of the big science market are the RI's technology transfer staff' lack of flexibility and lack of knowledge on the private sector (Byckling et al., 2000). The procurement policies of publicly funded research organisations can limit innovation capacity if perfect competition is prioritised over close collaboration with suppliers. However, in supplier relationships, high engagement and high continuity have very positive effects on innovation potential (Åberg & Bengtson, 2015). Therefore, the next hypothesis is formulated as follows:

H2. The easier the communication process (to get and to ask for information about a project) is, the more likely it is for a company to benefit from collaboration.

Because of the specific fundamental science field, a company benefits from participation in scientific conferences, use of RI facilities, and common publications. Science-related events are important occasions for establishing RIC (Bressan, 2004). In turn, CERN organises special targeted events called *Industrial Days@CERN* to promote its Member States' national industries, to diversify its pool of suppliers and to balance the industrial returns across the Member States (Hartley, 2021). Therefore, the third hypothesis is formulated as follows:

H3. The more a company participates in science-related events, the more likely it will obtain benefits.

2.2.4 Relationship attributes

Relationship attributes are characterised by procurement activity, the duration of the relationship duration in the RIC and the presence of collaboration with other RIs.

The Big science market is a unique venue for testing new developments, learning and expanding business. Therefore, guidelines are needed for major research centres to be able to attract and motivate the best industrial partners and establish mutually beneficial cooperation through partnerships between industry and big science. Radical projects often face internal resistance within a company's own culture, people and processes, and investors may view radical product and business development as indications of a lack of focus. Thus, for an innovation to flourish, external resources, potential users, test facilities, and an initial market around it are needed (Vuola & Hameri, 2006). CERN, by publicly providing some business opportunities at other RIs on its procurement website[8], opens its market with its collaborative network to its industrial partners. Consequently, the fourth hypothesis is formulated as follow:

H4. Benefits of RIC to industry are influenced positively by a collaborative network with other RIs. Thus, producing parts for other scientific laboratories is likely to positively impact collaboration outcomes.

Public procurement is described as “a demand-driven tool” for inspiring innovation (Lember et al., 2014). The money volume of the procurement orders received shapes the relationship between an RI and its suppliers (Florio et al., 2018). Likewise, learning and innovation benefits appear to be regulated by the quality of the supplier’s relationship with CERN: the greater the amount of social capital built into the relationship is, the greater the learning and innovation benefits are (Autio et al., 2003). Thus, many RIC benefits are associated with procurement activity. This leads to the next hypothesis:

H5. The more procurement activities between a company and the scientific project there are, the more benefits by the company obtains.

The collaboration should not be too supply-oriented, however, which means that the company should be able to benefit from the collaboration even if it does not end up with a supply contract with CERN. Both parties ultimately need innovation, so their strategic needs must match in their technology cooperation. The process of developing a new product is changed in such a way that the industry shares the stages of prototyping, testing and verification with a big science centre, while maintaining its ability to launch a single product on the mainstream market based on a new innovative technology (Vuola & Hameri, 2006). Technology transfer is not a one-way process only from fundamental research to industry but a two-way process where the accumulation of information and experience from both parties provides solutions and new insights with both epistemic and economic impacts (Autio et al., 2003). Therefore, the last hypothesis is as follows:

[8] *Business Opportunities at Other Institutes | Procurement and Industrial Services Group* (no date). Available at: https://procurement.web.cern.ch/home/business-opportunities-other-institutes (Accessed: 24 January 2022).

H6. The longer the relationship between a company and CERN/CLIC is, the more benefits the company obtains.

Evaluation of the literature allowed to distinguish the RIC outcomes and the factors motivating and forming it. The reviewed studies led to the conclusion that collaboration with industry has an important role for RIs' staff in giving additional practical knowledge as well as receiving additional data from industrial partners for further R&D. Whereas, collaboration of industry with universities has an essential role in the establishment of joint research projects and development programs as well as in finding solutions to existing problems. Both actors, academia and industry should be interested in cooperating to develop innovative technologies and methods.

3 RESEARCH METHODOLOGY

3.1 Research design

The present chapter introduces the research methodology. The research design was constructed in two phases. The first phase combined deductive qualitative and quantitative research, based on the data collected internally. The second phase was hypothetic research, based on the data collected externally. Thus, the described multimethod approach involved the application of several sources of data and research methods to the investigation of research questions. The main advantages of multimethod work were mentioned by Tashakkori & Teddlie, (1998): triangulation – seeking to validate data and results by combining a range of data sources, methods, or observers; creativity – discovering fresh or paradoxical factors that stimulate further work; and expansion – widening the scope of the study. Collecting different kinds of data by different methods from different sources provided a wider range of coverage that resulted in a fuller picture of the societal impact under study than would have been achieved otherwise (Bonoma, 1985).

For a more comprehensive approach to the evaluation of the societal impact of an international project at the development phase, this study was conducted on two research lines: impacts from the perspective of CLIC through internal data-gathering and impacts from the perspectives of industries through an industrial survey (see Figure 3). SIA, as underlined in chapter 2.1, has an impact on different groups: early-career researchers, scientists, industry, and the general public, who are the direct or indirect users of the benefits as well as those who can suffer from the negative aspects of an RI. Therefore, the completed picture can be drawn only by assessing impacts from diverse viewpoints. Thus, in this study the effects of the large-scale international accelerator study are argued and evaluated from the internal and external viewpoints to consider the insights of scientists inside the project and of the project's industrial partners, who are among the project's major external collaborators.

The overall research design of SIA of CLIC was explained from internal viewpoint and external viewpoint (Figure 3). Thus, it followed the recommendations from the previous studies (Barrow, 2000; Scaringella & Chanaron, 2016) to identify the impact for different impact groups and to explain the impact from different views. The internal viewpoint was represented by identifying the conceptual framework of SIA and explaining three major impact fields. The external viewpoint was represented by identifying the benefits from RIC and explaining its influencing factors. The two-phase study allowed to assess societal impact of the large project from two biggest stakeholders—academy and industry. Internal phase covered the impact from academic point of view, based on the previous developed cost-benefit model (Sartori et al., 2014), using the data collected internally and calculating three major impact fields, while external phase covered the impact from industrial point of view, using the data collected from the industry (Autio et al., 2003; Castelnovo et al., 2018). The later also explained the enhancing or diminishing mechanism in RIC for created benefits through developed hypotheses testing.

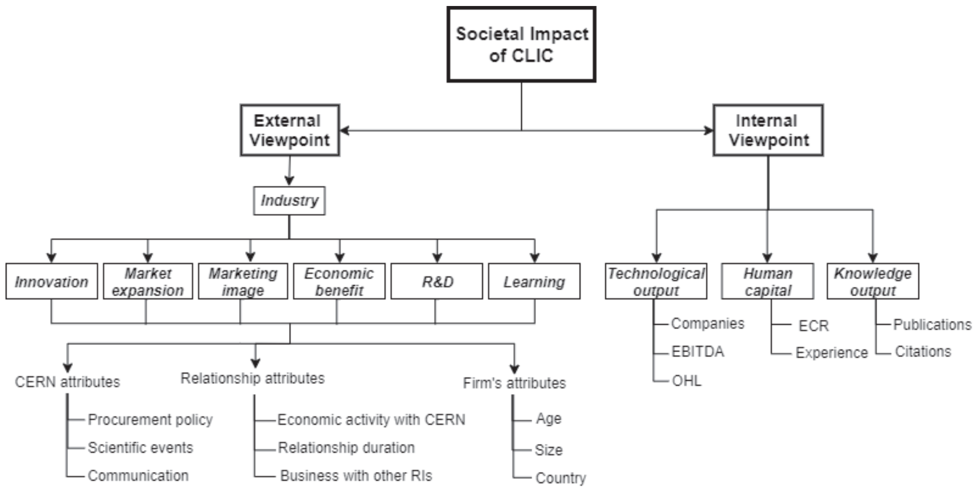

Figure 3. Research design

The internal viewpoint focuses on three assessment categories that had been demonstrated in earlier research as among the most beneficial fields for an RI: technological output, knowledge production and human capital formation. These fields represent about 67.63% of the total economic NPV of LHC [based on Florio et al. (2015)]. However, the full model for the SIA of CLIC will be covered in the next chapter still. In the framework of this research, the impacts from the internal viewpoint are represented by the benefits from the three mentioned assessment fields. The previous similar studies on LHC (Florio et al., 2015) and CNAO (Battistoni et al., 2016) were based on socio-CBA. The estimation was done after the commissioning of the infrastructures and the value of the benefits was extrapolated to the future. CLIC presents a slightly different case because the project still has the status of a study. This means that its benefits will be calculated based on past experience, and the calculated value will not be extrapolated to the future.

The external viewpoint on the project impacts is represented by the industrial partners' feedback on the benefits of RIC. First, the main outcomes of the partnership between industry and a Big Science centre will be condensed and represented as (1) economic, (2) marketing, (3) market expansion, (4) learning, (5) R&D, and (6) innovation outcomes (see Figure 4).

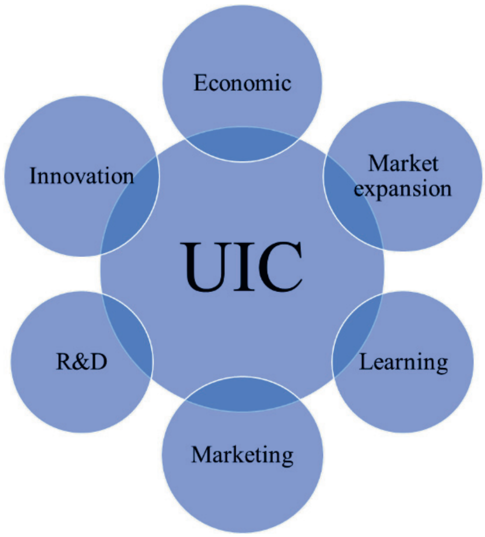

Figure 4. The benefits for industry from procurement activities.

Second, the literature review demonstrated a higher tendency to use survey data for the evaluation. Thus, to achieve the aim of this study, the impacts are assessed using a distributed online survey, which is dedicated to the benefits in terms of learning, innovation, performance of company-suppliers through procurement and business with CLIC.

The conceptual frameworks for two phases are discussed thoroughly later in this chapter. The presented research design covered the SIA from two perspectives and allowed to answer the research questions. However, the further research can include even more perspectives than presented in this study.

In general, the data for the two abovementioned research lines are collected via the industrial and scientific domains. The former is an outcome of CLIC's influence on company-suppliers, and the information is collected via online questionnaires distributed among the firms and completed through direct interviews to close any information gaps in the data. The initial industrial data were derived from procurement orders and commercial contracts with suppliers from the CERN procurement database. The scientific domain was investigated through bibliometric research represented by publications and through collaborations represented by the institutes and people involved in the CLIC study. The CERN Document Server (CDS) is used for preliminary information on publications, reports, notes, and proceedings. The CERN human resource database provides information on specialists and students.

Hereafter, the CLIC study, together with the methodology for the two revealed stages of impact assessment from the internal and external perspectives, are introduced.

3.2 Compact Linear Collider

The LHC will continue its operation for approximately 20 years. Simultaneously, diverse studies are being conducted for the design of a future large-scale machine. One of the options is the Compact Linear Collider (CLIC). One of the first publications about a linear collider machine dates back to 1985 (Lawson, 1985). CLIC is an international study for a future high-gradient multi-TeV linear accelerator machine for colliding electrons and positrons, with the centre-mass energy from 380 GeV for the first stage and up to 3 TeV for the third stage of the project (see Figure 5). The international collaboration constitutes more than 70 institutes from more than 30 countries around the world. The collaboration work has continued for over 20 years, within which the last 10 years saw intensive prototyping in the proof-of-concept phase. Hence, CLIC is a good research platform for evaluating the benefits of collaboration between industry and a research organisation in the development stage.

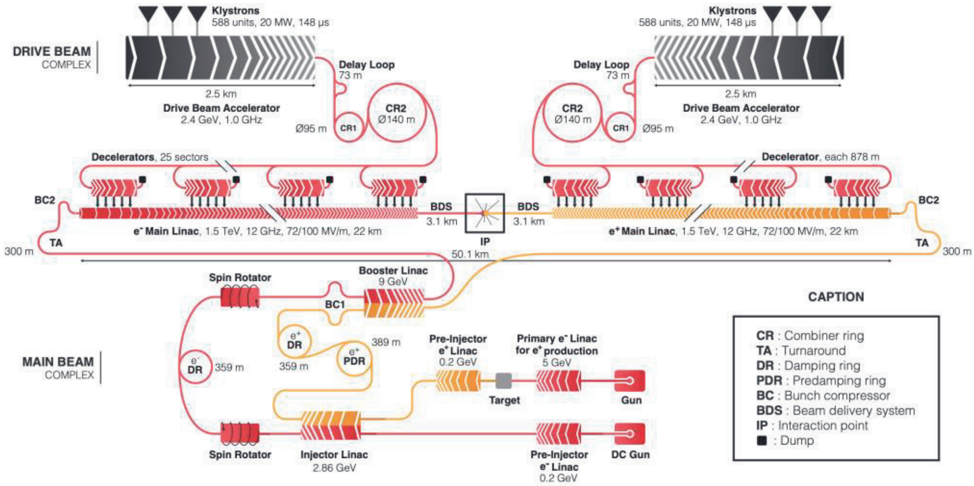

Figure 5. CLIC layout

CLIC is considered a mature project that is ready to be built but has the status of a study, which means that it has not been approved yet by the European Strategy for Particle Physics for construction as the next accelerator machine. The proposed schedule in case of the acceptance of the project is shown in Figure 6. The construction of the first CLIC energy stage is proposed to start in 2026, with the first beams to be available by 2035. Accordingly, a six-year preparation phase is foreseen prior to the start of the construction.

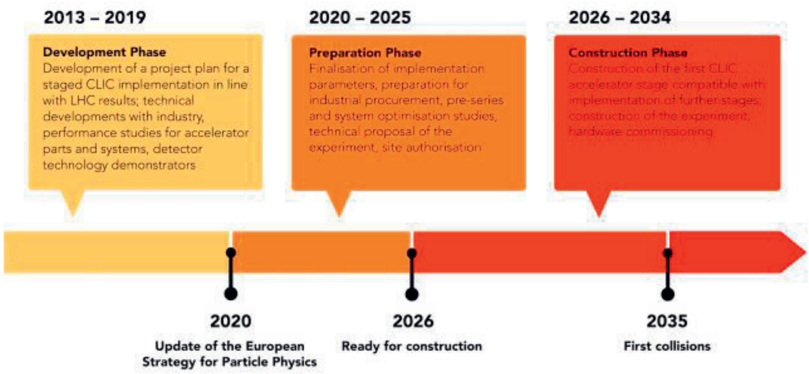

Figure 6. Timescale of the CLIC project

Based on the technology-driven schedule shown in Figure 7, the full lifecycle of the machine, including its construction, installation and commissioning, is about 34 years.

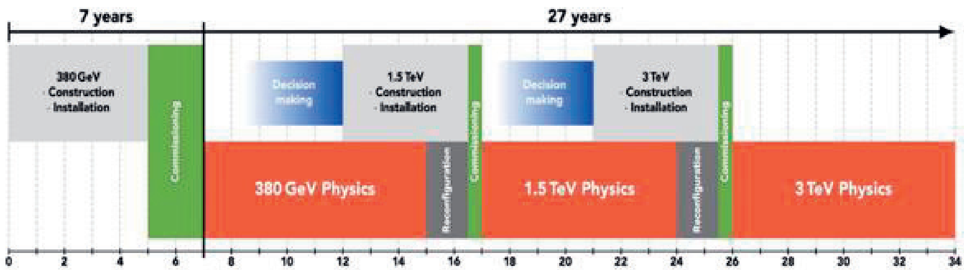

Figure 7. Technology and construction-driven CLIC schedule

CLIC is based on an innovative two-beam system in which the RF power is extracted from a low-energy but high-intensity drive beam and transferred to a main beam (Figure 8). The CLIC test facility at CERN has proven the feasibility and efficiency of the working principle (Ruber et al., 2013; Rossi et al., 2013). The compactness of the accelerator arises from the use of normal-conducting accelerating structures working at a very high accelerating gradient of more than 100 MV/m. To achieve this gradient, relatively high-frequency 12 GHz X-band accelerating structures are utilised. The production of the X-band structures and components requires several advanced and innovative technologies such as single-diamond ultra-precision machining, additive manufacturing, diffusion bonding, electron beam welding, special surface treatment, alignment techniques and ultra-high vacuum systems.

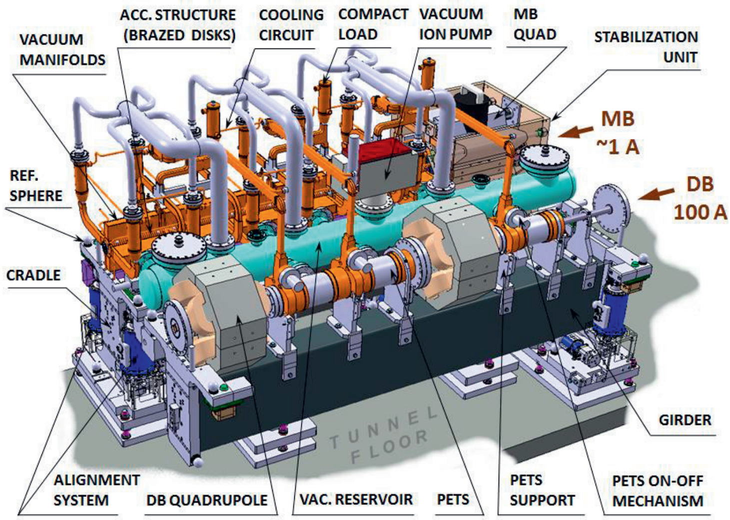

Figure 8. CLIC two-beam module

At present, only a few companies in the world have adequate manufacturing capabilities for even just the prototypes. The mass production of the CLIC components will likely yield to major technological improvements/upgrades through knowledge and technology transfer. CLIC qualifies potential suppliers that go through the knowledge transfer mechanism to develop the emergency technology for this particular market and clients.

Meanwhile, many other emerging applications based on CLIC technologies are being realised and anticipated. There is also a worldwide collaboration called CompactLight (D'Auria et al., 2019), that aims to make the X-band technologies a standard in accelerator facilities and to make them more affordable to manufacture and operate. CLIC will naturally benefit from the experience and results of such international collaboration.

CLIC technologies are applicated well beyond the project itself. Its most crucial application is in the medical field for the cancer treatment accelerators. An example is the ADAM project for advanced oncotherapy (Degiovanni et al., 2016). The last and more recent application is for FLASH radiotherapy in collaboration with CHUV (Centre Hospatilier Universitaire Vaudois, Lausanne; Bourhis et al., 2019). The ProBE structure for the proton beam linac is being developed in collaboration with a UK university (Pitman et al., 2017) and others. Beside the medical projects, CLIC involves institutes around the world that are also creating impacts at the local scale in the fields of employment, technology development and research.

Table 1 lists some CLIC collaborator projects. Thus, facilities can benefit from the compact solution, which is one of the key attributes of the CLIC accelerator.

Table 1. CLIC collaborator projects.

Nr	Name	Collaborator	Country	Direct / indirect application	Beam Energy	Application
1	FLASH	CHUV	Switzerland	X-band Radiotherapy	5.6 MeV (first treatment	Medical
2	ADAM	ADAM/AVO	Switzerland/UK	Proton therapy		Medical
3	PROBE	Lancaster University	UK	C-band Proton therapy	230 MeV	Medical
4	SwissXFEL (Milne et al., 2017)	PSI	Switzerland	C-band FEL	6 GeV	Scientific (material, art) Technological Medical (analysis of bio-molecules)
5	SMART* LIGHT (*Smart*Light — Eindhoven University of Technology Research Portal*, 2021)	Eindhoven University of Technology	The Netherlands	FEL	35 MeV	Scientific Medical Cultural (art)
6	COMPACT LIGHT	EU project	EU project	FEL	5.5 GeV (Di Mitri *et al.*, 2019)	Scientific
7	CLARA (Clarke et al., 2013)	Daresbury	UK	FEL	250 MeV	Scientific
8	UKFEL	Not approved	UK			
9	eSPS	Not approved	Switzerland		3.5 GeV	Scientific

3.3 Collaboration between CERN and industry

CERN is an international organisation whose capital and operating costs are supported by its Member States through contributions (see Figure 9). The Big Science centre pays back by adjudicating procurement contracts to suppliers. There is no restriction in the size of the company suppliers, but there is a rule on the origin of products or services in terms of known well-balanced and poorly balanced countries[9]. The choice of a supplier is adjusted by balancing the economic feedback to the country contributors. The annual contribution of countries for CERN supplies in 2019 and its comparison with the payback from CLIC are shown in

[9] "Industrial Returns for CERN Member States | Procurement and Industrial Services Group," *https://procurement.web.cern.ch/home/industrial-returns-cern-member-states.* https://procurement.web.cern.ch/home/industrial-returns-cern-member-states (accessed Apr. 26, 2021).

Figure 10. Figure 11 presents an overview of the locations of CLIC's industrial partners.

Transfer of knowledge and technology is one of the missions of RIs. CERN has been performing systematic technology transfer since 1988. Its current policies state that impact shall have priority over revenue creation in its transfer activities (Nilsen & Anelli, 2016). Autio, Bianchi-Streit and Hameri (2003) found that in most high-tech supply contracts, suppliers have received significant marketing benefits from CERN and, in addition, 38% of the study respondents have developed new products or services as a direct result of their project with CERN, 42% have expanded their international presence and 44% reported significant technological learning.

CERN is engaging in different modes of knowledge transfer, which Nilsen and Anelli (2016) summarised as follow:

1. Licensing. Traditional, both academic and commercial. The authors presented the Medipix project (Amaldi, 1999) as one of the most successful licensing cases of CERN.

