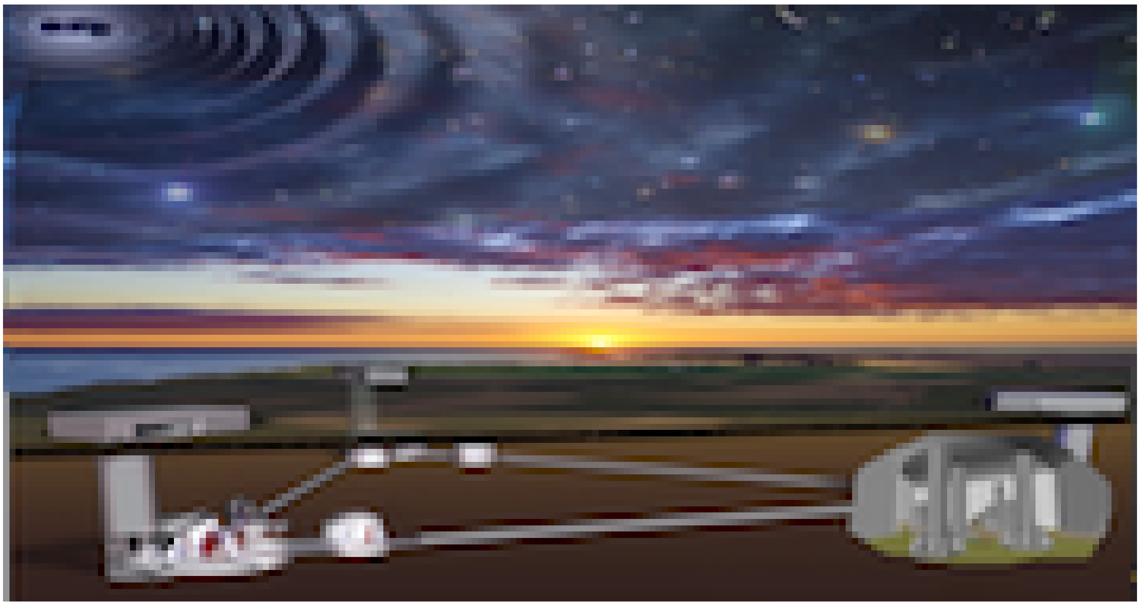
Einstein Telescope: An assessment of its economic, social and environmental impact in Sardinia



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1. Introduction

This study, conducted by a research group of the University of Sassari, provides an ex ante assessment of the potential socio-economic impact of the construction and operation phases of the Einstein Telescope (ET), a large research infrastructure project, if it is built at Sos Enattos (Sardinia), the Italian candidate site to the ESFRI ROADMAP 2021. The results of the study, in terms of the estimated impact in its various dimensions, are still partially uncertain due to the preliminary planning stage of the project. Some decisions concerning the design of the infrastructure as well as the technologies that the ET might require are currently still pending. This might imply a further update of the budgeted construction and operation costs at a future stage of the planning process, which, in turn, would necessitate an update of the estimated impacts. However, given the methodology adopted and the quality of the information already available, which is fully reflected in the study, the reported estimates should be considered a trustworthy measure of the effects that the ET will have at the provincial, regional, national and international levels. Three sources of impact are evaluated: economic impact, social impact and environmental impact. The study is structured in four main sections: I. The socioeconomic context: Sardinia and the Sos Enattos area; II. Economic impact; III. Social impact; and IV. Environmental impact.

The first section provides a profile of the region of Sardinia as well as of the site area of Sos Enattos and the province in which it is situated. The region, the site area and the province are described in detail in terms of demography, economy and entrepreneurial activity, human capital, the innovation and research environment, and logistics features. Such descriptive analysis shows that the region constitutes an ideal location to host a large research infrastructure project such as the ET.

The second section addresses the estimation of the economic impact. The analysis considers the two main phases of the ET project, construction and operation, separately. Both phases are predicted to generate a significant economic impact by boosting economic activity (overall output), value added (GDP) and employment in the region, as well as in Italy and other countries. Overall, over the entire construction period, the construction phase is expected to produce an increase in economic activity of approximately 6.2 B€ which corresponds to a GDP effect of approximately 2.3 B€ and to induce an employment effect of approximately $36,000$ FTE jobs. The operation phase is projected to generate an annual expected flow of economic activity of 127 M€ 45.3 M€ of GDP and more than 700 FTE jobs.

The social impact, described and estimated in the third section, refers to the projected effect of the ET on society by pushing scientific and technological boundaries, fostering innovation, and creating high-skilled human capital. These impacts are doubtlessly relevant and their effects spread at an international scale. However, one main result is that the effects would play a key role in a region such as Sardinia by enhancing economic performance and resilience.

The last section outlines the predicted environmental externalities produced by the ET. The project is expected to have a low negative impact on the environment as a whole since it would involve the reuse of existing infrastructures on the decommissioned mining site. The construction phase would have larger externalities in terms of underground soil consumption due to the size of the underground tunnels. However, there is a plan to use the extracted soil in the environmental restoration of local decommissioned quarries.

2. The socio-economic context: Sardinia and the Sos Enattos area

In this chapter, we provide a detailed overview of the socioeconomic characteristics of Sardinia, the Italian region where the ET candidate site of Sos Enattos is located. This analysis provides elements to evaluate the Sos Enattos site, and more generally Sardinia, as the candidate location for the ET. The key features emerging from our analysis are the following:

i. **A mostly rural yet active and improving region**. Sardinia generally and the area of Sos Enattos specifically are mostly rural. The socio-economic system is less developed and competitive relative to the European Union (EU) average, with a moderate propensity to innovate. Importantly, as emerges from the descriptive statistics we discuss in section 2.1, there has been a generalized tendency towards improvement in many socio-economic dimensions of the region, including the propensity to innovate, educational achievements of the population, and so on. This tendency is confirmed when we compare Sardinia to the rest of Italy (see section 2.2).

