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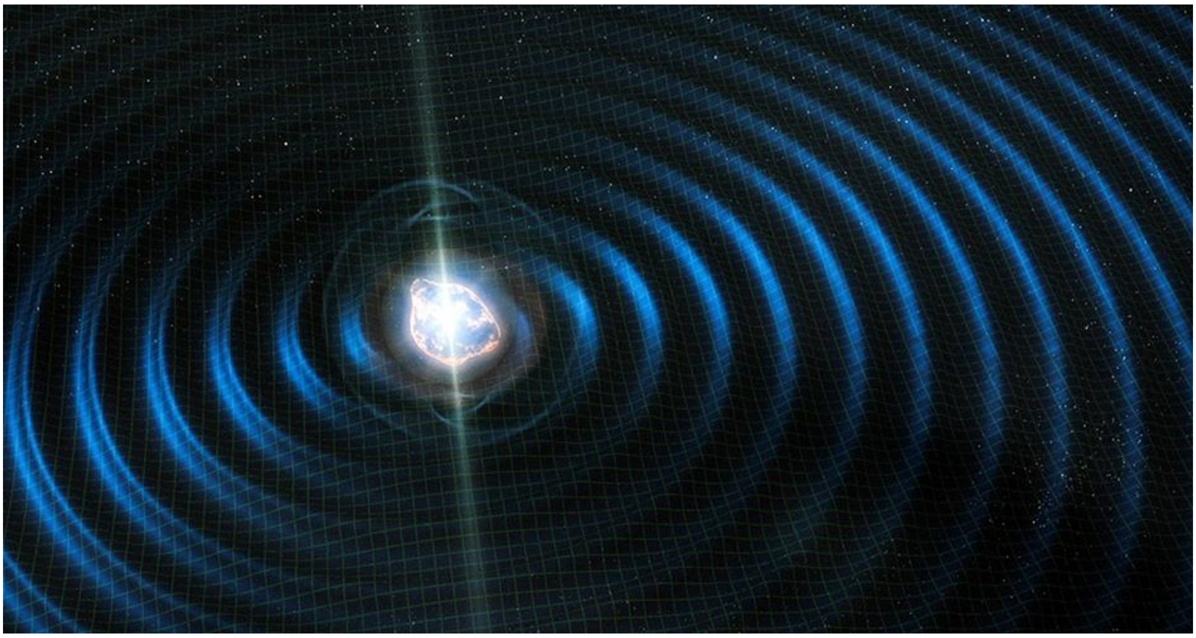
Impact assessment of the Einstein Telescope

Final report, 28/09/2018



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Joost van Barneveld
Lisanne Saes
Ivette Oomens
Geert van der Veen

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Management summary

This study, performed by Technopolis Group, is a first attempt to estimate the impacts that the building and operation of the Einstein Telescope (ET) in the ELAt region (Eindhoven-Leuven-Aachen triangle) might have, against the alternative scenarios of not investing in such a telescope in Europe at all and investing in an ET that is located elsewhere in Europe. The outputs of all scenarios show many uncertainties, not only because of the early stage of the planning process - where many decisions still have to be taken – but also because the realisation of an ET needs a number of innovations (which are inherently uncertain and can have large impacts on both inputs (cost of ET) and impacts (e.g. economic spin-offs from ET). Furthermore, the realisation of such a large research infrastructure requires contributions from many countries, where the outcome of the negotiations between these countries about their contributions and what they want to receive in return (in terms of compensation orders, etc.) is very uncertain as well. In addition to the impacts of the ET, this study also specifically looked at the impact of the ETpathfinder (an R&D facility in the ELAt region to develop technologies relevant for the ET), as decisions on the ETpathfinder have to be taken in the short term.

In the **Baseline scenario** there is no investment in the ET, nor in the ETpathfinder, from the three countries Belgium, Germany and the Netherlands. This also means that there will be no effects to be attributed to ET, apart from the fact that the investment money needed for the ET and the ETpathfinder can be invested in other activities.

Realising the ET in the ELAt region (**ET-ELAt scenario**) has the largest impacts. Costs are high (total investment for the three ELAt countries estimated at M€ 400-700; operational costs M€ 10-20/y), but benefits may be high as well, including high visibility, large scientific effects and impact on scientific position, very positive organisational effects in the scientific world in the region, potential large innovation in key enabling technologies and economic spin-offs (at suppliers of ET technology) and large regional economic effects from the building and the operation of ET (rough estimate: 500 direct FTE, 1150 indirect FTE).

In the **ET-elsewhere scenario** the telescope is built with participation of BE/DE/NL, but not in the ELAt region. This reduces the investments needed, but also very strongly reduces regional effects and effects on scientific reputation and diminishes (to a lesser, but not easily estimated extent) scientific effects. Agreements on high-tech procurement between participating countries may safeguard the innovation effects in this scenario.

Setting up an **ETpathfinder** is a strategic move for the region. It will organise the scientific and industrial network in the ELAt region and, if done well, will lead to a better position of the region to realise the ET. Most importantly it will generate research at far shorter notice than the actual ET so that network, scientific and innovation benefits with direct and indirect impacts in the region will be realised within short term.

Summary

Introduction

In 2015, exactly 100 years after Albert Einstein's prediction, gravitational waves were observed for the first time. This opened new windows for the study of the basic physics of our universe. A new generation of gravitational telescopes is needed to bring science further. These telescopes should be able to better distinguish between the origin of the gravitational waves and to measure gravitational waves more precisely with a much higher sensitivity than the present generation of telescopes. In Europe, scientists have taken the initiative for one of such telescopes, the Einstein Telescope (ET). A possible location for the ET is the South of Limburg, in the middle of the Eindhoven-Leuven-Aachen triangle, the cross-border high-tech region in North-western Europe.

This study, performed by Technopolis Group, is a first attempt to estimate the impacts that the building and operation of the ET in the ELAt region (Eindhoven-Leuven-Aachen triangle) might have, against the alternative scenarios of not investing in such a telescope in Europe at all and investing in an ET that is located elsewhere in Europe. The outputs of all scenarios show large uncertainties, not only because of the early stage of the planning process - where many decisions still have to be taken – but also because the realisation of an ET needs a number of innovations (which are inherently uncertain) and can have large impacts on both inputs (cost of ET) and impacts (e.g. economic spin-offs from ET). Furthermore, the realisation of such a large research infrastructure requires contributions from many countries, where the outcome of the negotiations between these countries about their contributions and what they want to receive in return (in terms of compensation orders, etc.) is very uncertain as well.

For this study, the ELAt region has been seen as host-country consortium, consisting of Belgium, Germany and the Netherlands.

Impacts

The impacts of a research infrastructure occur in three phases: the preparation phase, the construction phase and the operational phase.

In the **preparation phase** it is determined what the specs of the ET will be, where it will be located and how it will be administratively run (governance). These choices determine to a large extent the impacts later in the process, and where these impacts are likely to land. It is however not only a process of negotiation, of which the outcome is determined by the financial contribution of the countries involved, it is also a process of scientific and technological development which is supposed to result in the best design for the telescope to achieve its scientific role (and those parties who contribute most to that process of discovery also are in a good position to contribute to building and operating the ET later on).

The intention of the ELAt region is to organize a substantial the scientific and technological development in the ETpathfinder. The ETpathfinder is an R&D facility in the ELAt region to develop technologies relevant for the ET (which are to a large extent key enabling technologies as identified by e.g. the Dutch government), and thereby organizing and strengthening scientific and technical expertise in the region and offering opportunities for breakthrough innovation. ETpathfinder will strengthen the position of the region as a candidate for the location of ET by initiating and supporting cooperation and attracting knowledge and R&D long before the building of ET will start. If ET will be located in the region, ETpathfinder will still be useful as an R&D centre next to ET (since ET will be focused on observation not on R&D). The initial investment in the ETpathfinder is limited and the operational costs are modest and will be covered by the research institutes involved.

Even if ET will not be located in the region, the ETpathfinder will have had its effects on new (key enabling) technologies that enable the building of the ET, reduce costs for the ET and offer opportunities for (breakthrough) innovations, improving scientific cooperation in the region (already started), and on

organising the different stakeholders in the region. Furthermore, the ETpathfinder facilities offer opportunities to attract leading international researchers on a permanent basis (discussions are going on) and for shorter term research projects. The permanent researchers (expectations are that a group of researchers can be attracted if Maastricht University will become a member of Nikhef) can form a nucleus for Maastricht University's long-cherished wish to broaden its academic profile.