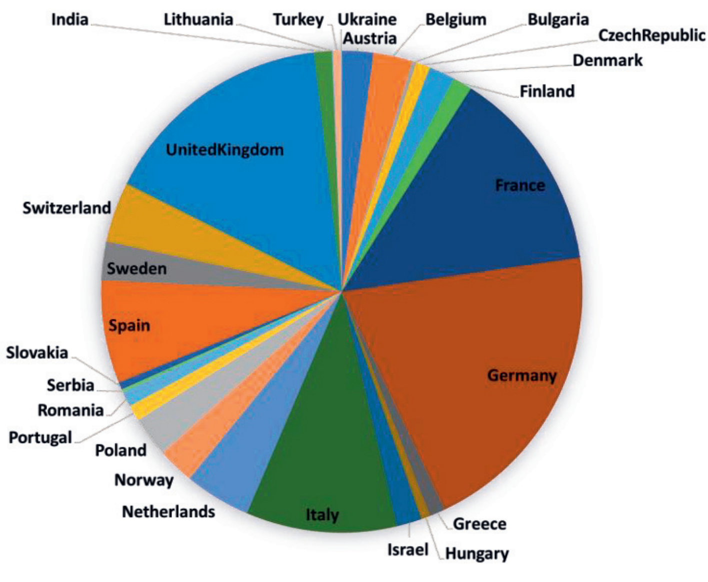

Figure 9. Annual Contributions of CERN Member States to the CERN budget 2019 (*2019 Annual Contributions to CERN Budget | Finance and Administrative Processes Department*, 2020)

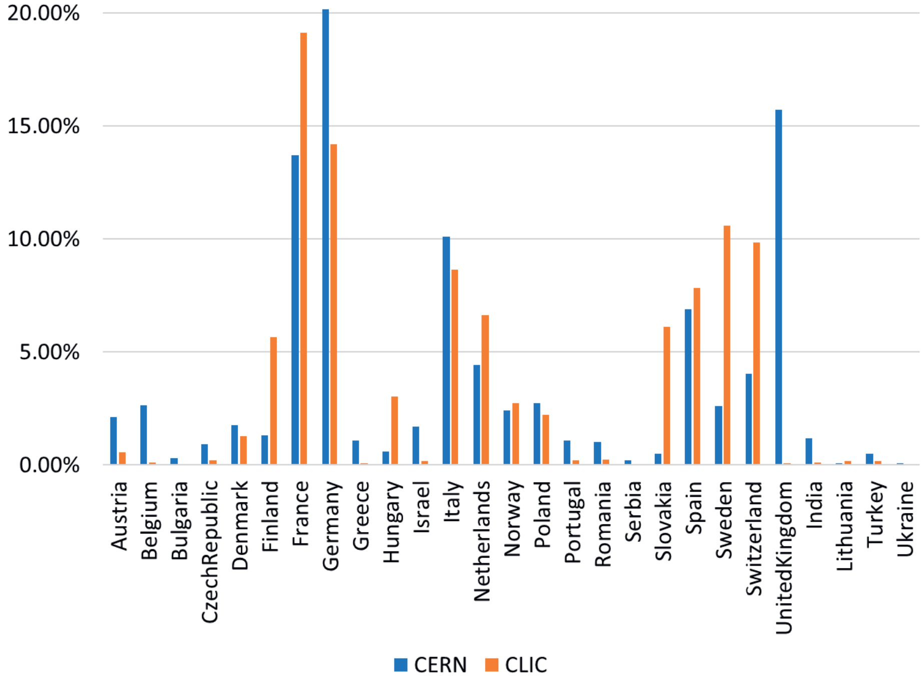

Figure 10. CERN versus CLIC

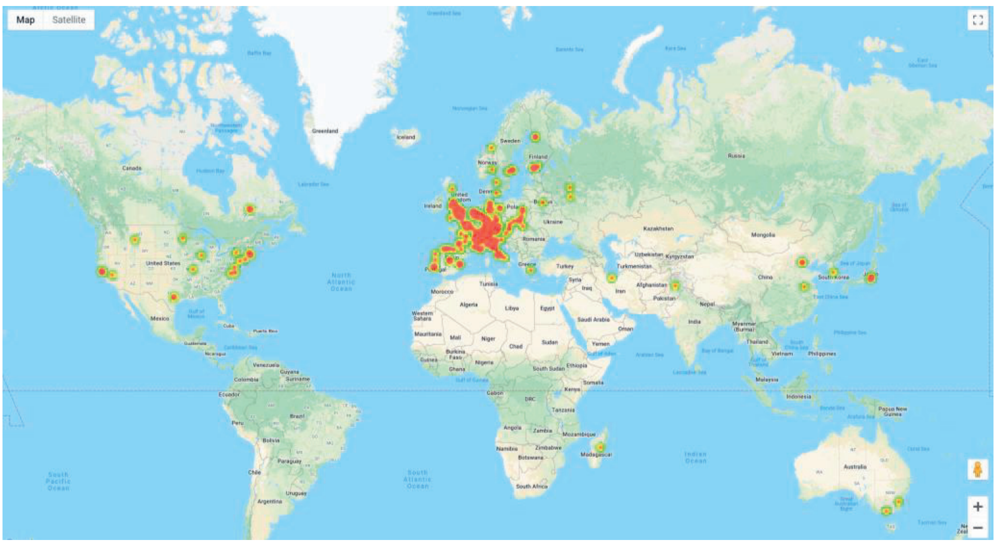

Figure 11. CLIC industrial partners

2. Collaborations, services and consultancy. Only considering CERN-specific knowledge, as CERN has no mission to serve as a contract research facility. The goal of this kind of collaborative agreement is to generate technological results with a potential for commercial exploitation. Service and consultancy agreements are often integrated in license agreements.

3. Open-Source software. The Open-Source approach is applied to all software development owned by CERN *per se*. This has resulted in some powerful instance of knowledge dissemination, the most famous example of which is the development of the World Wide Web.

4. Open Hardware allows anyone to study, modify, use, and produce a design. It began at CERN in 2009. Currently CERN counts more than 100 projects with 17 companies involved (Nilsen & Anelli, 2016). CERN often acts as the pilot user of new hardware. Open Hardware projects have led to many commercially successful products. The Open Hardware concept simplifies technology transfer to collaborators and companies and allows measurement of the impact and profiting from outside developments.

5. Spin-off and start-up companies. Spin-off companies may be especially impactful in delivering knowledge to society. Thus, CERN recently put in place significant efforts to better facilitate the creation of spin-offs (Amaldi, 1999). Spin-offs from CERN and the case of TuoviWDM have been discussed by Byckling *et al.* (2000).

6. EU projects. The EU framework programs have been important instruments for connecting CERN to external actors and for funding research that is not part of CERN's core mission. Through these programs, CERN has cooperated with 526 partners, including 126 companies. Some of those programs also allowed for large-scale training of young researchers.

7. Human capital as part of RIs' mission to train the next generation of scientist and engineers (Catalano et al., 2015; Catalano, 2018; Camporesi et al., 2017). In 2014, 30% of CERN staff held contracts with limited duration. Also, CERN's various student and fellow programs allow high staff turnover and high spin-off of human capital to society. In addition, the around 100,000 annual visitors of CERN take human capital to society, although the impact of such visits is difficult to measure.

8. International collaboration for medicine. Much of new particle physics can be applied to some medical fields, which is why CERN is actively collaborating with the health sector. One of the most interesting fields now is the field of hadron therapy, and cancer treatment in general. One of the recent examples related to CLIC

technologies is the FLASH project (Bourhis et al., 2019). Other projects have already been mentioned in Table 1.

CERN's Knowledge Transfer (KT) Group[10] (*Accelerating Innovation @ CERN | Knowledge Transfer*, 2022) works proactively to maximise the dissemination of technologies and the impact of CERN in society by actively scouting for opportunities to accelerate innovation and work with leading industries in the medical field, aerospace, cultural heritage and Industry 4.0. Every year, the group issues a report that highlights the success stories.

The Procurement and Industrial Services Group[11] (*Home | Procurement and Industrial Services Group*, 2022) is responsible for procurement at CERN. For orders valued below CHF 200,000, the price enquiry system is used, whereas for larger orders, invitations to bid are used. These allow all potentially interested firms from Member States to bid; but before they can do so, they are required to complete a market survey that informs both parties of the requirements for cooperation.

In summary, industry and research have to join forces to accelerate progress and innovation. "CERN's industrial suppliers are crucial to advancing its scientific mission. It is through successful collaborations with businesses across a variety of industries that advancements in accelerators, detectors, computing and many other areas become realities" (Hartley, 2021).

3.4 Conceptual framework of Societal Impact Assessment: Internal viewpoint

The SIA is evaluated from an internal viewpoint through the data collected inside the project. In this study, the SIA categories are presented and evaluated based on earlier approaches. The impact fields are established based on the literature reviewed in chapter 2.1. Figure 12 shows a finalised methodological CLIC appraisal model. The framework combines EIA (Johansson, 2016) 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 of their appraisal. The calculation is performed for technological,

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[10] *Accelerating Innovation @ CERN | Knowledge Transfer* (2022). Available at: https://kt.cern/ (Accessed: 24 January 2022).

[11] *Home | Procurement and Industrial Services Group* (2022). Available at: https://procurement.web.cern.ch/ (Accessed: 24 January 2022).

human capital and knowledge outputs. However, hereinafter, the measurable benefits and costs are discussed for the full SIA model.

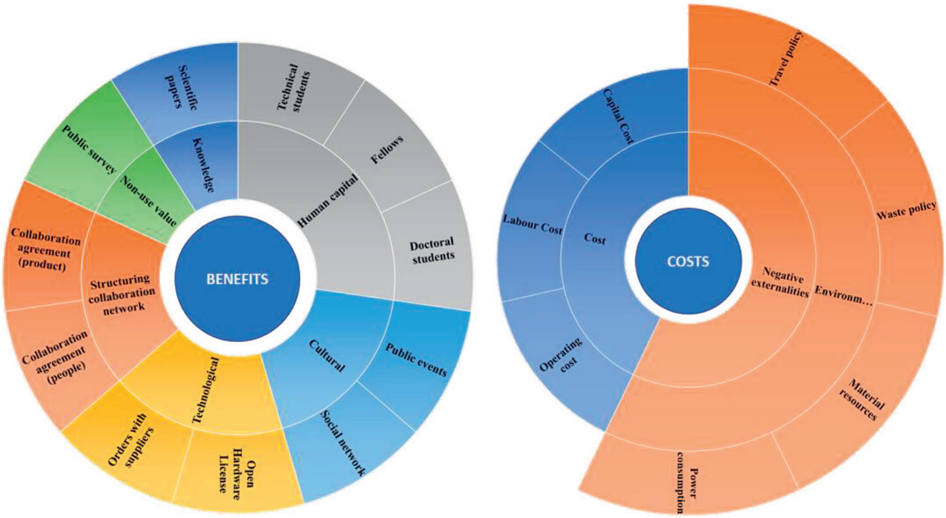

Figure 12. Benefits and costs for the SIA

Measurable benefits

Knowledge outputs (S) are new knowledge created based on produced scientific publications. The value is calculated based on the number of papers and its citations, 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 dedicated 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[12] and the Open Hardware Repository[13].

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

[13] "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).

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 an effect 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 effect 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 (Ruber et al., 2013) and the test module lab (Rossi et al., 2013); (2) number of public events, such as CERN Open Days (*CERN Open Days 2019 | Open Days 2019*, 2019), 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 (*Home | CLIC - Compact LInear Collider*, n.d.), 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 an effect of the formation of scientific collaborative networks.

The formation of collaboration network creates the benefits at different geographical levels. Universities are benefiting 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, which small institutes not always are. Moreover, the collaboration network creates additional advantages for industrial partners in terms of access to a list of qualified suppliers that have already proven their ability to provide high-quality products or services. Finally, the structuring network is like a big family with common scientific goals and motivations.

In the framework of this study, information on different types of collaboration agreements is collected, which forms an overall picture of the universities and institutes involved. CLIC has around 130 collaboration contracts with 180 universities and institutes (as of 2012).

The indicators are the number of collaboration agreements and related procurement activities, publications and ECRs related to CLIC. This can be claimed as a second-tier impact field, and CLIC's correlated share of the impact has to be established.

Economic costs

The cost estimation is presented in the CLIC project implementation plan (PiP) (Aicheler et al., 2018).

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) has been reviewed earlier in the CLIC EIA (Waaijer, 2011). Moreover, some estimations of power and energy consumption are reported in the CLIC PiP (Aicheler et al., 2018).

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 (Johansson, 2016), 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 (Florio & Sirtori, 2016), 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 the 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 due to limited time and resources and because earlier studies (Florio, Forte and Sirtori, 2015;

Battistoni *et al.*, 2016) have mentioned the three categories as the biggest benefits areas (Figure 13). 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.

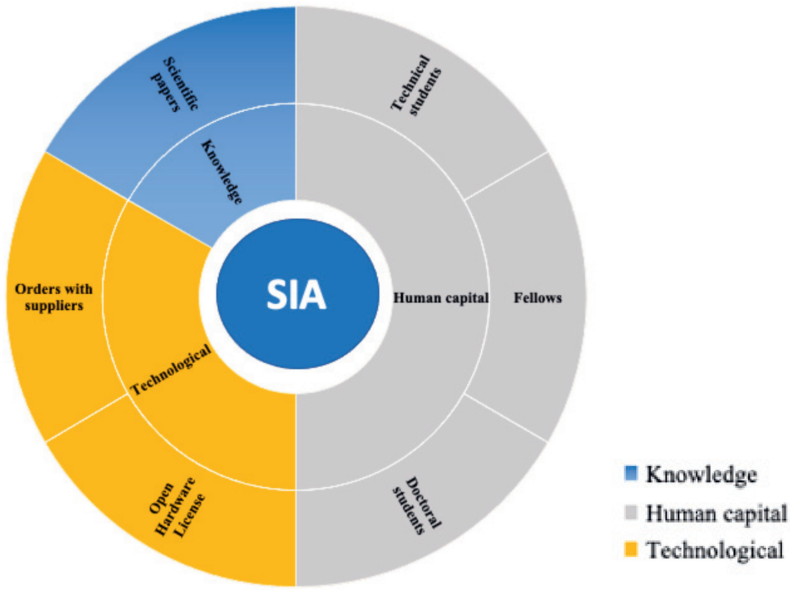

Figure 13. The assessed impact areas.

The economic cost 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 negative externalities of CLIC have already been discussed by Waaijer, (2011). However, this study does not include the final CBA. The final comparison is possible only when all the assessment fields have been measured. Therefore, it is proposed in the framework of the further study.

The guide to CBA (Sartori et al., 2014) issued by the European commission (EC) presents an economic appraisal tool. The appraisal steps from the guide are shown in Figure 14. Thus, 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, which is represented by the calculation of the economic net present value (ENPV). The value presents the difference between the discounted total social benefits and the costs. 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:

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

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

ENPV < 0 indicates that the society is better without the project—the opposite of the case when ENPV > 0, which means the society benefits from the project. Therefore, ENPV is the most important and reliable social CBA indicator and should be used as the main reference economic performance signal for project appraisal. "*Every project with an ERR*[14] *lower that the social discount rate or a negative ENPV should be rejected. A project with a negative economic return uses too many social valuable resources to achieve too modest benefits for all citizens. From EU perspectives, sinking a capital grant in a project with low social returns means diverting precious resources from a more valuable development use"* (Sartori et al., 2014).

Hereinafter, equation (2) of the ENPV calculation for a funded RI (FRI) complements the graphical representation in Figure 13 with the following categories: measurable benefits, economic costs and non-use value.

$$ENPV_{FRI} = \underbrace{[S + T + H + Str + C]}_{\text{MEASURABLE BENEFITS}} - \underbrace{[K + L_S + L_O + O + E]}_{\text{ECONOMIC COST}} + \overbrace{B_n}^{\text{NON-USE VALUE}}, \qquad (2)$$

[14] Economic rate of return

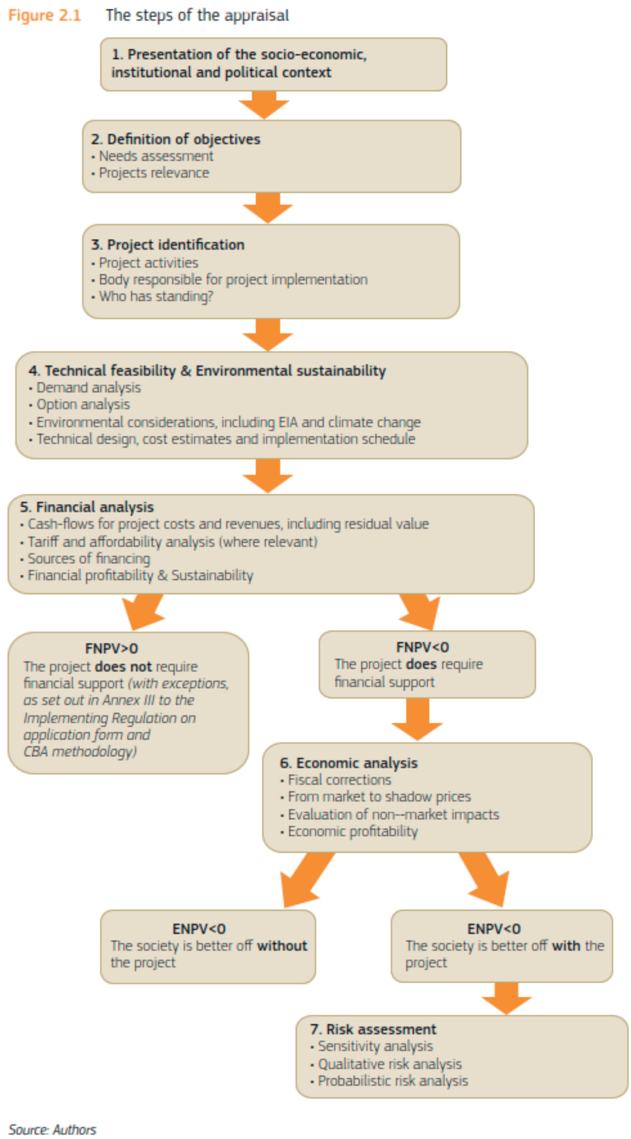

Figure 14. Appraisal steps from EU 2014.

3.4.1 Data model

The data model was built based on the previously introduced methodology, with following the parameters.

Timeframe

The data used in this study were collected from the active development phase of the project in the 2009 – 2019 period. The biggest volumes of procurement activities and research were performed at this period. Moreover, the earlier data were more difficult to collect.

Assessment categories

The data collection was focused on the aforementioned main assessment categories identified for this study: human capital via young researchers; technological impact on industries and knowledge benefits through publications. The data gathering for other categories has already been launched but must still be reviewed in the next related studies.

Social groups concerned

The main social groups concerned in the full assessment model are scientists, students and young researchers, firms in the procurement chains and other organisations, institutions, and the general public, including onsite and website visitors and other media users. This study focuses on ECRs, scientists and industry. Figure 15 presents the initial data gathered through multiple sources before filters were applied.

Figure 15. CLIC Data model.

3.4.2 Data collection

Data collection is a time-consuming procedure. It cannot be completely done by a machine or a programming code, even though the biggest part of the data collection was done with the help of an IT engineer who created a special code for data extraction. The data were collected from multiple sources using data triangulation. Hereinafter, data sources are specified according to the evaluated field.

Knowledge output (S): The data were collected from the internal CERN Document Server (CDS) [15], Inspire[16] and Collaboration institutes sources.

Technological output (T): The data were collected from orders recorded in the CERN procurement database and from an online survey on the spread of CLIC technologies and other clients.

Human capital (H): The data were collected from the CERN procurement database.

3.4.3 Benefits

Technological output

The technological outputs or benefits to firms-suppliers resulting from CERN contracts were already discussed in the earliest study (Bianchi-Streit et al., 1984) and are presented herein as increased turnover and cost savings:

$$Benefits = Increased\ Turnover + Cost\ Savings, \quad (3)$$

Moreover, the researchers calculated a utility/sales ratio based on the interviews with related companies. 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.

$$Utility = Sales \times corrected \frac{utility}{sales} ratio, \quad (4)$$

[15] "CERN Document Server," 2020. http://cds.cern.ch/ (accessed Apr. 27, 2020).

[16] "Home - INSPIRE," 2020. https://inspirehep.net/ (accessed Apr. 27, 2020).

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:

$$EBITDA\, margin = \frac{EBITDA}{total\, revenue}, \quad (5)$$

In other words, the EBITDA margin measures a company's operating profit as a percentage of its revenue. EBITDA is mentioned in earlier similar empirical studies (Battistoni et al., 2016; Cerb, 2019; Florio et al., 2016; Puliga et al., 2018). EBITDA allows evaluation of the true performance of the company not excluding expenses. Thus, the incremental turnover related to an RI can be computed as follow:

$$Incremental\, turnover = EBITDA \times Utility\, ratio \times sales\, from\, an\, RI, \quad (6)$$

Where the sales will be equal to the total value of the procurement orders received from CLIC.

Open Hardware License

Another component 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, Florio et al., (2016) discussed the software developed to analyse the LHC experimental data, which was made available for free. The benefit was calculated by multiplying the number of downloads and establishing the price of an equivalent commercial tool.

Open Hardware was highlighted in chapter 3.2 as one of the knowledge transfer models used at CERN (Nilsen & Anelli, 2016) to govern the use, copying, modification and distribution of hardware design documentation, as well as the manufacture and distribution of products (Chesta et al., 2013). 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.

Human capital output

One of our 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 (Florio et al., 2016), and for the next HL-LHC, up to 2038, the benefits raised up to 40% (Bastianin, 2018). Both estimations are based on the premium salary expectations, derived from Camporesi *et al.*, (2017). 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 and 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 (see Figure 16).

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 (Sartori et al., 2014), is:

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

The data were collected from the CERN procurement database. It provided the information on the contract type and the numbers of years of work at CLIC for fellows and doctoral and technical students.

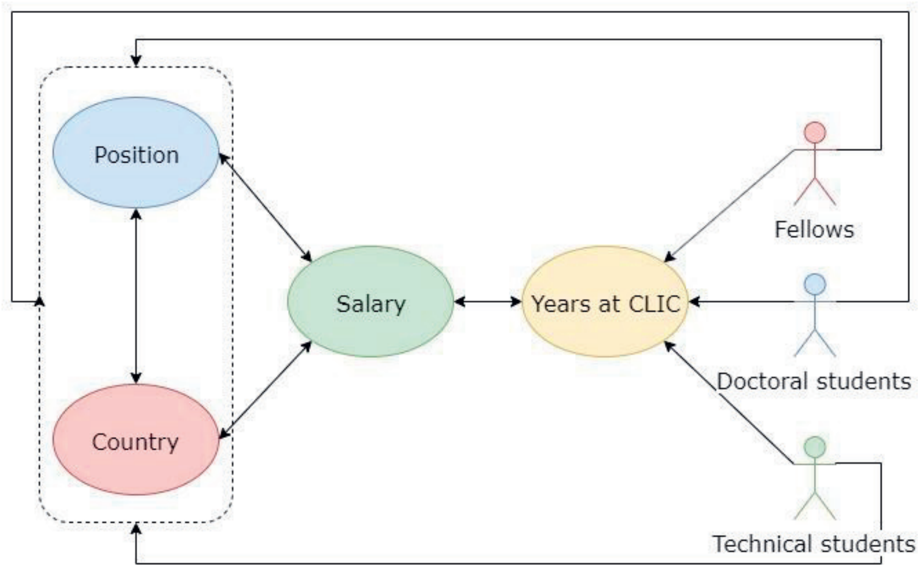

Figure 16. Human capital data model.