ii. **Relevant population of firms**. One-third of the $143,257$ firms located in Sardinia operate in sectors of strategic value for ET construction and operation. Such sectors include civil engineering and specialized constructions, IT services, transport and storage, accommodation services, etc. Sardinian firms are generally of a small size. However, approximately 330 firms operating in sectors relevant to the ET have a sales volume larger than 2 M€. Most firms in these sectors are profitable, and there has been a generalized tendency towards an increase in size.

iii. **Logistics**.Sos Enattos is well connected to urban areas, ports and airports. The airport and port of Olbia (north-east) are 50 minutes away (70 km) by car. Other ports and airports (Porto Torres, Alghero, Cagliari) are approximately 200 km away and are well connected by means of highways. The surrounding area of Sos Enattos is home to a system of accommodation facilities that has a capacity of approximately 150 people per day within a 15-minute drive, which increases to $6,140$ if we consider a driving distance of half an hour.

iv. **Presence of a system of research infrastructure**. An important local research network is constituted by the two public universities (University of Sassari and University of Cagliari); the ARIA Project; the Sardinia Radio Telescope (SRT); the Space Propulsion Test Facility; the Sardinia Aerospace District (DASS); the 5 branches of the Consiglio Nazionale delle Ricerche, the regional agency for research Sardegna Ricerche; and the CRS4, an interdisciplinary research centre established by the Regional Government of Sardinia (RAS) in 1980 with the scientific supervision of Carlo Rubbia. All these research institutions receive support from the RAS, which channels substantial quantities of financial resources received from the EU within the EU Fifth Programme according to the Smart Specialization Strategy (S3) pursued by the RAS. Key pillars of the S3 include developing the ICT sector and, importantly, new technologies and materials. In line with the S3, RAS has financed relevant start-up grants to the universities of Cagliari and Sassari for the development of research infrastructure. One of these grants (approximately 3.5 M€) has been assigned to the University of Sassari to develop the site of Sos Enattos with a research project called SarGrav.

These four features combined with the geological characteristics of Sardinia provide a unique combination that makes the Sos Enattos area an ideal location for the ET. The rural character of the Sos Enattos area and its low population density combine with the geological properties of the land to provide the ideal physical environment for the experiments that will take place at the ET. In turn, these physical traits match very well with the presence of a regional network of large research institutions and of a significant population of local firms operating in sectors that could provide goods and services relevant to the ET at both the construction and operation stages, together with a regional transportation system that connects the candidate site with the rest of Europe. Finally, we observe that the fact that Sardinia is relatively less developed than the EU average in socio-economic terms constitutes a plus, as there is robust evidence that large public research infrastructure projects generate a larger impact in less developed regions compared to more developed ones (Hallonsten et al., 2004). Intuitively, if the necessary conditions in terms of provision of the goods and services needed for the construction and operation of the infrastructure are guaranteed – as is the case in Sardinia – the marginal economic effect of the investment associated with the implementation of the ET is bound to be larger the lower the level of economic activity of the hosting area in the absence of the ET. An additional important consideration is the fact that Sardinia has re-entered the set of less-developed regions, as this ensures that the regional government of the island will have access to substantial financial resources from the EU for investment purposes.

In summary, a unique combination of physical and socioeconomic characteristics makes Sos

Enattos the perfect location for the ET.

2.1. Sardinia vs other European regions

The OECD classifies regions into three main types: (i) mostly urban (when more than 70% of the population lives in a metropolitan area); (ii) mostly intermediate (when between 70% and 50% of the population lives in a metropolitan area), and (iii) mostly rural (when less than 50% of the population lives in a metropolitan area). Following this classification, figure 2.1 shows that, like other regions of the Italian Mezzogiorno and some central and north-eastern regions, Sardinia can be considered mostly rural. With a GDP 31% lower than the EU average

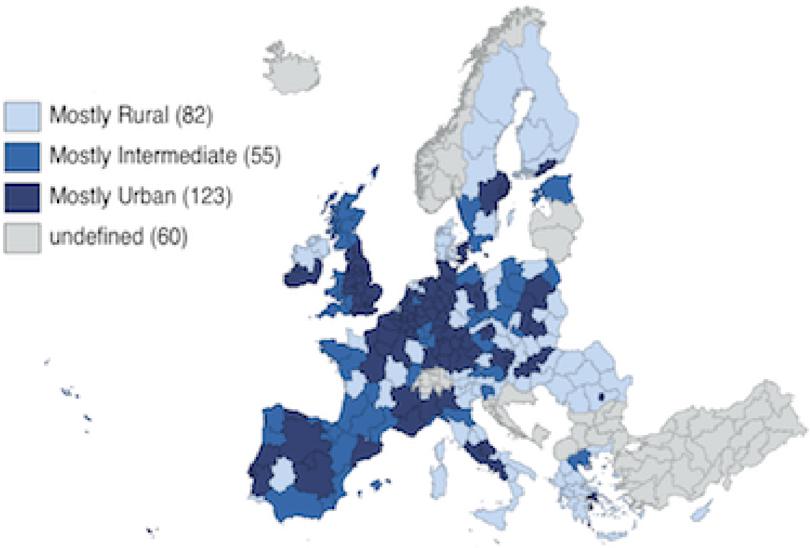

Figure 2.1.: EU classification of rural-urban regions (2015). For each class, the number of regions is reported in brackets. Our elaboration with OECD data.

in terms of purchasing power, i.e., in real terms, Sardinia ranks 214^{th} out of 276 EU regions (see also figure 2.2). The European Commission defines two specific types of lagging regions: “low growth” and “low income” regions. The “low growth” category includes less developed and transition regions (with GDP per capita up to 90% of the EU average) that (i) did not converge to the EU average between the years 2000 and 2013 and (ii) have GDP per capita in PPS below the EU average in 2013. Correspondingly, the low income regions are those with a GDP per capita in PPS below 50% of the EU average in 2013. As figure 2.3 shows, in 2015, Sardinia was classified as low growth within the group of lagging regions, a feature common to almost all Mediterranean and eastern regions of the EU. As figure 2.4 illustrates, between 2013 and 2017, Sardinia was among the 137 EU regions with GDP per capita dynamics weaker than those of the EU average. As shown in figure 2.5, Sardinia, like many areas of Europe, was severely

