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1. Introduction

ACTRIS Research Infrastructure is a pan-European initiative that unites the observations and related research of aerosols, clouds, and trace gases amongst European partners to provide high-quality research infrastructure services to a wider user community. Integrating European ground-based stations equipped with advanced atmospheric probing instrumentation, ACTRIS will have the essential role to support building of new knowledge as well as policy issues on climate change, air quality, and long-range transport of pollutants. The ESFRI Roadmap 2016 identified ACTRIS as a new important pan-European research infrastructure for the European scientific community. With ESFRI-status, ACTRIS shall further develop its organizational and operational framework, and long-term strategic goals. In this context, the ACTRIS PPP aims at defining the most appropriate and cost-efficient long-term organization of ACTRIS. The analysis of the socio-economic impacts attributed to ACTRIS could provide useful insights regarding the social return of the investment required for the development, operation and maintenance of this research infrastructure and the formulation of the appropriate operational scheme.

In general, ACTRIS, as any other research infrastructure, creates positive socio-economic effects through different impact pathways:

- At consortium level, as research institutes, universities, companies, etc., involved in the development, maintenance and operation of the infrastructure in question will benefit through knowledge creation, technological developments, human capital enhancement, creation of new jobs, etc.
- To the wider research community, as research teams, organizations and programs utilizing the outcomes provided by ACTRIS will improve their modelling, satellite data calibration / validation and atmospheric climate services and products.
- To the society, as local authorities, environmental protection agencies, industries, ministries, international organizations, weather services, etc., will utilize ACTRIS outcomes to optimize their environmental strategies and improve their decision-making processes.

This study aims at exploring the socio-economic impact generated to the ACTRIS consortium and associated business from the development, operation, and maintenance of the ACTRIS infrastructures (i.e., the first impact pathway among those identified above), while the other categories of socio-economic effects mentioned above will be examined in the context of ACTRIS PPP at a later stage. Consequently, the analysis focuses on the impacts related to the development of human capital, creation of new scientific knowledge, enhancement of innovation, contribution to economic growth and employment, etc. For each impact category identified, a set of Key Performance Indicators (KPIs) will be defined and quantified, which will facilitate the effective monitoring and quantification of this type of socio-economic impacts.

More generally, the study will help to better understand the benefits generated to organizations and institutions that participate in the development, operation, and maintenance of a large research infrastructure like ACTRIS. Furthermore, to the extent that these impacts will be quantified (and if possible monetised) it will provide useful insights for evaluating the social return of the investment required for developing and maintaining ACTRIS infrastructure, facilitating an integrated cost-benefit analysis of the infrastructure in question.

The present report is structured as follows:

Chapter 2 provides a description of the methodological framework developed and implemented for analysing the socio-economic effects at consortium level attributed to ACTRIS infrastructure. This comprises: (i) a discussion of the main types of socio-economic effects created to organizations engaged in ACTRIS development, operation and maintenance; (ii) the design of a questionnaire survey that was distributed to and answered by partners of ACTRIS in order to collect necessary information on possible socio-economic impacts; and (iii) a brief description of the input-output analysis framework that has been used to estimate the macroeconomic effects associated with ACTRIS development and operation.

Chapter 3 presents the results of the analysis. Four basic types of socio-economic impacts are analysed, namely impact on human capital creation, impact on scientific activity, impacts on innovation and macroeconomic effects. For each impact category a number of KPIs has been identified and quantified on the basis of data collected for past activities in the context of ACTRIS as well as on projections made by national teams for future developments of ACTRIS in each participating country.

Finally, in *Chapter 4* the main findings of the study are summarised, and conclusions are drawn.

2. Methodological framework

2.1 Overview

In general, research infrastructures refer to facilities, resources (including human) and related services needed by the research community to conduct research in a specific scientific or technological field. Consequently, research infrastructures comprise (Griniece et al., 2015):

- Major equipment or group(s) of instruments used for research purposes;
- Permanently attached instruments, managed by the facility operator for the benefit of researchers, industrial partners and society in general;
- Knowledge-based resources such as collections, archives, structured information or systems related to data management, used in scientific research;
- Information and communication technology (ICT) –based infrastructures or ‘e-infrastructures’ such as grid, computing, and software communications;
- Any other entity of a unique nature that is used for scientific research.

Furthermore, Griniece et al. (2015) distinguish different types of research infrastructures based on their geographical distribution, namely:

- Single-site facilities, with a unified body of equipment at one physical location.
- Distributed facilities, which comprise a network of distributed instrumentation or collections, archives and scientific libraries.
- Mobile facilities, such as mobile vehicles specially designed for scientific research.

- Virtual facilities, which are ICT-based systems for scientific research, including high-capacity communication networks and computing facilities.

Undoubtedly, research infrastructures are complex and innovative systems, which are usually developed, maintained, and operated by organizations (universities, research centers, innovative businesses, etc.) with specialized personnel and significant experience in the relative scientific field. Like any other infrastructure, they are accompanied by investment, operating and maintenance costs, as well as potential economic benefits from the commercial exploitation of either the infrastructures themselves or the products and services they generate, and which are made available to the potential users. Apart from these traditional costs and benefits, the organizations involved in the development and operation of a research infrastructure will be benefited through knowledge creation, technological developments, human capital enhancement, creation of new jobs, etc.

For the analysis of these indirect effects on the Organizations involved in the development and operation of ACTRIS infrastructure, a methodological framework has been developed and implemented in the context of this study, comprising the following steps:

1. Mapping out all indirect impacts to the organizations involved in the development, operation, and maintenance of the infrastructures in question.
2. For each significant impact identified in the previous step a set of key performance indicators (KPIs) has been defined for its effective monitoring and quantification.
3. The necessary data for the quantification of the KPIs defined above were collected with a survey of the Organizations involved in ACTRIS infrastructure development and operation, through the completion of an appropriately designed questionnaire. This is of particular importance as the ACTRIS infrastructures are developed in several sites across Europe.
4. The data collected from the survey, in conjunction with other relative information were utilized for the quantification of the selected KPIs. The analysis could provide aggregated results at national level or totally for the whole infrastructure under consideration, as well as, to the extent possible, per € million spending, which can be used for a rough approximation of these effects in cases of future expansion of the infrastructure or in countries without detailed information. Most of the data collected in the context of step 3 have been aggregated in order to estimate the defined KPIs at national and/or research infrastructure level. As regards the macroeconomic effects associated with ACTRIS infrastructure, the collected data were used to develop the vector of investments in the context of the input – output analysis.

More detailed information on the applied methodological framework is given in the following sections.

2.2 Mapping the socioeconomic impacts and defining KPIs for their monitoring and quantification

Griniece et al. (2015) provides a detailed list of potential socioeconomic effects attributed to the investments in research infrastructures, further disaggregated to the design and construction phase as well as to the operational phase. Among them, those related to organizations involved in the development and operation of the research infrastructures, comprise:

Impact on human capital creation: Modern research facilities can serve as magnets to retain and attract staff with special abilities and skills. This includes researchers, technicians, students, etc., who can work in the research infrastructure either as permanent or part-time staff. Furthermore, the research infrastructure offers training and educational opportunities and favours exchange of expertise and mobility of researchers, contributing to the development of high-level scientists, technicians, etc.

Impact on scientific activity: Participation in the development and operation of research infrastructures results in the accumulation of new knowledge, improves existing methodological approaches, and tools, and enhances fundamental science and technological developments. In most cases the involved scientists have access to huge volumes of primary data and consequently the opportunity to process them in different ways, generating innovative products, services, and approaches. Furthermore, the availability of advanced equipment improves the quality of the collected data and information, gaining international recognition and reputation.

Impact on innovation: The involvement of an organization in the development and operation of a research infrastructure creates several opportunities for enhancing innovation. Usually, several collaborations with other research organizations and businesses within the country or abroad are developed, facilitating knowledge transfer. Furthermore, research facilities generate knowledge that businesses cannot acquire through their networks. Specifically, new products, services, methodologies, etc. are being developed, with a view the information gathered through the research infrastructure to be exploited in a wide range of problems and applications. Often, even the development of research infrastructures, due to their complexity, requires innovative solutions which can then be implemented in other fields as well.

Macroeconomic effects: Investment in developing and operating of research infrastructure creates, as any other investment, positive macroeconomic effects, mainly in terms of economic growth, job creation, increased public revenues, etc. These include: (i) direct effects created to the organizations and businesses involved in the development and operation of the research infrastructure in question; (ii) indirect effects, distributed throughout the economy, as the development and operation of the research infrastructure requires the purchase of goods and services such as construction materials and equipment, maintenance tools, and supplies as well as manpower essentials such as food, clothing, spares, safety equipment, etc.; and (iii) induced effects, based on the purchases made by those engaged directly or indirectly in the above activities (employees), due to the increased available income.