Knowledge output

For the evaluation of the knowledge outputs or benefits of FRIs to scientists the bibliometric techniques applied in several studies (Davidse & Van Raan, 1997; Del Bo, 2016; Brown *et al.*, 2021; Simmonds *et al.*, 2016; Belz, 2016) can also be used. One of the well-explained approaches to evaluating the fundamental science knowledge outputs of large-scale infrastructure was presented by Florio & Sirtori (2016). Such established approach has also been implemented in a health care project of CNAO (Battistoni et al., 2016) and in HL-LHC (Bastianin, 2018). 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 forecasting and monetising the outputs and calculating the ENPV.

There are two important numbers 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. Moreover, for already operating facilities, the total value comprises the following: (1) the past number of project-related scientific publications (L0) and citations in L1 scientific papers and (2) the forecasted number of publications for the evaluation period. Thus, the following important parameters are considered in the calculation (Florio et al., 2016):

(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 Florio et al. (2016), 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 $\sum_{t=0}^{\tau} 1/n_t$. In addition to the listed parameters, Brown et al. (2021) considered 8 as the average number of authors per paper and 9 as the estimated time that each co-author spends working on a single paper. However, the marginal value of a paper, as calculated in two studies has a significant range. The Diamond Light Source (DLS) in the UK (Brown et al., 2021) calculated the marginal value of various research fields and arrived at the following numbers: biology – £76,267; chemistry – £59,865 and physics – £84,191. CNAO assumes that the unit production cost/values of L0 and L1 papers are approximately €275 and €265, respectively. LHC (Florio et al., 2015) calculated the marginal social value (MSV) of its publications and forecasted their trajectories over a period of 50 years. The MSV picked in 2013, at around 14,000 k€ for L1 papers, 4400 k€ for L0 citations, and 17,500 k€ for L1 citations. The average number of citations per publication also differs from one study to another. LHC forecasted an average of four citations per paper, whereas CNAO used a mean value for the citation factor that was between 1 and 2, although DLS had a higher mean number equal of 25.33.

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 and the Inspire database (see Figure 17).

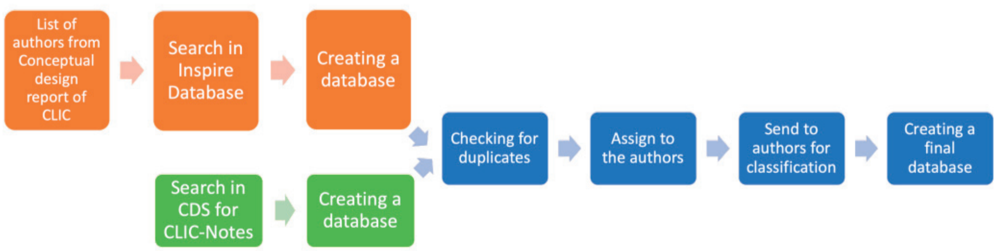

Figure 17. Publication data collection.

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 and can be removed. 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:

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

3.5 Conceptual framework of Societal Impact Assessment: External viewpoint

The SIA was evaluated from an external viewpoint by industrial partners through the data collected via an online survey of CLIC suppliers. The focus of this study is the evaluation of the collaboration between research organisations and industry. The conceptual framework was built heavily on the earlier research on RIC, paying specific attention to fundamental science RI. Hereinafter, the term RIC is used as a general term for the relationship between academies, universities, RIs, Big Science and industry. This assumption is presumed to be appropriate for this study and should not lead to any misleading results thereof. This study set out to evaluate six possible outcomes of RIC generated during the development and planning phase of the CLIC study.

The conceptual model, including the variables and the hypotheses, is summarised in Figure 18. The development of the measures was justified from previous research and discussed in chapter 2.2.

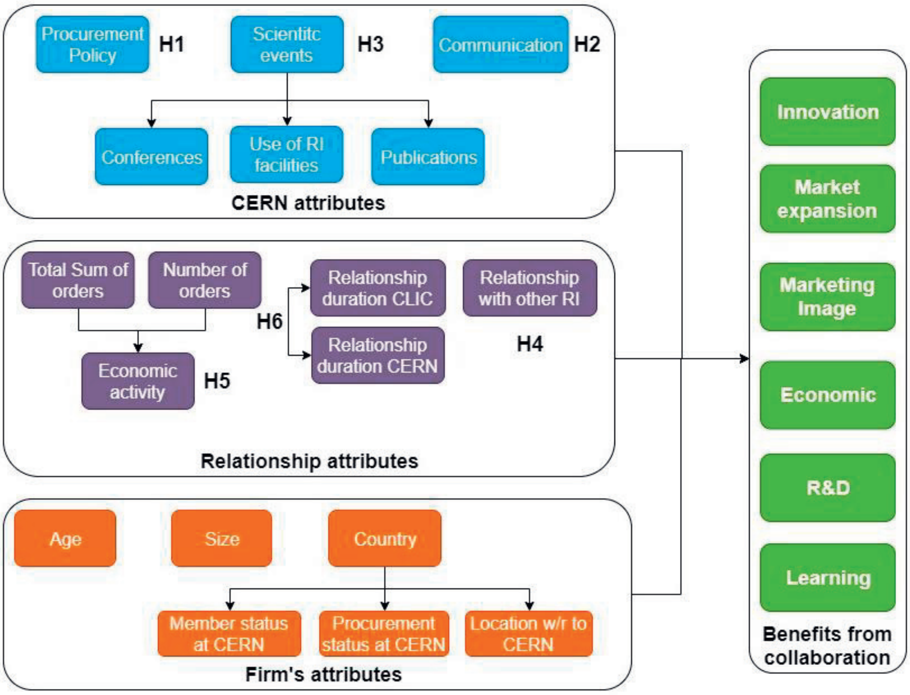

Figure 18. Conceptual Model.

3.5.1 Data Collection

The primary data were collected first from the CERN procurement database and second from an online survey of CLIC suppliers in November 2020 via the Webropol platform[17].

The sampling was done based on the initial data from the CLIC procurement database. All orders were from 2009 to the start of 2020. Based on the extracted value, about 930 organisations, including commercial companies and different research institutions, were found. Several filters were applied. First, non-commercial organisations and companies that provide services, education, and catering were removed from the search results to focus only on hi-tech firms. Second, procurement-intensive suppliers with a total procurement amount higher than 19

[17] "Surveys By The Millions | Webropol," https://webropol.com/. https://webropol.com/ (accessed Mar. 02, 2021).

kCHF were retained. The final sample included 152 suppliers which was about 47% of the initial procurement data and about 69% of the number after excluding the contracts for services and institutional collaborations (see Figure 19).

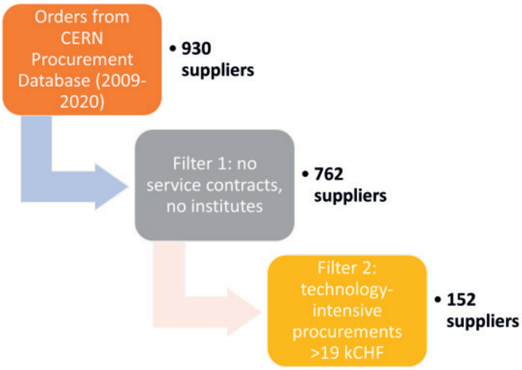

Figure 19. Industrial settings.

3.5.2 The Survey

The survey distribution was done in two steps. The pilot distribution was done by email to known suppliers to collect their feedback and check the clarity and comprehensibility of the questions. The pilot version was distributed to 22 suppliers in the period of February to April 2019.

The pilot distribution revealed that the questions were clear, and that the companies did not have difficulties in giving their feedback. For the final distribution an electronic survey platform was used which allowed a convenient sharing of the survey with suppliers and the easier accessibility and analysis of the results. Moreover, the online platform created equal conditions for the respondents, which guaranteed the reliability of the data collection process. The e-survey platform options were Google Forms, Survey Monkey, the CERN workspace platform and Webropol. The last was found to be the most convenient and practical way of distributing and collecting feedback. The last version of the questionnaire was distributed at the end of November 2019 to the rest of the suppliers, and a reminder was sent to them after two weeks, right before Christmas. A total 57 suppliers responded in the second round of which 54 gave feedback and 3 refused to provide information. One reason for the refusal was that the size of the business with CERN is small compared to the total turnover of the company. The final achieved reply rate was 48.7%, with the pilot group included (see Figure 20).

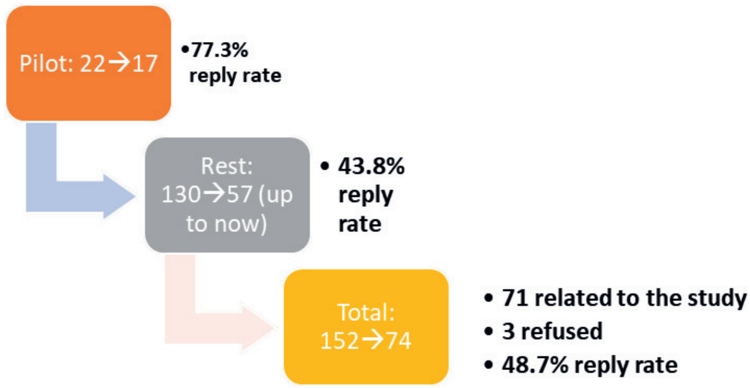

Figure 20. Survey reply rate.

3.5.3 Survey variables

The survey responses were gathered to obtain the variables employed in the statistical analysis. Six dependent variables were identified as benefits of a supplier from RIC: (1) increased knowledge, (2) market expansion, (3) enhanced marketing image, (4) improved economic performance, (5) improved internal R&D process and (6) learning or quality improvement of (6.1) a service, (6.2) a process and (6.3) logistics.

Dependent variables or Benefits from collaboration

Knowledge benefit or innovation was measured on a Likert scale of 1 to 5. The variable represents how a firm used new knowledge gained from the collaboration in its other business lines. A value of 1 meant strong disagreement with the mentioned statement and 5 meant strong agreement with it.

Market expansion was measured on a Likert scale of 1 to 5. The variable represents how a firm increased the number of its clients for the same technology during the collaboration with CERN. A value of 1 meant strong disagreement with the mentioned statement and 5 meant strong agreement with it.

Marketing image was measured on a Likert scale of 1 to 5. The variable represents a firm's agrees experience of marketing benefits in terms of reference and image lifting due to its collaboration with CERN. A value of 1 meant strong disagreement with the mentioned statement and 5 meant strong agreement with it.

Improved economic performance was measured with two values: the annual company turnover related to CERN and the annual company turnover related to other scientific laboratories. Both values were transformed to the same Likert scale of 1 to 5, as for the other dependent variables, and the average of the two values was used for the regression analysis. The variable represents how a firm economically benefits by providing related services and products to CERN or to other scientific laboratories. Therefore, a value of 1 meant there was no related % of turnover and 5 meant there was 100% turnover related to the technology provided to scientific laboratories.

R&D was measured on a Likert scale of 1 to 5. The variable represents how a firm improved its R&D operations due to its collaboration with CERN. A value of 1 meant strong disagreement with the mentioned statement and 5 meant strong agreement with it.

Learning benefits were broken down into three categories: improved quality of provided services, improved internal production processes and improved logistics.

Learning about or improving the quality of provided services was measured on a Likert scale of 1 to 5. The variable represents how a firm improved its provided services due to its collaboration with CERN. A value of 1 meant strong disagreement with the mentioned statement and 5 meant strong agreement with it.

Learning about or improving the quality of internal production processes is measured on a Likert scale of 1 to 5. The variable represents how a firm improved its production process due to its collaboration with CERN. A value of 1 meant strong disagreement with the mentioned statement and 5 meant strong agreement with it.

Learning about or improving the quality of logistics was measured on a Likert scale of 1 to 5. The variable represents how a firm improved its logistics due to its collaboration with CERN. A value of 1 meant strong disagreement with the mentioned statement and 5 meant strong agreement with it.

The independent variables were grouped into three categories: the firms' attributes, the RI attributes, and the relationship attributes. The firms' attribute variables were controlled.

Control variables or Firms' attributes

The ability of industry to collaborate with Big Science centre depends on the firm's attributes, such as its size, age, and field of operations. Large enterprises are more easily motivated to invest resources in research and development than small companies are (Florio et al., 2018; Levy et al., 2009). Large companies gain more knowledge benefit through RIC than smaller companies do. According to Soh and Subramanian (2014), younger companies benefit more from RIC than older companies do due to their creativity and entrepreneurial character. They also benefit from academic inputs. The role of geographic proximity has been widely discussed in relevant literature. It is one of the influential factors in collaborations (Levy et al., 2009). Still, Gibson et al. (1994) claimed that proximity is less important for firms seeking basic research than for firms seeking applied research. Likewise, Arundel & Geuna (2004) disagreed on the crucial effect of geographic proximity in a consortium's collaboration but confirmed its key role for local research universities. The three mentioned factors—age, size, and location—introduced to act as controls of the benefits of RIC to industry.

Firm's size is a dummy categorical variable, defined by the company annual turnover and coded as 1 if the supplier is a micro enterprise (≤ €2 million revenue), 2 if small (€2 million ≤x≤ €10 million), 3 if medium-sized (€10 million ≤x ≤ €43 million) and 4 if large (≥ €43 million). The value was extracted from the survey.

Firm's age is a numerical variable in years that measures the age of the supplier on the year of the survey, 2020. The value was extracted from the survey.

Country code 1 (the member status at CERN) is a dummy categorical variable that measures the status of the supplier's country at CERN[18]. The status presents the level of relationship of a country with CERN. The data were used as stated in May 2020. The variable was coded as 1 if the country was not a CERN Member State, 2 if an observer, 3 if an associate Member State member and 4 if a Member State.

Country code 2 (procurement status at CERN) is a dummy categorical variable that measures the industrial return from CERN. The industrial return is defined as the return coefficient of a country over a period of years. It is represented by the ratio between a country's percentage share of the value of all supply contracts and that country's contribution to the CERN budget. The data were used as stated in May 2020. The variable was coded 1 if the supplier was not on any list, 2 if in a very poorly balanced country (return coefficient < 0.4), 3 if the country is poorly balanced ($0.4 <$ return coefficient < 1), and 4 if the country is well balanced (return coefficient ≥ 1).

Country code 3 (location with respect to CERN) is a dummy categorical variable that measures the geographical location of the supplier regarding CERN. It was coded as 1 if the distance was over 1500 km, 2 if less than 1500 km, and 3 if the country of the supplier is on the border with Switzerland.

Independent variables or CERN attributes

CERN's attributes were measured with the following variables.

Procurement policy is represented by two ordinal variables: "*How difficult it was to start collaboration with CERN?*" and *"How difficult do you find the CERN procurement/tender process?"*. Each was coded from 0 to 10 on a Likert scale that represented the firm's level of agreement on the cited statements. The value was 0 for *'not at all difficult'* and 10 for *'extremely difficult'*.

Communication is represented by two ordinal variables "*It is easy to know whom to contact when a problem occurs during the production/procurement*" and *"It is easy to find/ to get the required information about the project"*. Both variables were measured on a Likert scale of 1 to 5, with a value of 1 meaning *'strongly disagree'* and 5 meaning *'strongly agree'*.

The group of scientific events was captured by the following ordinal variables.

[18] "Member States | CERN," *https://home.cern/about/who-we-are/our-governance/member-states*. https://home.cern/about/who-we-are/our-governance/member-states (accessed Mar. 01, 2021).

Conferences is the ordinal variable, was measured on a Likert scale of 1 to 5. The variable indicates the firm's level of agreement on the statement *"the company participates in scientific conferences, workshops, fairs"*. A code of 1 meant *'strongly disagree'* and 5 meant *'strongly agree'*.

Use of RI facilities is the ordinal variable, was measured on a Likert scale of 1 to 5. The variable indicates the firm's level of agreement on the statement *"the company will appreciate a possibility to use CERN Infrastructure for their current or future needs"*. A code of 1 meant *'strongly disagree'* and 5 meant *'strongly agree'*.

Publications is the ordinal variable, was measured on a Likert scale of 1 to 5. The variable indicates the firm's level of agreement on the statement *"the company produced publications due to business with CERNs"*. A code of 1 meant *'strongly disagree'* and 5 meant *'strongly agree'*.

Independent variables or Relationship's attributes

The last group of variables presents the relationship attributes: economic activity, relationship with CERN and relationship with other RIs.

Economic activity was captured by the following two numerical variables.

Total amount charged from the budget is a numerical variable measured by the total amount of money that the supplier received from CLIC. The value was extracted from the CERN procurement database.

Total number of orders is a numerical variable measured by the total count of orders that the supplier received from CLIC. The value was extracted from the CERN procurement database.

The relationship with CERN was captured by the following two ordinal variables.

The duration of the supplier's relationship with CLIC was calculated as the difference between the year of this study (2020) and the year of the supplier's first order from CERN's CLIC study team. The item has a discrete value. The value was extracted from the CERN procurement database.

The duration of the supplier's relationship with CERN was calculated as the difference between the year of this study (2020) and the year when the supplier started collaborating with CERN. The date was provided by the supplier. The item has a discrete value. The value was extracted from the survey.

The supplier's relationship with another RI is a numerical value measured by the numbers of institutes collaborating with the supplier. The value was extracted from the survey. Table 2 shows the full list of variables.

Table 3 demonstrates the Pearson's correlation that measures the statistical relationship between two variables. Thus, it provides information on the magnitude and direction of the association. Moreover, following Autio and Hameri (2003), the presented results confirm that the relationship benefits occur together. There is a high correlation between the five types of benefits. The exception is the economic outcome. Therefore, a supplier that derives one type of benefit from CERN procurement activities is also more likely to derive other types of benefits from the same relationship. The LHC study (Autio et al., 2003) demonstrated a high inter-correlation between learning, innovation, and performance impacts from technological procurement by government-funded science organisations.

Table 2. Variables

Variable	Mean	Std. Dev
Dependent variables		
Innovation/knowledge benefit	3.23	1.256
Market expansion	2.83	1.352
Marketing image	3.37	1.256
Economic	1.42	0.551
R&D	3.14	1.447
Improve of quality of provided services	3.15	1.203
Improve of quality of internal production processes	3.08	1.156
Improve of quality of logistics	2.89	1.115
Control variables		
Firms' attributes		
Size	2.577	1.0510
Age of the company	42.75	28.249
Country code 1 (status with CERN)	3.68	0.770
Country code 2 (balanced, data on the 18.5.2020 (*Industrial Returns for CERN Member States' Procurement and Industrial Services Group*, no date))	3.25	1.065
Country code 3 (Location)	2.49	0.754
Independent variables		
RI attributes		
Procurement policy		
How difficult it was to start collaboration with CERN?	5.41	1.968
How difficult do you find the CERN procurement/tender process?	4.90	2.132
Communication		
Know whom to contact when a problem occurs during the production/procurement	3.76	1.236
Find/ to get the required information about the project	3.54	1.119
Scientific events		
The company participates in scientific conferences, workshops, fairs etc.	3.44	1.432
The company will appreciate a possibility to use CERN Infrastructure for their current or future needs	2.44	1.481
The company produced publications due to business with CERN	1.93	1.138
Relationship attributes		
Economic activity		
Total Sum of Charged to Budget Code (CHF)	293776	720495.5
Total Count of Order Item	16.56	30.153
Relationship with CERN		
Relation duration with CERN	18.56	13.017
Relation duration with CLIC	7.72	3.131
Relationship with other RI		
Do you have collaboration/business with other Research Institutes (number)?	4.46	4.991

Table 3. Pearson's correlation

	Innovation	Market Expansion	Marketing image	Economical	R&D	Improve of quality of provided services	Improve of quality of internal production processes	Improve of quality of logistics	Size	Age of the company	Country code 3 (Location)	How difficult it was to start collaboration with CERN?	How difficult do you find the CERN procurement/tender process?	find/ to get the required information about the project	The company participates in scientific conferences, workshops, fairs etc.	The company will appreciate a possibility to use CERN Infrastructure for their current or future needs	The company produced publications due to business with CERN	Total Sum of Charged to Budget Code (CHF)	Total Count of Order Item	Relation duration with CERN	Relation duration with CLIC	Do you have collaboration/business with other Research Institutes (number)?
Innovation	1.000																					
Market Expansion	0.671**	1.000																				
Marketing image	0.436**	0.466**	1.000																			
Economical	0.168	0.294*	0.031	1.000																		
R&D	0.635**	0.677**	0.529**	0.206	1.000																	
Improve of quality of provided services	0.676**	0.666**	0.567**	0.157	0.685**	1.000																
Improve of quality of internal production processes	0.715**	0.704**	0.559**	0.142	0.753**	0.833**	1.000															
Improve of quality of logistics	0.610**	0.631**	0.478**	0.190	0.674**	0.716**	0.850**	1.000														
Size	0.246*	0.090	0.097	-0.156	0.143	0.024	0.053	0.062	1.000													
Age of the company	-0.201	-0.213	-0.132	-0.282*	-0.075	-0.276*	-0.277*	-0.165	0.189	1.000												
Country code 3 (Location)	-0.104	-0.001	-0.073	-0.074	-0.078	-0.054	0.034	-0.001	0.104	0.089	1.000											
How difficult it was to start collaboration with CERN?	0.118	0.171	0.233	0.028	0.195	0.238*	0.154	0.125	0.123	-0.109	0.074	1.000										
How difficult do you find the CERN	0.104	0.049	-0.040	0.099	-0.097	-0.066	-0.101	-0.023	0.039	-0.160	0.057	-0.024	1.000									

procurement/tender process?																						
find/ to get the required information about the project	0.238*	0.202	0.346**	0.038	0.262*	0.298*	0.219	0.198	0.116	-0.162	0.072	0.366**	-0.002	1.000								
The company participates in scientific conferences, workshops, fairs etc.	0.358**	0.334**	0.267*	0.247*	0.459**	0.416**	0.357**	0.273*	-0.094	-0.025	-0.004	-0.003	0.239*	0.191	1.000							
The company will appreciate a possibility to use CERN Infrastructure for their current or future needs	0.430**	0.458**	0.251*	0.424**	0.464**	0.282*	0.345**	0.298*	0.005	-0.189	-0.247*	0.168	0.005	0.271*	0.205	1.000						
The company produced publications due to business with CERN	0.361**	0.391**	0.218	0.129	0.449**	0.269*	0.341**	0.354**	0.172	-0.009	0.108	0.147	0.091	0.030	0.431**	0.425**	1.000					
Total Sum of Charged to Budget Code (CHF)	0.020	0.194	0.139	-0.111	0.157	0.091	0.115	0.025	-0.040	-0.144	-0.042	0.099	-0.157	0.115	0.212	0.126	0.200	1.000				
Total Count of Order Item	0.132	0.145	-0.101	-0.083	0.103	0.133	0.139	0.155	0.027	-0.064	0.246*	0.026	0.035	0.029	0.078	-0.106	0.042	0.168	1.000			
Relation duration with CERN	-0.167	0.082	0.003	-0.018	-0.075	-0.077	-0.123	-0.056	0.090	0.351**	0.410**	0.037	0.196	-0.118	0.104	-0.103	0.265*	0.051	0.040	1.000		
Relation duration with CLIC	0.296*	0.235*	0.008	-0.072	0.050	0.000	0.105	0.130	0.152	0.020	0.169	-0.032	0.009	-0.046	0.044	-0.056	0.167	0.218	0.420**	0.164	1.000	
Do you have collaboration/business with other Research Institutes (number)?	0.250*	0.467**	0.287*	0.210	0.321**	0.354**	0.206	0.156	-0.144	-0.084	-0.031	0.236*	0.147	0.205	0.379**	0.330**	0.240*	0.389**	0.074	0.200	0.051	1.000

***, **, * denote significance at the 1%, 5% and 10% level respectively.

4 RESULTS AND DISCUSSION

4.1 Phase 1. Societal Impact Assessment: Internal viewpoint

This chapter presents an evaluation of our three impact fields: technological output, human capital formation and knowledge formation. The mentioned fields are those where the biggest of benefits have been seen for LHC. Nevertheless, for the complete picture of the societal impact, further evaluation must be accomplished.