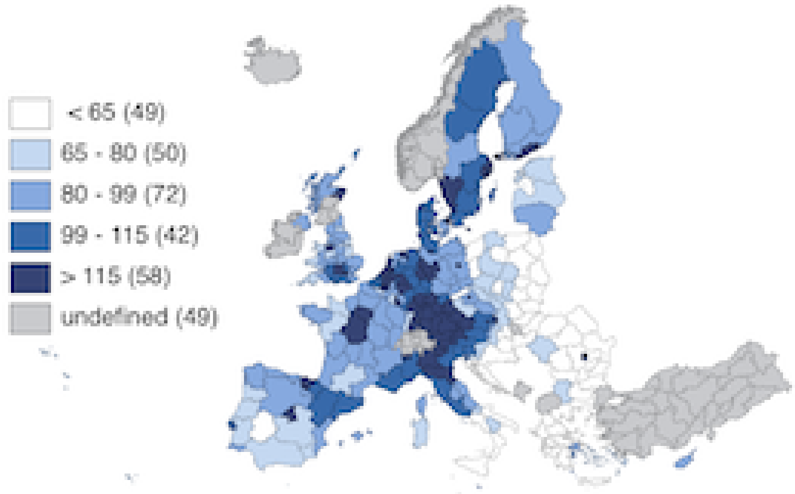

Figure 2.2.: EU regional GDP per capita in PPS (2017) (% of EU 28 average). For each class, the number of regions is reported in brackets. Our elaboration with Eurostat data.

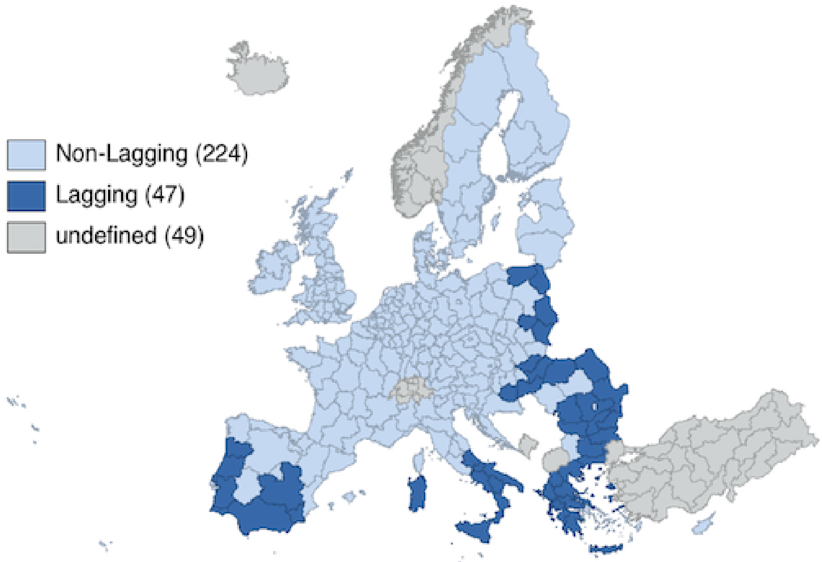

Figure 2.3.: EU classification of lagging regions. For each class, the number of regions is reported in brackets. Our elaboration with European Commission data.

affected during the economic downturn that took place in 2007-2009, and it was unable to keep up with the average growth pace of the EU during 2009-2014. As a consequence of the slowdown

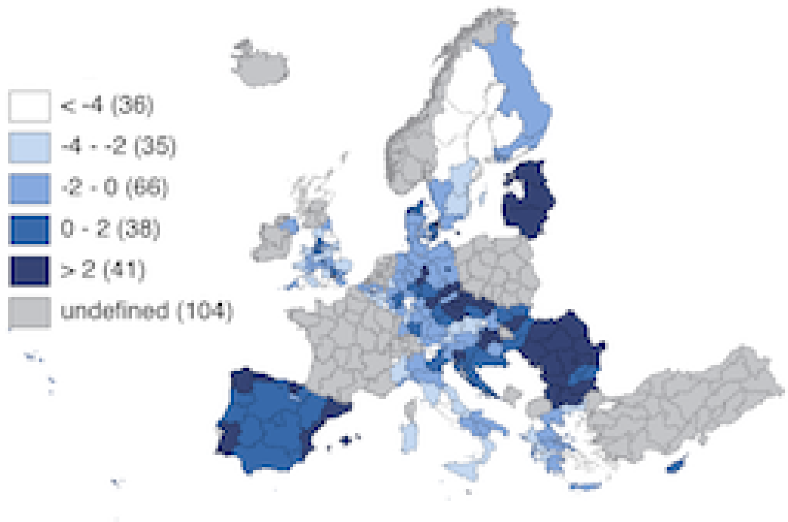

Figure 2.4.: EU % change in regional GDP per capita in PPS (2013-2017, UE28 average=100). For each class, the number of regions is reported in brackets. Our elaboration with Eurostat data.

during the 2009-2014 period, Sardinia has recently re-entered the less developed region pool (i.e., regions with GDP per capita below 75% of the EU average). Importantly, this implies that Sardinia will have access to greater financial support from EU Cohesion Policy funds. Certainly, this will imply more availability of financial resources for investments in sectors and activities relevant for the ET project. However, as figure 2.5 shows, things have improved since 2014, as the region has started to grow at a positive rate. The growth performance of the island is reflected in that of productivity, which is the main engine of economic growth. Sardinia is also below the EU average in terms of labour productivity. In 2017, the labour productivity of Sardinia stood at 62.2 K€ per worker, close to the EU average of 64 K€ per worker but far from the best regional performances of central and northern EU regions (figure 2.6). However, over the period 2013-2017, labour productivity grew at a positive rate, 2.9%, which explains the recovery in growth rates, even though this productivity performance is still well below EU standards (see also figure 2.7).