For ET's **construction phase** the overall investment volume is estimated at between B€ 1 and B€ 1.5. We have used the average figure of B€ 1.3 in our calculations as the initial investment estimate for ET while we note that there is still much uncertainty in this figure. The investments are for around 70% in fairly low tech (i.e. site development) and for around 30% in high-tech. The low-tech component will, because it is location-bound, have its main impacts in the region and on a fairly short term. There will be a direct economic effect on the building industry and its suppliers of some M€ 900, and an indirect effect as a consequence of the increased economic building activity (on local shopkeepers, etc.) of approximately M€ 500. In case the ET is not built in the ELAt region, these local effects will of course not be located in the ELAt region. The flipside of this is that the investments that are needed from the region and the national/regional governments of Belgium/Germany and the Netherlands can be significantly smaller.

The investments in high-tech are less location bound: the high costs per unit (and the limited volumes of the equipment) make production elsewhere viable. Since with large Research Infrastructures there generally is a relation between investment of partners in such an infrastructure and the return they want to get out of it in terms of opportunities for their local industries, there should be attention for agreeing on procurement rules so that every party involved gets a fair share that fits their capabilities and needs.

Possible impacts of these high-tech investments are in science (development of new knowledge needed to build the telescope) and in technology and innovation (new technologies that result from the challenge to build the telescope). In the ELAt region these are at the moment mainly expected in technologies for reducing vibrations (including cryogenic operated mirrors), the optic interferometer, on diagnostic equipment (including measurement and control software) and from the spillovers of these effects in the economic and societal domain.

In the economic domain there is a large uncertainty of the magnitude of the effects and when and where they occur, but since technological boundaries are pushed they may be large. In the societal domain impacts are in strengthening the scientific network, the increased collaboration in the field of education, the attraction of knowledge, talent and entrepreneurship to the region and the improved brand and/or reputation of the region.

In the **operational phase,** once the ET is used for gathering data, there are direct economic effects from the operation of the telescope (employment for scientists, technicians and other staff). Assuming that the operational costs amount to some B€ 1.95 (5% of investment costs, for a period of 30 years), and a multiplier of 1.55 (based on literature on economic impacts from other large Research Infrastructures) the operational phase should generate a gross economic effect of B€ 3 or a net effect of B€ 1 – these are additional expenditures generated due to the project. The project should generate significant direct and indirect employment, with respectively a total of 500 and 1150 man-years, spread over a period of 30 years. The direct employment relates to researchers and technologists, support staff, maintenance and to realising equipment upgrades driven by developing needs of the researchers (e.g. in the domain of data management, optics and sensors). The indirect economic effects are generated through scientists and technicians spending their wages, through exploitation of scientific findings and through continued effects in technology and innovation (based on the earlier developed technologies). In addition to the effects already realised during the building phase, additional effects on clustering and on reputation can be expected during the operational phase. This can then also have effect on the inclination of young people to choose a study in the science and technology field and/or it can increase tourism to the region (esp. if an attractive visitor centre is realised).

Scenarios

Four scenarios are distinguished for the ET investment, each with different expected impacts.

First, in the **baseline scenario**, there is no investment from the Netherlands, Belgium and Germany in the ET, nor in the ETpathfinder. This also means that there will be no effects to be attributed to ET.

Second, setting up an **ETpathfinder** is a strategic move for the region. It will lead to a better position of the region to realise the ET and generate research at far shorter notice than the actual ET so that network, scientific and innovation benefits with direct and indirect impacts in the region will be realised within a short term. There are also positive impacts if the ET will be built elsewhere in Europe. The following two scenarios are on building the ET. Both ET scenarios can only be realised with coordinated preparation activities that could be well organised within an ETpathfinder trajectory.

In the third scenario, the **ET-ELAt scenario**, the ET is built in the ELAt region. This scenario requires large investments from the (National and regional) governments involved from Belgium, Germany and the Netherlands, but also obtains the highest benefits. The impacts contain high visibility, large scientific effects and impact on scientific position, very positive organisational effects in the scientific world in the region, potential large innovation in key enabling technologies and economic spin-offs (at suppliers of ET technology) and large regional economic effects from the building and the operation of ET.

In the **ET-elsewhere scenario**, the fourth scenario, the telescope is built with participation of Belgium, Germany and the Netherlands, but not in the ELAt region. This reduces the investments needed, but also very strongly reduces regional effects and effects on scientific reputation and diminishes (to a lesser, but not easily estimated extent) scientific effects. Agreements on high-tech procurement between participating countries may safeguard the innovation effects in this scenario.

1 Einstein Telescope: Project overview

1.1 Scientific mission

The mission of the Einstein Telescope (ET) is the following:

> *"To detect and study gravitational waves that are produced by violent events throughout the universe" (Nikhef, 2016)*

Current physics models, most notably in the area of astroparticle physics, are running towards their limits. Attempts to unite the standard model with the general theory of relativity, resulted in the little satisfying conclusion that our current instrumentation can only explain 4% of the existing universe. The rest is assumed to consist of *dark matter* and *dark energy* (MAbernathy, 2011). We therefore have a blind spot.

Gravitational waves are ripples in the fabric of space-time and were already predicted to exist by Albert Einstein in 1916. From the four fundamental forces of nature (gravitational force; weak nuclear force; electromagnetic force; and strong nuclear force) the gravitational force is still the least understood and worst tested one. Since the (public announcement of) the observation of gravitational waves in 2015, exactly 100 years after Albert Einstein's prediction, physicists worldwide have the confirmation that gravitational waves can be used as a new way of sensing in the area of physics.

Gravitational-wave telescopes can provide insight in dark matter as well as many other big questions. An increasing amount of detail is needed for this. The current observations of gravitational waves at the Large Interferometer Gravitational Observatory (LIGO) in the United States and Virgo in Pisa can be compared with a very grainy black and white picture, while HD colour pictures are needed to bring science further. Currently, the race to make better detectors is ongoing. These detectors should be able to better distinguish between the origin of the gravitational waves and to measure gravitational waves more precisely with a much higher sensitivity. The ET fits within this global race of scientists.

Worldwide, there are currently seven realised or planned gravitational wave telescopes. The existing five telescopes (LIGO, Virgo, LCGT, Astrowatch and AIGO) are first or second-generation telescopes. In September 2015 LIGO observed a gravitational wave for the first time. This was made public in February 2016. Since then, LIGO detected gravitational waves five more times. Each case gave new and interesting information. For example, several observations detected gravitational waves from colliding black holes and in October 2017 the first observation of gravitational waves from a pair of inspiraling neutron stars was announced. Gravitational waves are believed to be created by a few dozen different phenomena, where the cases detected so far have seen two of these phenomena. Scientists were already able to use this information to solve several big mysteries in the last few years, like evidence that black holes merge.

Third generation telescopes have not been built yet and the existing first or second-generation telescopes cannot be upgraded to third generation telescopes. The Einstein Telescope (ET) could be the first one. The third-generation telescopes will be ten times more sensitive than the current telescopes. It should detect gravitational waves several times a day, compared to several times a year now. The different telescopes will observe different wavelengths in order to look at different parts of the universe and gather complementary data.

1.2 Key technologies

Large research facilities like the ET stretch the boundaries of technology due to the specifications that go beyond existing technologies. In this way large research facilities are drivers for key enabling technologies (like nanotechnologies, photonics and light technologies, advanced materials, life sciences technologies, data handling and engineering and fabrication technologies), that can be the base for radical innovations. For example, image sensors in digital cameras originate from astronomy, the world-wide-web (www) is a spin-off from CERN and the last Fast Fourier Transform Algorithm – essential for WiFi chips – finds its origin at ASTRON in Dwingeloo.

At the ET, the size of the detector will be significantly larger than the size of the currently available instruments (MAbernathy, 2011). While Virgo is three kilometre and LIGO is four kilometre long, the arm length of the ET is intended to be ten kilometre. This will allow to lower the influence of displacement noise to a tolerable level. The ET will consist of three arms, arranged in a triangular pattern. Each pair of arms will contain two interferometers, one specialised in detecting low-frequency and the other in high-frequency gravitational waves, which makes six interferometers in total. For each of these arms, tunnels will need to be dug at a depth of between 200-300 meters, using civil engineering.