4.1.1 Technological output

The technological output is based on CLIC's estimation of its benefits to companies-suppliers. Following Florio's research methodology, the components of the technological impact of an international study are (1) through procurement activities and (2) through the use of existing software. In the technological output evaluation for CLIC, the same methodology was kept. Data were collected from the CERN procurement database and from an industrial survey, which is discussed in detail in chapter 4.2. The initial data were collected from the CERN procurement database. Information on 15,000 orders and 930 suppliers were collected. After applying filters, the sample group comprised 152 companies and the accumulated value of the orders was cut off at 19 kCHF. Figure 21 demonstrates the total number of orders initially collected from the CERN procurement database, where the total number of orders >19 kCHF by column and row represents the total number of suppliers in the two mentioned cases.

Figure 22 embodies the CLIC order contributions according to the country of each supplier. The highest economic return was registered by industrial partners in France, Germany, Sweden, and Switzerland. France is also listed as a country closely located to CLIC, while Sweden provides one of the most expensive technologies required for CLIC: klystrons and modulators.

Figure 21. Number of CLIC orders with suppliers.

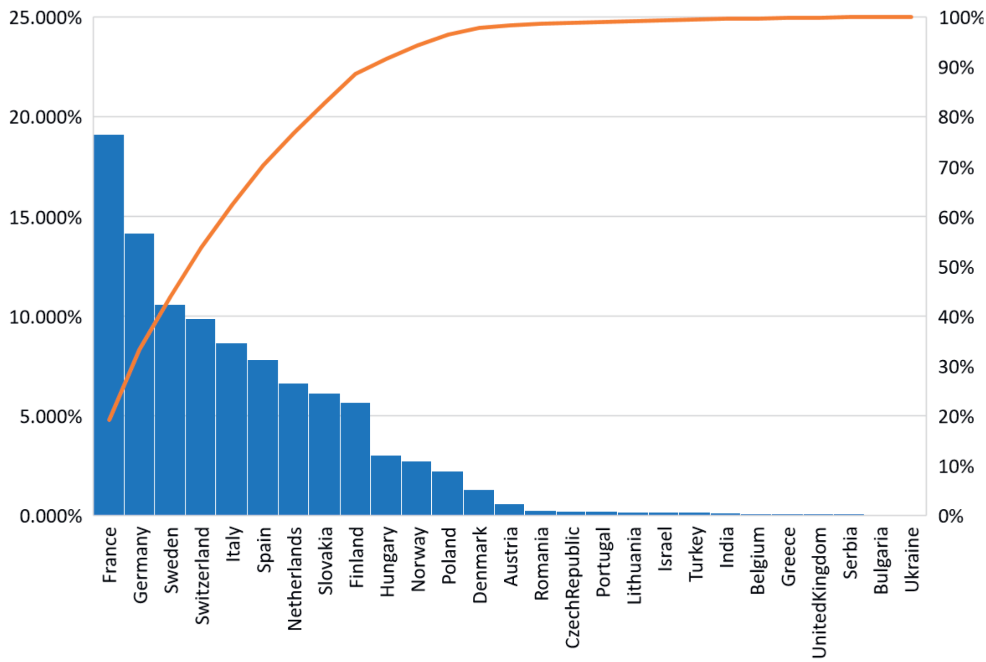

Figure 22. CLIC contribution

Thus, in Table 4 the results of the incremental profits of firms are summarised based on the following indicators: (1) EBITDA, extracted from the CLIC suppliers' sample; (2) EBITDA, extracted from the high-tech companies matched with the CLIC and LHC activity codes; and (3) incremental profits, proportional to the increase in the number of clients because of the CLIC technology and because of the collaboration with CLIC.

Table 4. Incremental profits to firms.

Method	Margin	Sample	Source	Value	STD	Benefits Total MCHF	STD MCHF
1	EBITDA	CLIC suppliers	Orbis.com	10.4%	7.2%	8.754	6.06
2	EBITDA	Suppliers matched with LHC activity codes	Orbis.com	13.1%		11.03	
3	Increase in clients (self-estimation from the industrial survey)	CLIC suppliers	Industrial Survey	11.1%	21.2%	9.34	17.85

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% (Florio et al., 2016) and for CNAO, 7% (Battistoni et al., 2016).

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 detailed information on the industrial settings is presented in chapter 3.4.

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 4).

Open Hardware License

Simultaneously with the industrial study, the CLIC X-band production team created a web page for the open hardware license (OHL) components. The page provides access to technical 3D models and manufacturing drawings for main CLIC X-band components that have already been developed at CERN (Figure 23). A new concept of OHL shares the same principle as that of a well-known open-source software concept (Feller & Fitzgerald, 2002): anyone should be able to (1) access the source, (2) study it, (3) modify it and (4) share it under the same license conditions. Thus, the entire scientific community benefits from the introduced improvements. Moreover, open dissemination is sometimes the best way to achieve wide and long-lasting effects, especially when a low initial investment is needed to reach an exploitable maturity level (Chesta et al., 2013).

Figure 23. OHL for CLIC X-band 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.

Table 5. 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

Assuming that the research and development time from was 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. 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 5). 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.

4.1.2 Human capital output

Based on the data collected, the biggest part of the young researchers came from the UK (17%), Italy (12%), Spain (11%) and France (10%) (Figure 24). They were 22% female and 78% male. It is interesting that the gender distribution changed with the development of their career. Thus, from 25% female technical students, 22% pursued the doctoral studies and only 18% pursued post-doctoral studies and fellowships (Figure 25). The 106 doctoral students were from 44 universities: 30% from the UK, 12% from Switzerland, 11% from Spain, 8% from Italy and 8% from France. The 68 technical students came from 54 universities: 16% from Finland, 15% from Italy, 12% from Greece, 7% from Norway and 7% from France. The 63 fellows came from 15 countries: 17% from Spain, 16% from Italy, 14% from France, and 10% from Germany (Figure 26).

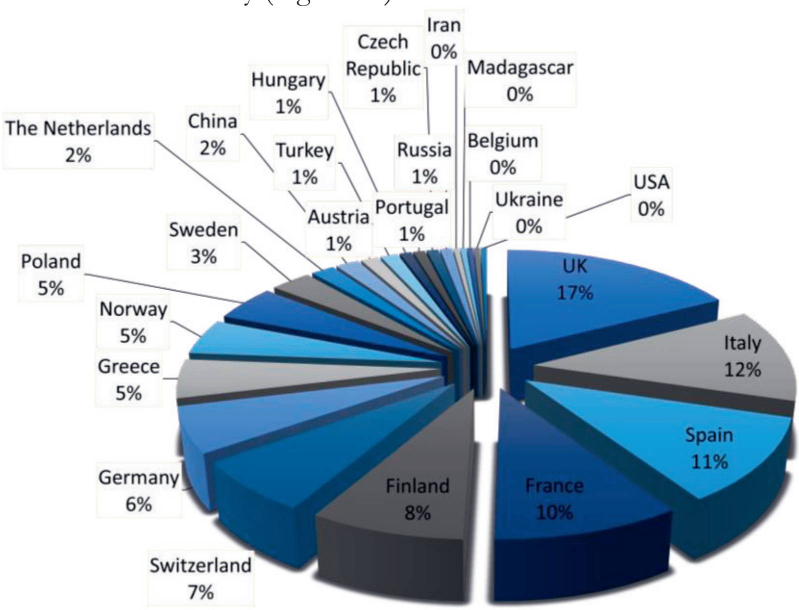

Figure 24. Countries of CLIC ECR.

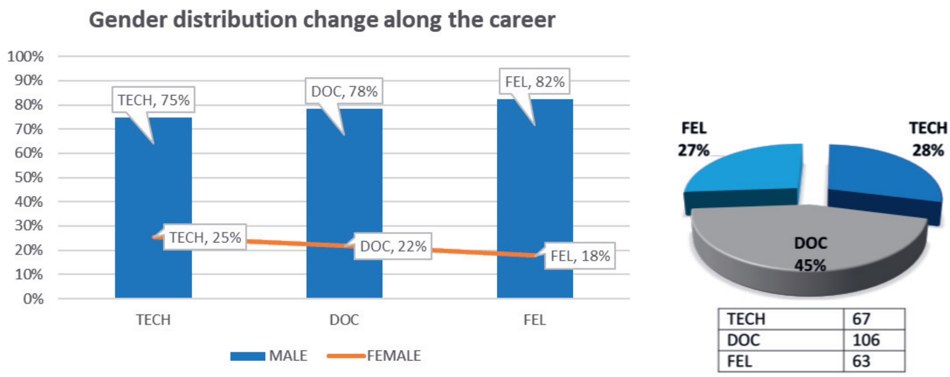

Figure 25. ECR distributions.

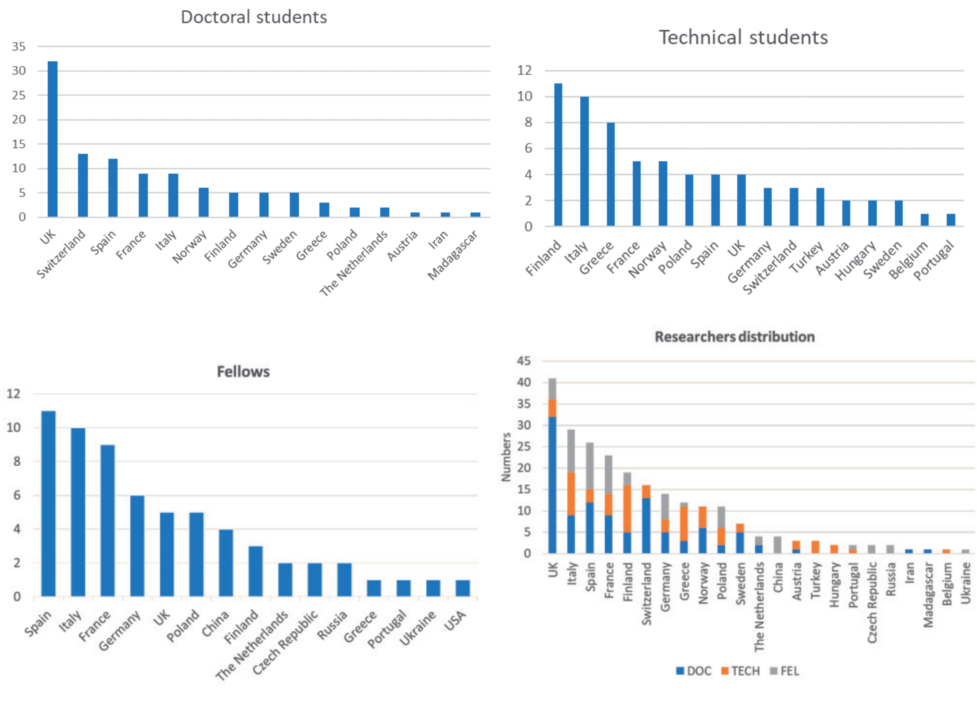

Figure 26. ECR countries.

The post-CLIC career choice shifted towards the Academy. More than 50% ECRs stayed in academy and research centres; 20%, in industry; and 10%, in other fields (see Figure 27 a and b). In general, 25%, 22% and 19% of the ECRs stayed at CERN after participating in technical, doctoral and fellowship programs. The decrease in the percentage is logical because first, each higher career step at CERN is more difficult because of its general employment rules; and second, researchers choose to go back to their home countries after completion of their first career steps. In turn, about 55% of technical students embark on a PhD program after CERN and 31% stay to do a PhD at CERN.

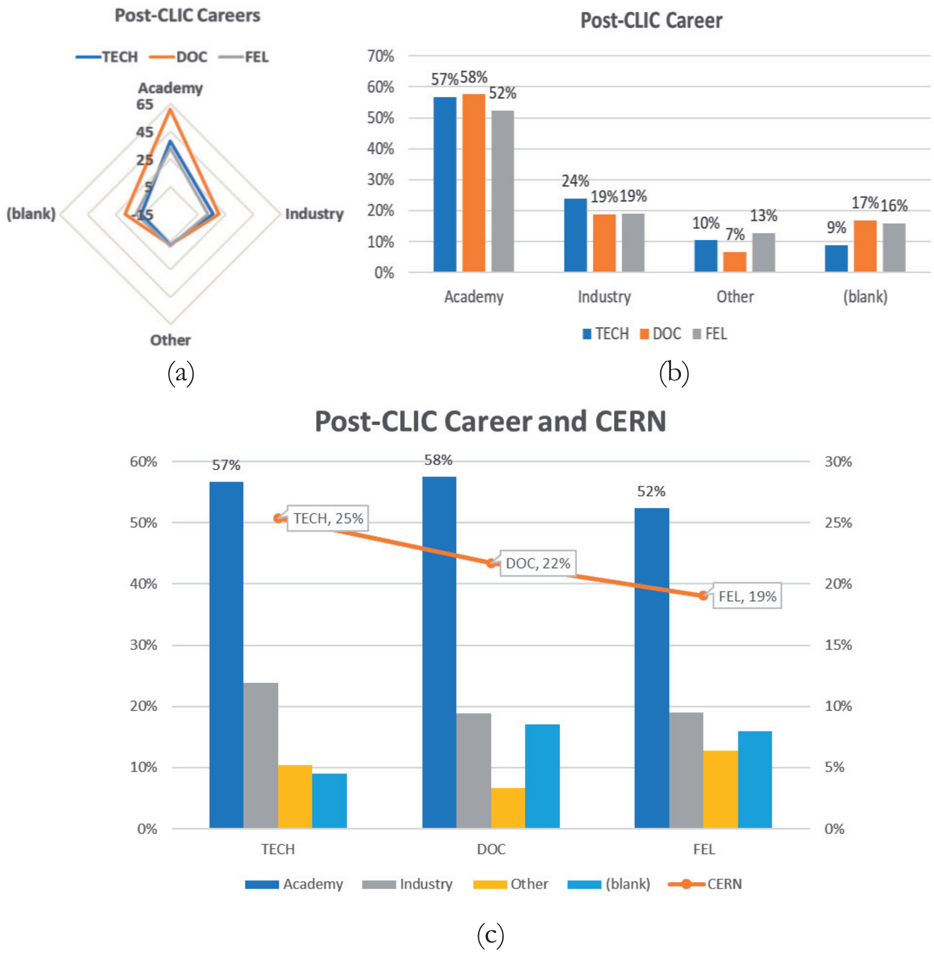

Figure 27. Post-CLIC careers.

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. There are three categories of ECRs: technical students, doctoral students and fellows (see Table 6).

The salary premium was calculated based on the data collected from two sources, allowing the benchmarking of the results:

- $\Delta\ salary_i$ from payscale.com[19];

where $\Delta\ salary_i$ is the difference in salaries between skilled and average specialists per profession: engineers, researchers and managers; and

- percentage premium from the LHC study (Florio et al., 2015)– of 11.8%.

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

Table 6. Salary premium.

Category	Source	Not discounted CERN salary premium (CHF)	Discounted salary CERN premium (CHF)	Benefit/Cost ratio
Technical students	Payscale.com	Over 40 years: 245975 Per year: 6149	Over 40 years:142141 Per year: 3554	6.3
	11.8%	Over 40 years: 388706 Per year: 9718	Over 40 years: 224621 Per year: 5615	10
Doctoral students	Payscale.com	Over 40 years: 386292 Per year: 9657	Over 40 years: 223227 Per year: 5580	4.3
	11.8%	Over 40 years: 388706 Per year: 9718	Over 40 years: 224621 Per year: 5615	4.3
Fellows	Payscale.com	Over 35 years: 269809 Per year: 7709	Over 35 years: 165641 Per year: 4441	0.9
	11.8%	Over 35 years: 340130 Per year: 9718	Over 35 years: 208805 Per year: 5220	1.2

The values were calculated based on different sources. 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.

4.1.3 Knowledge output

From CDS all publication mentioned as CLIC-Notes were extracted. For the Inspire database the search was done by the authors, as previously defined based on the CLIC Conceptual Design Report's author list (Aicheler et al., 2012) and the keyword *'CLIC'*. The results were combined in the single database and checked for the duplicates. Later, each publication was assigned to a responsible person for further

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

appraisal of its applicability. Thereby, the publications were distributed and each person responsible was asked to confirm the relevance of the paper and to specify a publication topic and related technology. The person received the list of publication topics and technologies, preliminarily defined based on the procurement database and CDS.

After the aforementioned manipulation, the database counts became 1767 publications and 61 authors or responsible persons. However, the final distribution was done for 1635 publications and 45 authors because of the retirement of some authors and the impossibility of assigning their works to another person. The summary is presented in Table 7. The distributed publications are 93% of the initial total number. Thirty-two responsible persons provided feedback on 79% of the initial publications and 74% of the final count. Moreover, some authors completed the initial data with about 8% more publications.

Table 7. Database of publications

	Publications	Received	From total
Sent	1635	1400 (+8% of new)	93%
Classified	1299	79%	74%
Total	1767	108%	

Based on the collected bibliometric data, the most cited authors, topics and years were identified.

The number of citations per paper was collected through two databases: Inspire and GoogleScholar (see Figure 28).

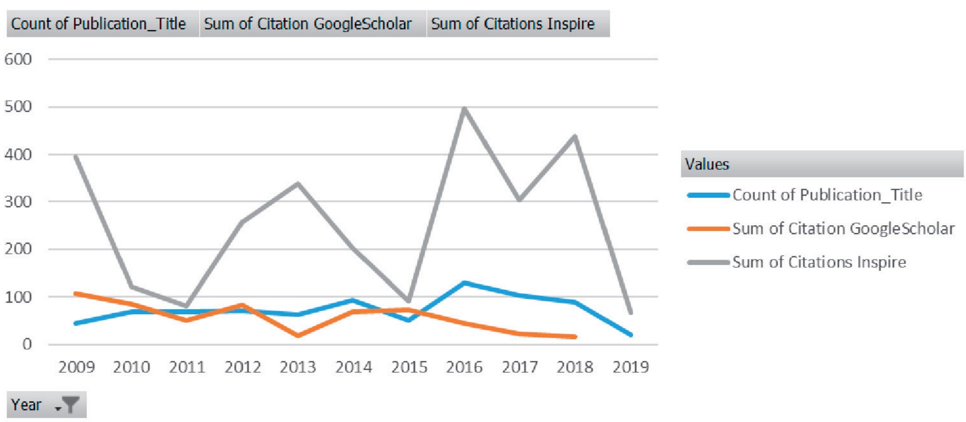

Figure 28. L0 and citations by L1(1)

The average number of citations per paper is 3.5. Figure 29 shows the number of papers per year for CLIC from 1985 to 2019. The citations by L1 were collected from 2007, considering the timeline of the intense CLIC research and its development period.

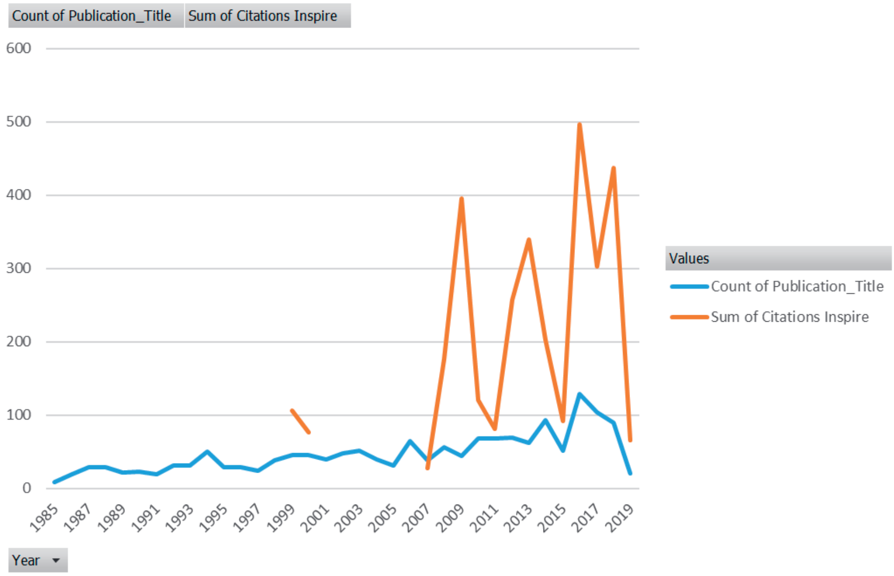

Figure 29. L0 and citations by L1 (2)

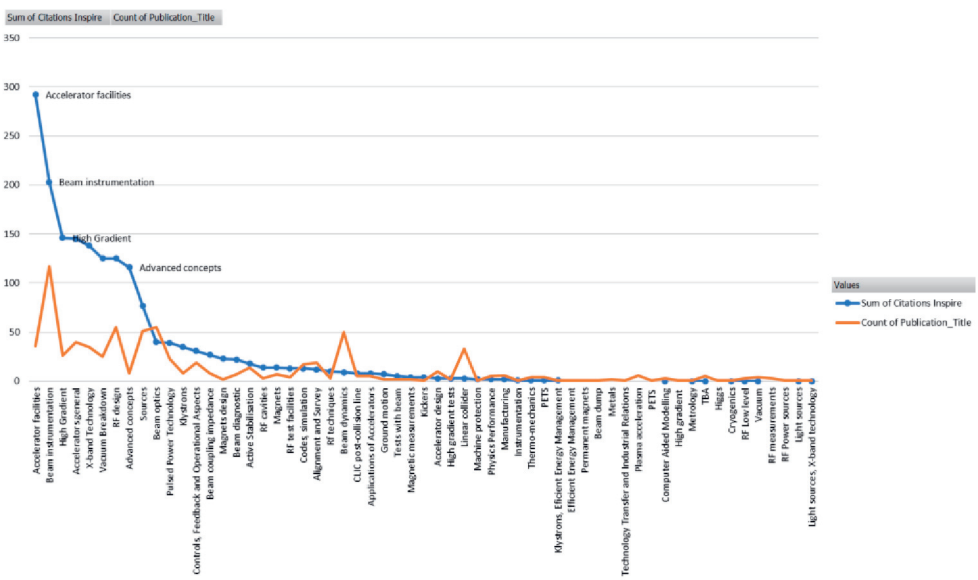

Figure 30. Citations versus publication topic

According to the data collected from Inspire, the most cited topics arranged in descending order, are the X-band technology, Accelerator facilities, Beam Diagnostic, Beam Optics, High Gradient and Vacuum Breakdown (Figure 30).