For many economists the employment effects associated with an investment do not constitute a socioeconomic impact, as in perfectly competitive markets the existence of any unemployment rates represents temporary situations, in which individuals leave one job and move to another, trying to obtain additional skills in order to find a better position in the labor market, etc., and therefore, unemployment does not have any social cost (Markandya, 1998). This type of unemployment is defined as natural unemployment. In cases where the economies are characterized by unemployment rates close to natural unemployment rates (i.e., 3–5%), the increased demand for jobs due to an investment will be only realized through a decrease in other jobs, so there will be merely a change in the allocation of jobs, but not a net increase. However, these ideal conditions are far from the reality that the majority of people face in both developed and developing economies. During the last 2–3 decades unemployment is among the most

significant problems that societies have to deal with and a primary worry among those that are presently employed. The political pressure for the governments to take measures to decreasing the unemployment rate is high, and this is reflected in several EU official documents, where the adoption of policies that enhance employment opportunities is of high priority. It is, therefore, logical to assume that the creation of new jobs in economies with unemployment levels higher than the natural unemployment rate results in social benefits, which should be taken into account in decision-making processes.

Aiming to track the various impact categories associated with the ACTRIS research infrastructure on the organizations involved in its development and operation, several Key Performance Indicators (KPIs) were identified and are presented in Table 2.1 below. Subject to data availability from the Organizations involved in ACTRIS development and routine operation, maintenance and upgrading, these KPIs can be estimated at: (i) national level; (ii) research infrastructure level; and (iii) per € million spending, facilitating a rough approximation of the corresponding effects in countries without analytical data and for future developments of the infrastructure under consideration.

Table 2.1: Overview of Key Performance Indicators used to quantify the socioeconomic effects on the organizations involved in developing and operation/maintenance of ACTRIS RI.

Impact category	Key Performance Indicators	Comments
Human capital creation	Number of Ph.D. students carried out research at the RI	
	Number of graduates that have used the RI for their Master thesis	
	Number of graduates trained on RI	Other than those used the RI for their Ph.D. or Master thesis
	Number of foreign students (i.e., Ph.D./M.Sc.) as % of all students trained on the RI	
	Research and technical staff attracted to be employed on RI	To the extent possible, a distinction between permanent and contractual staff should be made.
	Percentage of the research and technical staff attracted from abroad	
Scientific activity	Number of articles published in scientific journals with peer-review	Concerns publications that are based on ACTRIS produced knowledge
	Number of articles published in proceedings of international conferences	Concerns publications that are based on ACTRIS produced knowledge
	Number of books (chapters or extended sections)	Concerns publications that are based on ACTRIS produced knowledge

	Number of Ph.D. dissertations completed	Concerns Ph.D. dissertations that have been predominately- or partly-based on the use of RI in question.
	Number of patents' applications	
	Number of patents granted	
	Number of new methodologies, prototypes or designs developed	
	Number of scientific events organized on topics relating to ACTRIS RI.	To the extent possible, provide information about workshops, conferences, working groups, or any other event.
Innovation	Total volume of funding associated with R&D projects commissioned to the Research Groups involved in ACTRIS RI	To the extent possible, this indicator should be disaggregated on the basis of the source of funding (i.e., EC or other international agencies, national authorities, private sector) The projects included should predominantly or partially utilize the ACTRIS RI
	Number of start-ups and/or spin-offs created utilizing products or expertise gained from the ACTRIS RI	
	Total turnover and earnings of the start-ups and/or spin-offs created	
	Procurement contracts signed for development and upgrade of research equipment.	Include number and budget
	Number of companies involved in development and upgrade of research equipment.	
Macroeconomic effects	Total spending for developing and operating ACTRIS RI	To the extent possible all these indicators should be estimated separately for developing and operation/maintenance of the RI in question
	Total impact on Gross Value Added from development and operation ACTRIS RI	
	Direct, indirect and induced effects on employment attributed to development and operation of ACTRIS infrastructure	
	Total impact on available income attributed to development and operation of ACTRIS infrastructure	

	Impact on Gross Value Added attributed to research activities utilizing ACTRIS RI	
	Direct, indirect and induced effects on employment attributed to research activities utilizing ACTRIS RI	
	Total impact on available income attributed to research activities utilizing ACTRIS RI	

2.3 Design of the survey

The analysis of the socio-economic impact of ACTRIS on the organizations involved in the development, maintenance, and operation of the infrastructure under consideration was based on a field survey and the completion of a properly designed questionnaire by the project participants.

The questionnaire was initially designed by National Observatory of Athens (NOA) and a preliminary draft was sent to other partners engaged in Task 8.1 of ACTRIS PPP, namely University of Helsinki (UHEL), the National Research Council of Italy (CNR), the French National Centre for Scientific Research (CNRS), and the Romanian National Institute of R&D for Optoelectronics (INOE), for possible comments, modifications, etc. The final version of the questionnaire was distributed to the national ACTRIS contact persons in each country participating in ACTRIS, as defined in the ESFRI Roadmap (2016). Consequently, each participating country in the context of the ACTRIS PPP had to fulfill one questionnaire, providing aggregated data at national level by including all organizations of the country engaged in development, operation, and maintenance of ACTRIS infrastructure.

The time available to the national contact persons to complete the questionnaire was initially 3 months (15 June to 15 September 2017), however some completed questionnaires were received by the end of October 2017.

The developed questionnaire is presented in Appendix. It is organized in 6 sections:

- Section I comprises introductory questions such as the name and affiliation of the responsible for completing the questionnaire, the Institutes in each country that participate in ACTRIS research and their role, etc.
- Section II deals with the impacts of ACTRIS on the development of human capital, collecting data on the number of people trained or working in the infrastructure under consideration, the percentage of those coming from abroad, etc.
- Section III explores the influence of ACTRIS on research activities of the participating Institutions, through the presentation of relative publications, scientific events, new methodologies and prototypes developed, patents granted, etc.

- Section IV exams the business opportunities related to innovation, focusing on the number of projects and total volume of funding attracted that predominantly or partially utilize the RI in question.
- Section V deals with the macroeconomic effects attributed to the development, operation and maintenance of ACTRIS RI, examining the contribution of these activities to economic development, creation of employment, etc.
- Section VI collects information for the wider impact of ACTRIS RI on research community, identifying organizations and type of activities that use the ACTRIS products and outcomes to improve their research work.

In total it comprises 44 questions, collecting various data that will allow the quantification of the KPIs defined in the previous section. Data should be completed for two periods, namely 2008-2016 (i.e., the period that basic elements of the ACTRIS infrastructure were established and initially operated) and 2017-2019, covering future developments of the infrastructure in question in the context of ACTRIS PPP.

11 countries completed the questionnaire out of a total of 20 participating in the ACTRIS PPP. Specifically, responses were received from Germany, United Kingdom, Spain, Finland, Poland, Romania, Italy, France, Bulgaria, Switzerland, and Greece, covering the activities of 98 organizations engaged in ACTRIS development and operation. This sample constitutes a significant part of the ACTRIS community as the countries responded to the questionnaire have approximately a 77% share of the budget in the context of ACTRIS PPP, 75% in ACTRIS I and 77% in ACTRIS-2.

2.4 Estimation of macro-economic effects through input – output analysis

2.4.1 Overview

As already mentioned, in the present study, the macroeconomic implications associated with the development and operation of the ACTRIS infrastructure will be quantified. The analysis is done for the whole European economy, as analysis at national level requires more detailed data and a determination of the percentage of expenditures incurred domestically in each country, which is quite difficult given the dispersion of this infrastructure and the strong partnerships of the participating groups.

As a large-scale investment, ACTRIS contributes directly to the economy through direct payments, taxes, creation of employment, etc. In addition, the realization of the activities associated with the research infrastructure development, maintenance and operation requires the purchase of goods and services such as construction materials and equipment, maintenance tools, and supplies as well as manpower essentials such as food, clothing, spares, safety equipment, etc., enhancing further the economic development at both local, national and regional level (indirect economic effects). Furthermore, as those engaged directly or indirectly in these activities will increase their available income for spending, additional economic effects are expected due to the increased consumption for purchasing goods and services (induced economic impacts). In the context of this analysis, we have analysed all the direct, indirect and induced macroeconomic effects associated with ACTRIS development, maintenance and operation activities, namely:

- Contribution to GDP through changes in Gross Value Added (GVA),
- Employment effects,
- Changes in available income.

The quantification of these effects is based on input-output analysis, which is shortly presented in Section 2.4.2. The multipliers that can be derived from input-output tables and used for estimating the impacts on GDP, employment and other macroeconomic parameters are presented in Section 2.4.3.

2.4.2 Input – output analysis

Input-output analysis is a methodological approach, which can evaluate the effects of an investment on key socio-economic variables taking into account the inter-sectoral linkages in the economy where the investment in question is realized. Specifically, input-output tables provide a complete overview of the monetary flows representing the exchange of goods and services in an economic system for a given year, either between producers and consumers or among economic sectors. The standard representation of the input-output model in matrix notation is defined in the following Equation, which allows constructing disaggregated multipliers in order to estimate the direct, indirect and induced impacts of a project (Leontief, 1966; Eurostat, 2008):

$$X = (I - A)^{-1} Y \quad (1)$$

where,

X: is the vector of output of the economy in question (all elements of the vector are expressed in €).