Key technologies that will be part of the development of the ET are:

- **(Quantum) optics**: For the ET it is necessary to produce extremely precise silicon mirrors (with a diameter of about 50-60cm).
- **Strongly cooled silicon (cryogenics)**: The mirrors for the low-frequency optimised interferometers will need to be cooled to about 250 degrees Celsius below zero by using strongly cooled silicon to reduce the thermal noise and meanwhile preventing expansion as a result of small temperature changes.
- **Ultramodern lasers:** Extremely stable and relatively high-power lasers are crucial components of laser interferometers. Compared to existing facilities, the wavelength of the laser needs to be extended, from one micron to 1,5 or even two microns in view of the transmission window of silicon.
- **A vacuum system:** The system with the silicon mirrors should not only be cold (cryogenic) but also vacuum to a very high degree to ensure the laser light is undisturbed. This means that the full ten km long arms between the mirrors of the interferometer arms have to be evacuated to very low residual partial gas pressures.
- **Seismic isolation:** The main optics of the ET need to be very well isolated against seismic ground motion.
- **Measuring and control software**: It is essential for the ET to develop robust, flexible and very high precision measuring and control software, using the latest technologies.
- **Data handling and data management**: The amount of data that will be gathered by the ET requires exquisite data handling and data management, especially when data from the ET is combined with data from other telescopes such as SKA.

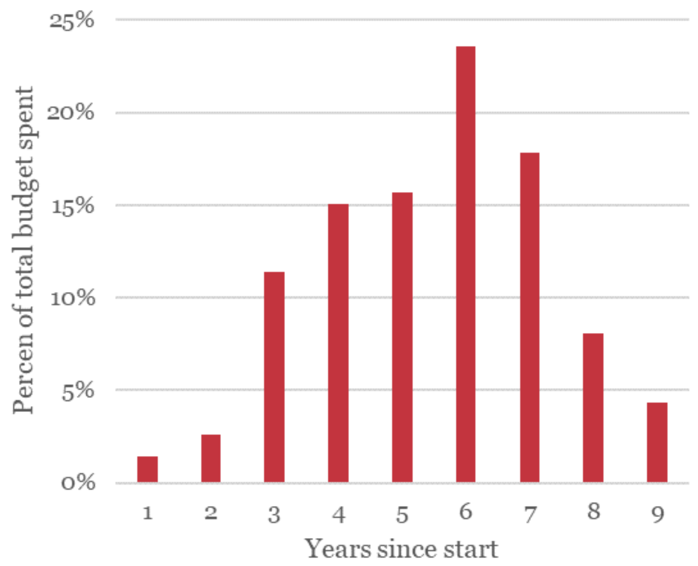
In sum, the design and construction of an infrastructure like the ET needs the development of several important key technologies. This provides opportunities for private companies to (co-)develop and deliver these technologies, and to use these technologies as a basis for further research and (radical) innovations.

1.3 Budget and planning

The most recent planning and budget estimates that have been published formally are those from the ET design study, which was an FP7 project in 2011 (ET Science Team, 2011). The design study estimated the investment volume for the first phase of the device (single xylophone detector mode, including all site works but with only a limited optical and vacuum setup) at M€768 excluding contingency, estimated at 30%. More recent estimates from experts (unsubstantiated by a study) suggest that an investment volume between B€ 1 and B€ 1,5 might be more realistic. We will use the average figure of B€ 1,3 in our calculations as the initial investment estimate for ET while we note that there is much uncertainty in this figure.

Estimates of the construction time needed lie between six and ten years (ET Science Team, 2011; KNAW, 2016). The timing of the capital expenses is graphed below. Note that on the horizontal axes, we denote time as year 1, year 2, etc, because in the design study the foreseen start of construction was 2018, while clearly construction hasn't commenced yet.

Figure 1 Investment schedule for ET. Horizontal axis indicates time in years since project start. Total project sum is estimated at B€ 1.3 in 2018.



Source: Einstein Telescope design study

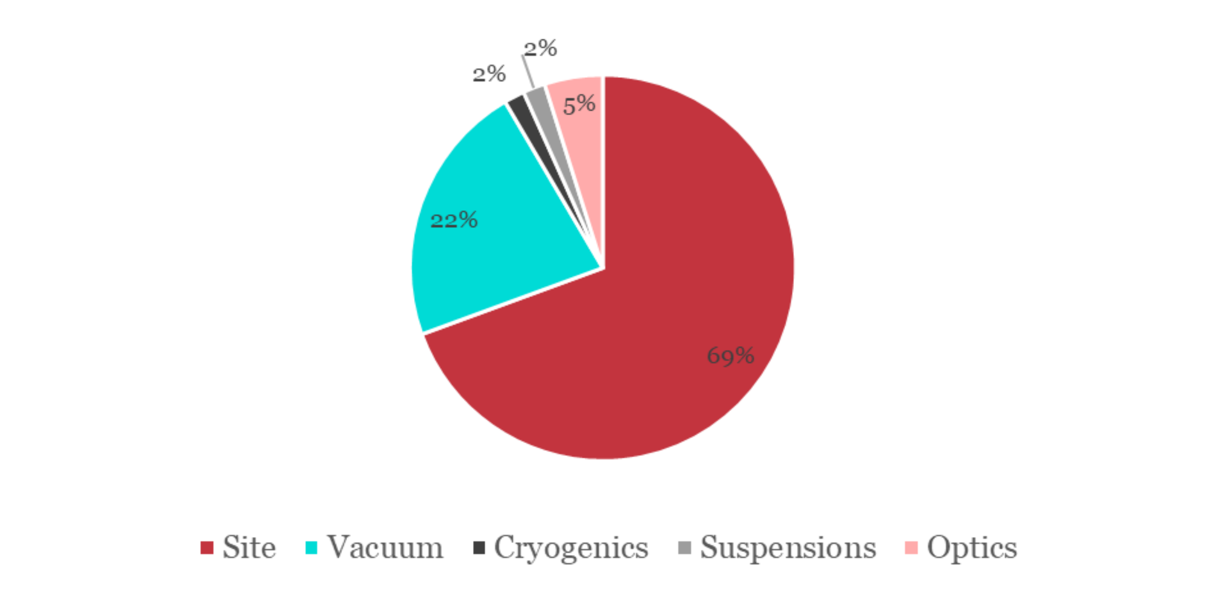
These figures relate only to the investments needed for realising the infrastructure. For the operational costs, often a figure of 10% of the investments is quoted as operational expenses for large research infrastructures. But interviewees reason that this figure would be too high, in this case because the largest fraction of work is in earth moving and site preparations, that afterwards do not require a 10% upkeep. In fact, most operational costs are usually allocated to scientific and technical staff. If we note that a GW telescope is a passive installation that requires limited handling and operations, the same interviewee assessed that a better estimate lies within the range of some 2-5%, amounting to M€20-50 annually. This figure is in line with the estimation of M€ 30 mentioned in the KNAW-Agenda Grootschalige Onderzoeksfaciliteiten (KNAW, 2016). Also, this shows some coherence with expert estimates for the need for scientific and technical staff generated for this study (M€ 6-45/y, 50-300 staff, at K€ 125-150/y).

Expert interviews suggest that ET should be operational for some 30 years. In this study, we have assumed M€ 65 annual operational costs, equal to 5% of the investment budget. Over the total running time of the telescope (30 years), the operational expenses would amount to some B€ 1.95.

The budget estimates for designing and constructing ET reveal that site preparations (69%) and vacuum systems (22%) dominate the budget. Site preparation includes direct costs for the safety and security systems, cooling and ventilation systems, 31km of tunnelling, surface buildings (among others control and computer rooms, offices, cleanroom facilities, mechanical and electronics workshops, visitor and check-in facilities). Construction works for these items are expectedly done by local entrepreneurs as it is not practical to fly in either the machinery, the personnel or materials. Therefore, local entrepreneurs are probably more interested and more likely to make a good offer.

Vacuum systems are expected to be sourced within Europe. The Einstein Design study explicitly mentions suppliers in France, and one in Australia (ET Science Team, 2011). It is expected that many customisations to the vacuum systems are necessary during and after installation, which requires proximity to the site of engineers from the supplier. In addition, the weight and sheer amount of the stainless steel parts drive a choice for local sourcing to reduce transport costs. This would argue for European supply.