An earlier research by Abt & Garfield (2002) 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 (Battistoni et al., 2016) 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 8 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 8. 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 (Battistoni et al., 2016)	30
Average references per paper (Giffoni & Vignetti, 2019)	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	73-196

4.2 Phase 2. Societal Impact Assessment: External viewpoint.

Today, academia is not only responsible for knowledge generation and transfer, but it also actively participates in the commercialisation of knowledge. Entrepreneurial universities are contributing to the development of society, working in parallel on research and new technology development. A university has an essential role in the creation of start-up companies and in industrial progress.

4.2.1 Descriptive Statistics

The initial results of the direct survey are based on the responses of 74 suppliers in 16 countries, mainly France (23%), Switzerland (18%), Italy (14%) and Germany (11%) (see Figure 31).

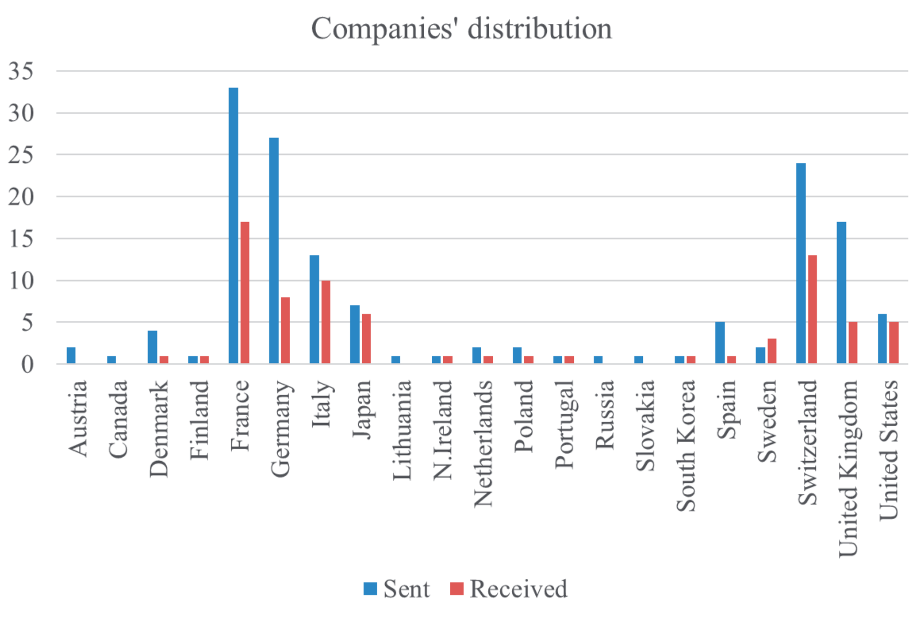

Figure 31. Reply rates distribution of countries.

The respondent firms were micro, small, medium and large companies (18.31%, 32.39%, 22.54% and 26.76%, respectively; Figure 32). Small companies dominated slightly. On average, each supplier processed 18 orders (standard deviation = 31) and received 29,207 CHF per order (standard deviation = 83,152 CHF). An RI supplier collaborates with 4.46 other RIs (standard deviation = 4.9).

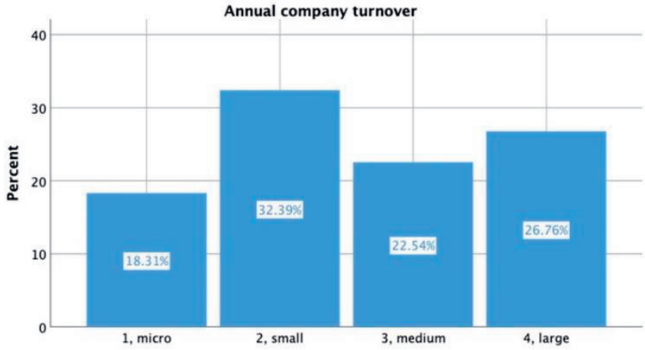

Figure 32. Size of companies based on their annual turnover.

The average duration of the companies' relationship with CLIC is 7.72 years (standard deviation = 3 years), and the average duration of their relationship with CERN is 18.56 years (standard deviation = 18 years) (see Figure 33).

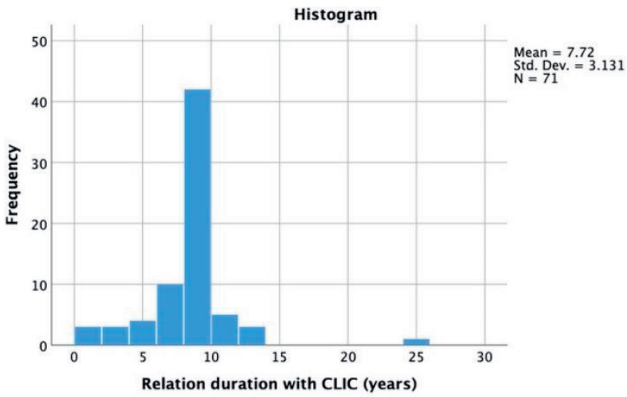

Figure 33. Relationship duration.

The average supplier age is 42.75 years (standard deviation = 28 years) (see Figure 34).

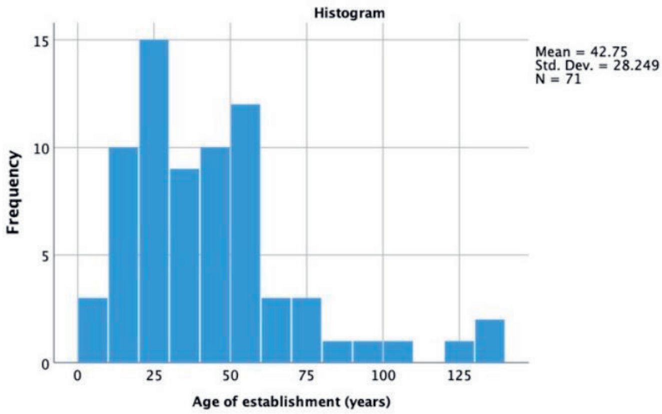

Figure 34. Age of establishment.

The data were processed using linear regression analysis. Six types of benefits were measured as the dependent variables: innovation, market expansion, marketing image, economic outcome, R&D and improved quality of processes and services. The aim was to identify correlations between the benefits of suppliers from RIC and some of the possible factors suggested by the concerned literature.

4.2.2 Assumptions on use of Linear Regression Analysis

A major advantage of linear regression analysis is that it allows for checking of the significance and impact of each independent variable on the dependent variable. The result is the weight of each component to the final value.

Using the collected data, to study the impact of the factors on the benefits from RIC, a linear regression analysis was performed, in which the following central assumptions initially checked: (1) linearity of parameters, (2) independence of errors; (3) homoscedasticity of errors, (4) normal distribution of errors and (5) absence of multicollinearity. Due to the collinearity between multiple control variables, 'Country code 1', 'Country code 2' and 'It is easy to know whom to contact when a problem occurs during the production/procurement' were excluded from the further analysis. The final conceptual model of the influencing factors is presented in Figure 35.

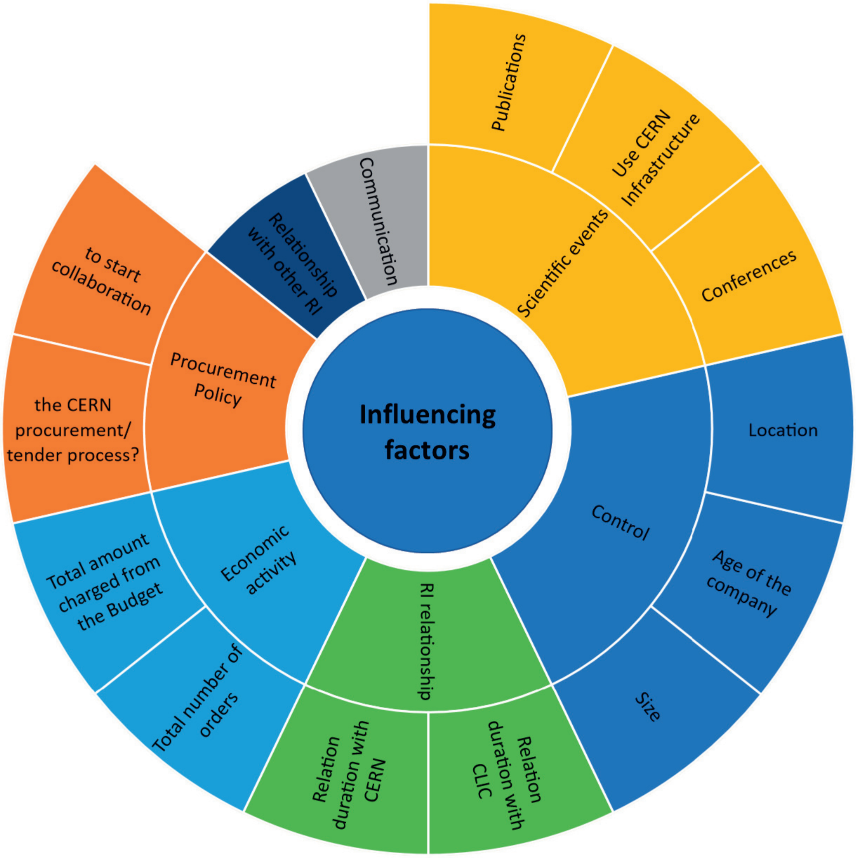

Figure 35. Conceptual model of influencing factors

4.2.3 Linear Regression Analysis

A linear regression model was used to analyse the correlations between the six types of benefits and the set of variables and to test the hypotheses (Figure 36). From the three groups of attributes—the firms' attribute, the RI attributes and the relationship attributes—seven sets of independent variables were distinguished: (1) the control variable, (2) the procurement policy, (3) communication, (4) scientific events, (5) economic activity, (6) relationship with CERN/CLIC and (7) relationship with other RIs. Each benefit from the RIC, as a dependent variable, was evaluated by analysing the eight linear regression models. Thus, the first model tested the significance of the control variables: the size, age, and location of companies. Each of the next models considers a possible influencing factor (set) one at time, and only the last model, N8, included all possible influencing factors. Such, the Model N2 comprised the control variables and the set of variables N2, the Model N3 incorporated the control variables and the set of variables N3 and so on.

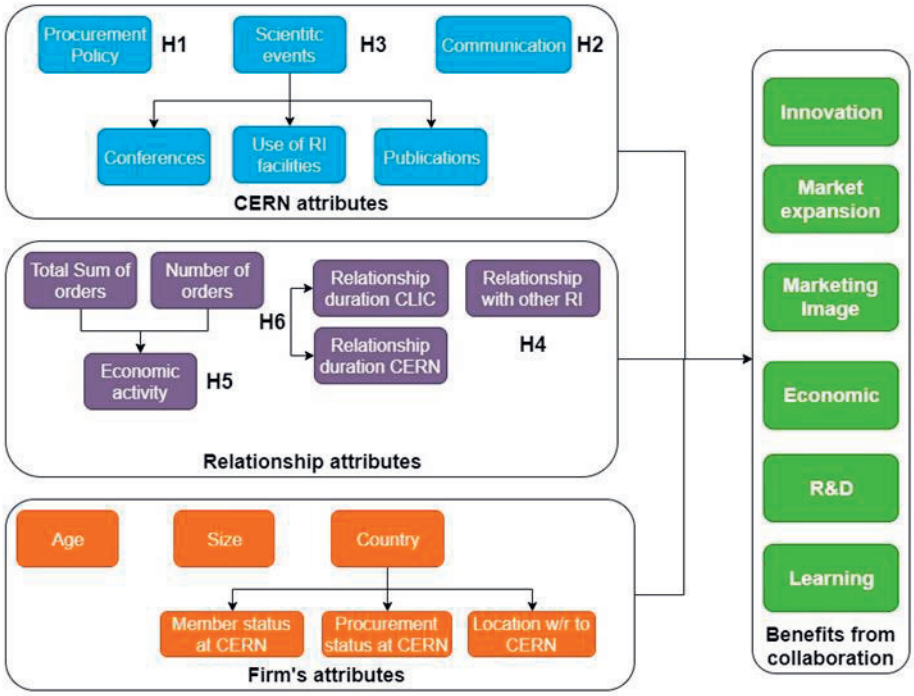

Figure 36. Test models.

4.2.4 Findings

The results of the regression analysis of each type of benefit are reported in two summary tables. The first table presents the estimates of the regression, with the concerned benefit as the dependent variable and with the F and R square values of the models. The R value corresponds to the data that fit the proposed linear regression model or, in other words, to how well the model explains the data. For each model VIF value was not an issue. The second table summarises the hypothesis test results indicating if a hypothesis is *'confirmed'*, *'partially confirmed'* or *'rejected'* depending on the significance correlation of several (partial) variable or all variables representing an influencing factor.

Innovation

In this study, innovation is used as a synonym for the knowledge benefit, following Fabiano et al., (2020), who discussed the knowledge and technology transfer in the analysis of innovation. The benefit is represented by the ability of companies to implement new knowledge gained from their collaboration in other business lines.

The analysis revealed the influence of three distinguished attributes on the innovation benefit during the development and planning phase of CLIC. The results of the statistical testing of the eight concerned linear regression models are summarised in Table 9. Table 10 reports the hypothesis test results.

Table 9 shows the significance of all eight regression models, with the F values between 2.206 and 6.321 and the R2 values between 13.7% and 52.3%. The highest F and R2 values and therefore, the highest fit of the data to the proposed linear models, were shown by model N4 when scientific events were included (37,2%), and by model N8 when all possible influencing factors were included (52.3%). The highest significance level of the linear regression, $p < 0.01$, was achieved by model N4, with the scientific events as the explanatory variable; by model N6, with the relationship duration with CERN/CLIC as the explanatory variables; by model N7 with relationship with other RIs as explanatory variable; and by model N8, where all influencing factors were presented.

Table 9 shows the estimates of the models and the changes in the variables' statistical significance for each model. Thus, when the firms' main attributes (age, size and location) were controlled, the reported model did not change its significance either by incorporating the procurement policy of the RI (model N2) or by extending the communication factors (model N3). However, participation in scientific events, mainly attending conferences ($p < 0.05$) and having the possibility of using CERN's infrastructure facilities ($p < 0.1$) showed a statistically significant positive effect on the knowledge benefit from the collaboration (model N4), together with the duration of the firm's relationship with CLIC ($p < 0.05$, model N6) and the firm's collaboration or business with other RIs ($p < 0.05$, model N7). The economic activity, specifically the total amount charged from the budget, showed no influence as the only influencing factor (model N5) but showed a statistically significant negative impact ($p < 0.05$) in combination with other variables (model N8). The same phenomena are presented for the duration of the firm's relationship with CERN ($p < 0.1$). Conversely, model N8 showed neither that having business with other RIs nor age are important when all possible influencing factors are introduced.

TABLE 9. LINEAR REGRESSION ANALYSIS. INNOVATION

Dependent variable: Technical knowledge gained from CERN related technologies or services are used in other business lines

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Size	0.305 (0.139)**	0.291 (0.142)**	0.279 (0.139)**	0.303 (0.125)***	0.302 (0.139)**	0.262 (0.135)**	0.342 (0.135)***	0.264 (0.123)**
Age of the company	-0.248 (0.005)**	-0.227 (0.005)*	-0.213 (0.005)*	-0.190 (0.005)*	-0.240 (0.005)**	-0.204 (0.005)*	-0.232 (0.005)**	-0.135 (0.005)
Country code 3 (Location)	-0.114 (0.191)	-0.123 (0.194)	-0.127 (0.189)	-0.052 (0.176)	-0.153 (0.198)	-0.114 (0.201)	-0.110 (0.184)	-0.046 (0.187)
Procurement Policy								
How difficult it was to start collaboration with CERN?		0.069 (0.075)						-0.001 (0.067)
How difficult do you find the CERN procurement/tender process?		0.066 (0.069)						-0.025 (0.062)
Communication								
Find/ to get the required information about the project			0.18 (0.13)					0.046 (0.124)
Scientific events								
The company participates in scientific conferences, workshops, fairs etc.				0.295 (0.098)**				0.268 (0.103)**
The company will appreciate a possibility to use CERN Infrastructure for their current or future needs				0.294 (0.1)**				0.247 (0.102)**
The company produced publications due to business with CERN				0.061 (0.139)				0.109 (0.140)
Economic activity								
Total amount charged from the Budget					-0.034 (0.000)			-0.243 (0.000)**
Total number of orders					0.152 (0.005)			0.03 (0.004)
Relationship with CERN								
Relation duration with CERN						-0.121 (0.012)		-0.223 (0.012)*
Relation duration with CLIC						0.299 (0.045)**		0.320 (0.043)***
Relationship with other RI								
Do you have collaboration/business with other Research Institutes (number)?							0.276 (0.028)**	0.181 (0.030)
F value	3.542	2.206	3.325	6.321	2.437	3.801	4.420	4.393
R square	0.137**	0.145*	0.168**	0.372***	0.158**	0.226***	0.211***	0.523***

Note: Standardised coefficients and robust standard errors in parenthesis. ***, **, * denote significance at the 1%, 5% and 10% levels respectively.

As a result of the statistical analysis all eight linear regression models presented significant positive effects of the company's size ($p < 0.05$), and seven models presented significant negative effect of the company's age ($p < 0.1$), on the innovation benefits from the collaboration with CLIC.

This study answers the research questions and validates all six hypotheses (see Table 10). It evaluates the roles of the attributes of the firms, CERN and relationship in generating the innovation benefit from the partnership with RIs. Hence, the knowledge benefit is influenced positively by the involvement of a company in scientific events. On the contrary, the two other CERN attributes, that is, its procurement, and communication policies, do not have a significant impact on the innovation outcome.

Table 10. Innovation. Hypothesis testing.

Hypothesis	Status
H1. The benefits to industry from RIC are influenced negatively by the procurement policy of RIs.	Rejected
H2. The easier the communication process (getting and asking for information on a project) is, the more likely it is that a company will benefit from collaboration.	Rejected
H3. The more a company participates in scientific events, more likely it is to obtain benefits.	Partially Confirmed
H4. Benefits are influenced positively by a collaborative network. Thus, producing parts for other scientific laboratories is likely to positively impact a company's collaboration outcomes.	Confirmed
H5. The more procurement activities a company has with a scientific project, the more the company will benefit.	Confirmed
H6. The longer the relationship between a company and CERN/CLIC is, the more the company will benefit.	Partially Confirmed

This benefit is also shaped by the relationship's attributes such as the duration of the firm's relationship with CERN/CLIC, and its collaborative network, where it mainly produces parts for other scientific laboratories.

The economic activity as the total amount charged from the budget showed a negative effect on the gaining of knowledge benefits. The firm's attributes such as its size and age play also important roles in its gaining of profits from RIC. Thus, the findings partially confirmed Hypothesis 3 and Hypothesis 6, and confirmed Hypothesis 4 and Hypothesis 5 but rejected Hypothesis 1 and Hypothesis 2.

Market expansion

The market expansion benefit to industry is represented by an increase in the number of clients for the same technology because of the firm's collaboration with CERN.

The analysis showed the influence of the three distinguished attributes on the generation of the market expansion benefit during the development and planning phase of CLIC. The results of the statistical testing of the eight concerned linear regression models are summarised in Table 12. Table 11 reports the hypotheses test results.

Table 12 shows the significance of four of the eight regression models, with the F value between 2.045 and 6.606 and the R2 value between 13.6% and 45.6%. The highest R2 values and therefore, the highest fit of the data to the proposed linear models, was seen in model N4 when scientific events were included (32,5%) and in model N8 when all possible influencing factors were included (45.6%). The highest significance level of the linear regression, $p < 0.01$, was seen in model N4 with the scientific events as the explanatory variable; in model N7 with the relationship with other RIs as the explanatory variable; and in model N8 where all the influencing factors were presented.

Built on the multiple regression analysis for the market expansion benefit from the RIC, the most significant factors were collaboration or business with other RIs ($p < 0.01$) and the possibility of using CERN infrastructure ($p < 0.01$).

Table 12 shows the estimates of these models and the changes in the statistical significance of the variables for each model. Thus, when the firm's main attributes (age, size, and location) were controlled, the reported model did not change either after incorporation of the procurement policy of the RI (model N2), or after extension of the communication factors (model N3), or after the performance of the economic activities (model 5). However, participation in scientific events had a statistically significant positive effect on the market expansion benefit from the collaboration (model N4). Mainly, a higher significance was seen for the possibility of using the CERN infrastructure facilities ($p < 0.01$), and a lower significance as seen in for participation in conferences ($p < 0.1$). Thus, the use of CERN infrastructure generates more benefits for industry than participating in conferences. Market expansion depends on the duration of the firm's relationship with CLIC ($p < 0.1$, model N6) and on the firm's collaboration or business with other RIs ($p < 0.01$, model 7). The final model, N8, by considering all possible influencing factors, highlights again the importance to market expansion of having possibility of using CERN infrastructure ($p < 0.05$) doing business with other RIs ($p < 0.05$).

As a result of the analysis and considering only the statistically significant regression models N4, N6, N7 and N8, the company's size ($p < 0.1$) was seen as important only in model N7, together with collaboration with other RIs ($p < 0.01$). Three models—N6, N7 and N8—showed significant negative effects of the company's age ($p < 0.1$) on the market expansion benefit from the collaboration with CLIC. However, the firms' attributes did not play any significant role when participation in scientific events is considered (model N4).