Y: is the vector of final demand of the economy (all elements of the vector are expressed in €).

I: is the identity matrix.

A: is an $n \times n$ matrix of technical coefficients. A technical coefficient a_{ij} is defined as the amount of production of sector i used by sector j in order for the latter to produce one unit of output. Through these coefficients one can estimate the direct impacts from an increase in final demand for a particular commodity on the various economic sectors.

The $(I-A)^{-1}$ is the $n \times n$ matrix of input–output multipliers, or the Leontief inverse. The rows and columns of the Leontief inverse matrix are the sectors of the economy and each element b_{ij} of this matrix shows the total required increase in the production of sector i to meet an increase of one unit in the final demand of sector j . The sum of all the elements of the j column of the Leontief inverse matrix gives the output multiplier of the sector j , which shows the total change in gross output (or sales) of the entire economy created by a change in the final demand of sector j by 1 €.

There are two types of Leontief inverse matrices, where each one of them provides a different type of multiplier. The first named Type I, includes the relationship among various economic sectors and is used to estimate the indirect economic effects. The second one named Type II, includes additionally the effect of households' consumption (by expanding the matrix with one column, namely the households' expenditure and one row, namely the compensation of employees) and is used in combination with Type I Leontief inverse to estimate the induced effects of a policy or project.

It is also worth mentioning that the input-output analysis is based on certain assumptions/prerequisites (Trewin, 2000), namely homogeneity (i.e., each sector produces a single output, has a single input structure and there is no substitution between the products of different sectors), proportionality (i.e., the change in output of a sector will lead to proportional changes in the quantities of its intermediate and primary inputs), and no existence of externalities (i.e., the production process of each sector does not affect the production activities of any other sector). Even though these assumptions are far from being realistic given the multiplicity and variability of processes in modern economies, input–output analysis is still considered as an attractive and powerful tool that is capable of adequately capturing the inter-linkages within an economic system. Since radical changes in economic structure can be assumed to occur relatively slowly, the results derived from such models can remain robust for many years.

2.4.3 The framework for estimating the macroeconomic effects

Input-output tables can be used to estimate several of the macro-economic effects associated with a policy or an investment. These comprise impacts on employment, GVA, wages, taxes on products and production, etc. To this end, the total investment in question is disaggregated to a number of distinct economic sectors, which are included in the input-output table. It is assumed that the marginal change MX_j in the activity of sector j caused by the realization of the project in question incurs an analogous change in the level of various macro-economic parameters (i.e., employment, GVA, wages, taxes on products and production) that can be approximated by the following simple formula:

$$ME_j = MX_j \cdot \frac{E_j}{X_j} \quad (2)$$

Where ME_j is the marginal change of the macroeconomic parameter E , which characterizes sector j , from the marginal change MX_j of the output (X) of sector j . Thus, the direct effects on employment, GVA, wages, taxes on products and production, etc., from ACTRIS development and operation result as the sum of all marginal changes estimated in all sectors of the economy affected by the project in question.

The indirect and induced effects on these macro-economic parameters can also be estimated exploiting the input-output table through appropriate multipliers. As in the case of output, there are two types of macro-economic multipliers. Specifically:

- The Type I multiplier of the macro-economic parameter E ($M_{I,E}$) calculates the increase of E in the whole economy (direct and indirect effects) due to a unit direct increase of E in sector j :

$$M_{I,E,j} = \sum_{i=1}^n \frac{e_i \cdot b_{ij}}{e_j} \quad (3)$$

where $M_{I,E,j}$ is the Type I multiplier for the macro-economic parameter E and sector j , e_i (or e_j) is the corresponding macroeconomic effect creating in sector i (or j) per €1 of total output per sector i (or j) and b_{ij} is the Leontief coefficient which depicts direct and indirect impacts on the demand for the output of sector i as a result of changes in the demand of sector j .

- The Type II multiplier of the macro-economic parameter E ($M_{II,E,j}$) measures the ratio of direct, indirect and induced effects on E to the direct change of E in sector j:

$$M_{II,E,j} = \sum_{i=1}^n \frac{e_i \cdot b'_{ij}}{e_j} \quad (4)$$

where b'_{ij} is the Type II Leontief coefficient.

By implementing this accounting framework, the macroeconomic effects attributed to the investments under examination per sector of economic activity can be estimated for the entire lifetime of a project or a policy in question. The results will be more reliable for the first years of the analysis while uncertainties increase in the long-run as the structure of the economy changes.

A key assumption for the analysis is to what extent the necessary equipment for developing and maintaining the infrastructure as well as the additional expenditures due to the increased income, occurs in the economy considered or elsewhere abroad. In the latter case, the estimation of the associated macroeconomic impacts should be based on this part of the expenditures that are spent inside the economy in question.

2.4.4 Implementation for ACTRIS

The analysis is based on specific technological and economic data for the ACTRIS research infrastructure that have been provided by participating countries through the questionnaires. These data provide the essential background information for estimating the direct impacts of the reference infrastructure on economic development and on employment. The indirect and induced macroeconomic implications of the project on value added, employment and available income have been analysed through Input–Output multipliers, taking into account the inter-sectoral linkages of the European economy.

3. Results

3.1 Impact on human capital creation

As already mentioned, the development, operation, maintenance and upgrading of a research infrastructure offer important opportunities for strengthening human capital creation, through supporting educational activities, facilitating scientific co-operation, and creating employment opportunities in specialized and high-level positions. Research infrastructures are stimulating and dynamic places, giving to young fellows and Ph.D. students the opportunity to interact with other students and scientists from different contexts (Florio and Sirtori, 2014). Thanks to observation and practice on the work place, but also to the participation in meetings, seminars, workshops, conferences and other events, most of students coming to the research infrastructure for short or long periods benefit from the development of their skills, ranging from technical and scientific abilities, to personal ones, related for example to the improvement in the communication, managerial, negotiating and organizational capabilities. With some

adjustment most of the skills acquired at the research infrastructure could be utilized even in domains outside their own research field (Florio and Sirtori, 2014). In addition to human capital formation for students, some skills can also be acquired by scientists, engineers and technical staff working at the research infrastructure in the context of the on-the-job learning (Florio and Sirtori, 2014). All these observations apply in particular to ACTRIS, as it constitutes a research infrastructure related to cutting-edge scientific fields such as climate change, atmospheric pollution and air quality, atmospheric dynamics, water cycle dynamics, etc.

In the context of this study, the quantitative analysis of the impact on human capital formation was based on the data collected through the survey carried out at universities, research centers and organizations involved in the development and operation of ACTRIS research infrastructure and participate in ACTRIS PPP. Table 3.1 presents the performance of the KPIs defined in Section 2.2 for human capital formation on the basis of the information provided at national level through the filled questionnaires. The selected KPIs are presented: (i) for the period 2008-2016 on the basis of actual data reported by the organizations participated in the survey; and (ii) for the 3-year period 2017-2019 aggregating projections provided by the same organizations. Given that the KPIs in Table 3.1 are aggregated at infrastructure level on the basis of the data provided at national level they should be taken as the lower limit of ACTRIS's contribution to human capital development, as a number of countries / institutes did not fill in the questionnaire.

Even under these limitations, contribution of ACTRIS to the development of human capital is quite significant, as during the period 2008-2016:

- Around 950 Masters and Ph.D. students carried out part of their research in ACTRIS research infrastructures.
- More than 2,200 graduates received training in ACTRIS infrastructures.
- Specialized research and technological staff had the opportunity to work in the research infrastructure, either under permanent (above 310 people) or part-time (about 300 people) employment status.
- ACTRIS infrastructure in each country has been a major pole of attraction for specialized staff and students from other countries, with 27% of trainees and 18% of research and technological staff coming from abroad.

The preliminary results for the 2017-2019 period shows that the ACTRIS will continue to contribute in the development of human capital. It is worth mentioning that one in four trainees and researchers / technicians working on ACTRIS infrastructures are expected to come from abroad, strengthening the European Research Area in terms of integration.

Table 3.2 presents an attempt to assess the impacts previously reported to all organizations participating in ACTRIS. Given that in 2011-2015 the ACTRIS-I was the main program that covered the needs of the infrastructure in question, the extrapolation is based on the share of the budget had in the context of ACTRIS-I the Institutes that participated in the survey undertaken in this study (i.e., approximately 75%). The results do not differ substantially if the extrapolation is based on the share of budget that the respondents had in the context of ACTRIS-2 (approximately 77%).