In 2018, 40% of the working age population of Sardinia was employed (in total, $582,055$ individuals). The overall employment rate is approximately 14 percentage points lower than the EU average of 54% (see also figure 2.8). However, it increased by 2.7 percentage points over five years (2014-2018). The employment rate of people aged $15-24$ is 16%, against the EU average of 35.3% (figure 2.9). Yet, also in this case, there was an improvement over the

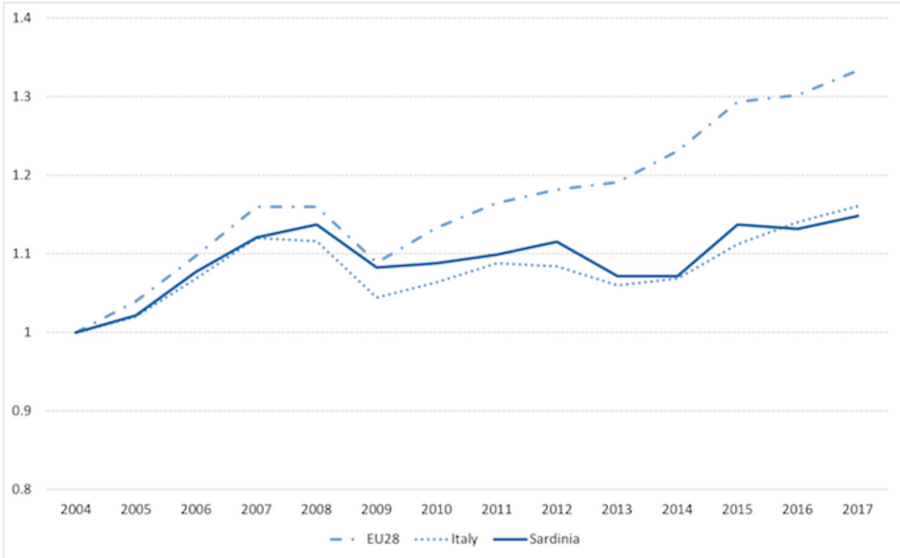

Figure 2.5.: Growth of GDP per capita in PPS (2004-2017). Our elaboration with Eurostat data.

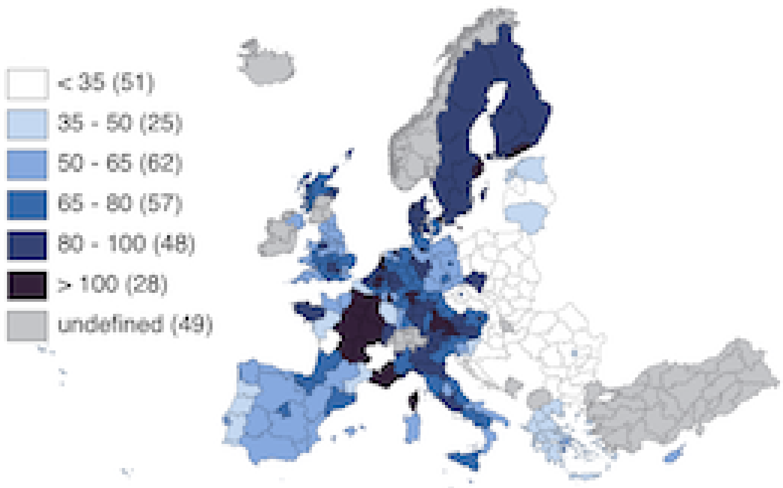

Figure 2.6.: EU regional labour productivity (2017, GDP per worker, thousand euro). For each class, the number of regions is reported in brackets. Our elaboration with Eurostat data.

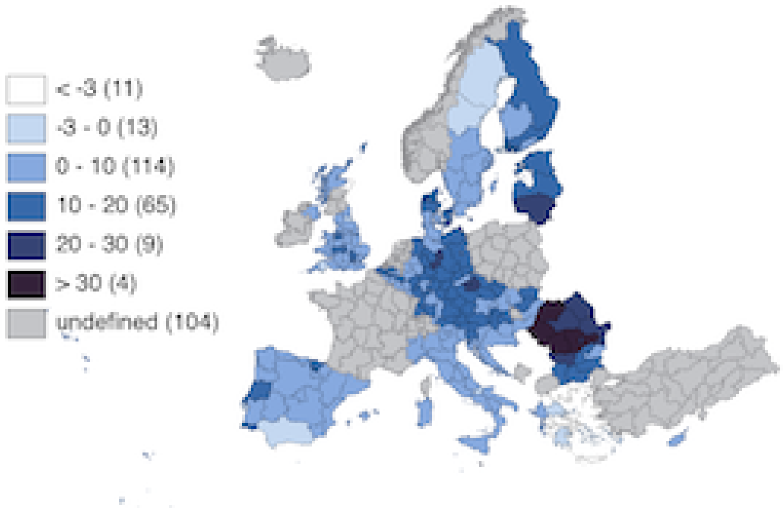

Figure 2.7.: EU regional labour productivity growth (2013-2017). For each class, the number of regions is reported in brackets. Our elaboration with Eurostat data.

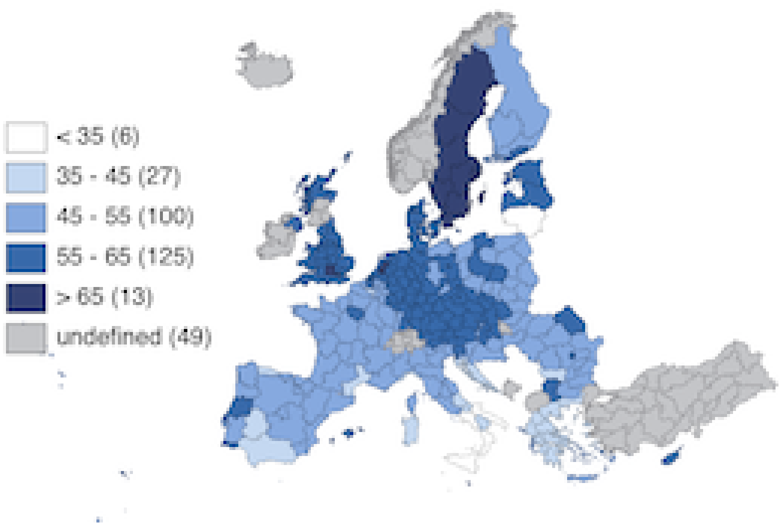

Figure 2.8.: EU regional employment rate of people aged 15 years or over (2018). For each class, the number of regions is reported in brackets. Our elaboration with Eurostat data.