Figure 2 Allocation to technologies of Einstein Telescope's main investments



Source: Einstein telescope design study

Cryogenic systems can be sourced globally: the design study mentions suppliers in the US, Japan and Switzerland. Finally, for the optics and lasers no suggestions of suppliers have been given.

1.4 International context

It is clear from the figure above that the ET is set to operate in an international context of observatories. At present Advanced Ligo (USA) and Virgo (Pisa, funded by Italy and France), the GEO-HF (Germany, funded by Germany and the UK), and the KAGRA observatory in Japan are operating. Scientists from LIGO in the USA and GEO in Germany combine their observations in the Ligo Scientific Collaboration (LSC), on which scientists from an additional 100 institutions in 18 countries work for scientific analysis.

Virgo and LIGO have formalized their collaboration in a MoU, and both of themalso mention collaborations, joint observation runs and joint discoveries on their official websites. New plans for the combined operation of current GW telescopes are mentioned to start in 2019 after upgrades to Virgo and LIGO. The KAGRA telescope is expected to join the combined observatory once data and detectors are up to specs, as described by (Aggarwal, 2018). This paper also notes that observation data for all devices is combined and openly available. What's more, when gravitational events are found, collaborations with optical and radio astronomy are set up to observe the events in as much detail as possible. This practice is called the "multimessenger" approach which should shed new light on astronomy and astroparticle physics.

This makes it clear that the ET will operate as part of a true global effort to observe the universe with new eyes. For what concerns the European consortium behind the ET, the European Science Forum for Research Infrastructures should give the most details. The 2016 ESFRI roadmap (ESFRI, 2016) mentions the ET but only to the extent that "there is a concept" and indeed, a submission to enter the roadmap is yet to be made. The ET website mentions the 2020 roadmap as its target, and a letter of intent supporting the submission to this roadmap is open for signature by European scientific institutions. A glimpse on who these European supporters are is given in the next section.

1.5 Stakeholders

There is a large **global scientific community** that can benefit from the ET and that is interested in its development for scientific reasons. The output created by the ET will impact researchers in the field of astronomy, astrophysics, cosmology and fundamental physics worldwide.

In Europe, there is a select group of institutes in the field of gravitational wave experimental research that have partnered in a design study project for the ET, supported by the European Commission under the Framework Programme Seven (FP7). These institutes are:

- The European Gravitational Observatory (EGO), including participating labs from Hungary, Poland and Spain;
- Instituto Nazionale di Fisica Nucleare (Italy);
- Max-Planck-Institut für Gravitationsphysik (Germany);
- Centre National de la Recherche Scientifique (France);
- University of Birmingham (UK);
- University of Glasgow (UK);
- Nikhef (Netherlands);
- Cardiff University (UK).

If the ET will be built, a possible location of the ET is in the heart of the ELAt region (Eindhoven-Leuven-Aachen triangle, Figure 3).

Figure 3 The ELAt region (Eindhoven-Leuven-Aachen triangle)

Source: Province of Limburg (2018)

For this, a collaboration of the Netherlands with other countries is necessary, where Belgium and Germany are the most obvious countries to collaborate with. Currently, a collaboration of Nikhef – the National Institute for subatomic physics in the Netherlands – together with several universities from the Netherlands is trying to connect the different stakeholders. The institute has a large network in the international research community and industry. The Nikhef-network is fully exploited to engage important stakeholders. This is an ongoing process, with more and more (regional) partners showing their interest in the ET.

In the region, stakeholders concern the scientific community, the high-tech industry, political and budgetary stakeholders and citizens. The **regional scientific community** includes several universities and research institutes, such as the University of Antwerp, the KU Leuven, Gent University, University of Hasselt, University of Luik (Luik), the VUB and ULB (Brussels), the Université Catholique de Louvain (Louvain-la-Neuve), the Fraunhofer Institute for Laser Technology (Aachen) and the Rheinisch-Westfälische Technische Hochschule (Aachen). There are also multiple universities from the Netherlands that have shown an interest in the ET, including the University of Maastricht, Eindhoven

Technical University, the University of Twente and the TU Delft. These aforementioned regional scientific stakeholders have already made their interest in the ET explicit.

Second, the **high-tech industry** in the different regions surrounding foreseen location of the ET is an important stakeholder as these could produce prerequisite and required technologies. At the moment, there are at least 50 companies in the ELAt-region that have shown their possible interest in the ET. These companies are experienced in the development of technologies related to engineering and production, materials, cryogenics and vacuum technology, optics, ICT, electronics and geo intelligence. Companies such as VDL-ETG, JPE, IBS and Demaco have also signed a letter of intent to make their interest more explicit.

Third, there are **political and budgetary stakeholders** such as the Belgian federal and regional governments, the investment company LRM and the agency POM, the German government of Nordrhein-Westfalen and the Bundesministerium für Bildung und Forschung (BMBF) and the Dutch Ministries of Economic Affairs, Education, Culture and Science, and Finance as well as the Dutch Research Organisation (NWO). Other stakeholders are local/regional political actors that represent communities in the ELAt region that will be affected by the development of the ET, such as the Städteregion Aachen and Belgian and Dutch Limburg. In the Netherlands, the major regional stakeholder that is currently involved in the ET project is the Dutch province of Limburg. The ET is already mentioned on several Dutch roadmaps and agenda's, such as: the Dutch Roadmap for Large-Scale Scientific Infrastructure (NWO, 2016), the agenda of the Royal Netherland Academy of Arts and Sciences (KNAW, 2016) and the Dutch National Research Agenda (NWA, 2015).

Finally, there is the **general public (citizens)** in the different countries involved. The opinion of the general public on the ET will play an important role in the commitment of regional and national politicians to this project. Interviewees indicate the opinion of the general public can have both positive and negative effects. For example, it can have a negative effect when people feel the money spent on an ET is better spent elsewhere or when citizens in the ELAt-region feel the building of the ET will disturb their peace and quiet (especially in the building phase). On the other hand, it also has a positive effect if they feel it can contribute to their peace and quiet on the longer term. Other positive effects can occur when the ET captures the imagination and people are proud of the ET and feel this project may increase the liveability in the region. Finally, building the ET can also change the general public: regional communities can be impacted by the development and activities of the ET and national opinion on science in general can be influenced by the development and discoveries of the telescope.

1.6 ETpathfinder

To prepare for the development and construction of the ET in the ELAt region, Nikhef took the lead for setting up an ETpathfinder. This ETpathfinder is an (at present) intended R&D facility in the province of Dutch Limburg to develop technologies relevant for the ET, and thereby organizing and strengthening scientific and technical expertise in the region.

This ETpathfinder will be used to develop technologies that can be used for the ET and other third-generation telescopes. Focus will be on technologies for reducing vibrations (including cryogenic operated mirrors), the optic interferometer and on diagnostic equipment, including measurement and control software. Internationally there are more plans for R&D facilities, but they focus on different technologies, making them complementary.

The research will be focused on developing technologies for the ET. However, current interferometers, like LIGO and Virgo and possible third-generation telescopes at other continents like the Cosmic Explorer can use the knowledge developed in the ETpathfinder as well.

The main infrastructure of the ETpathfinder will be 25 by 25 meters large and will contain a cleanroom and a vacuum system. The location will be determined end 2018, the Chemelot Campus is a possible location, mentioned in the Interreg application. The plan is to start building the facility in 2019. It will take three years to build phase one of the ETpathfinder.

To set up the physical infrastructure of the ETpathfinder a Dutch-Belgian-German consortium applied for Interreg funding in spring 2018. A granting decision is expected for the end of 2018/early 2019. In the meantime, a second application is being prepared by this Dutch-Belgium-German consortium. The detailed content of this application is not clear yet, but it will be complementary to the first application. In the first application it is stated that the money will be used to build the facility. The required capacity for R&D activities and engineering (that is the manpower) will be financed by the partners of the consortium.

2 Impacts in preparation phase

In this chapter we will describe the impacts in the preparation phase of the Einstein Telescope (ET). In this phase, all preparation needed before the building of the ET will take place: for example, it will be determined what the specs of the ET will be, where it will be located and how it will be administratively run. These choices determine to a large extent the impacts later in the process, and where these impacts are likely to land. It is however not only a process of negotiation, of which the outcome is determined by the financial contribution of the countries involved, it is also a process of scientific and technological development which is supposed to result in the best design for the telescope to achieve its scientific role (and those parties who contribute most to that process of discovery also are in a good position to contribute to building and operating the ET later on). The intention of the ELAt region is to organize the scientific and technological development in the ETpathfinder. The ETpathfinder is therefore also taken into account when looking at the impacts in the preparation phase.