Last, with a view to facilitate the utilization of these results in future evaluations of the research infrastructure under consideration, two additional generalized indicators were developed, namely:

- The number of students trained per € million spending in the research infrastructure.
- The number of graduates trained per € million spending in the research infrastructure

The number of students trained comprises all students carried out part of their Master or Ph.D. research in ACTRIS infrastructures. The expenditure (i.e., spending) used in the denominator of the above indicators, includes the total costs of deployment, operation, maintenance and upgrading of the infrastructure during the reporting period, as well as the budget of the research programs realized in the infrastructure in the respective period.

Using data from the completed questionnaires for the 2008-2016 period, it was estimated that spending € 1 million to development, maintenance and upgrading of ACTRIS infrastructures as well as for relevant research activities contributes to the training of 2.2 students at doctoral or postgraduate level and 5.1 graduates.

Table 3.1: Impact of ACTRIS RI on human capital creation based on data collected from the countries participated in the survey undertaken in the context of ACTRIS PPP.

KPIs	2008-2016	2017-2019
Number of Ph.D. students carrying out research at the RI	608	244
Number of graduates that have used the RI for their Master thesis	347	162
Number of graduates trained on RI	2226	825
Number of foreign students as % of all students trained on the RI	27%	23%
Research and technical staff attracted to be employed on RI (permanent staff)	312	276
Research and technical staff attracted to be employed on RI (contractual staff)	302	255
Percentage of the research and technical staff attracted from abroad	18%	24%

Table 3.2: Approximate estimates of ACTRIS RI impact on human capital creation during the period 2008-2016 for all countries participating in ACTRIS.

KPIs	2008-2016
Number of Ph.D. students carrying out research at the RI	811
Number of graduates that have used the RI for their Master thesis	463
Number of graduates trained on RI	2967
Research and technical staff attracted to be employed on RI (permanent staff)	415
Research and technical staff attracted to be employed on RI (contractual staff)	402

3.2 Impact on scientific activity

As expected, the development and operation of a research infrastructure has a significant impact on the creation, further development, and diffusion of scientific knowledge.

Organizations involved in the development and operation of the infrastructure are among the main beneficiaries, as they have direct access to the whole scientific information being gathered through the infrastructure. Part of this information will be elaborated and published in scientific journals, conferences, etc., or will be available through international scientific databases, so that it can be used by the whole scientific community. However, the groups involved in the operation of the infrastructure have the advantage of accessing all information, earlier than other groups, which is an important asset for their scientific performance.

Furthermore, the availability of advanced equipment influences the way that scientific groups organize themselves. It can significantly increase the productivity of research teams, as they do not need to seek and arrange experimentation and testing opportunities on limited-availability facilities or abroad (Griniece et al., 2015).

Dealing with complex issues, unique devices and great volumes of data, organizations that operate research infrastructures are forced to develop innovative approaches and techniques to deal with various emerging issues that often extend scientific knowledge.

Also, research infrastructures are gradually becoming a pole of attraction for scientists and scientific groups from abroad or other organizations at national level, who are interested in carrying out part of their scientific research in the infrastructure in question. This enhances scientific co-operation, facilitates the diffusion of knowledge and the scientific dialogue, while organizations operating the infrastructure gain reputation and recognition. All these result in attracting additional funding for research and development, which is very critical for the sustainability and enhancement of research groups in a competitive environment.

Of course, a research infrastructure causes wider implications on the research community and scientific knowledge, as organizations not directly involved in the operation of the research infrastructure can benefit from the results and products generated by using them to develop new or improve existing methodological approaches and tools in various fields. However, this study focuses on the impact of the ACTRIS research infrastructure on the scientific activities of the organizations involved in the development and operation of the research infrastructure. The wider impact of ACTRIS on research community will be analyzed in the context of another deliverable.

Through the field survey, sufficient information was collected from various countries participating in ACTRIS PPP to quantify the KPIs identified in Section 2.2 for this type of impacts. Table 3.3 presents the results of the analysis at the research infrastructure level (i.e., aggregating the data collected at national level from the countries participated in the survey). The main findings are summarized below.

ACTRIS has achieved to provide a unique EU Research Infrastructure platform for aerosols, clouds, and short-lived gas-phase species.

In the period 2008-2016 ACTRIS has resulted in approximately 3,700 scientific papers, 2,200 articles published in proceedings of international conferences, and 85 book chapters or extended sections. Extrapolating these indicators to the whole ACTRIS community on the basis of the approach presented in Section 3.1, it was found that ACTRIS produced almost 8,000 scientific publications during the period 2008-2016. In other words, for every € million spent on developing, operating, maintaining, upgrading or undertaking research in ACTRIS infrastructure, more than 13 high-quality scientific publications are produced (Table 3.4). This high scientific productivity is expected to continue in the upcoming years, as for the period 2017-2019 the organizations involved in ACTRIS PPP estimate that their relevant publications will approach 1,800.

Table 3.3: Impact of ACTRIS RI on scientific activities based on data collected from the countries participated in the survey undertaken in the context of ACTRIS PPP.

KPIs	2008-2016	2017-2019
Number of articles published in scientific journals with peer-review	3675	1052
Number of articles published in proceedings of international conferences	2185	679
Number of books (chapters or extended sections)	85	34
Number of Ph.D. dissertations completed	419	152
Number of patents' applications	19	4
Number of patents granted	12	4
Number of new methodologies, prototypes or designs developed	114	30
Number of workshops organized	176	53
Number of conferences organized	50	17
Number of working groups established	108	37
Other scientific events (summer and training schools, steering committee meetings, campaigns etc.)	106	13

Also, during the period 2008-2016, approximately 420 Ph.D. dissertations were completed that have been predominantly or partly-based on the use of ACTRIS research infrastructure. This corresponds to 46 completed Ph.D. dissertations per year or to 1 completed Ph.D. dissertation per €1 million spending. In addition, another 152 doctoral theses that utilize ACTRIS infrastructure are expected to be completed in the three-year period 2017-2019.

The innovative character of ACTRIS and the high-level research carried out on its premises is confirmed also by the 19 patent applications filed in the period 2008-2016, 12 of which have already been granted. Among them:

- Patent DE 102008050201 A1 describes a transmitter-receiver optics based on a lens beam expander that can be used for overlap adjustment.
- Patent DE 102006005325 B4 describes a laser ring-resonator with a sophisticated combination of optical prisms which allows for compensating the astigmatism of thermal lensing of laser media. The prisms turn orientation and polarization of the laser beam in a certain way, independently from wavelength and strength of thermal lensing and are therefore suitable for high power laser applications, such as lidar.

- Patent ES 2 409 804 B1 concerns an aspiration sampler for micrometric atmospheric particles deposited in road traffic.
- Patent US 11/438689 concerns a sampling device for introduction of samples into analysis system.

In addition, ACTRIS resulted in the development of approximately 110 new methodologies, prototypes or designs during the period 2008-2016, while 30 more are expected during the 3-year period 2017-2019. These achievements were used to further advance and disseminate integration tools to fully exploit the use of multiple atmospheric techniques at ground-based stations through creating innovative techniques for air quality and risk management. More specifically, new well-described measurement guidelines and standard operation procedures have been developed for atmospheric trace gases, i.e. new inlet system, organic nitrogen sampling, novel carbonyl sampling, new methodologies for measuring aerosol absorption, VOC, NO_x, SOA-bound peroxides, imidazoles, sugar and sugaralcohols, dimeric compounds and functionalized carboxylic acids. A prototype of a new lidar system has been developed and implemented at several stations, along with a software prototype for aerosol typing from multiwavelength Raman lidar and the airborne multiwavelength high spectral resolution lidar (MULTIPLY). A new optical ice particle counter was also established in order to study microphysics-turbulence interaction (TOPS-ICE and SHERLOCC). A simultaneous transmission and simultaneous reception cloud radar, PollyXT, near-range receiver for lidar, mobile SAEMS, RR Polly, a camera-controlled high-precision solar tracker system for FTIR-spectrometers and several others.

Table 3.4: Approximate estimates of ACTRIS RI impact on scientific activities per € 1 million spending.

KPIs	2008-2016	2017-2019
Number of scientific publications	13.6	8.4
Number of Ph.D. dissertations completed	1.0	0.7
Number of new methodologies, prototypes or designs developed	0.3	0.1

3.3 Impact on innovation

In principle, building and operating a new large and complex research infrastructure can be an important source of innovation through several ways.

First, the cooperation of research teams involved in the development and operation of the research infrastructure contributes to the diffusion of knowledge and facilitates the technological transfer. Thus, the research groups involved in these activities, acquire additional experiences, skills, and technical knowledge, which help them to participate in international research consortia in this scientific field, attracting additional funding to their organizations.

Furthermore, it is widely accepted that dealing with complex issues and unique devices for research infrastructures operating at the edge of the science is very likely to generate technological and industrial innovation. This facilitates the development of collaborations between the research community, industry

and other stakeholders wishing to utilize or advance further these technological innovations in their production processes, decision-making, etc.

An additional innovation outcome associated with the development and operation of research infrastructures is the creation of spin-offs or start-ups, aimed at commercializing achievements developed in the research infrastructure. Thus, knowledge generated using the research infrastructure in question can be diffused into the market in the form of innovative products, processes, or services.