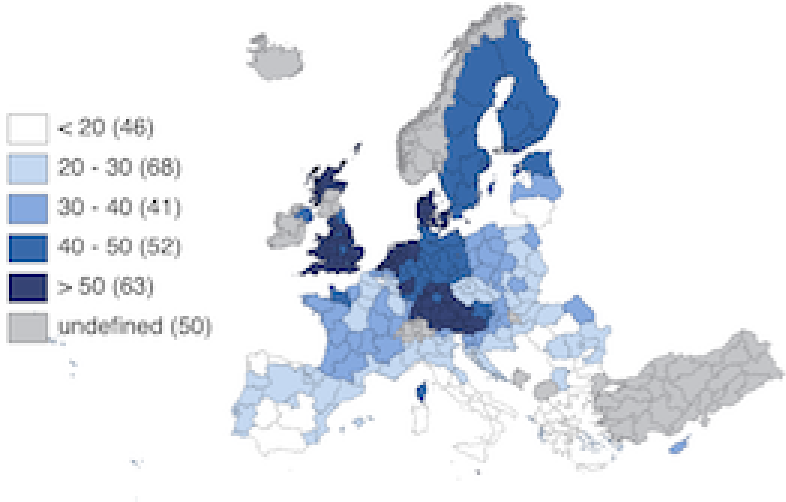

Figure 2.9.: EU regional employment rate of people aged $15-24$ (2018). For each class, the number of regions is reported in brackets. Our elaboration with Eurostat data.

period 2014-2018, as the employment rate was 14.3% in 2014, once again linked to the improved productivity.

With an unemployment rate of 15.4%, that is, approximately $105,244$ unemployed people in 2018, Sardinia saw an improvement on the figures of previous years (17.3% in 2016 and 17% in 2017), while still remaining 8.5 percentage points above the EU average of 6.9% (see also figure 2.10 for a cross country comparison). The unemployment rate worsens considerably when considering the $15-24$ age cohort. In 2018, 35.7% of workers in this cohort were unemployed, against the EU average of 15.2% (see figure 2.11 for a cross region comparison). Nonetheless, it is worth noting that this figure is the lowest registered over the last 5 years (it was 46.8% in 2017).

Education and training are key elements in the enhancement of labour productivity and regional growth. Increasing investment in education and skills is essential to this purpose. EU strategies target the achievement of tertiary education of 40% of people aged 30-34 by 2020 (Europe 2020 Strategy). In 2018, this figure for Sardinia was approximately 21.5%, still far below the EU average of 40.7% (figure 2.12), but it registers a significant increase of 4 percentage points over the 2014-2018 period. Notwithstanding the relative weakness of Sardinia with respect to the EU in terms of both employment and educational levels, the positive evolution of unemployment rates and educational levels is remarkable and encouraging and suggests that the policy mix of the regional government, including interventions in the labor market as well as in financing and promoting education at all levels, have had an impact.

Every three years, the DG REGIO of the European Commission classifies EU regions ac-

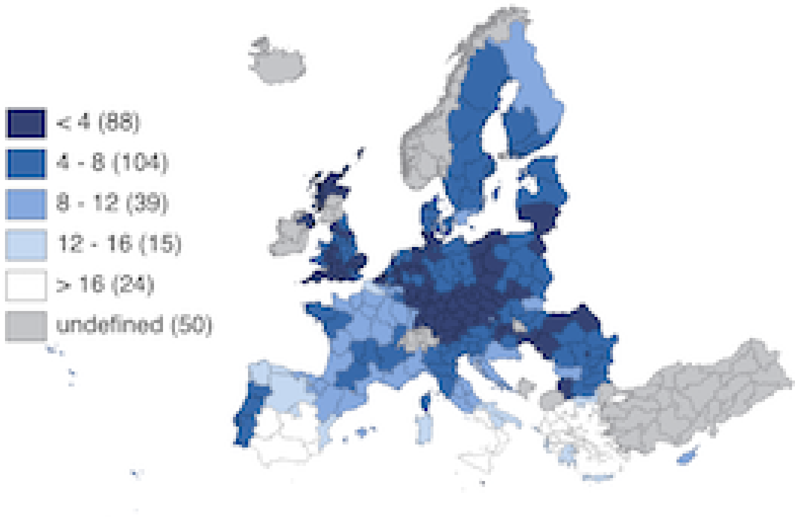

Figure 2.10.: EU regional unemployment rate of people aged 15 years or over (2018). For each class, the number of regions is reported in brackets. Our elaboration with Eurostat data.

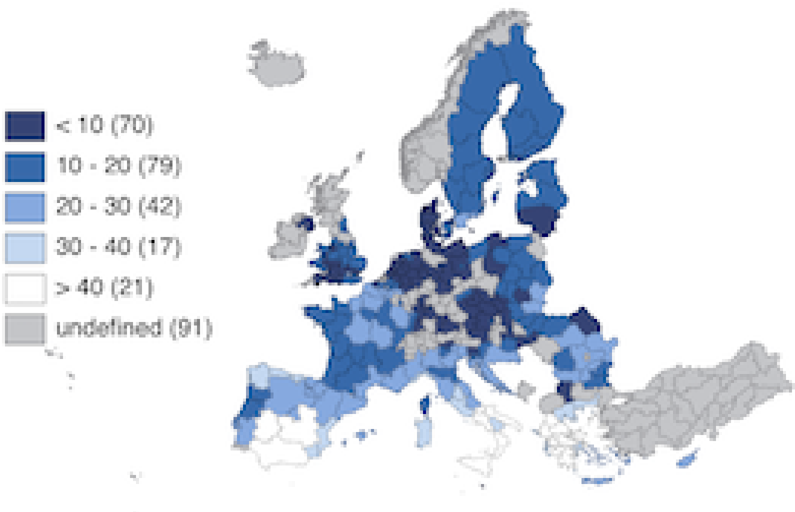

Figure 2.11.: EU regional unemployment rate of people aged $15 - 24$ (2018). For each class, the number of regions is reported in brackets. Our elaboration with Eurostat data.