2.1 Technological impacts

The research topics of the ETpathfinder are chosen to develop essential technologies that will make ET possible. These essential technologies are often key enabling technologies with, at least in theory, very broad application potential. The research will be focused on keeping the costs for the ET as low as possible and will furthermore make it easier to estimate the costs of the ET. Once there, the ETpathfinder will already improve the local R&D infrastructure. Especially testing technologies in (e.g. lasers, mirrors, cryogenics and vacuum systems) in this facility can be interesting for (new) companies.

There are already more than fifty companies that showed some kind of interest in involvement in the ETpathfinder. Some of these companies also indicated that they would be willing to invest in technology development. However, most companies need more information to specify how they see their role and what the impact on their company could be.

It is expected that the ETpathfinder can already have an added value in getting economic activity in the technological fields of the ET in the ELAt region (Eindhoven-Leuven-Aachen triangle). New technologies can be developed and tested here, creating more knowledge and innovation in the region. Several companies in the region already stated that the spillover in economic activity and innovation and entrepreneurship in the region, which is already partly achieved in the preparation phase if the ETpathfinder will be build, is more important for them than the direct impacts of working on the ET. Even though they cannot predict what kind of spin-offs will occur and how economic activity will develop, they trust that more economic activity will lead to innovation that will benefit them somehow and they indicate they want to be involved. Especially since all technologies that needs to be developed have an innovation part.

> *“If you bring technologies together and you bring it to extremes, always new things arise.”*

Although spin-off technologies are impossible to predict, several interviewees mention possibilities for spin-offs from the ET in the areas of High tech and Life Sciences & Health. An example of a possible spin-off from is in new laser technology. For the ET, the extension of the laser wavelength is important: from one micron to 1 – 2.5 micron. There is a large number of additional laser applications for these wavelengths. For example, it can be interesting for the welding of special plastics and for spectroscopic measurements in medical applications. Cholelithotripsy, the distraction of stones in the body, can also be done with pulsed infrared lasers. Aachen is doing a lot of research on lasers and there are several companies in Aachen working on lasers as well. They would also benefit from the developments as it might increase their markets. Also, in the fields of precision engineering, software and computing, data analysis, vacuum systems and vibration damping technological spin-offs can be expected. If the

ETpathfinder is built some of the effects can already occur in the preparation phase and spin-off technologies could occur earlier.

2.2 Societal impacts

The ETpathfinder can also play a central role in organising the different stakeholders in the region and strengthen the cooperation. If companies are interested and the cooperation between the countries and different knowledge fields goes well, this strengthens the regional consortium for the ET. This will not only put scientific and industrial players from the region in a good position to optimise their returns from building and developing the telescope but will also increase the chances of building the ET in ELAt region, by showing that the expertise and knowledge needed for the ET is present in this region, and that willingness to cooperate within ET exists.

The first impacts on collaboration are already realised, even before the ETpathfinder has started: a cross-border collaboration between knowledge institutes in the Netherlands, Belgium and Germany has been set up already, bringing the scientific research in the field of gravitational waves and innovation in high-tech systems and materials closer together.

The network of the ELAt region will especially benefit from the ET: the regions around Leuven, Aachen and Eindhoven are known for their technical clusters and positive benefits are expected to result from tighter collaboration between these clusters. Working together on the development of technologies, using the ETpathfinder, can already strengthen the collaboration in the preparation phase.

2.3 Impacts on the science community in the ELAt region

Because of the possibility of locating the ET in the ELAt region, both RWTH Aachen University and Maastricht University increased activities in fields related to ET in the preparation phase. The RWTH already has a research institute in particle physics and if the ET will come to the region, this institute will probably move (or expand) their activities more in the direction of gravitational waves research. Maastricht University has the intention to broaden its academic profile and the area of gravitational waves is interesting as it is an unexploited area with a large potential. The cooperation between Aachen and Maastricht was quite limited, but a shared ambition in the field of gravitational waves gives a strong basis for collaboration. There are already discussions between the two universities about a joined bachelor-master curriculum. In Belgium, scientists stated the ET is the first project in which all Belgium universities are interested. Joint operation of the ET will bring the universities closer together and make it easier to collaborate.

Furthermore, the ETpathfinder facilities (esp. the unique ability to operate mirrors at cryogenic temperatures) offers opportunities to attract leading international researchers for permanent positions (discussions are going on) and for shorter term research projects. Especially in combination with the (to be established) 'Institute for Gravitational Research' in Maastricht. The permanent researchers (expectations are that a group of researchers can be attracted if Maastricht University will become a member of Nikhef) can form a nucleus for Maastricht University's long-cherished wish to broaden its academic profile.

3 Impacts in construction and operation phase

This chapter will give an indication of the impacts in the construction and operation phase of the Einstein Telescope (ET). Although it would be interesting to keep effects of these phases apart, this was not possible, because there are no economic data available for the effects of the separate phases, but only for the combination.

3.1 Economic impacts

3.1.1 Methodology

To estimate the economic effects of realising the ET, we have reviewed the employment and multiplier effects of several large physics research infrastructures. Assuming that such effects scale linearly with the investments made, we estimated the ET's economic effects based on other infrastructure's economic performances.

There are some important assumptions and remarks to mention. We took into account that a telescope that collects astronomic data is of less direct use to industry than a device with a similar level of technical complexity in which varied tests can be performed, since a telescope cannot be used for materials research with direct industrial relevance (as synchrotrons can). Also, it should be noted that it is not possible to make a distinction between gross and net employment effects in this study, as only the SKA study (Koopmans, Van Barneveld, Van der Veen, 2016) explicitly makes this distinction. Finally, input/output (I/O) analyses used in the studies we looked at usually do not regard the actual output of research infrastructures such as publications, innovations, public private partnerships and other such effects

Table 1 Economic data for various research infrastructures. Currencies in millions EUR 2013. The figures

Research Infra-structure	Time win-dow (years)	Gross expen-diture (M€)	Gross bene-fits (M€)	Net bene-fits (M€)	Direct employ-ment (person -years)	Total employ -ment (person -years)	Direct FTE/ M€	Total FTE/ M€	Multi-plier	Original currency
CERN LHC	33	13,500	16,400	2,900	-	-	-	-	1.21	EUR 2013
FERMILAB	1	385	517	132	1,942	4,529	5.1	11.8	1.34	USD 2010
SKA	10	195	306	112		1,550		8	1.57	EUR 2016
SRS	27	739	1,234	495	6,183	-	7.7	-	1.67	GBP 2010
TRIUMF	10	390	687	297	5,311	11,733	13.6	30.1	1.76	CAD 2013
CERN (1993 study)	1	917	-	-	3,000		6.0			CHF1993
Australian Synchrotron	25	500	867	367	-	11025		22.1	1.73	AUD 1999

Time window: The period of time in years under consideration for establishing the effects of the installation (y). A larger time window means more costs for operations but also more employment generated; **Gross expenditures** The sum of all expenditures (M€) attributable to the installation (capital and operational) over the time window considered. Note that for most studies, the actual construction of the infrastructure does not fall within the time window; **Gross benefits** All benefits (M€) accrued attributable to the research infrastructure within the time window; **Net benefits** Gross benefits minus gross expenditures (M€); **Direct employment** Full Time Employment (FTE) years summed over the lifetime of the installation (also known as "person years" or "man-years"), directly paid by the research infrastructure or its contractors; **Total employment** Sum in person years of direct and indirect employment (caused e.g. by spending salaries of those directly employed in the region); **Direct FTE/M EUR** Calculated as direct employment divided by the gross expenditures; **Total EUR/FTE** Calculated as total employment divided by the gross expenditures; **Multiplier** Calculated as gross benefits divided by the gross expenditures. "For every X euro I invest, I get [multiplier]*X euros in return.