Consequently, the study answers the related research questions and validates all six hypotheses (see Table 11). It evaluates the role of the attributes of firms, CERN, and relationship in the market expansion outcome due to partnership with RIs. Hence, the market expansion benefit is enhanced by the involvement of a company in scientific events, by the duration of its relationship with CLIC, and by its collaborative network, where it mainly produces parts for other scientific laboratories. The firm's attributes such as size and age also play important roles in RIC. On the contrary, neither the procurement nor communication policies, on the contrary, affected the evaluated outcome. Thus, the results partially confirmed Hypothesis 3 and Hypothesis 6, and confirmed Hypothesis 4, but rejected Hypothesis 1, Hypothesis 2, and Hypothesis 5.

Table 11. Market expansion. Hypothesis testing.

Hypothesis	Status
H1. The benefits to industry from RIC are influenced negatively by the procurement policy of RIs.	Rejected
H2. The easier the communication process (getting and asking for information on a project) is, the more likely it is that a company will benefit from collaboration.	Rejected
H3. The more a company participates in scientific events, more likely it is to obtain benefits.	Partially Confirmed
H4. Benefits are influenced positively by a collaborative network. Thus, producing parts for other scientific laboratories is likely to positively impact a company's collaboration outcomes.	Confirmed
H5. The more procurement activities a company has with a scientific project, the more the company will benefit.	Rejected
H6. The longer the relationship between a company and CERN/CLIC is, the more the company will benefit.	Partially Confirmed

TABLE 12. LINEAR REGRESSION ANALYSIS. MARKET EXPANSION

Dependent variable: The number of clients for the same technology has increased during the collaboration with CERN

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Size	0.134 (0.156)	0.114 (0.158)	0.112 (0.156)	0.111 (0.139)	0.134 (0.155)	0.107 (0.153)	0.197 (0.138)*	0.141 (0.141)
Age of the company	-0.239 (0.006)**	-0.217 (0.006)*	-0.208 (0.006)*	-0.168 (0.005)	-0.208 (0.006)*	-0.291 (0.006)**	-0.211 (0.005)*	-0.212 (0.006)*
Country code 3 (Location)	0.006 (0.214)	-0.004 (0.216)	-0.006 (0.213)	0.076 (0.197)	-0.016 (0.220)	-0.095 (0.229)	0.012 (0.188)	0.004 (0.215)
Procurement Policy								
How difficult it was to start collaboration with CERN?		0.134 (0.083)						0.004 (0.077)
How difficult do you find the CERN procurement/tender process?		0.013 (0.077)						-0.121 (0.072)
Communication								
Find/ to get the required information about the project			0.156 (0.146)					0.001 (0.143)
Scientific events								
The company participates in scientific conferences, workshops, fairs etc.				0.217 (0.110)*				0.157 (0.119)
The company will appreciate a possibility to use CERN Infrastructure for their current or future needs				0.349 (0.112)***				0.279 (0.118)**
The company produced publications due to business with CERN				0.121 (0.155)				0.083 (0.161)
Economic activity								
Total amount charged from the Budget					0.151 (0.000)			-0.119 (0.000)
Total number of orders					0.106 (0.006)			0.058 (0.005)
Relationship with CERN								
Relation duration with CERN						0.179 (0.014)		0.062 (0.014)
Relation duration with CLIC						0.211 (0.051)*		0.188 (0.049)
Relationship with other RI								
Do you have collaboration/business with other Research Institutes (number)?							0.478 (0.029)***	0.335 (0.035)**
F value	1.498	1.133	1.549	5.143	1.461	2.045	6.606	3.355
R square	0.063	0.080	0.086	0.325***	0.101	0.136*	0.286***	0.456***

Note: Standardised coefficients and robust standard errors in parenthesis. ***, **, * denote significance at the 1%, 5% and 10% levels respectively.

Marketing image

The marketing image benefit of the industry is represented by some marketing benefits in terms of reference and image lifting due to a firm's collaboration with CERN.

The analysis showed the influence of three distinguished attributes on the generation of the marketing image benefit during the development and planning phase of CLIC. The results of the statistical testing of the eight concerned linear regression models are summarised in Table 13. Table 14 reports the hypothesis test results of all discussed statistical models.

Table 13 shows the significance of only two of the eight regression models with the F value equal to 2.36 and 2.707 and the R2 value equal to 12.5% and 14.1.%. The values correspond to model N3 ($p < 0.05$) and model N7 ($p < 0.1$). The former regression included the communication factor, and the latter included collaboration or business with other RIs.

Table 13 shows the estimates of the models and the changes in the statistical significance of the of variables for each model. Thus, by controlling the firm's main attributes (age, size, and location), the reported model did not change significantly either after the incorporation of the procurement policy of the RI (model N2), or after participation in scientific events (model N4), or after the performance of economic activities (model N5), or after including the duration of the firm's relationship CERN/CLIC (model N6). However, communication with CERN ($p < 0.01$) had a statistically significant positive effect on the marketing image benefit from the collaboration (model N3). The benefit depends on the firm's having collaboration or business with other RIs ($p < 0.05$, model N7). The final model, N8, was not statistically significant.

As a result of the analysis and considering only the statistically significant regression models N3 and N7, neither the company's size nor its age played a significant role ($p < 0.1$) in the marketing image outcome from the collaboration with CLIC.

This study thus answers the related research questions and validates all six hypotheses (see Table 14). It evaluates the role of the attributes of firms, CERN, and relationship in generation of the marketing image benefit from the partnership with RIs. Hence, the marketing image benefit is influenced by the communication policy of CERN, and by the collaborative network, where the firm mainly produces parts for other scientific laboratories. The firm's attributes such as its size and age do not play important roles in the generation of the marketing image from RIC. Neither

TABLE 13. LINEAR REGRESSION ANALYSIS. MARKETING IMAGE

Dependent variable: The company has some marketing benefits in term of reference and image lifting due to its collaboration with CERN								
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Size	0.133 (0.146)	0.107 (0.147)	0.085 (0.141)	0.140 (0.146)	0.137 (0.146)	0.135 (0.150)	0.173 (0.142)	0.121 (0.153)
Age of the company	-0.151 (0.005)	-0.131 (0.006)	-0.086 (0.005)	-0.119 (0.005)	-0.142 (0.006)	-0.183 (0.006)	-0.134 (0.005)	-0.144 (0.006)
Country code 3 (Location)	-0.073 (0.201)	-0.085 (0.200)	-0.098 (0.192)	-0.040 (0.206)	-0.037 (0.208)	-0.111 (0.224)	-0.069 (0.194)	-0.089 (0.232)
Procurement Policy								
How difficult it was to start collaboration with CERN?		0.211 (0.077)*						0.077 (0.083)
How difficult do you find the CERN procurement/tender process?		-0.055 (0.071)						-0.151 (0.078)
Communication								
Find/ to get the required information about the project			0.330 (0.132)***					0.233 (0.155)*
Scientific events								
The company participates in scientific conferences, workshops, fairs etc.				0.232 (0.115)*				0.183 (0.128)
The company will appreciate a possibility to use CERN Infrastructure for their current or future needs				0.157 (0.117)				0.001 (0.127)
The company produced publications due to business with CERN				0.031 (0.162)				0.071 (0.174)
Economic activity								
Total amount charged from the Budget					0.144 (0.000)			-0.051 (0.000)
Total number of orders					-0.129 (0.005)			-0.142 (0.005)
Relationship with CERN								
Relation duration with CERN						0.102 (0.014)		0.060 (0.015)
Relation duration with CLIC						-0.006 (0.050)		0.055 (0.053)
Relationship with other RI								
Do you have collaboration/business with other Research Institutes (number)?							0.298 (0.029)**	0.174 (0.037)
F value	0.888	1.211	2.707	1.740	0.945	0.623	2.360	1.439
R square	0.038	0.085	0.141**	0.140	0.068	0.046	0.125*	0.265

Note: Standardised coefficients and robust standard errors in parenthesis. ***, **, * denote significance at the 1%, 5% and 10% levels respectively.

procurement nor economic activities, impacted the assessed outcome. The findings partially confirmed Hypothesis 4, and confirmed Hypothesis 2, but rejected Hypothesis 1, Hypothesis 3, Hypothesis 5, and Hypothesis 6.

Table 14. Marketing image. Hypothesis testing.

Hypothesis	Status
H1. The benefits to industry from RIC are influenced negatively by the procurement policy of RIs.	Rejected
H2. The easier the communication process (getting and asking for information on a project) is, the more likely it is that a company will benefit from collaboration.	Confirmed
H3. The more a company participates in scientific events, more likely it is to obtain benefits.	Rejected
H4. Benefits are influenced positively by a collaborative network. Thus, producing parts for other scientific laboratories is likely to positively impact a company's collaboration outcomes.	Partially Confirmed
H5. The more procurement activities a company has with a scientific project, the more the company will benefit.	Rejected
H6. The longer the relationship between a company and CERN/CLIC is, the more the company will benefit.	Rejected

Economic benefit

The economic benefit for industry is represented by the related companies' turnover of their supplied services or products.

The analysis showed the influence of three distinguished attributes on the generating economic benefit during the development and planning phase of CLIC study. The results of the statistical tests for the eight concerned linear regression models are summarised in Table 15. Table 16 reports the hypothesis test results of all discussed statistical models.

Table 15 shows the significance of four of the eight regression models, with the F values between 2.299 and 4.006 and the R2 values between 9.2% and 36.2%. The highest R2 values and therefore, the highest fit of the data to the proposed linear models, corresponded to model N4 when scientific events were included (27,3%) and to model N8 when all possible influencing factors were included (36.2%). The highest significance level of the linear regression $p < 0.01$ was related to model N4, with the scientific events as the explanatory variable. The medium significance level $p < 0.05$ corresponded to model N8, where all the influencing factors were presented.

Table 15 shows the estimates of these models and the changes in the statistical significance of the variables for each model. Thus, by controlling the firm's main attributes (age, size, and location), the reported model did not change either after the incorporation of the procurement policy of the RI (model N2), or after the extension of the communication factors (model N3), or after the introduction of the duration of the firm's relationship with CERN/CLIC (model N6). However, participation in scientific events, mainly attending conferences ($p < 0.1$) and having the possibility of using CERN's infrastructure facilities ($p < 0.01$) had a statistically significant positive effect on the economic benefit from the collaboration (model N4). Thus, the use of CERN infrastructure generates more economic benefits for industry than participating in conferences. The latter became more significant ($p<0.05$) when it appeared with other factors (model N8). Economic activity, specifically the total amount charged from the budget showed no influence as the only affecting factor (model N5) but showed a statistically significant negative impact ($p < 0.05$) in combination with other variables (model N8).

As a result of the analysis and considering only the statistically significant regression models N1, N4, N7 and N8, the company's age showed a significant negative effect ($p < 0.1$ and $p < 0.05$) on the economic benefit from the collaboration with CLIC. However, the firms' size and location did not play any significant role.

Consequently, the study answers the related research questions and validates all six hypotheses (see Table 16). It evaluates the roles of the attributes of firms, CERN, and relationship in the economic benefit due to the partnership with an RI. Hence, the discussed benefit is influenced by the involvement of a company in scientific events and by its economic activities with CLIC. The latter, presented by the total amount charged from the budget, demonstrated a negative effect on obtaining the benefits. On the contrary, two other CERN attributes, the procurement, and communication policies, did not show a significant impact on the economic outcome. Only the company's age, among the firm's attributes, showed an important role in gaining profits from RIC. The findings partially confirmed Hypothesis 3 and Hypothesis 5, but rejected Hypothesis 1, Hypothesis 2, Hypothesis 4, and Hypothesis 6.

TABLE 15. LINEAR REGRESSION ANALYSIS. ECONOMIC BENEFIT

Dependent variable: Economic	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Size	-0.103 (0.062)	-0.110 (0.064)	-0.104 (0.064)	-0.088 (0.059)	-0.103 (0.062)	-0.093 (0.063)	-0.079 (0.062)	-0.039 (0.062)
Age of the company	-0.259 (0.002)**	-0.244 (0.002)*	-0.257 (0.002)**	-0.188 (0.002)*	-0.285 (0.002)**	-0.305 (0.002)**	-0.249 (0.002)**	-0.306 (0.002)**
Country code 3 (Location)	-0.040 (0.086)	-0.046 (0.087)	-0.041 (0.087)	0.071 (0.083)	-0.028 (0.089)	-0.085 (0.095)	-0.038 (0.085)	0.052 (0.095)
Procurement Policy								
How difficult it was to start collaboration with CERN?		0.020 (0.034)						0.002 (0.034)
How difficult do you find the CERN procurement/tender process?		0.067 (0.031)						-0.085 (0.032)
Communication								
Find/ to get the required information about the project			0.012 (0.059)					-0.152 (0.063)
Scientific events								
The company participates in scientific conferences, workshops, fairs etc.				0.205 (0.046)*				0.280 (0.052)**
The company will appreciate a possibility to use CERN Infrastructure for their current or future needs				0.420 (0.047)***				0.450 (0.052)***
The company produced publications due to business with CERN				-0.132 (0.065)				-0.177 (0.071)
Economic activity								
Total amount charged from the Budget					-0.146 (0.000)			-0.271 (0.000)**
Total number of orders					-0.067 (0.002)			-0.049 (0.002)
Relationship with CERN								
Relation duration with CERN						0.142 (0.006)		0.128 (0.006)
Relation duration with CLIC						-0.060 (0.021)		0.022 (0.022)
Relationship with other RI								
Do you have collaboration/business with other Research Institutes (number)?							0.177 (0.013)	0.094 (0.015)
F value	2.260	1.388	1.672	4.006	1.777	1.584	2.299	2.266
R square	0.092*	0.096	0.092	0.273***	0.120	0.109	0.122*	0.362**

Note: Standardised coefficients and robust standard errors in parenthesis. ***, **, * denote significance at the 1%, 5% and 10% levels respectively.

Table 16. Economic benefit. Hypothesis testing.

Hypothesis	Status
H1. The benefits to industry from RIC are influenced negatively by the procurement policy of RIs.	Rejected
H2. The easier the communication process (getting and asking for information on a project) is, the more likely it is that a company will benefit from collaboration.	Rejected
H3. The more a company participates in scientific events, more likely it is to obtain benefits.	Partially Confirmed
H4. Benefits are influenced positively by a collaborative network. Thus, producing parts for other scientific laboratories is likely to positively impact a company's collaboration outcomes.	Rejected
H5. The more procurement activities a company has with a scientific project, the more the company will benefit.	Partially Confirmed
H6. The longer the relationship between a company and CERN/CLIC is, the more the company will benefit.	Rejected

Research and Development

The R&D benefit for industry is represented by an improvement in its R&D operations due to its collaboration with CERN.

The analysis showed the influence of the three distinguished attributes on the generation of the R&D benefit during the development and planning phase of CLIC.

The results of the statistical testing of the eight concerned linear regression models are summarised in Table 17. Table 18 reports the hypothesis test results of all discussed statistical models.

Table 17 shows the significance of three of the eight regression models with the F value between 2.990 and 7.046 and the R2 value between 15.3% and 48.6%. The highest R2 values and therefore, the highest fit of the data to the proposed linear models, corresponded to model N4 when scientific events were included (39,8%), and model N8 when all the possible influencing factors are included (48.6%). The highest significance level of the linear regression $p < 0.01$ is related to model N4 with the scientific events as the explanatory variable and to model N8, where all the influencing factors were presented.

Built on the multiple regression analysis for the R&D benefits from RIC, the most significant factors are collaboration or business with other RIs ($p < 0.01$), participation in scientific conferences ($p < 0.01$) and the possibility of using CERN infrastructure ($p < 0.01$).

Table 17 shows the estimates of the models and the changes of the statistical significance of the variables for each model. Thus, by controlling the firm's main attributes (age, size, and location), the reported model did not change either after incorporation of the communication factor (model N3), or after the performance of the economic activities (model 5), or after the inclusion of the duration of relationship of the firm with CERN/CLIC (model N6). However, the procurement policy, specifically 'How difficult is the CERN procurement/tender process?', had no influence as the only affecting factor (model N2) but had a statistically significant negative impact ($p < 0.05$) in combination with other variables (model N8). Participation in scientific events had a statistically significant positive effect on the R&D improvement because of the collaboration (model N4). A high significance was seen for participation in conferences and the possibility of using CERN's infrastructure facilities ($p < 0.01$). The R&D benefit depends on collaboration or business with other RIs ($p < 0.01$, model 7). The final model, N8, by considering all possible influencing factors, highlighted again the importance of participating in scientific conferences ($p < 0.01$) and having the possibility of using CERN infrastructure ($p < 0.1$).

As a result of the analysis and considering only the statistically significant regression models N4, N7 and N8, the company's size ($p < 0.1$) was important only in the model N7, together with the collaboration of the firm business with other RIs ($p < 0.01$). However, the firm's age and location did not play any significant role in achieving the R&D outcome from the RIC.

Consequently, the study answers the related research questions and validates all six hypotheses (see Table 18). It evaluates the role of the attributes of firms, CERN, and relationship in the R&D outcome due to the partnership with RIs. Hence, the discussed benefit is influenced by the involvement of a company in scientific events, by its having a collaborative network where it mainly produces parts for other scientific laboratories, and by the procurement policy of CERN. Nevertheless, neither the communication policy nor the economic activities, nor the duration of the firm's relationship duration with CERN/CLIC impacted the evaluated outcome. The results partially confirmed Hypothesis 3, and confirmed Hypothesis 1 and Hypothesis 4, but rejected Hypothesis 2, Hypothesis 5 and Hypothesis 6.

TABLE 17. LINEAR REGRESSION ANALYSIS. R&D

Dependent variable: Collaboration with CERN helps to improve R&D operations at the company

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Size	0.171 (0.169)	0.154 (0.170)	0.135 (0.167)	0.159 (0.141)	0.170 (0.169)	0.164 (0.173)	0.216 (0.161)*	0.175 (0.147)
Age of the company	-0.099 (0.006)	-0.094 (0.006)	-0.051 (0.006)	-0.032 (0.005)	-0.072 (0.006)	-0.088 (0.007)	-0.079 (0.006)	-0.028 (0.006)
Country code 3 (Location)	-0.087 (0.232)	-0.092 (0.232)	-0.105 (0.227)	-0.026 (0.199)	-0.108 (0.240)	-0.081 (0.258)	-0.082 (0.219)	-0.027 (0.223)
Procurement Policy								
How difficult it was to start collaboration with CERN?		0.170 (0.089)						0.062 (0.080)
How difficult do you find the CERN procurement/tender process?		-0.109 (0.082)						-0.229 (0.0075)**
Communication								
Find/ to get the required information about the project			0.245 (0.156)**					0.040 (0.149)
Scientific events								
The company participates in scientific conferences, workshops, fairs etc.				0.349 (0.111)***				0.363 (0.123)***
The company will appreciate a possibility to use CERN Infrastructure for their current or future needs				0.321 (0.113)***				0.243 (0.122)*
The company produced publications due to business with CERN				0.137 (0.157)				0.184 (0.168)
Economic activity								
Total amount charged from the Budget					0.132 (0.000)			-0.099 (0.000)
Total number of orders					0.098 (0.006)			0.115 (0.005)
Relationship with CERN								
Relation duration with CERN						-0.033 (0.016)		-0.110 (0.014)
Relation duration with CLIC						0.046 (0.058)		-0.015 (0.051)
Relationship with other RI								
Do you have collaboration/business with other Research Institutes (number)?							0.343 (0.033)***	0.145 (0.036)
F value	0.895	1.130	1.740	7.046	0.963	0.557	2.990	3.786
R square	0.039	0.080	0.095	0.398***	0.069	0.041	0.153**	0.486***

Note: Standardised coefficients and robust standard errors in parenthesis. ***, **, * denote significance at the 1%, 5% and 10% levels respectively.

Table 18. R&D. Hypothesis testing.

Hypothesis	Status
H1. The benefits to industry from RIC are influenced negatively by the procurement policy of RIs.	Confirmed
H2. The easier the communication process (getting and asking for information on a project) is, the more likely it is that a company will benefit from collaboration.	Rejected
H3. The more a company participates in scientific events, more likely it is to obtain benefits.	Partially Confirmed
H4. Benefits are influenced positively by a collaborative network. Thus, producing parts for other scientific laboratories is likely to positively impact a company's collaboration outcomes.	Confirmed
H5. The more procurement activities a company has with a scientific project, the more the company will benefit.	Rejected
H6. The longer the relationship between a company and CERN/CLIC is, the more the company will benefit.	Rejected

Learning for provided services

Learning about or improving the quality of firm's provided services to industry is represented by an improvement in its provided services due to its collaboration with CERN.

The analysis showed the influence of the three distinguished attributes on the generation of the benefit about the provided services benefit during the development and planning phase of CLIC. The results of the statistical test of the eight concerned linear regression models are summarised in Table 19. Table 20 reports the hypothesis test results of all discussed statistical models.

Table 19 shows the significance of five of the eight regression models with the F value between 2.042 and 4.191 and the R2 value between 13.6% and 43.2%. The highest R2 values and therefore, the highest fit of the data to the proposed linear models, corresponded to model N4 when scientific events were included (27,9%), and model N8 when all the possible influencing factors were included (43.2%). The highest significance level of the linear regression $p < 0.01$ was related to model N4 with the scientific events as the explanatory variable, to model N7 with the firm's relationship with other RIs as the explanatory variable and to model N8, where all the influencing factors were presented.

Built on the multiple regression analysis for the learning benefit from the RIC, the most significant factors were the participation in conferences ($p < 0.01$) and the collaboration or business with other RIs ($p < 0.01$).

Table 19 shows the estimates of the models and the changes in the statistical significance of the variables for each model. Thus, by controlling the firm's main attributes (age, size, and location) the reported model did not change after incorporation of the duration of the firm's relationship with CERN/CLIC (model N6). However, participation in scientific events, mainly attending conferences ($p < 0.05$) had a statistically significant positive effect on the benefit from the collaboration ($p < 0.01$, model N4), together with the collaboration or business with other RIs ($p < 0.05$, model 7). The procurement policy ($p < 0.1$) and the communication policy ($p < 0.05$) had significant impacts on the learning about and quality of the provided services (models N2 and N3). The economic activity, specifically, the total amount charged from the budget, had no influence as the only affecting factor (model N5) but had a statistically significant negative impact ($p < 0.1$) in combination with other variables (model N8).

As a result of the analysis and considering only the statistically significant regression models, the company's age ($p < 0.05$) had a significant negative effect on its learning benefits from its collaboration with CLIC. However, the firm's size and location did not play any significant role.

The study answers the related research questions and validates all six hypotheses (see Table 20). It evaluates the roles of the attributes of the firms, CERN, and relationship in generating the benefit of learning about the provided service from the partnership with an RI. Hence, the learning about the quality of the provided service is influenced positively by the involvement of a company in scientific events and in the RI's communication policy, and negatively by CERN's procurement policy. The benefit is also shaped by the relationship's attributes such as the collaborative network, mainly by producing parts for other scientific laboratories. The economic activity as the total amount charged from the budget has a negative effect on the obtaining of the learning benefits in combination with other factors. The firm's age also plays an important role in gaining profits from RIC. The findings partially confirmed Hypothesis 1, Hypothesis 3 and Hypothesis 5, and confirmed Hypothesis 2 and Hypothesis 4 but rejected Hypothesis 6.