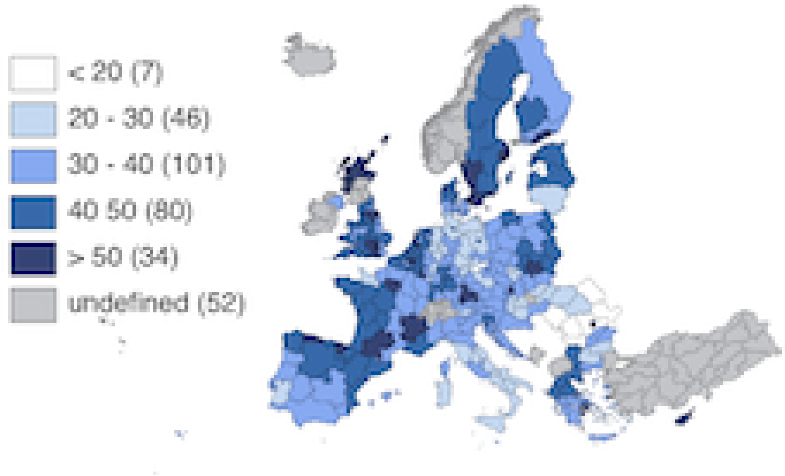

Figure 2.12.: Educational attainment of people aged $30-34$ (2018, %). For each class, the number of regions is reported in brackets. Our elaboration with Eurostat data.

cording to their competitiveness. Regional competitiveness is the ability of a region to offer an attractive and sustainable environment for firms to operate and for residents to live and work.[1] This is measured by the Regional Competitiveness Index, which combines 11 indicators. Basic indicators include measures of the role of institutions, macroeconomic stability, infrastructure, health and basic education. More advanced studies assess (i) the composition of the labour force in terms of education, training and lifelong learning experiences; (ii) the size of the labour market and its efficiency; (iii) technological readiness; (iv) business sophistication and (v) innovation. The index compares the competitiveness of each region with respect to the average of the EU28, which is set to 0. Accordingly, regions with a score higher (lower) than zero are more (less) competitive than the average. Figure 2.13 shows that Sardinia maintains an intermediate level of competitiveness, which places the region below the EU average, similar to many other peripheral areas.

Moreover, the European Commission classifies EU regions according to the level of innovation assessed with the Regional Innovation Scoreboard (RIS) (`http://ec.europa.eu/growth/industry/innovation/facts-figures/regional_en`). This index measures the performance of regional systems of innovation and is based on 18 indicators. The indicators include measures of human resources, attractive research systems, innovation-friendly environments, innovative SMEs and the linkages among them, intellectual assets, employment impacts, and sales impacts. RIS compares the performance of each region with respect to the average of the EU28 (EU=100). This means that regions with scores higher than 100 are more innovative, on aver-

[1] See `https://ec.europa.eu/regional_policy/en/information/maps/regional_competitiveness/` for a definition.

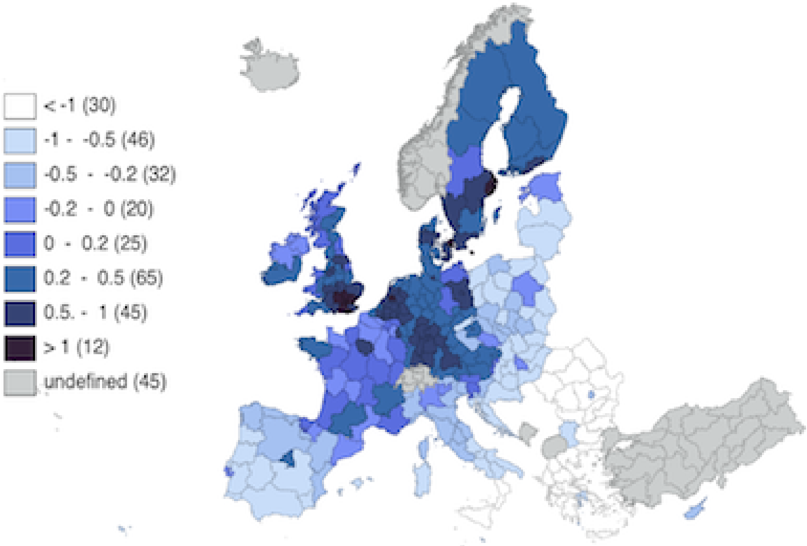

Figure 2.13.: EU regional Competitiveness Index (2016). For each class, the number of regions is reported in brackets. Our elaboration with Eurostat data.

age, while regions with scores lower than 100 are less innovative. The regions are then classified into four performance groups as follows:

i. Innovation leaders: regions with a relative performance more than 20% above the EU average in 2019

ii. Strong innovators: regions with a relative performance between 90% and 120% of the EU average in 2019

iii. Moderate innovators: regions with a relative performance between 50% and 90% of the EU average in 2019

iv. Modest innovators: regions with a relative performance below 50% of the EU average in 2019

Sardinia is among the moderate innovator regions, along with the other Italian regions and southern and eastern European regions (figure 2.14). Importantly, over the last five years (2015-2019), Sardinia has registered an improvement on its Regional Innovation Scoreboard, which increased by 0.3%.