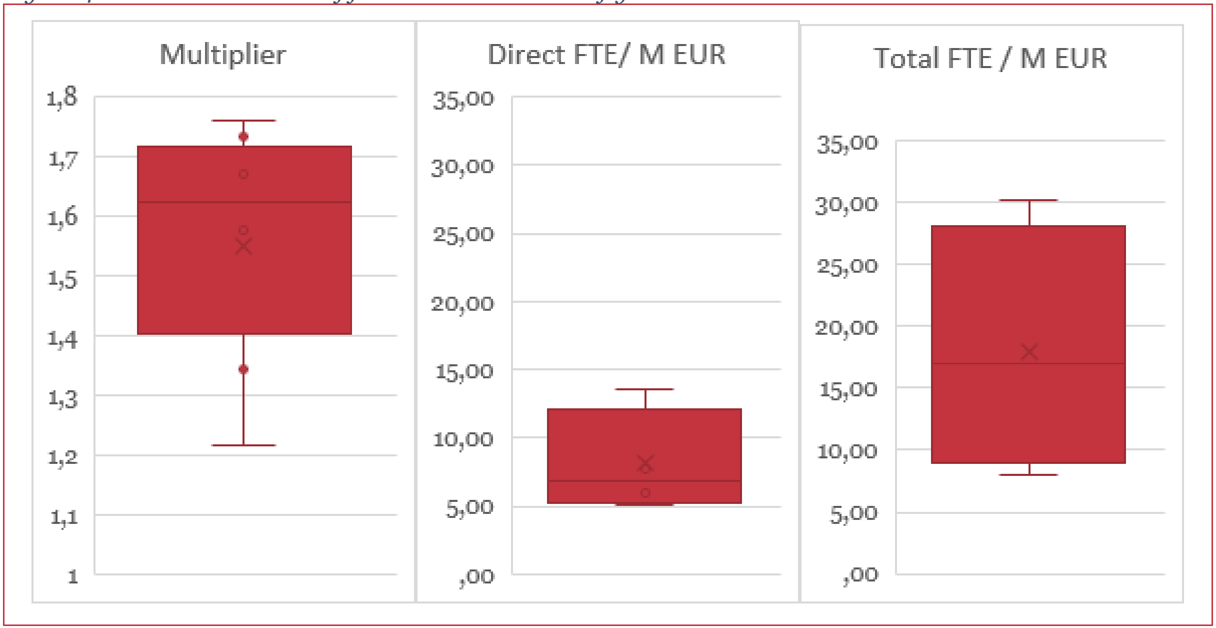
The table above shows the data found for the research infrastructures under consideration. Shaded columns indicate calculated numbers. All currencies have been converted to 2013 Euro: first by inflating the currency to 2013 values with national inflation values, then converting with the annual averaged exchange rate of the foreign currency versus the euro in 2013.

3.1.2 Multiplier and Employment effects

We have used the multiplier and labour effects from the studies above and regarded them as statistic phenomena that should guide our establishment of a reasonable value. In this choice we have regarded whether scaling effects were present: whether larger investments yield disproportionally larger returns. The conclusion is that such effects do not exist within the set, as is expected from linear models.

To establish a multiplier and labour effect for the ET based on the sample, we show the box plots below as a suitable representation:

Figure 4 Statistical overview of found indicators. Euro figures in thousands



Source: Technopolis group

The box plots indicate a large spread of the found values. X marks the average, the "box" contains the centre two quartiles: the upper first quartile above the red horizontal (median) line, the lower first quartile below the red horizontal line. For the multiplier, we argue it is fair to use the mean value: 1,55 as it is close to the figure for the (ex ante) evaluation of the impact of a Dutch participation in the Square Kilometre Array. This datapoint thus adds a recent, Dutch high-tech installation to the dataset[1]. The figures for direct and total FTE per euro spent show a more symmetrical distribution, but the difference between minimum and maximum is much larger: Factors of 2.7 and 3.8 divide the minimum and the maximum values for direct and total employment respectively. Although these ranges are large, the symmetry in the distribution suggests that the mean represents a reasonable impression to be used as a first estimate for ET. What's more, the mean figure for direct employment (8 FTE/ M EUR) is about half the mean figure for total employment (17.97 FTE/ M EUR). This is in line with observations for Fermilab and TRIUMF, where a factor of two also divides total and direct employment.

[1] Though we have tried to include more ex-post, western-european installations, we were not able to find useful data from, for example, the LOFAR installation in the Netherlands or the European Spallation Source in Lund (Sweden).

We thus conclude the economic data review with a choice for the *mean sample values* as given below:

Table 2 Calculated values for economic effects for large Research Infrastructures

Indicator	Value
Multiplier	1.55
Direct FTE per M EUR	8
Total FTE per M EUR	18

Source: Technopolis Group

3.1.3 Location of economic impacts

Multiple studies note that regional economies absorb the largest part of the economic effects (Hickling Arthurs Low, 2013; STFC, 2010; Sallee, 2011). In the case of Daresbury Synchrotron Radiation Source, it was even found that 90% of economic impact is achieved locally (Womersly, 2012). However, the actual division of benefits to the region of interest depends on many decisions and negotiations (on e.g. financial contributions and procurement rules) still to take place, so the magnitude of the economic impacts in the region depends heavily upon the negotiations on financial contributions and procurement rules.

As shown in paragraph 1.3, the largest part of investments (69%) for the ET is on site preparation and construction ('digging the tunnels'). This low-tech component will, because it is location-bound, have its main impacts in the region and on a fairly short term. This cannot easily be spent remotely, which is why this "lower tech" engineering will mostly take place in the region.

The investments in high-tech are less location bound: the high costs per unit (and the limited volumes of the equipment) make production elsewhere viable. Since with large Research Infrastructures there generally is a relation between investment of partners in such an infrastructure and the return they want to get out of it in terms of opportunities for their local industries, there should be attention for agreeing on procurement rules so that every party involved gets a fair share that fits their capabilities and needs.

3.2 Scientific impacts

Scientific impacts will take place in the operation phase, when data is available from the ET.

3.2.1 Scientific fields

Information from the ET will be used in many scientific fields. It will impact astronomy, astrophysics, cosmology, nuclear physics and particle physics. Einstein's theory of general relativity can be tested with the ET, more particularly it can be tested if there are deviations of this theory, like frequency dependent effects of gravitational waves (dispersion). Because the ET can detect many different phenomena, the application of the information is also large. The ET can detect gamma-ray bursts and binary coalescences, but also fast-spinning single neutron stars and probably many new phenomena. This will help in looking back to the early universe, much further than we currently can, which is 370.000 years after the big bang.

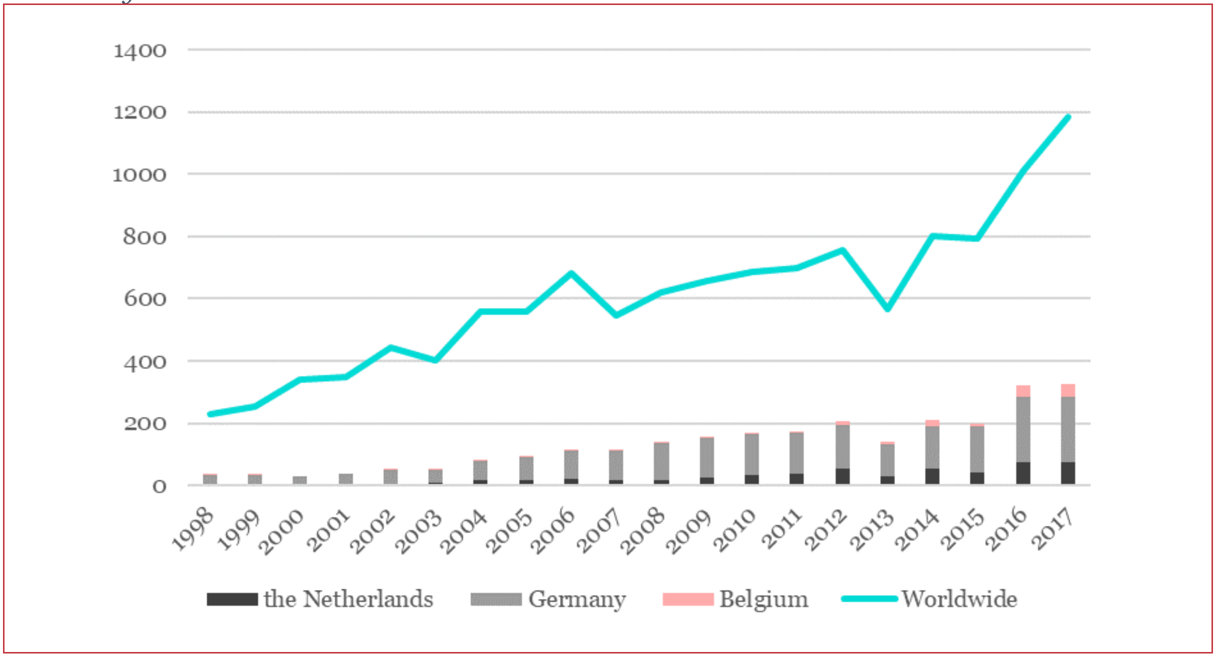
Scientists also expect that this will lead to more interdisciplinarity in science. It can unify several scientific fields who do not collaborate much now. Examples are cooperation between nuclear physics, particle physics, astrophysics, gravity, mathematics, high energy and instrumentalists.