TABLE 19. LINEAR REGRESSION ANALYSIS. LEARNING AND QUALITY OF SERVICE

Dependent variable: Improve of quality of provided services	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Size	0.083 (0.137)	0.061 (0.137)	0.045 (0.134)	0.104 (0.128)	0.081 (0.138)	0.084 (0.140)	0.129 (0.130)	0.132 (0.128)
Age of the company	-0.288 (0.188)**	-0.279 (0.005)**	-0.237 (0.005)**	-0.258 (0.005)**	-0.273 (0.005)**	-0.302 (0.005)**	-0.268 (0.005)**	-0.312 (0.005)**
Country code 3 (Location)	-0.037 (0.188)	-0.044 (0.187)	-0.056 (0.184)	-0.008 (0.181)	-0.067 (0.196)	-0.053 (0.210)	-0.033 (0.177)	-0.078 (0.070)
Procurement Policy								
How difficult it was to start collaboration with CERN?		0.201 (0.072)*						0.097 (0.070)
How difficult do you find the CERN procurement/tender process?		-0.106 (0.066)						-0.295 (0.065)**
Communication								
Find/ to get the required information about the project			0.259 (0.126)**					0.094 (0.130)
Scientific events								
The company participates in scientific conferences, workshops, fairs etc.				0.379 (0.101)***				0.380 (0.108)***
The company will appreciate a possibility to use CERN Infrastructure for their current or future needs				0.142 (0.103)				0.013 (0.107)
The company produced publications due to business with CERN				0.025 (0.142)				0.072 (0.147)
Economic activity								
Total amount charged from the Budget					0.031 (0.000)			-0.230 (0.000)*
Total number of orders					0.125 (0.005)			0.140 (0.005)
Relationship with CERN								
Relation duration with CERN						0.044 (0.013)		0.023 (0.012)
Relation duration with CLIC						-0.005 (0.047)		-0.044 (0.045)
Relationship with other RI								
Do you have collaboration/business with other Research Institutes (number)?							0.349 (0.027)***	0.257 (0.031)*
F value	2.034	2.042	2.838	4.133	1.449	1.206	4.191	3.048
R square	0.083	0.136*	0.147**	0.279***	0.100	0.085	0.203***	0.432***

Note: Standardised coefficients and robust standard errors in parenthesis. ***, **, * denote significance at the 1%, 5% and 10% levels respectively.

Table 20. Quality of service. Hypothesis testing.

Hypothesis	Status
H1. The benefits to industry from RIC are influenced negatively by the procurement policy of RIs.	Partially Confirmed
H2. The easier the communication process (getting and asking for information on a project) is, the more likely it is that a company will benefit from collaboration.	Confirmed
H3. The more a company participates in scientific events, more likely it is to obtain benefits.	Partially Confirmed
H4. Benefits are influenced positively by a collaborative network. Thus, producing parts for other scientific laboratories is likely to positively impact a company's collaboration outcomes.	Confirmed
H5. The more procurement activities a company has with a scientific project, the more the company will benefit.	Partially Confirmed
H6. The longer the relationship between a company and CERN/CLIC is, the more the company will benefit.	Rejected

Learning for internal production processes

Learning about or improving the quality of the production process of industry is represented as an improvement in the production process due to its collaboration with CERN.

The analysis showed the influence of the three distinguished attributes on the generation of the benefit of learning about the internal production processes during the development and planning phase of CLIC. The results of the statistical test of the eight concerned linear regression models are summarised in Table 21. Table 22 reports the hypothesis test results of all discussed statistical models.

Table 21 shows the significance of five of the eight regression models with the F value between 2.157 and 4.191 and the R2 value between 9.1% and 37.4%. The highest R2 values and therefore, the highest fit of the data to the proposed linear models, corresponded to model N4 when scientific events were included (28,6%) and model N8, when all the possible influencing factors were included (37.4%). The highest significance level of the linear regression $p < 0.01$ was related to model N4 with the scientific events as the explanatory variable, and the significance level $p < 0.05$ was related to model N8, where all the influencing factors were presented.

Built on the multiple regression analysis for the learning benefit from RIC, the most significant factors are the procurement policy ($p < 0.05$), participation in conferences ($p < 0.05$) and the company's age ($p < 0.05$).

Table 21 shows the estimates of these models and the changes of the statistical significance of the variables for each model. Thus, by controlling the firm's main attributes (age, size, and location) the reported model did not change after the incorporation of the communication policy (model N3), the economic activities (model N5), the duration of the firm's relationship with CERN/CLIC (model N6), and the firm's collaboration or business with other RIs (model N7). However, participation in scientific events, mainly attending conferences ($p < 0.05$), and having the possibility of using CERN's infrastructure facilities ($p < 0.1$), had a statistically significant positive effect on the learning benefit from the collaboration (model N4). The procurement policy, specifically 'How difficult is the CERN procurement/tender process?', had no influence as the only affecting factor (model N2) but had a statistically significant negative impact ($p < 0.05$) in combination with other variables (model N8).

As a result of the analysis and considering only the statistically significant regression models, the company's age ($p < 0.05$) had a significant negative effect on the learning benefits from the collaboration with CLIC. However, the firm's size and location did not play a significant role.

The study answers the related research questions and validates all six hypotheses (see Table 22). It evaluates the role of the attributes of the firms, CERN, and relationship in generating the benefit of learning about internal production processes from the partnership with an RI. Hence, the learning on the quality of production processes is influenced positively by the involvement of a company in scientific events and negatively by CERN's procurement policy. The latter showed a negative effect on the obtaining the learning benefit in combination with other factors. The firm's age also plays an important role in obtaining profits from RIC. The findings partially confirmed Hypothesis 1 and Hypothesis 3 but rejected all other hypotheses.

TABLE 21. LINEAR REGRESSION ANALYSIS. LEARNING AND QUALITY OF PROCESS

Dependent variable: Improve of quality of internal production processes	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Size	0.105 (0.131)	0.101 (0.132)	0.081 (0.132)	0.099 (0.123)	0.104 (0.132)	0.090 (0.133)	0.132 (0.130)	0.108 (0.130)
Age of the company	-0.301 (0.005)**	-0.315 (0.005)**	-0.269 (0.005)**	-0.254 (0.004)	-0.283 (0.005)**	-0.275 (0.005)	-0.289 (0.005)**	-0.272 (0.005)**
Country code 3 (Location)	0.049 (0.180)	0.053 (0.180)	0.037 (0.179)	0.090 (0.173)	0.026 (0.188)	0.063 (0.200)	0.052 (0.177)	0.093 (0.197)
Procurement Policy								
How difficult it was to start collaboration with CERN?		0.100 (0.070)						0.045 (0.071)
How difficult do you find the CERN procurement/tender process?		-0.156 (0.064)						-0.261 (0.066)**
Communication								
Find/ to get the required information about the project			0.163 (0.123)					0.012 (0.131)
Scientific events								
The company participates in scientific conferences, workshops, fairs etc.				0.271 (0.096)**				0.329 (0.109)**
The company will appreciate a possibility to use CERN Infrastructure for their current or future needs				0.220 (0.098)*				0.180 (0.108)
The company produced publications due to business with CERN				0.102 (0.136)				0.129 (0.148)
Economic activity								
Total amount charged from the Budget					0.062 (0.000)			-0.133 (0.000)
Total number of orders					0.102 (0.005)			0.086 (0.005)
Relationship with CERN								
Relation duration with CERN						-0.077 (0.012)		-0.096 (0.012)
Relation duration with CLIC						0.099 (0.045)		0.062 (0.045)
Relationship with other RI								
Do you have collaboration/business with other Research Institutes (number)?							0.202 (0.027)	0.073 (0.032)
F value	2.224	1.864	2.157	4.282	1.543	1.489	2.478	2.391
R square	0.091*	0.125	0.116*	0.286***	0.106	0.103	0.131*	0.374**

Note: Standardised coefficients and robust standard errors in parenthesis. ***, **, * denote significance at the 1%, 5% and 10% levels respectively.

Table 22. Quality of process. Hypothesis testing.

Hypothesis	Status
H1. The benefits to industry from RIC are influenced negatively by the procurement policy of RIs.	Partially Confirmed
H2. The easier the communication process (getting and asking for information on a project) is, the more likely it is that a company will benefit from collaboration.	Rejected
H3. The more a company participates in scientific events, more likely it is to obtain benefits.	Partially Confirmed
H4. Benefits are influenced positively by a collaborative network. Thus, producing parts for other scientific laboratories is likely to positively impact a company's collaboration outcomes.	Rejected
H5. The more procurement activities a company has with a scientific project, the more the company will benefit.	Rejected
H6. The longer the relationship between a company and CERN/CLIC is, the more the company will benefit.	Rejected

Learning for quality of logistics

Learning about or improving the quality of logistics for industry is represented by an improvement in the logistics of the company due to its collaboration with CERN.

The analysis showed the influence of the three distinguished attributes on the generation of the benefit of learning about the quality of logistics during the development and planning phase of CLIC. The results of the statistical tests of the eight concerned linear regression models are summarized in Table 24. Table 23 reports the hypothesis test results of all discussed statistical models. No significant influencing factors were identified. Therefore, all hypotheses are rejected.

Table 23. Quality of logistics. Hypothesis testing.

Hypothesis	Status
H1. The benefits to industry from RIC are influenced negatively by the procurement policy of RIs.	Rejected
H2. The easier the communication process (getting and asking for information on a project) is, the more likely it is that a company will benefit from collaboration.	Rejected
H3. The more a company participates in scientific events, more likely it is to obtain benefits.	Rejected
H4. Benefits are influenced positively by a collaborative network. Thus, producing parts for other scientific laboratories is likely to positively impact a company's collaboration outcomes.	Rejected
H5. The more procurement activities a company has with a scientific project, the more the company will benefit.	Rejected
H6. The longer the relationship between a company and CERN/CLIC is, the more the company will benefit.	Rejected

TABLE 24. LINEAR REGRESSION ANALYSIS. LEARNING AND QUALITY OF LOGISTICS

Dependent variable: Improve of quality of logistics	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Size	0.096 (0.130)	0.087 (0.133)	0.072 (0.131)	0.066 (0.126)	0.093 (0.131)	0.079 (0.132)	0.117 (0.131)	0.044 (0.136)
Age of the company	-0.183 (0.005)	-0.179 (0.005)	-0.151 (0.005)	-0.144 (0.005)	-0.173 (0.005)	-0.175 (0.005)	-0.174 (0.005)	-0.145 (0.005)
Country code 3 (Location)	0.005 (0.179)	0.002 (0.182)	-0.007 (0.178)	0.022 (0.178)	-0.034 (0.186)	-0.007 (0.198)	0.007 (0.178)	-0.024 (0.207)
Procurement Policy								
How difficult it was to start collaboration with CERN?		0.094 (0.070)						0.017 (0.074)
How difficult do you find the CERN procurement/tender process?		-0.053 (0.065)						-0.142 (0.069)
Communication								
Find/ to get the required information about the project			0.165 (0.122)					0.099 (0.138)
Scientific events								
The company participates in scientific conferences, workshops, fairs etc.				0.155 (0.099)				0.166 (0.114)
The company will appreciate a possibility to use CERN Infrastructure for their current or future needs				0.157 (0.101)				0.113 (0.113)
The company produced publications due to business with CERN				0.205 (0.140)				0.255 (0.155)
Economic activity								
Total amount charged from the Budget					-0.024 (0.000)			-0.191 (0.000)
Total number of orders					0.154 (0.005)			0.135 (0.005)
Relationship with CERN								
Relation duration with CERN						-0.019 (0.012)		-0.054 (0.013)
Relation duration with CLIC						0.126 (0.044)		0.084 (0.047)
Relationship with other RI								
Do you have collaboration/business with other Research Institutes (number)?							0.158 (0.027)	0.055 (0.033)
F value	0.838	0.654	1.092	2.493	0.793	0.699	1.065	1.401
R square	0.036	0.048	0.062	0.189**	0.058	0.051	0.061	0.259

Note: Standardised coefficients and robust standard errors in parenthesis. ***, **, * denote significance at the 1%, 5% and 10% levels respectively.

4.3 Discussion of results

The objective of this study was to evaluate the societal impact of an international project that is still in the study phase from internal and external viewpoints. The benefits to industry and the RI itself were assessed from the earliest phase, that is, the development phase. Moreover, the relationship of industry-university to Big Science was observed in detail from the external perspective of industrial partners by assessing the influencing factors for creating sustainable and long-term productive partnerships. Thus, the societal impact was evaluated through two research lines: from inside CLIC projects and outside the companies' prospects. The research study aimed to provide answers to four main questions. Table 25 shows the research questions and connects them to the main findings. The next two subchapters, 4.3.1 and 4.3.2, discuss the findings for each research line in detail.

Table 25. Main findings of the study.

Research questions	Main findings
(RQ1) What types of benefits does an international project at the development phase generate from an internal viewpoint?	The study found that the societal benefits from the international study from the internal viewpoint of the CLIC study are human capital formation, knowledge creation and technological output.
(RQ2) What types of benefits does an international project at the development phase generate from an external viewpoint?	The study found that the benefits of a large-scale international project on one of its impact groups, its industrial partners are innovation, market expansion, marketing image enhancement, economic benefits, R&D processes and learning about the quality of services and internal production processes.
(RQ3) What factors influence RIC outcomes?	Through a deep literature review, three groups of influencing factors were distinguished in RIC: the firm's attributes, the RI' s attributes, and the relationship's attributes.
(RQ4) How do the identified influencing factors enhance or diminish the benefits from RIC?	The influencing factors were discussed from industrial partners' perspectives and the findings are in the next paragraph. Based on the results of the regression analysis result, the size and age of companies can influence the benefit creation. The size of the company showed a significant positive effect on the benefit creation, while the age showed a significant negative effect. The location of a company did not show any impact on the benefits. The RI's procurement and communication policies had statistically significant impacts on the benefits of RIC to companies. The participation of companies in scientific events such as conferences and workshops and their having the possibility of using the RI facilities for some of their business lines enhanced their profits especially in terms of R&D processes and learnings. The duration of the firms' relationship with CLIC and their collaborative network with other RIs positively influenced the impact of RIC on them, while the duration of their relationship with CERN had a negative effect on their innovation benefit.

4.3.1 Societal Impact Assessment: Internal viewpoint

The proposed conceptual framework fulfilled two central functions: (1) it defined impact domains and (2) it defined the measures through which different types of impact materialised. The three main categories, previously shown as the main benefit areas (Florio, Forte and Sirtori, 2015; Battistoni *et al.*, 2016), were calculated, and presented above.

The continuation of this study is foreseen as the evaluation of the missing impact areas for the construction of an overall picture of the societal impact of a large-scale project at the very early R&D phase, and the forecasting of the impact for the next years, considering the machine construction and the operational and labour costs. The present and subsequent research and the model presented here will be instrumental in bridging the gap existing today in developing a common methodology for SIA of RIs.

However, even with a still incomplete picture the benefits, the positive impacts can already be disclosed to the CLIC study after the first stage of the collaboration.

Table 26 summarises the calculation of the three SIA fields: technological output, human capital formation and knowledge creation.

Technological output

The calculation of the technological outcome combines the calculation of the economic benefits based on the EBITDA with that of the utility ratio because of the use of the already created conceptual design via the CERN OHL. The first calculation was performed using different margins, by projecting the incremental profits on the share of the part related to CLIC. 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 (Battistoni et al., 2016; Florio et al., 2016). 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 later is in line with Florio et al., (2016), 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. However, RIC started creating benefits for both stakeholders already at the development phase of the international study. The results of SIA from industrial viewpoint are discussed later in this chapter.

Table 26. SIA benefits summary.

Benefits	Value (MCHF)	Benefits/cost ratio
Technological		
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	19.1	Incorporated in the above calculation
Human capital		
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
Knowledge		
Average references per paper (Battistoni et al., 2016)		92.3
Average references per paper (Giffoni & Vignetti, 2019)		73.2
Average references per paper (the study's sample)		196

Human capital output

Additionally, to calculate the NPV, the CLIC study benefits more from involving technical and doctoral students than fellows, since part of its financial contribution is paid for by concerned collaborations or universities—48% for doctoral students and 25% for technical students. Furthermore, fellows request a higher salary and therefore, a larger subsidy from the RI. Moreover, estimation of the human capital does not count other outputs such as the effect at the local level. Because of the international nature of CERN, most ECRs come from abroad, which forces them to rent in the nearby French and Swiss areas, as well as to use different social and commercial services. For instance, the rental price is around ~ 1000 CHF/per person and per month. Nevertheless, the output has to be carefully evaluated since it could come with some negative impacts on the environment such as increasing constructions and cars (Waaijer, 2011). Additionally, when the students receive grants for their studies other countries are liberated from funding but at the same time, they receive trained high-quality specialists. Thus, the finding is in line with Florio et al. (2016) who stated that students and young scientists who spend a period working within a major RI earn higher human capital relative to their peers. However, the authors expected salaries as the main expenditure during the operation period.

An extra point for the discussion is methodology. This study used a debatable approach. In the previous and present studies, the sample was formed only by the former researchers, but a comparison with a not-treated sample could be essential. It may be crucial to compare two peer groups of ECRs—one with training at CERN and the other, without.

Knowledge output

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.

Moreover, the data collection in this study was difficult as it still required manual intervention since online databases—in this study, Inspire—sometimes indicate wrong numbers of references. Therefore, for more accurate estimation, each publication unit has to be reviewed one by one.

According to Florio et al. (2016), the societal value of scientific outputs can be estimated as the cost of the publication L0 multiplied by the degree of influence of that piece of knowledge on the scientific community. Florio's approach may appear captious and contentious in a sense. Regardless, until now, the LHC's scientific evaluation uses the most complete technique of socio-economic impact evaluation. For the aim of this study of calculating the benefit/cost ratio, such technique is enough. However, for the final cost and benefit comparison the evaluation of the production cost of a CLIC paper and its citation is required.

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.

Florio et al. (2016) considered that 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, what is the case for LHC, constructed at the place of the Large Electron-Positron Collider (Myers, 1991). Florio et al. (2016) discussed that 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. 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.

Some criticisms of the model can be introduced (Schopper, 2016). 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 (1) to forecast the benefits for the future and (2) to compare such benefits with the costs as was done in the previous topical studies (Florio et al., 2015; Battistoni et al., 2016).

4.3.2 Societal Impact Assessment: External viewpoint

The literature review identified six benefits of RIC for industry and the possible diminishing and reinforcement of the influencing factors, validated empirically. The aim of this study was to identify the mentioned outcomes of the collaboration of a firm with an international project that is still in the study phase from the company perspective and the effects of the influencing factors on the creation of the benefits, using multiple linear regression statistical analysis. The significance of the key factors to certain benefits were identified and are summarised in Figure 37 and Table 27.

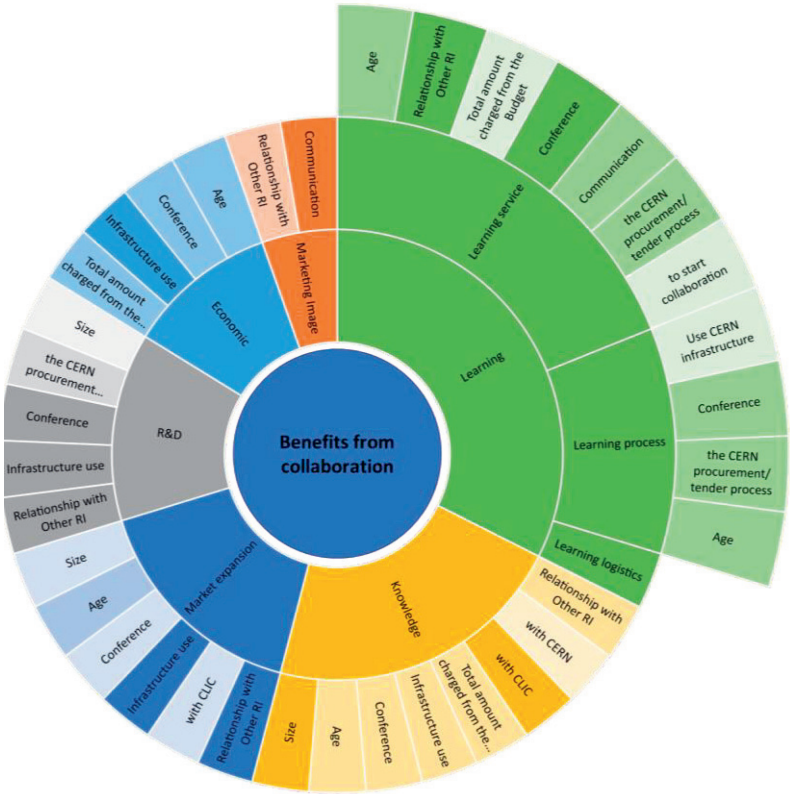

Figure 37. Benefits from RIC and influencing factors

Figure 37 shows the benefits from RIC and their influencing factors. The significance levels are indicated using color codes, that is, with greater benefits signified by more intense colors. Table 27 repeats the results shown in Figure 37 but reports only statistically significant models with standardised coefficients of the linear regression models.

Table 27. Multiple Linear Regression results.