Also, firms and laboratories along the research infrastructure's supply chain often do not have ready-made solutions to the types of problems that arise when involved in the design, construction, and operation or upgrading of a complex instrument or structure. When a procurement contract is signed between the representative of the research infrastructure and the suppliers, a close collaboration between the two parties starts giving firms the opportunity of getting new knowledge and skills, that can be utilized at a later stage to improve their sales and technological performance.

In the context of this study, an initial attempt to quantify the impact on innovation associated with ACTRIS research infrastructure was made through the KPIs presented in Section 2.2. Quantification of KPIs was based on data gathered through the survey done in the organizations participating in ACTRIS PPP. Table 3.5 presents the performance of these KPIs at research infrastructure level (i.e., aggregating the data provided at national level from the participating countries) taking into account data reported by the organizations involved for the period 2008-2016 as well as preliminary estimates for the period 2017-2019. Some key findings from this analysis are summarized as follows:

- The ACTRIS research infrastructure has already attracted considerable funding for research and development, approaching € 208 million in 2008-2016 (approximately € 23 million a year), while estimates for additional research projects in the 2017-2019 which make use of the infrastructure under consideration amount to € 87 million.
- Focusing on research infrastructure partnerships with industry and more generally the private sector, it has been shown that the funding received exceeds € 16 million in the period 2008-2016, while additional € 12 million are expected in the period 2017-2019.
- Extrapolating the data derived by questionnaires to whole ACTRIS community it was found that funding for research and development activities associated with ACTRIS infrastructure exceeds € 270 million during the period 2008-2016.
- For the period 2008-2016, it was found that per € 1 million invested in the development, maintenance and upgrading of the research infrastructure in question, another € 0.92 million was attracted through the funding of research and development programs. However, it should be noted that this ratio may have been overestimated, as a significant part of the ACTRIS infrastructures (and consequently the relative investments) were developed before 2008, which is the 1st year of our analysis. According to the data provided by one key ACTRIS country, covering the period 2000-2016, the research funding attracted per € 1 million invested corresponds to € 0.11 million. On the other hand, another country with very intense activities in the context of ACTRIS showed that having already developed the main infrastructures, the research funding

attracted may be 6 times higher compared to the funds required for further development and upgrading the infrastructures in question.

- The development and operation activities of the research infrastructure in question have already led to the creation of 9 start-ups/spin-offs and 3 more are expected in the next period. However, their turnover and profitability are still low.
- Over 2008-2016, more than 200 contracts were signed by organizations involved in ACTRIS with approximately 97 private companies to develop and upgrade the research infrastructure. Additional 90 contracts are expected in the 2017-2019 period, further widening the number of businesses involved in these activities.

Table 3.5: Impact of ACTRIS RI on innovation based on data collected from the countries participated in the survey undertaken in the context of ACTRIS PPP.

KPIs	2008-2016	2017-2019
R&D projects commissioned by EC or other international funding Agencies utilizing ACTRIS (in € millions)	77.5	18.3
R&D projects commissioned by National Authorities utilizing ACTRIS (in € millions)	113.9	57.0
R&D projects commissioned by private sector utilizing ACTRIS (in € millions)	16.3	11.9
Number of start-ups and/or spin-offs created utilizing products or expertise gained from ACTRIS	9	3
Total turnover of start-ups and/or spin-offs (in € millions)	1.0	2.4
Total earnings of start-ups and/or spin-offs (in € millions)	0.2	1.3
Number of procurement contracts signed for development and upgrade ACTRIS infrastructure	208	90
Number of companies involved in development / upgrading ACTRIS infrastructure	97	76

3.4 Macroeconomic effects

In the context of this study the macroeconomic effects associated with the development, operation, maintenance, and upgrading of the ACTRIS research infrastructure during the period 2008-2016 are estimated for the entire European economy through input – output analysis. To this end, the total input - output table covering the 28 EU Member States was used, while the estimated macroeconomic impacts are calculated at EU level plus Switzerland¹. Specifically, the analysis is based on the input – output table of the European Union (EU-28) for 2010, which is available from the Eurostat database. Even though in the database more recent input - output tables for the entire European economy were available, the analysis used the 2010 table, as it concerns a year within the reference period of this study (2008-2016),

¹ The total input-output table of the European Union does not include the finances of countries that are not EU-Member States. However, the estimated macroeconomic effects attributed to ACTRIS research infrastructure takes also into account the investment in one country that is not an EU Member State (i.e., Switzerland), as this is a small percentage of the total investment and the structure of the economy of that country is more or less similar to that of the European Union.

but also because for this year, input - output tables have been published for almost all EU countries, thus facilitating a comparative analysis at national level.

Knowing the total spending for developing, maintaining, upgrading, and operating the research infrastructure in question as well as its sectoral decomposition is essential for estimating its macroeconomic impacts and performing the input-output simulation. The total amount of spending for all the above-mentioned activities during the period 2008-2016 was collected at national level through the questionnaires and is estimated at € 436 million. Approximately 33% of these costs concern the development of ACTRIS infrastructure, 19% maintenance and upgrading activities, while the remaining 48% is related to its operation through the implementation of various research programs and scientific activities. As some countries did not respond to the survey, the total spending associated with the research infrastructure in question over the period considered is expected to be even higher. A critical issue for the analysis is to what extent these expenditures will be undertaken domestically (i.e., inside the European economy) or some of the equipment / materials will be imported from abroad, influencing the volume of money that will be spent domestically. Given that the analysis is undertaken for the entire European economy and the specialized equipment and services that require these projects, we consider that all expenditures related to ACTRIS infrastructure are made within the European Union. However, an analysis at national level can significantly differ from these results taking into account only the domestic expenditures.

It is worth mentioning that the development, maintenance and upgrading activities of research infrastructures are not included as distinct sectors in the input – output table, while only operation of the infrastructure could be considered that is covered by the sector “Scientific research and development services”. Therefore, as described in the proposed methodological framework in Section 2.4, the analysis is undertaken by disaggregating the expenses associated with the development, maintenance and upgrading of the research infrastructure in question to the predefined economic sectors included in the input–output table. Aiming at facilitating the disaggregation of the expenditures made for the development and operation of ACTRIS infrastructure, the 65×65 input–output table of the European economy has been chosen for the quantitative analysis. Table 3.6 summarizes the analysis of spending for the development, maintenance, upgrading and operation of ACTRIS research infrastructure during the period 2008-2016. As already mentioned data on total spending was derived from the questionnaires, while their distributions in various economic sectors are based again on data provided through the questionnaires as well as on expert judgements, since some countries did not provide the relevant information, or the disaggregation covered only part of the total spending.

Table 3.6: Sectoral decomposition of the expenditures undertaken during 2008-2016 for development, maintenance and operation of ACTRIS research infrastructure.

Economic sectors	Development		Maintenance & upgrading		Operation (research activities)		Total spending	
	Spending (in € millions)	Percentage (%)	Spending (in € millions)	Percentage (%)	Spending (in € millions)	Percentage (%)	Spending (in € millions)	Percentage (%)
Computer, electronic and optical products	50.21	35%	32.67	39%	0.00		82.88	19%
Electrical equipment	2.87	2%	1.68	2%	0.00		4.54	1%
Machinery and equipment n.e.c.	14.35	10%	4.19	5%	0.00		18.54	4%
Constructions and construction works	44.47	31%	0.00		0.00		44.47	10%
Scientific research and development services	25.82	18%	43.56	52%	208.73	100%	278.11	64%
Other professional, scientific and technical services	5.74	4%	1.68	2%	0.00		7.41	2%
Total	143.47	100%	83.77	100%	208.73	100%	435.97	100%

In Table 3.7, the impact per effect (direct, indirect and induced) attributed to the development, maintenance and operation activities of ACTRIS infrastructure on the value added (in million €), employment (in full-time equivalent person-years) and available income (in million €) are presented. During the period 2008-2016 the ACTRIS infrastructure resulted in an increase of the Valued Added of the European economy by € 615 million. About 33% of this value added was created directly, 27% indirectly and 40% is induced. In addition, almost 50% of the value added is associated with the research activities undertaken in the infrastructure. For the same period the total effects on employment were estimated at 9,796 person-years, which correspond to 1088 full time equivalent jobs, of which 22% is created directly, 30% is created indirectly and 48% is induced. Approximately 46% of the created employment is associated with research activities developed in ACTRIS infrastructure. The countries participating in the survey reported that the development, maintenance and operation of ACTRIS infrastructure resulted in the creation of 1,577 person-years of employment during the period 2008-2016. This is at the same order of magnitude but slightly higher compared to the approximately 1,248 person-years of employment estimated by our model that are created directly in the sectors “Scientific research and development services” and “Other professional, scientific and technical services”. Also, the study on socioeconomic effects undertaken in the context of ACTRIS-I estimated that the employment effects attributed to ACTRIS during the period 2006-2015 reach 1,500 person-years (Soutukorva and Hasselström, 2015), which is at the same order of magnitude but a bit lower compared to our estimates for direct employment associated with ACTRIS activities during the period 2008-2016, amounting to 2,170 person-years. It is important to note here that a part of this new employment is expected to be temporary (for example infrastructure, construction and design related jobs) and a part is expected to be permanent (maintenance jobs). No matter the type of employment created, the activities undertaken for the development, maintenance and operation of ACTRIS infrastructure during the period 2008-2016 have resulted in an increased available income by € 323 million or € 36 million per year.