2.2. Sardinia in the Italian context

Sardinia represents an interesting case given its geographical as well as socio-economic distinctiveness with respect to other national territories. It is the second main Italian island,

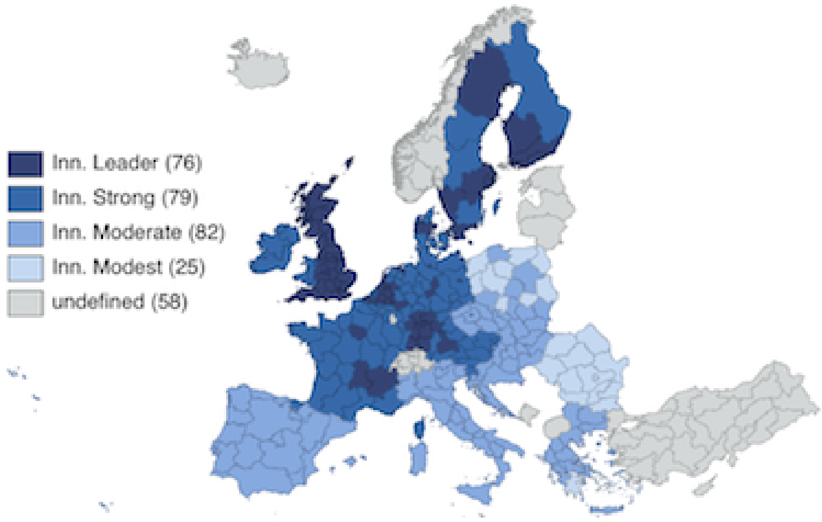

Figure 2.14.: EU regional Innovation Scoreboard (2019). For each class, the number of regions is reported in brackets. Our elaboration with European Commission Data.

and, despite its geographical position (peripheral but closer to the central regions), its socio-economic characteristics make it somewhat similar to the Italian Mezzogiorno. In the following subsections, we compare Sardinia to the rest of Italy in terms of demographics and economic indicators.

2.2.1. Demographics

According to the National Institute of Statistics (ISTAT), as of 1 January 2018, the population of Sardinia consisted of $1,648,176$ individuals. Approximately 3.3% of the population is composed of foreigners.[2] The population dynamics over recent years have registered a negative trend, with a decrease of almost 5,000 individuals every year. This is the result of the evolution of mortality and birth rates over the past 10 years (see figure 2.15).

The birth rate has been persistently lower than the national average, while the mortality rate is clearly approaching the national average, despite still being lower. In terms of migration, in 2017, the flow of migrants amounted to 38.017 units, approximately 5.4% higher than the previous year. The majority of these movements are internal (approximately $23,000$ people changed location within Sardinia), while the remaining part is due to inflows from other Italian regions and from abroad.

Life expectancy at birth also increased over the past 10 years, but it is still lower than the national average (see table 2.1). Over the same period, the average age of the population increased by 2.7 years to reach 46 years in 2018, which is higher than the corresponding national

[2] The national average is 8.5%.

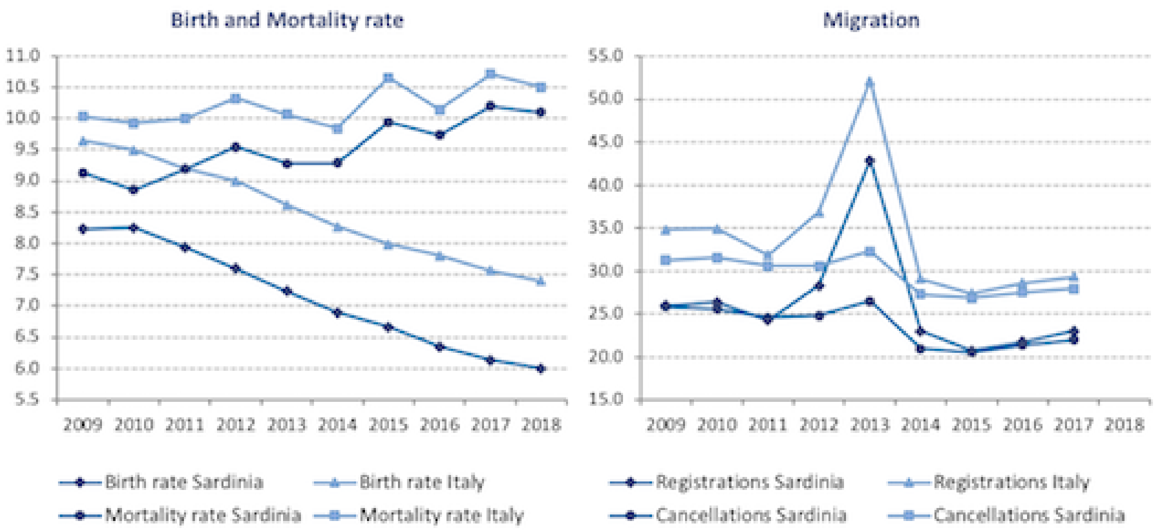

Figure 2.15.: Birth rate, mortality rate and migration (2009-2018). Our elaboration with CRENoS and Istat data.

value. As reported in table 2.1, the comparison of the percentages of young and old populations suggests that the structure of the population is changing towards an inverted pyramid shape.

Table 2.1.: Indicators of structural demography (%) years 2009 and 2018, CRENoS elaboration on Istat data.

	Sardinia		**Italy**	
	2009	**2018**	**2009**	**2018**
Life expectancy at birth	81.3	82.8	81.4	82.7
Average age of population	43.3	46.4	43.2	45.2
Young population rate	12.4	11.4	14.1	13.4
Elderly population rate	18.9	23.2	20.3	22.6
Structural dependency index	45.7	52.9	52.4	56.1
Elderly population index	152.2	203	144	169

2.2.2. Economics

In 2017, the overall GDP of the region was approximately 31.3 billion euros, with an increase of 0.8% with respect to 2016. In the same year, GDP per capita was 20, 900 €, higher than the average GDP per capita of the Italian Mezzogiorno (18, 850 €) and lower than the national

(28, 900 €) and centre-north (33, 833 €) averages. In 2017, GDP per capita increased by 1, 5% over its 2016 level (see figure 2.16).