	Size	Age of the company	Country code 3 (Location)	How difficult it was to start collaboration with CERN?	How difficult do you find the CERN procurement/tender	find/ to get the required information about the project	The company participates in scientific conferences,	The company will appreciate a possibility to use CERN	The company produced publications due to business with CERN	Total amount charged from the Budget	Total number of orders	Relation duration with CERN	Relation duration with CLIC	Do you have collaboration/business with other Research	R square value
1 Knowledge	.305**	-.248**													0.137**
2	.291**	-.227*													0.145*
3	.279**	-.213*													0.168**
4	.303***	-.190*					.295**	.294**							**0.372*** **
5	.302**	-.240**													0.158**
6	.262**	-.204*											.299**		0.226***
7	.342***	-.232**												.276**	0.211***
8	.264**						.268**	.247**		-.243**		-.223*	.320***		**0.523*** **

	Size	Age of the company	Country code 3 (Location)	How difficult it was to start collaboration with CERN?	How difficult do you find the CERN procurement/tender	find/ to get the required information about the project	The company participates in scientific conferences,	The company will appreciate a possibility to use CERN	The company produced publications due to business with CERN	Total amount charged from the Budget	Total number of orders	Relation duration with CERN	Relation duration with CLIC	Do you have collaboration/business with other Research	R square value
2 Expansion															
2															
3															
4							.217*	.349***							**0.325*** **
5															
6		-.291**											.211*		0.136*
7	.197*	-.211*												.478***	0.286***
8		-.212*						.279**						.335**	**0.456*** **
3 Marketing Image															
2															
3						.330***									0.141**
4															
5															
6															
7														.298**	0.125*
8															
4 Economic		-.259**													0.092*
2															
3															
4		-.188*					.205*	.420***							0.273***
5															
6															
7		-.249**													0.122*
8		-.306**					.280**	.450***		-.271**					**0.362** **
5 R&D															
2															
3															
4							.349***	.321***							**0.398*** **
5															
6															
7	.216*													.343***	0.153**
8					-.229**		.363***	.243*							**0.486*** **
6.1 Learning service															
2		-.279**		.201*											0.136*
3		-.237**				.259**									0.147**
4		-.258**					.379***								0.279***
5															
6															
7		-.268**												.349***	0.203***
8		-.312**			-.295**		.380***			-.230*				.257*	**0.432*** **
6.2 Learning process		-.301**													0.091*
2															
3		-.269**													0.116*
4							.271**	.220*							0.286***
5															
6															
7		-.289**													0.131*
8		-.272**			-.261**		.329**								**0.374** **
6.3 Learning logistics															
3															
4															
5															
6															
7															
8															

Significance level: * <0.1, ** <0.05, *** <0.01

Industrial partners benefit from RIC already at the earlier phase of a fundamental scientific accelerator study by receiving knowledge and opportunities for market expansion, marketing image enhancement, economic growth, R&D improvement and learning about internal services and processes. The highest statistical significance and models' fits were seen for knowledge, market expansion, R&D and learning about service benefits from RIC, which are in line with the R&D mission of an international study at its early development phase.

The findings indicate the importance for companies of participating in scientific events organised by RIs to emphasise the most categories of the benefits, and of doing business with other RIs. On the other hand, Big Science centres can enhance the benefits for industry of collaborating with them by simplifying their procurement policy and having well-established communication channels.

The firm's age negatively affects its obtaining of on benefits. A similar effect was presented in Kodama (2008), where the age of the company was negatively correlated with its product development and R&D. This negative correlation can be explained by the fact that older companies tend to be more conservative and therefore, to be more reluctant to implement changes. Conversely, the size of the company positively influences its benefits. This can be explained by the fact that big companies often have more resources at their disposal for participation in innovation and with fewer risks. Larger companies generally have a good cushion for sustainable operations, and it is an increasingly common practice for them to have a separate department for collaboration with RIs. Klimczak et al. (2017) came to the same conclusion: small and medium-sized technological enterprises less effectively collaborate with institutions. However, the geo-proximity effect was not confirmed. This means that in this study, the benefits were not affected by the distance of the company's location from CERN. This finding contradicts that of other studies in this field (Levy et al., 2009) that indicate proximity to the RI is even more important in intensive bilateral relations with a university.

Scientific events and collaboration with other RIs remain among the most important factors of obtaining benefits from RIC. Business with other RIs has a high significance level for market expansion, R&D and learning about quality of service. As mentioned before, scientific conferences create myriad opportunities for networking and expanding contacts and for participating company to introduce itself in its specific market segment.

Economic activities, mainly 'the total CHF charged from the budget' did not show a significant impact on the benefits by themselves but had a significant negative effect when combined with other variables for innovation, economic benefits and learning about quality of service. The value of 'the total CHF charged from the budget' is measured by the total amount of money that the supplier has received from CLIC. In this study, such value was extracted from the CERN procurement database. Therefore, a bigger value appears because of rare orders for expensive hi-tech products or services or because of more frequent procurement transactions for off-the-shelf products or services. However, another variable, the 'total number of orders' did not have a significant impact on benefits. Thus, no clear conclusion can be made. Further research is needed.

The duration of a supplier's relationship with CLIC appeared important only for the knowledge and market expansion benefits. However, the duration of a company's relationship with CERN had a negative effect on the knowledge benefit in one case, but it was compensated for by the positive effect and the more significant effect of the company's relationship with CLIC.

The linear regression analysis revealed that the RI's procurement policy, mostly pertaining to the difficulties in starting collaboration, had a significant negative effect on obtaining the R&D benefits and the benefit of learning about quality. The companies were carefully selected by CERN's procurement Department, and those chosen must provide high-quality service. On the other hand, the difficulties in the procurement and tender process showed a significant negative influence on the R&D benefits and on the benefit of learning for process and service quality. This is in line with the hypothesis supported by the previous study that discussed the same problem in RIC—those restrictions in company interactions with RIs, such as due to strict procurement rules, limit their knowledge and technology benefits from RIs (Åberg, 2013). Therefore, an increase in interest in the benefits from RIC leads to an increased focus on the procurement policy.

Communication is statistically significant in enhancing a company's marketing image and learning about quality of services from a RIC.

The independent variables in the regression analysis in this study, such as the firm's location, production of publications and total number of orders, did not appear as significant influencing factors on the industrial benefits from RIC.

The findings are in line with earlier research that demonstrated that the various learning and innovation benefits (e.g., technological learning, organisational capability development and market learning) tend to occur together (Autio et al., 2003).

Figure 38 summarises the cumulative influencing factors. The graph shows the significance and frequency of the statistical relationships. Therefore, the first four most statistically significant and most frequently appearing influencing factors are the two control variables of the company's age and size, the two scientific variables of the participation of companies in scientific events and the possibility of using RI facilities, and the relationship variable of company's business with other RIs. Thus, the outcomes of RIC are mostly statistically explained by the mentioned factors. The rest of the factors occur less frequently and have less significant effects on the relationship outcomes, according to the statistical regression analysis based on the feedback of the companies-suppliers.

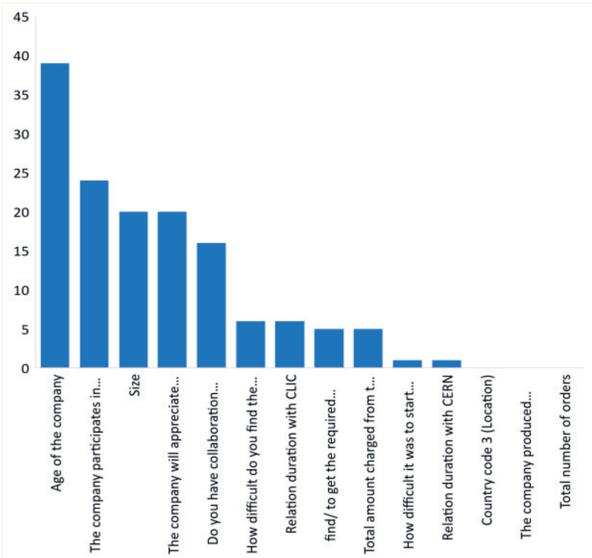

Figure 38. Influencing factors

5 CONCLUSIONS

5.1 Theoretical and managerial contributions

This study contributes to existing knowledge and understanding in two contemporary fields: SIA of fundamental science projects and RIC evaluation. The literature review showed the lack of studies on Big Science centres. However, findings of earlier studies remained relevant even for innovative science, as shown by the discussion on the SIA fields. The insights gained from this study may support the appraisal of similar scientific projects. Furthermore, new considerations should help to improve predictions of the impacts of an international project still at the development phase. The exercise of the benefit/cost ratio calculation and the introduction of some criticisms of the methods are additional contributions of this study to the existing knowledge base. The study contributes by building on existing practices and developing a comprehensive model reflecting the viewpoints of different stakeholders.

This study is a good supplement to further discussion and development of sustainable collaboration between industry and science. It sheds light on the important influencing factors of such collaboration and makes several contributions to the current literature on RIC. First, it confirms the presence of benefits for companies even at the early stage of an international study, starting at the development phase. The role of firms' attributes in the created collaborative outcomes is in line with the findings of other studies. A change in benefits appeared along the duration of the collaboration, but this phenomenon requires further investigation. Moreover, the findings presented significant effects of collaborating with other RIs and the duration of the CLIC – supplier relationship. It is important for companies to understand these effects which are explained by sharing a list of companies qualified for collaboration with other research institutes.

This study has important contributions as well to both the management of firm and the management of RI. Understanding the key influencing factors of RIC is essential for both stakeholders. A company willing to benefit from Big Science collaboration has to be well aware of which is the most beneficial field of research and technology for it to be involved in (Hameri, 1997). Companies profit not only economically by receiving procurement orders, but also from market expansion, marketing image enhancement, learning about and improving the quality of their internal processes and services and knowledge creation. By considering these key influencing factors, industrial management can increase the positive impact of its relationship with an RI, such as by participating in scientific conferences and collaborating with other research laboratories. The multilinear regression analysis of the benefits from RIC presented insights for the formation of effective and sustainable relationships between industry and academy. The managerial contribution of this type of studies was discussed by Angelis et al. (2019), that the usefulness of applying the developed approach to SIA of RI can be seen primarily through the lens of information it provides to policy-makers and RI managers. SIA can help to reconstruct mechanisms how investment in RI leads to specific impacts. This information can help not only to appraise the effects of RIs from policy-maker and funder perspective, but also meaningfully support RI managers in the design of operational strategies for enhancing impacts.

Although this study was based on a small sample of participants, the findings will be of interest to the management of international projects, since such findings provide indications of profits to industry as early as at the prototype phase of the project, even before the intense procurement period of construction begins. This means that earlier participation in R&D with an RI can be promoted to potential suppliers.

Thus, this study showed that a large-scale international study can already create benefits at its very early development phase from the internal and external points of view. The developed conceptual model can be used to defend the required public investments in fundamental research and can be used as a tool for emphasising profits for industrial partners from an unpredictable collaboration with science.

The study validates six hypotheses for each type of benefit (see Table 28).

Besides the mentioned scientific and managerial contributions of this study, the amount of the data collected herein opens wide perspectives and shows a high potential for further research to paint a full picture of the SIA for a large-scale scientific project.

Table 28. Summary of the hypothesis testing.

Hypothesis	Knowledge	Market expansion	Marketing Image	Economic	R&D	Learning service	Learning process	Learning logistics
H1. The benefits to industry from RIC are influenced negatively by the procurement policy of RIs.	Rejected	Rejected	Rejected	Rejected	Confirmed	Partially Confirmed	Partially Confirmed	Rejected
H2. The easier the communication process (getting and asking for information on a project) is, the more likely it is that a company will benefit from collaboration.	Rejected	Rejected	Confirmed	Rejected	Rejected	Confirmed	Rejected	Rejected
H3. The more a company participates in scientific events, more likely it is to obtain benefits.	Partially Confirmed	Partially Confirmed	Rejected	Partially Confirmed	Partially Confirmed	Partially Confirmed	Partially Confirmed	Rejected
H4. Benefits are influenced positively by a collaborative network. Thus, producing parts for other scientific laboratories is likely to positively impact a company's collaboration outcomes.	Confirmed	Confirmed	Partially Confirmed	Rejected	Confirmed	Partially Confirmed	Rejected	Rejected
H5. The more procurement activities a company has with a scientific project, the more the company will benefit.	Confirmed	Rejected	Rejected	Partially Confirmed	Rejected	Confirmed	Rejected	Rejected
H6. The longer the relationship between a company and CERN/CLIC is, the more the company will benefit.	Partially Confirmed	Partially Confirmed	Rejected	Rejected	Rejected	Rejected	Rejected	Rejected

5.2 Validity and reliability

Reliability and validity are concepts used to evaluate the quality of research. Reliability, validity and generalisability concepts are adopted by qualitative researchers to enhance the credibility of research (Mohajan, 2017). Reliability indicates the consistency of a measure, and validity indicates the accuracy of a measure (Cohen, 2013). The reliability and validity of the results of a study depend on the creation of a strong research design, the selection of appropriate methods and the careful and consistent conduct of the research. The validity and reliability of the two research phases in this study are hereby reviewed.

Societal Impact Assessment: Internal Viewpoint

Micro-foundation made CBA one of the most scientifically robust and methodologically sound analytical frameworks to support decision-making on public major investment decision and it was commonly accepted among policy-makers and economists worldwide (Giffoni et al., 2020). 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. Moreover, 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. 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 (Giffoni et al., 2020). The latter was implemented in another line of this study for RIC to shed light on factors determining the performance of this relationship. 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.

Giffoni et al., 2020 claimed that CBA had the potential to capture most of the effects expected by a RI. Estimations of shadow prices or willingness-to-pay were largely used in CBA for quantifying the price of goods in distorted markets or non-market goods. While there was an existing CBA model specifically developed for RI, further research was needed to test this theoretical model on existing RIs and tailor the traditional toolbox of CBA to the specificities of RIs. While there was consolidated body of literature on the evaluation of social benefits in the Education, Environmental and Cultural sectors that could be largely used to value specific benefits of RIs, additional work was needed to develop tools and methods to value other types of benefits as well as to develop reference values and parameters tailoring RIs specificities (Giffoni et al., 2020). 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. However, this study calculated only a part of the possible range of the expected impacts of a RI. The validity of this study can be improved by calculating all expected effects presented in the full SIA model.

Societal Impact Assessment: External Viewpoint

The validity of the survey results of this study were analysed through three types of validity: content, criterion, and construct validities (Messick, 1990).

Content validity indicates to which extent the measurement covers all aspects of the concept being measured. To ensure content validity in this study, the existing theory was reviewed to include many of the discussed influencing factors. The method and measurement technique were thoroughly researched and were based on existing knowledge for both SIA and RIC. The online survey was designed based on existing theory and findings of previous studies. The pilot distribution of the form tested the clarity and comprehensibility of the questions. Moreover, the sample group for the RIC evaluation was carefully selected to be representative of the population.

Criterion-related validity refers to the correlation between measures and some criterion variables that are considered a direct measures of the characteristic or behavior in question (Messick, 1990). The statistically significant correlation between the dependent variables and the independent variables were presented earlier in Table 8. Thus, these indicators can be deemed valid in terms of criterion-related validity (Carmines & Woods, 2005).

Construct validity indicates that the constructed model is grounded in theory. There are three steps to ensure construct validity: 1) specifying the theoretical relationships between the concepts; 2) examining the empirical relationships between the concepts; and 3) interpreting the empirical evidence in terms of how it clarifies the construct validity of the measure in question (Carmines & Woods, 2005).

The theoretical relationships between the central concepts under study have been presented and discussed in chapter 2, and the hypotheses have been derived based on extant research. These actions represent the first step of ensuring construct validity. The second step goes on to test the relationships empirically. This was done through constructing quantitative models that aim to verify the hypothesized relationships. As the third step, the empirically derived results have been reflected on using existing theory and their implications discussed. Many of the hypothesized relationships are at least partially supported, and the contradictory findings were also grounded in related research, thereby improving the construct validity of the research.

Reliability is considered in the data collection process by using a tool or technique for collecting data to ensure stable and reproducible results. The data collection has to be planned in such a way that the same steps are carried out for each measurement. In this study, reliability was guaranteed by collecting data through an online survey. Furthermore, reliability was ensured by standardising the conditions of the research to reduce the influence of external factors that might have caused variations in the results. Thus, in the experimental setup, all the firm-participants had the same kinds of initial information, and were tested under the same conditions, which were respected because of the online platform.

5.3 Research limitations

This dissertation analyses the benefits generated by a large-scale international study from the internal and external perspectives. The research setting, method and variables selected all presented limitations that were considered in the interpretation of the results. Some initial limitations were already discussed in the introduction chapter, 1.3, together with the definition of the scope of this study. Hereafter, the limitations are discussed separately from two research perspectives.

Starting from the first research line, 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. The methodological limitations of this approach were already introduced earlier, together with the conceptual uncertainties in monetising the benefits from basic science using the econometric approach (Salter & Martin, 2001). 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 (Martin, 1996; Schopper, 2016). Thus, an uncertainty can be introduced already in terms of the measured productivity and quality of Big Science through merely publication counts, which have to be replaced by qualitative assessment of the content of the science produced (Hallonsten, 2014). Moreover, the methodology can introduce a bias to a positive impact and underestimate other possible measures.

Considering the second research line—the impact assessment from the industrial point of view—this study was limited by a few other aspects. First, most of the theoretical background was built on the RIC literature, since there is still a lack of research on Big Science compared to the volume of research on universities (Autio, 2014). The overall missions of universities and Big Science are similar and connected to the promotion of science and its application. Thus, utilised variables and the model of the relation between them are adopted from the earlier research. However, the diversity between these two institutions was not considered in assessing the industrial benefits of collaboration and can be wider if the focus is narrowed to only Big Science RIs. Therefore, the theoretical background and the methodology were limited by the existing dimensions, and the interrelations between the dimensions were not evaluated.

Second, the data were collected via an online survey and normally from only one involved respondent per firm. Both aspects could have biased the data towards a more positive and subjective view. Likewise, non-response bias is recognised as a limitation in most surveys, and the procedure used to standardise data in the review has limitations that affected the interpretation of the results (Fanelli, 2009).

Third, the initial data themselves had limitations, as the procurement database did not give complete pictures of such data. Furthermore, only the procurement activities of the CLIC Accelerator studies[20] were focused on, and those of the CLIC Detector and Physics study[21] were not considered. The latter project involves the use of emerging technologies and a wide range of collaborative networks with other RIs and industries. Likewise, the procurement activities were limited to the period from 2009 to the start of 2020. However, this period was the most procurement intense period of the study, as it covered the prototyping. The industrial sample was selected based on the procurement activities with CERN for the CLIC study, which automatically removed non-commercial collaboration, such joint R&D activities.

There were also some limitations in the methods used in the analysis of the survey results. Linear regression has been critiqued for its application of Likert scale ordinal values and the small sample size. Moreover, the linear relation between the variables is imposed, and therefore, another correlation rule can be missed. Furthermore, some criticisms and limitations were discussed in terms of the presentation of the results of the regression, which was mainly focused on statistical measures such as correlations and best fits of the models. While regression analysis is good for data exploration, some information on units or dimensions can be questionable.

Likewise, the generalisation of the results of this study is subject to certain limitations. As the benefits were measured only through the survey, there could have been a bias due to the probability that the respondents were constituted from a sample with stronger feelings, opinions or even closer relationships with CERN. For instance, the small sample size of the companies for the outcome appraisal from the perspective of industry could have caused a bias because the companies wishing to collaborate with CERN can affect the measurement of various impact fields. Did the companies that participated fundamentally differ from those who did not? Thus, even with the high reply rate of the survey, the generalisation of the findings needs to be considered carefully due to the particularity of the presented case.

Finally, the main limitation is in the results, since not all the impact fields were measured and the views were limited to those of industrial partners and the scientific

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[20] "Home | CLIC Accelerator Activities." https://clic-study.web.cern.ch/ (accessed Dec. 07, 2020).

[21] "Home | CLIC Detector and Physics." https://clicdp.web.cern.ch/ (accessed Mar. 03, 2021).

community, while the views of other stakeholders, such as technical students, scientific staff and general public, were missing. They could have drawn a comprehensive picture of the societal impact of CLIC and deepened the conclusions on the benefits and drawbacks of the project at its development phase. Considerably assessing the benefits from more perspectives will be an important supplement to the construction of a complete appraisal model.

5.4 Suggestions for future research

The results and limitations of this study suggest that there are opportunities for future research. As this study was a first attempt to evaluate the societal impact of the CLIC study and only three impact fields were assessed. Further research can assess the missing fields to come up with a full picture of the SIA of CLIC (Figure 39). Thus, structuring collaboration, non-use value and cultural impact are suggested for further appraisal. Moreover, a cost comparison can be made to determine the complete benefit/cost ratio. The data have already been collected for few other categories and should be completed for the further evaluation. For example, the economic cost is presented in the PIP (Aicheler et al., 2018). Waaijer (2011) has discussed negative externalities. The full conceptual model has been discussed in the Methodology chapter (3.3) and distinguished from the literature review appraisal fields and approaches for the evaluation of all impact fields have been proposed.

Figure 39. A full model of SIA of CLIC

The appraisal of the missing impact areas and the extrapolation of the impacts to the next years will construct an overall picture of the societal impact of the large-scale project at the very early R&D phase.

Other essential complements to this study are case studies of real examples of successful RIC that highlight not only positive aspects of the collaboration but also possible issues (Vuola & Hameri, 2006). Likewise, the case studies can represent special models with companies that are using technologies beyond the CLIC project to show the spread and application of technologies outside CLIC.

Furthermore, this study can benefit from the implementation of the collaboration spotting tool which is a graph-based interactive visualisation tool for multi-dimensional data networks developed at CERN (Ouvrard et al., 2017; Agocs et al., 2017). Data analysis and data visualisation tools are becoming essential. A picture sometimes explains something better than any table. Plotted data give better overviews and help to highlight some inconsistences and missing points. There are currently many commercial tools in the market, for data plotting, based on a created data model. The data are transferred to the data visualisation tool, where they can form clusters and print links that were not visible before. Moreover, the visualised

CLIC data can be assessed using the social network analysis (SNA), which has great applications nowadays because of the increasing use of social networks as business platforms and for marketing promotions and other applications. The SNA will enable measurement of the relationships or interactions between individual actors and different formed clusters. The preliminary visualisation of the CLIC data has already been performed using the collaboration spotting tool. The initial steps such as the data model development, the database creation and the data transmission to the tool have been accomplished. However, the detailed analysis is still lacking.

The SIA has been demonstrated in this study from two angles: the angle of an RI and that of industry. Since in a relationship, there is always more than one key player, the other outputs can be crosschecked with the second party. Thus, the human capital formation impact can be studied through a survey of ex-ECRs. In summary, future research should look for multilevel, multi-domain frameworks that would capture a more nuanced and comprehensive picture of the societal impact of publicly funded scientific projects.

Furthermore, for RIC benefits a natural evolution of this study is to understand the following revealed phenomena through their further analysis: (1) the negative influence of the economic activities, as the total amount charged from the budget, on the RIC outcomes; and (2) the negative effect of the duration of the company's relationship with CERN. In line with the previous similar study (Autio et al., 2003), the findings of this study confirm that the benefits of RIC occur together. A supplier that derives one type of benefit from CERN procurement activities is also more likely to derive other types of benefits from the same relationship. This study demonstrated a high inter-correlation between innovation, market expansion, R&D and learning outcomes from technological procurement by government-funded science organisations. Therefore, further research could usefully explore if benefits tend to change along the RIC timeline. The timescale problem arose from the earlier measurements of impact that emphasised short-term benefits and probably ignored potential long-term impacts (Bornmann, 2012). Companies might develop certain benefits and freeze others during the collaboration period. Understanding of such possible changes can sustain partners' motivations in RIC and clearly identify associated short- and long- term goals (Autio et al., 1996). Thus, accomplishing the mentioned studies will (1) build a complete picture of the outcomes of RIC for industry and (2) evaluate the bias between the benefits with the passing of time.

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