Table 3.7: Estimated macroeconomic effects associated with the development, maintenance and operation of ACTRIS research infrastructure during the period 2008-2016.

Type of impact	Development	Maintenance & upgrading	Operation (research activities)	Total
<i>Impact on Gross Value Added (in € millions)</i>				
Direct	58	37	109	205
Indirect	61	32	74	167
Induced	75	45	124	244
Total	194	114	308	615
<i>Impact on Employment (in person-years)</i>				
Direct	913	388	870	2170
Indirect	1103	553	1296	2952
Induced	1438	858	2377	4674
Total	3454	1799	4543	9796
<i>Impact on Income (in € millions)</i>				
Direct	33	22	69	123
Indirect	33	17	40	89
Induced	34	20	56	110
Total	99	59	164	323

Table 3.8 summarizes the estimated macroeconomic effects associated with ACTRIS activities during the period 2008-2016 adjusted on a per € 1 million spending. The highest impact on value added was detected for research activities in the research infrastructure, while the highest impact on employment was estimated for the case of developing the research infrastructure in question. As the ACTRIS infrastructure was not developed in all EU countries simultaneously, while several countries participating in ACTRIS PPP did not provide detailed information on costs undertaken for developing, upgrading and/or operating the infrastructure, the estimated macroeconomics effects presented in Table 3.7 should be used with caution and are likely to underestimate the overall impact. However, the indicators presented in Table 3.8, provide a sound basis for calculating the macroeconomic effects of the infrastructure, subject to availability of more detailed data about past activities, but also in order to calculate the impact attributed to future developments of the infrastructure.

Table 3.8: Estimated macroeconomic effects associated with the development, maintenance and operation of ACTRIS research infrastructure per € 1 million spending.

Type of impact	Development	Maintenance & upgrading	Operation (research activities)	Total
<i>Impact on Gross Value Added (in € millions / € 1 million spending)</i>				
Direct	0.40	0.45	0.52	0.47
Indirect	0.43	0.38	0.36	0.38
Induced	0.52	0.53	0.59	0.56
Total	1.35	1.36	1.47	1.41
<i>Impact on Employment (in person-years / € 1 million spending)</i>				
Direct	6.4	4.6	4.2	5.0
Indirect	7.7	6.6	6.2	6.8
Induced	10.0	10.2	11.4	10.7
Total	24.1	21.5	21.8	22.5
<i>Impact on Income (in € millions / € 1 million spending)</i>				
Direct	0.23	0.26	0.33	0.28
Indirect	0.23	0.20	0.19	0.20
Induced	0.24	0.24	0.27	0.25
Total	0.69	0.71	0.79	0.74

Table 3.9 presents a sector distribution of the estimated employment effects associated with ACTRIS activities during the period 2008-2016, highlighting those economic sectors that will mainly benefit. These results have been derived by taking into account the estimated direct impact on employment by sector of economic activity and the components of the employment multipliers estimated for these sectors as described in equations 3 and 4 in Section 2.4.3. Having done the analysis for each economic sector in which direct employment is created, then the results obtained are summed up by sector of economic activity. As expected, direct results are concentrated in the sectors where the majority of spending takes place, namely “Computer, electronic and optical products”, “Construction and construction works”, and “Scientific research and development services”. The indirect and induced effects of the expenditures under consideration are transmitted, to a certain extent, to all the sectors of the economy. Specifically, the indirect effects are mostly concentrated in “Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services” (9% of indirect employment), “Wholesale trade services, except of motor vehicles and motorcycles” (9% of indirect employment), and “Legal and accounting services; services of head offices; management consultancy services” (7% of indirect employment). Regarding induced employment effects the most significant economic sectors are “Retail trade services, except of motor vehicles and motorcycles”, “Accommodation and food services” and “Products of agriculture, hunting and related services”. This distribution is mainly

influenced by the ways that households consume their available income as well as from the employment intensities of the various sectors of the European economy.

Table 3.9: Analysis of the employment effects attributed to ACTRIS infrastructure during the period 2008-2016 per industry (in person-years of full time jobs).

	Direct	Indirect	Induced	Total
Products of agriculture, hunting and related services	0	63	402	466
Products of forestry, logging and related services	0	8	10	18
Fish and other fishing products; aquaculture products; support services to fishing	0	1	7	8
Mining and quarrying	0	14	15	30
Food, beverages and tobacco products	0	21	182	203
Textiles, wearing apparel, leather and related products	0	20	76	96
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	0	28	18	47
Paper and paper products	0	15	14	30
Printing and recording services	0	30	22	52
Coke and refined petroleum products	0	2	4	5
Chemicals and chemical products	0	31	19	50
Basic pharmaceutical products and pharmaceutical preparations	0	5	6	11
Rubber and plastic products	0	55	28	83
Other non-metallic mineral products	0	45	19	64
Basic metals	0	46	11	57
Fabricated metal products, except machinery and equipment	0	133	42	175
Computer, electronic and optical products	384	58	13	455
Electrical equipment	28	48	19	95
Machinery and equipment n.e.c.	111	47	13	171
Motor vehicles, trailers and semi-trailers	0	32	42	75
Other transport equipment	0	7	4	10
Furniture and other manufactured goods	0	19	43	62
Repair and installation services of machinery and equipment	0	35	18	53
Electricity, gas, steam and air conditioning	0	25	40	65
Natural water; water treatment and supply services	0	5	15	20
Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	0	23	25	48
Constructions and construction works	400	169	113	682
Wholesale and retail trade and repair services of motor vehicles and motorcycles	0	57	121	178
Wholesale trade services, except of motor vehicles and motorcycles	0	254	234	488
Retail trade services, except of motor vehicles and motorcycles	0	91	756	848
Land transport services and transport services via pipelines	0	124	163	287
Water transport services	0	2	3	5

Air transport services	0	5	11	15
Warehousing and support services for transportation	0	53	53	106
Postal and courier services	0	49	45	94
Accommodation and food services	0	54	419	473
Publishing services	0	21	25	46
Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	0	11	19	30
Telecommunications services	0	21	36	57
Computer programming, consultancy and related services; Information services	0	73	37	110
Financial services, except insurance and pension funding	0	58	102	160
Insurance, reinsurance and pension funding services, except compulsory social security	0	7	34	42
Services auxiliary to financial services and insurance services	0	22	43	65
Real estate services excluding imputed rents	0	20	93	113
Legal and accounting services; services of head offices; management consultancy services	0	194	120	313
Architectural and engineering services; technical testing and analysis services	0	95	39	134
Scientific research and development services	1159	41	1	1201
Advertising and market research services	0	34	28	62
Other professional, scientific and technical services and veterinary services	89	48	31	169
Rental and leasing services	0	20	14	34
Employment services	0	157	72	229
Travel agency, tour operator and other reservation services and related services	0	6	18	24
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	0	261	162	423
Public administration and defence services; compulsory social security services	0	33	36	69
Education services	0	75	106	181
Human health services	0	13	114	127
Residential care services; social work services without accommodation	0	3	92	95
Creative, arts, entertainment, library, archive, museum, other cultural services; gambling and betting services	0	8	55	63
Sporting services and amusement and recreation services	0	9	40	48
Services furnished by membership organisations	0	18	21	39
Repair services of computers and personal and household goods	0	9	15	24
Other personal services	0	17	136	154
Services of households as employers; undifferentiated goods and services produced by households for own use	0	2	158	160
Total	2170	2952	4674	9796

4. Concluding remarks

The ACTRIS Research Infrastructure is a pan-European initiative that unites the observations and related research of aerosols, clouds, and trace gases amongst European partners to provide high-quality research infrastructure services to a wider user community. During the period 2008-2016 more than € 227 million have been invested in developing, maintaining and upgrading this research infrastructure, while the total investment is even higher as some of the infrastructures have been developed before 2008 and additional developments are planned for the upcoming years. Undoubtedly, ACTRIS constitutes a major investment and consequently an analysis of the socio-economic outcomes associated with its development and operation is of particular importance.

In general, ACTRIS, as any other research infrastructure, creates positive socio-economic effects: (i) at consortium level and the organizations participating in its development and operation; (ii) to the wider research community through the exploitation of ACTRIS outcomes; and (iii) to the society as a whole. This study presents an analysis of the socio-economic effects created to research institutes, universities, companies, and other organizations involved in the development, maintenance and operation of the ACTRIS research infrastructure. Specifically, we have distinguished four main categories of socio-economic effects at consortium level, namely:

- Impact on human capital creation.
- Impact on scientific activity.
- Impact on innovation.
- Macroeconomic effects.