3.2.2 Publications

Past performance may not be indicative of future results, but the number of publications in Scopus, the scientific literature database from Elsevier shows clearly that the number of publications on the topic "gravitational waves" is growing (Figure 5): it has tripled the last fifteen years and doubled in the last ten years. The Netherlands, Germany and Belgium together co-authored 27% of all the articles on gravitational waves worldwide. With 74 articles in 2017 the Netherlands contributed approximately 6%

of the total. Comparable growth rates (but at lower absolute levels are found for articles about ‘astroparticle physics’).

Figure 5 Articles on "gravitational waves" per year. Source: graph made by Technopolis, data from Scopus, search on “gravitational waves”



Source: Technopolis Group

The ELAt region (Eindhoven-Leuven-Aachen triangle) clearly has a strong position in the topic, which makes it easier to expand in the area. As the field of gravitational waves is still unexploited it can be expected that the number of publications will grow much further. This growth will be strongly dependent of third-generation telescopes, once they will be realized (probably first the ET in Europe and later the “Cosmic Explorer” in the United States). Access to data coming from the telescope is more relevant than the location of the telescope, since analysis of the data can be done from every location. However, on a European scale, scientists feel that Europe needs a third-generation telescope to be able to keep participating in this field worldwide. Now scientists work with data from LIGO and Virgo, but also work a lot with American instruments. Access in the future to American instruments is not secured while the science in the US is at least at comparable level and the number of publications from China is increasing so there ET contributes to safeguarding the European position. Within ET, a lead role in investing provides a good chance on a lead role in science, and, once the ET is up and running, possibly preferential access to data with the other participants (analogous to the SKA draft-agreements).

3.3 Technological impacts

The technological impacts already start in the preparation phase, if the ETpathfinder is being build. If the ET is built this will enhance the technological impact in the construction and operation phase. The ET will attract scientists and knowledge workers and, in their slipstream, could attract more economic activity. It could become the nucleus for cluster formation, realizing a regional ecosystem where new technologies are developed, and new companies are started.

The effects of technology and innovation at large Research Infrastructures can be big. For example, the World Wide Web was developed at CERN, following from their need to better communication among scientists worldwide. And other widely used technologies, like touchscreens, started their development path at CERN as well. Outside CERN an example is the development of optics, which can be used to read out sensors. These are used for mineral exploration, detecting earthquakes and navigation systems.

Research on the motion of mirrors used for the existing telescopes is also used to turning stem cells to bone cells.

3.4 Societal impacts

Most of the societal impacts take place in the construction and operation phase. One of the biggest societal impacts that interviewees expect to come from the ET, is on the community around it. The involvement of three different countries will not only make it possible to share the burden, but collaboration in the field of education, attraction and exchange of researchers is also expected. The region will attract knowledge: smart people, both workers (including scientists, engineers, PhD students and post-doctoral fellows) and students, that remain in the area and can be hired by local universities and companies. Furthermore, many interviewees believe that a large research infrastructure project such as the ET will encourage more students to follow a STEM- (Science, Technology, Engineering, Mathematics) education, both in higher education, vocational education and at universities. In order to reach the highest impact, it is recommended to think about how to engage schools and the public in what is being done. The availability of various education and training programmes in the region is a precondition – here players such as Eindhoven Technical University, the RWTH in Aachen, Liège University and Maastricht University come in. There for example is a possibility to increase the number of international bachelor and master programmes between Aachen and Maastricht. Maastricht is already working on broadening its academic profile with a sciences and engineering faculty and has two FTE working on this. With the arrival of the ET, Nikhef expects some of their scientists to move to the ELAt-region as well. Furthermore, there is a joined graduate school for PhD’s with Liège and Aachen. While many students currently leave the region after their bachelor to study a master in the Randstad region or to continue their studies in their home country, the ET can also connect students better to the region.

Another impact is the attraction of R&D and entrepreneurship to the region. Several interviewees state that large scale facilities often serve as a focal point for collaboration and communication of knowledge workers. It can also be a means to connect stakeholders that would otherwise have not collaborated with each other. Furthermore, spin-out companies often do not want to travel too far away from their base. The development of a knowledge cluster or science park around the facility can help with this attraction of R&D and entrepreneurship. The effect can be further extrapolated by for example the instalment of a department that promotes the valorisation of findings from the ET and investments in conference facilities, as is done in at the European Spallation Source in Sweden.

The accessibility of the ET location was mentioned by several interviewees as an important prerequisite of the number and sorts of people that will come to the facility. They emphasise the importance of improving transportation connections and promoting accessibility, for example, with nearby airports and with the cities Liège and Aachen. Small things, such as strategic direct train connections, can make a big difference on people coming to the facility. For example, a direct train connection between Schiphol Airport and Maastricht or train connections between Luik-Maastricht-Aachen can support the accessibility of the region. A direct train connection between Maastricht and Aachen is already being build and expected to be in operation in December 2018. There are also plans for a direct train connection between Maastricht and Luik.

Finally, the ET can also be used as a way of **branding** the region. Outreach in this sense is very important and can for example be done by installing a visitor’s centre. Interviewees have emphasised that other major research infrastructures such as LIGO and Virgo through their visitors centre often attract schools that come to join an interactive tour, which can again benefit STEM education. Combining the ET with the widely developed tourism sector in the ELAt-region might also provide extra impulses for the region. A proper branding strategy can not only be beneficial for the province of Dutch Limburg but also for Germany and Belgium. During the workshop in Leuven for this study it was recognised that science and society can be brought closer together in Belgium and that the ET could facilitate this.

In sum, there are many ways through which the ET can impact society, but there are also several preconditions for this to happen. A cluster of activity around the ET is necessary – when scientific activity and R&D do not take place on site or in the region, the social impact will be a lot lower: researchers do not meet each other, knowledge exchange and cooperation are not nurtured, and the region will be less attractive for visitors.

The arrival of the ET is also expected to increase exposure of the regional industry, especially since the ET project will be a cross-over between heavy scientific research in the field of gravitational waves and high-end innovation in the field of the top sector High Tech Systems and Materials.

3.5 Impacts on the science community in the ELAt region

If the ET will be built in the ELAt region this will have a positive effect on the reputation and international visibility of the region, and especially on nearby universities and knowledge institutes. People will associate the ET with these universities and institutes. Being one of the possible locations probably already helped in getting to host the LIGO-Virgo collaboration (LVC) meeting in fall 2018. It can also help nearby universities in getting higher international rankings and work as a catalyst for other sciences and technologies as well.

Scientists in the field of gravitational waves are already cooperating often and more than 600 scientists have indicated to support the ET project by signing the "Letter of Intent for the Einstein Gravitational Wave Telescope (ET) collaboration"[2]. Almost all of them are from Europe and a third is from Italy and a third from the ELAt countries.

[2] 606 signatures of the ET LOI at the date 24/08/2018 18:10:00. https://drive.google.com/file/d/1IjvTtHWFgzb8KQHjV27-pNkkiUnO6K0U/view

4 Discussion

In the discussion we will compare the expected impacts under different scenarios for the ET investment. The outputs of all scenarios show many uncertainties, not only because of the early stage of the planning process - where many decisions still have to be taken – but also because the realisation of an ET needs a number of innovations (which are inherently uncertain and can have large impacts on both inputs (cost of ET) and impacts (e.g. economic spin-offs from ET). Furthermore, the realisation of such a large research infrastructure requires contributions from many countries, where the outcome of the negotiations between these countries about their contributions and what they want to receive in return (in terms of compensation orders, etc.) is very uncertain as well.

4.1 Scenarios

In order to help decisionmakers deal with his uncertainty, we will discuss in this chapter a number of investment scenarios for participation in the ET. (Figure 6).

Figure 6 Scenarios for ET investment

Scenarios
Baseline: No investment in ET (from Belgium, Germany and the Netherlands)
PF: Investment in ETpathfinder alone
ET-ELAt: Participation in ET, location in the ELAt region
ET-elsewhere: Participation in ET (from Belgium, Germany and the Netherlands), location elsewhere

Source: Technopolis Group

4.2 Possible impacts for each scenario

In the **Baseline scenario** there is no investment in the ET, nor in the ETpathfinder, from the three countries BE, DE and NL. This also means that there will be no effects to be attributed to ET, apart from the fact that the investment money needed for the Telescope and the ETpathfinder can be invested in other activities. These other activities will also have their economic and social impact, but since the application is not clear, these impacts cannot be estimated (but should be subtracted from the ET impacts to obtain net impacts from the ET investments).

Setting up an **ETpathfinder** will organise the scientific and industrial network in the ELAt region (Eindhoven-Leuven-Aachen triangle) and, if done well, will lead to a better position of the region to realise the ET. It will also lead to a better position in getting a good return from investment in the ET if this is not built in the ELAt region (but elsewhere in Europe), because it can help to attain a leading scientific and technical role. Most importantly it will generate research at far shorter notice than the actual ET so that network, scientific and innovation benefits with direct and indirect impacts in the region will be realised within a short term. The ET will not be operational in the next decade and in the meanwhile the ETpathfinder can already attract knowledge, scientists and companies to the area. Such an ETpathfinder is a good way to combine the strength of the Euregio, which is necessary to realise ET in the ELAt region. It is believed by many people involved that the ETpathfinder will increase the chance of the ET being built in the region, because it will show that this region is capable of running the ET and the ETpathfinder will improve the knowledge base in the region. In case the ET will be built in the region, the ETpathfinder can give the area a head start.

For the ET we have defined two scenarios. In the first one, the **ET-ELAt scenario,** the ET is built in the ELAt region. The ETpathfinder costs have not been included in this scenario (nor in the ET-elsewhere scenario), but in practice both ET scenarios can only be realised with coordinated preparation activities that could be well organised within an ETpathfinder trajectory. Scenario ET-ELAt requires large investments from the (National and regional) governments involved from Belgium, Germany and the Netherlands. In this scenario the maximum in benefits is also obtained (see also the previous chapters):

- The visibility of a physical ET location increases the presence of the region in the world, by providing a strong contribution to the scientific reputation of the countries involved and the ELAt region;
- Scientific effects and scientific position;
- Organisational effects, e.g. attraction of top-scientists to the region, more intensive cross-border cooperation between the universities involved, a good focus for a sciences and engineering faculty at Maastricht University;
- When negotiated well, a strong position in the development trajectory of the ET equipment from industry from the ELAt region, and potential large innovation and economic spin-offs;
- Regional economic effects from the building and the operation of ET.

In this scenario it is assumed this has been done successfully, and the ETpathfinder can be seen as a precursor for and contributor to the effects of ET as a whole. Necessary for this are good people (that partially need to be attracted from outside the region) and good cooperation between (regional) institutes and universities. Part of this can be the start of a sciences and engineering faculty at Maastricht University with an institute for gravitational research. To achieve these network effects is an impact in itself, with probably sustainable spin-offs.

The second ET scenario is the **ET-elsewhere scenario.** In this scenario the Telescope is built with participation of Belgium, Germany and the Netherlands, but not in the ELAt region. This reduces the investments needed, but also very strongly reduces regional effects and effects on scientific reputation and diminishes (to a lesser, but not easily estimated extent) scientific effects. The effect on innovation potential is not clear, since the return for (Belgium, Germany and the Netherlands) industry depends on the investments from these countries. Assuming some kind of "juste-retour" for each country from its financial commitments, not building the telescope in the ELAt region will reduce the returns in low-tech (because the low-tech building and operation activities are location related and will not be in the ELAt region), which can increase the room for return for Belgium, Germany and the Netherlands in high-tech.

The ETpathfinder also has value in this scenario. Here the preparatory work done in the ETpathfinder can contribute to more successful positioning both with respect to science (at least a leading role in one of the work packages in ET) and innovation (good positioning of regional industry for orders to develop ET instrumentation). During ET operation the ETpathfinder can operate as an independent research center. Current research centers are also not located next to the telescopes. It is estimated that also without a telescope nearby, the ETpathfinder will be operated for at least 15 to 20 years. Again, good coordination and cooperation between institutes, universities and companies is a prerequisite for optimal results, and an impact.

If in the end it turns out that it is not viable to participate in the ET for the governments of Belgium, Germany and the Netherlands, most of the value of the ETpathfinder will only have been temporary, because the people attracted by the perspective of participation in the ETpathfinder will find new positions with those organisations involved in the ET. The technologies developed can still be used for other third-generation telescopes and some can be applied in other fields of technology. The effect on university cooperation and the University of Maastricht can however be more sustainable. Overall the added value of the ETpathfinder would be significantly smaller than in the ET-ELAt scenario.

The figure on the next page (Figure 7) shows the main impacts of the various scenarios.

*Figure 7 Impacts of ET investment**

	Baseline	**ETpathfinder**	**Einstein Telescope (ET)**	
Scenarios	Baseline: No ET participation	ETpathfinder	ET-ELAt	ET- elsewhere
Investments (rough estimate**)	0	Limited (M€10-30)	Very large (M€400-700)	Large (M€100-325)
Operational costs (rough estimate**)	0	M€0,1-0,2/y	M€ 10-20/y	M€7-13/y
Regional economic effects	0	Limited	Large	Limited
Organisational impact	0	Can be fairly large	Very Large	Large
Visibility, reputation	0	Limited	Large	Limited
Scientific impact	0	Limited	Very Large	Large
Innovation impact and long term economic impacts	0	Possibly large	Possibly very large	Possibly very large

* Assessments are made by Technopolis based on qualitative input by interviewees and own assessment based on literature. These are meant to help structure discussion about pros and cons of various scenarios, not as well-substantiated quantitative predictors of possible impact

** This is only an indicative range for the contribution of Belgium, Germany and the Netherlands. Actual values depend much on the total investment needed, the total number of participating countries and the negotiations between the parties on cost distribution. For the ESS in Sweden, Sweden provides 50% of upfront investments, and 10% of running costs. Here we state 30-60% upfront investment and 15-25% operational costs when ET is located in the region and 10-25% upfront investment and 10-20% of running costs when ET is located elsewhere. The estimate for the operational costs for the ETpathfinder includes running the clean room and consumables, but does not include the costs for doing research in the ETpathfinder.

4.3 Next steps

To achieve any impact, it is necessary to start with the preparations as soon as possible (or decide not to participate).

A condition for success is to get a place on the ESFRI Roadmap. To put the project on the roadmap there needs to be a good perspective for financing and some understanding of how governance and management will be organised. Here the scientific consortium (see chapter 1.5) needs to take scientific and organisational responsibility. Location choice is not part of this trajectory.

Once the ET is on the ESFRI Roadmap, location choice becomes important. At that moment national commitment (in case of ELAt commitment from national and regional governments in Belgium, Germany and the Netherlands) becomes important. Such commitment is however not organised overnight. Organisation of lobby activities towards the relevant governments in the three countries involved should therefore be part of the preparation activities. These lobby activities need to be carefully coordinated. The ETpathfinder can be a focal point for these activities. A specific (preferably cross-border) group within the ETpathfinder can prepare a sound business case, reach out to governments, explore further international cooperation and financing and include activities to involve the local community in the ELAt region.

Unique selling points of the ELAt region:

- Presence of a number of high quality universities in the neighbourhood;
- A good road and scientific infrastructure;

- Large international community in the area (including availability of international schools etc.) which makes it easier for scientists and families to settle;

It is recommended to come to agreement with other initiatives about a procedure to choose the location quite soon, including making agreements on procedures for financial commitments for both cases (location in own country, location elsewhere in Europe). Setting up a joint international committee of heavyweights with standing in political and scientific circles is suggested to arrange this issue.

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