For each impact category, a set of key performance indicators – KPIs – has been defined for its effective monitoring. The quantification of these KPIs is largely based on the results of a survey to partners of ACTRIS PPP undertaken during the 1st year of the project, through an appropriately designed questionnaire. In addition, the macroeconomic effects of the infrastructure in question have been estimated through input – output analysis for the economy of the entire European Union (EU-28).

Table 4.1 summarizes the results of this analysis for the period 2008-2016.

It is obvious that the ACTRIS contribution to the development of human capital is quite significant, as during the reference period more than 900 Masters and Ph.D. students carried out part of their research and more than 2,200 graduates received training in ACTRIS infrastructures.

Even more impressive is the impact on scientific activities. Publications in international journals exceeded 3,600, approaching 410 annually. In addition, patents, new methodologies, prototypes or designs have been developed and used to further advance and disseminate integration tools to fully exploit the use of multiple atmospheric techniques at ground-based stations through creating innovative techniques for air quality and risk management.

Furthermore, the ACTRIS research infrastructure already constitutes a significant pole of innovation, attracting considerable funding for research and development that almost reached € 210 million in 2008-2016 (approximately € 23 million a year).

All these activities have also significant macroeconomic implications and we found that for every € 1 million spending in developing, maintaining and operating ACTRIS infrastructures the European economy has benefited through an increase of the value added by € 1.41 million and the creation of 22.5 person-years of new employment.

Table 4.1: Summary of the socio-economic effects of ACTIS infrastructure at consortium level during the period 2008-2016.

KPIs	Total impact on the organizations participated in the survey	Total impact extrapolated to whole ACTRIS community ^a	Impact per €1 million spending
<i>Impact on human capital creation</i>			
Number of Ph.D. students carrying out research at the RI	608	811	2.2
Number of graduates that have used the RI for their Master thesis	347	463	
Number of graduates trained on RI	2226	2967	5.1
Number of foreign students as % of all students trained on the RI	27%		
Research and technical staff attracted to be employed on RI (permanent staff)	312	415	
Research and technical staff attracted to be employed on RI (contractual staff)	302	402	
Percentage of the research and technical staff attracted from abroad	18%		
<i>Impact on scientific activity</i>			
Number of articles published in scientific journals with peer review	3675	4899	13.6
Number of articles published in proceedings of international conferences	2185	2913	
Number of books (chapters or extended sections)	85	113	
Number of Ph.D. dissertations completed	419	558	1.0
Number of patents' applications	19		
Number of patents granted	12		
Number of new methodologies, prototypes or designs developed	114	152	0.3
Number of workshops organized	176	235	
Number of conferences organized	50	67	
Number of working groups established	108	144	
Other scientific events (summer and training schools, steering committee meetings, campaigns etc.)	106	141	
<i>Impact on innovation</i>			
R&D projects commissioned by EC or other international funding Agencies utilizing ACTRIS (in € millions)	77.5	103.3	0.92 ^b
R&D projects commissioned by National Authorities utilizing ACTRIS (in € millions)	113.9	151.9	
R&D projects commissioned by private sector utilizing ACTRIS (in € millions)	16.3	21.8	

Number of start-ups and/or spin-offs created utilizing products or expertise gained from ACTRIS	9	12	
Total turnover of start-ups and/or spin-offs (in € millions)	1.0	1.3	
Total earnings of start-ups and/or spin-offs (in € millions)	0.19	0.25	
Number of procurement contracts signed for development and upgrade ACTRIS infrastructure	208	277	
Number of companies involved in development / upgrading ACTRIS infrastructure	97	129	
<i>Macroeconomic effects</i>			
Direct impact on GVA (in € millions)	205	273	0.47
Direct impact on employment (person-years of full time jobs)	2170	2894	5.0
Direct impact on income (in € millions)	123	164	0.28
Total impact on GVA (in € millions)	615	821	1.41
Total impact on employment (person-years of full time jobs)	9796	13061	22.5
Total impact on income (in € millions)	323	430	0.74

^a These estimates derived by an extrapolation of the results of the survey, based on the share of budget that participating countries had in the context of ACTRIS I.

^b This figure is adjusted per € 1 million investment in developing and maintenance of the ACTRIS infrastructure.

However, the socio-economic impact of ACTRIS is not limited to the scientific groups participating in the program but diffused also into the wider scientific community. Currently, there are about 65 active sites involved in ACTRIS and almost 135 different atmospheric variables measured, comprising different trace gases, aerosol variables measured near the surface, aerosol profile variables and cloud profile variables. The availability of long-term observational data relevant to climate and air quality research on the regional scale throughout the ACTRIS network of stations provides essential information on aerosol sources and atmospheric processes. The new innovative products or outcomes of ACTRIS are mainly utilized in the following research activities: climate modelling, modelling of the atmospheric environment, satellite calibration and validation, weather forecast, air quality and impact on human health. It is apparent that the first three research activities and air quality monitoring are the main beneficiaries/users of the ACTRIS RI outcomes, as several members that participated in the survey (e.g., France, Finland, Germany, Greece, Italy, Poland, Romania, Spain, and United Kingdom) reported that they utilize ACTRIS products for the aforementioned activities. In fact, present climate models due to the fact that they consider aerosol formation and/or transformation significant they include a number of aerosol properties and atmospheric processes. Moreover, because of the adverse effects of atmospheric particulate matter on human health atmospheric environmental research is also focusing on atmospheric aerosols. Subsequently, groups involved in weather forecast, along with studying the impact of aerosol on human health are also utilizing ACTRIS RI outcomes for improving the performance of relevant research activities.

Furthermore, the new technological developments, patents relevant to ACTRIS RI observations are used in aerosol sampling and measurements, optical properties of aerosols and ice crystals for use in climate models, monitoring and model comparison exercises, weather forecast and climate models, validation of model's cloud schemes and impact of aerosol on human health and climate, calibration/validation/integration of satellite sensors, the improvement of the parameterizations used in global and regional-scale climate and air-quality models etc.

The ways that ACTRIS outcomes influence research activities of the wider scientific community will be investigated in detail during the 2nd year of ACTRIS PPP through a new survey to ACTRIS users.

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Appendix: Questionnaire of Task 8.1

EVALUATING THE SOCIO-ECONOMIC EFFECTS OF ACTRIS AT CONSORTIUM LEVEL

Information about this survey

The Research Infrastructure ACTRIS is a pan-European initiative that unites the observations and related research of aerosols, clouds, and trace gases amongst European partners to provide high-quality research infrastructure services to a wider user community. The ESFRI Roadmap 2016 identified ACTRIS as a new important pan-European research infrastructure for the European scientific community. With ESFRI-status, ACTRIS shall further develop its organizational and operational framework, and long-term strategic goals. In this context, the ACTRIS Preparatory Phase Project (ACTRIS PPP) aims at defining the most appropriate and cost-efficient long-term organization of ACTRIS. The analysis of the socio-economic impacts attributed to ACTRIS will provide useful insights regarding the social return of the investment required for the development, operation and maintenance of this research infrastructure and the formulation of the appropriate operational scheme.

The purpose of this survey is to explore the socio-economic impacts generated to the ACTRIS consortium from the development, operation, and maintenance of the ACTRIS infrastructures, through the completion of a questionnaire. The research will help to better understand the benefits generated to organizations and institutions that participate in the development, operation, and maintenance of a large research infrastructure like ACTRIS. Furthermore, it will provide useful insights for evaluating the social return of the investment required for developing and maintaining ACTRIS infrastructure.

The questionnaire should be completed by the national ACTRIS contact persons in each country participating in ACTRIS, as defined in on the ESFRI Roadmap 2016 (one questionnaire per participating country). It is organized in 6 sections.

The deadline for answering the questionnaire is September 15, 2017. Your participation to the survey is voluntary.

Your Participation and Informed Consent

Your participation in this study will consist of a completion of a questionnaire. You will be asked a series of questions about the participation of the Organization(s) of your country to ACTRIS research infrastructure and the potential socio-economic impacts generated. Please feel free to co-operate with colleagues when answering the questionnaire, if you think it is necessary. Your participation to the survey is fully voluntary, and you may pass on any question that makes you feel uncomfortable. You are encouraged to ask questions or raise concerns at any time about the nature of the study or the methods used.

The only personal details that will be asked from you will be your name and position in your organization. Insights gathered by you and other participants will be used in writing a research report for the socio-economic impacts of ACTRIS infrastructure. All gathered information will be grouped together at ACTRIS consortium level such that no personal data will be traceable from the end product. The individual answers and informed consent forms will be stored by NOA until the end of the project. All of your information and responses to the questionnaire will be kept confidential.

In the last question you will be asked to provide names and contact details of users of ACTRIS outcomes and products in your county. It is on your responsibility to ask and obtain permission from these individuals for providing their names and contact information.

By signing below I acknowledge that I have read and understood the above information. Please print and sign this page, and send a scanned copy of it to the e-mail address below.

Signature _____ Date _____

If you have any questions please contact Prof. Nikos Mihalopoulos (nmihalo@noa.gr, +30 210 8109121)

I. INTRODUCTORY DATA

I.1 What is your name:

I.2 Affiliation and country (please also indicate your Institute):

I.3 Please indicate all the Institutes and/or Organizations of your country that participate in ACTRIS:

I.4 Please provide an overview of the role of the Institutes of your country in ACTRIS research:

(please, indicate in the boxes below the number of the Institutes of your country that have the corresponding role in ACTRIS research)

Infrastructure management	<input type="text"/>
Infrastructure user	<input type="text"/>
Infrastructure / access provider	<input type="text"/>
Undertaking research	<input type="text"/>
Data provider	<input type="text"/>
Data user	<input type="text"/>
Other (please specify)	<input type="text"/>

For the questions included in next Sections (II-V):

- *Try to give numeric estimates for the indicators included in the corresponding Tables.*
- *Data should be completed for two periods, namely 2008-2016 (the development period or ACTRIS infrastructure) and 2017-2019 (the duration of the ACTRIS PPP). Please use statistical data for the former and estimates for the latter.*
- *Provide aggregated data for all the Institutions of your country engaged in development, operation, and maintenance of ACTRIS infrastructure.*

II. IMPACT ON HUMAN CAPITAL CREATION

Please provide estimates on how development and operation of ACTRIS infrastructure in your country contributes to the development of human capital.

Indicators	2008-2016	2017-2019
II.1 Number of Ph.D. students carrying out research at the RI		
II.2 Number of graduates that have used the RI for their Master thesis		
II.3 Number of graduates trained on RI ^[1]		
II.4 Number of foreign students (Ph.D. / M.Sc.) as % of all students trained on the RI		
II.5 Research and technical staff attracted to be employed on RI as Permanent staff Contractual staff		
II.6 Percentage of the research and technical staff attracted from abroad.		

^[1] Do not include students that use the RI directly for their Masters and Ph.D. thesis work.

III. IMPACT ON SCIENTIFIC ACTIVITY

Please provide data on the influence that ACTRIS infrastructure has on the scientific activities of the institutions of your country engaged in development, operation, and maintenance of ACTRIS RI.

Indicators	2008-2016	2017-2019
III.1 Number of articles related with research using ACTRIS RI published in scientific journals with referees ^[1]		
III.2 Number of articles related with research using ACTRIS RI published in proceedings of international conferences ^[1]		
III.3 Number of books (chapters or extended sections) that are based on ACTRIS produced knowledge ^[1]		
III.4 Number of Ph.D. dissertations completed ^[2]		
III.5 Number of patents' applications ^[3]		
III.6 Number of patents granted ^[3]		
III.7 Number of new methodologies, prototypes or designs developed ^[4]		
III.8 Number of scientific events organized on topics relating to ACTRIS RI Workshops Conferences Working groups Other (please specify)		

^[1] Please provide a list of these articles/books to develop a unified list for all the consortium avoiding double-counting.

^[2] Concerns Ph.D. dissertations that have been predominately- or partly-based on the use of RI in question.

^[3] Please provide some additional information on the patents granted or applied

^[4] Please provide some additional information on the new methodologies, prototypes or designs developed.

IV. IMPACT ON INNOVATION

Please provide data on how ACTRIS infrastructure influences innovation and related business opportunities at your country?

Indicators	2008-2016	2017-2019
IV.1 Number of R&D projects commissioned by European Commission or other international funding Agencies to the Research Groups involved in ACTRIS RI ^[1]		
IV.2 Total volume of funding (in millions €)		
IV.3 Number of R&D projects commissioned by National Authorities to the Research Groups involved in ACTRIS RI ^[1]		
IV.4 Total volume of funding (in millions €)		
IV.5 Number of R&D projects commissioned by private sector to the Research Groups involved in ACTRIS RI ^[1]		
IV.6 Total volume of funding (in millions €)		
IV.7 Number of start-ups and/or spin-offs created utilizing products or expertise gained from the RI in question		
IV.8 Total turnover (in millions €) ^[3]		
IV.9 Total earnings (in millions €) ^[3]		
IV.10 Procurement contracts signed for development and upgrade of research equipment		
IV.11 Number of companies involved		

^[1] Identify research projects of your Institutions that predominantly or partially utilize the RI in question.

^[2] Collaborative research concerns the utilization of the RI from external researchers that pay service fees.

^[3] Provide aggregated figures for all companies and for the corresponding period.

V. MACROECONOMIC EFFECTS

The following questions are aiming to help us to estimate the macroeconomic impacts attributed to development and operation of ACTRIS RI. Please provide aggregated data for all the Institutions of your country engaged in development, operation, and maintenance of ACTRIS infrastructure.

A. Development of the RI

Indicators	2008-2016	2017-2019
V.1 Total investment undertaken for developing ACTRIS RI (in million €)		
V.2 Total budget of procurement contracts signed for development of research infrastructure and equipment (in million €) ^[1]		
V.3 Please identify the main categories of suppliers and provide a breakdown of the total budget attributed to them: ^[2] <i>Suppliers of Electrical equipment</i> <i>Suppliers of Computer, electronic and optical products</i> <i>Suppliers of Machinery and equipment</i> <i>Construction</i> <i>Hotels and restaurants</i> <i>Professional, scientific and technical activities</i> <i>Other (please specify)</i>		
V.4 How many jobs have been directly generated for setting up the physical infrastructure (in man-years of full time equivalent jobs) ^{[3], [4]}		
V.5 If possible, provide estimates on how many jobs have been generated to suppliers for setting up the physical infrastructure (in man-years of full time equivalent jobs)		

^[1] This should be a sub-total of the budget identified in the previous line.

^[2] This classification follows the NACE rev.2 codes for economic activities.

^[3] Do not include employees of suppliers.

^[4] For a person who worked 6 months in 2009, 3 months in 2010 and 3 months in 2011 in developing ACTRIS RI you should write 1 man-year in the column 2008-2016.

B. Maintenance and operation of the RI (including data collection and quality control)

Indicators	2008-2016	2017-2019
V.6 Total expenditures undertaken for maintaining and operating ACTRIS RI (in million €) ^[1]		
V.7 Total budget of procurement contracts signed for maintaining and operating of research infrastructure and equipment (in million €) ^[2]		
V.8 Please identify the main categories of suppliers and provide a breakdown of the total budget attributed to them: ^[3] <i>Suppliers of Electrical equipment</i> <i>Suppliers of Computer, electronic and optical products</i> <i>Suppliers of Machinery and equipment</i> <i>Construction</i> <i>Hotels and restaurants</i> <i>Professional, scientific and technical activities</i> <i>Other (please specify)</i>		
V.9 How many jobs have been directly generated for maintaining and operating ACTRIS RI (in man-years of full time equivalent jobs) ^{[4], [5]}		
V.10 If possible, provide estimates on how many jobs have been generated to suppliers for maintaining and operating ACTRIS RI (in man-years of full time equivalent jobs)		

^[1] Please include salaries, operation costs, purchase of equipment and services, etc., for the whole period identified in the corresponding column.

^[2] This should be a sub-total of the budget identified in the previous line.

^[3] This classification follows the NACE rev.2 codes for economic activities.

^[4] Do not include employees of suppliers.

^[5] For a person who works full time in operating ACTRIS RI the period 2008-2016 you should write 9 man-years. For a person who works half time the same period you should write 4.5 man-years.

C. Research related to ACTRIS

This Table should be completed in case that in Section IV you identified that there is funding from research projects, and/or turnover from start-ups and/or spin-offs utilizing ACTRIS RI.

Indicators	2008-2016	2017-2019
V.11 How many jobs have been directly generated to your Institutions or to start-ups/spin-offs associated with research activities utilizing ACTRIS RI (in man-years of full time equivalent jobs)		
V.12 If possible, provide estimates on how many jobs have been indirectly (e.g., external contractors) generated to your Institutions or to start-ups/spin-offs associated with research activities utilizing ACTRIS RI (in man-years of full time equivalent jobs)		

VI. WIDER IMPACT ON RESEARCH COMMUNITY

VI.1 Please identify research activities in your country that use the outcomes and/or products of ACTRIS RI.

(please, tick one or more of the boxes; if necessary add additional activities)

- Weather forecasting modeling
- Climate modeling
- Modeling of the atmospheric environment
- Satellite cal/val
- Other (please specify)

VI.2 Please give some additional information on how ACTRIS products and outcomes are utilized in the research activities identified in the previous question.

VI.3 Provide contact details for the users of ACTRIS outcomes and products in your county.

(if possible specify at least one user for each of the research activities identified in Question VI.1.

Remember to ask for permission from these individuals for adding their information.)