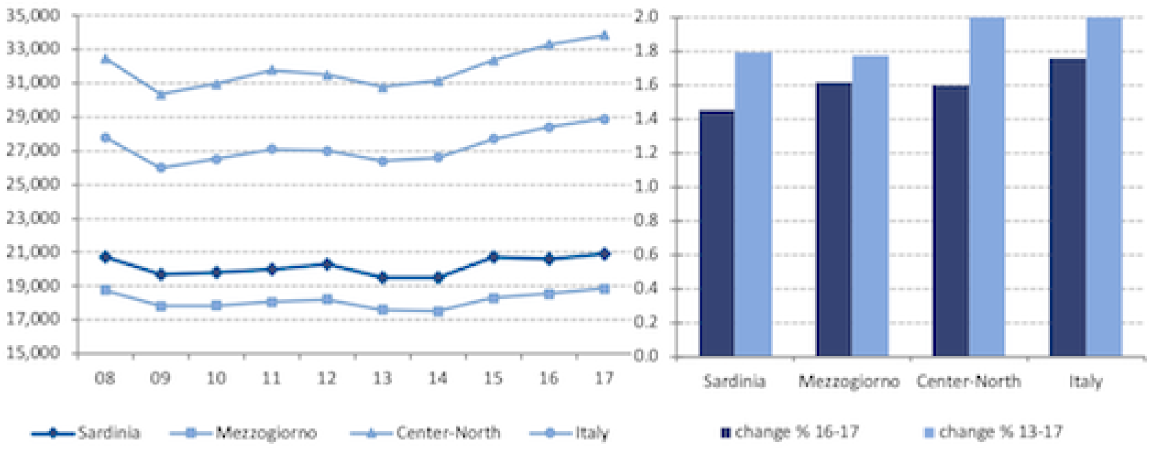

Figure 2.16.: GDP per capita in PPS (2008-2017, euro); annual change (2016-2017, %) and annual average change (2013-2017, %). Our elaboration with Eurostat data.

As figure 2.17 shows, Sardinian GDP per capita is also lower than the Italian average when measured in purchasing power standards, i.e., in real terms. This is in line with the other southern Italian regions, whose level of GDP per capita significantly differs from that of the majority of the central and northern regions. This tendency is associated with a lower growth performance compared to the Italian average (see figure 2.18).

Regarding consumption, in 2017, Sardinian households spent 22.1 billion € in goods and services. As figure 2.19 shows, consumption increased by 1.2% in 2017, reaching 13, 407 € per capita. This tendency is common to all Italian macro areas.

2.2.3. Entrepreneurial activity

In 2018, the number of companies operating in Sardinia increased by 348 units with respect to 2017, thus reaching 143, 299 units in total. Figure 2.20 shows the evolution of entrepreneurial density in Sardinia compared to other Italian macro areas over the period 2009-2018. In 2018, the density of entrepreneurial activity in the region equalled 87.1 enterprises per 1000 people. Importantly, entrepreneurial density is higher in Sardinia than in all other macro areas of Italy.[3] In line with the national trend, in Sardinia, the density of firms increased by 0.3% over its 2017 level, thereby confirming the post-crisis positive tendency that started in 2014.

Table 2.2 shows the percentage of firms by sector in 2018. Agriculture has 34, 350 firms, 24% of the total number of Sardinian firms. Tourism is a key sector in the region, with more units

[3]Entrepreneurial density in the North is 86.8 per 1, 000 people, against the national average of 85.2.

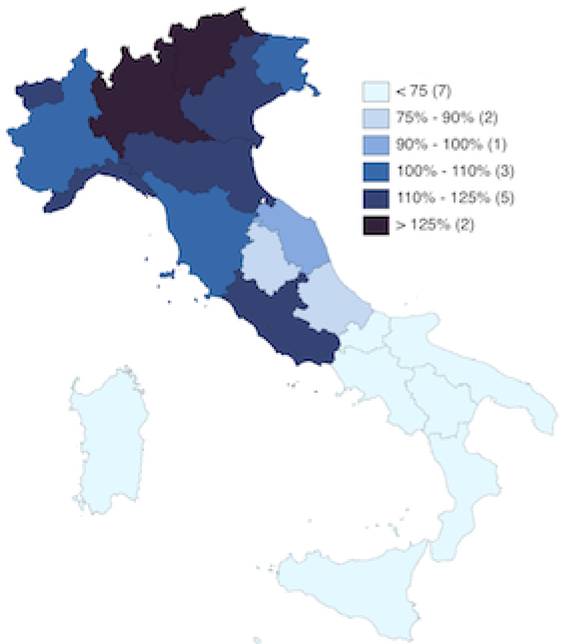

Figure 2.17.: Italy regional GDP per capita in PPS (2017, % of national average). For each class, the number of regions is reported in brackets. Our elaboration with Istat data.

than other Italian regions, especially the Mezzogiorno area, where the competitors of Sardinia in this branch of activities are mainly located. The sector grew by 2.5% from the previous year, accounting for 8.8% of the total number of Sardinian firms. Finally, firms in the construction sector are $19,676$ in total, which corresponds to a relative share of 13.7% in the population of Sardinian firms. Retail firms number $37,832$ and have a share of 26.4% in the total number of firms on the island.

In section 2.5, we provide a more disaggregated analysis of the population of firms, focusing on sectors that are strategically relevant for the ET project.

2.2.4. Labour market and human capital

In 2018, the regional employment rate was 40.2%, significantly higher than that in the Mezzogiorno area (34.7%), albeit below the national average of 44.6%.[4] The total number of employed people grew significantly from 2017 to 2018 (+3.8%), registering the highest annual change in comparison to the other areas of Italy. Additionally, the variation over the period $2013-2017$ was positive and in line with the national trend (figure 2.21). The regional scenario worsens if we look at people aged 15-24. The youth employment rate of Sardinia in 2018 is 16%, which is 3.1 percentage points below the national average (19.1%, figure 2.22) but still higher than the

[4] The average national value is driven by the high employment rate of the centre-north (49.8%).

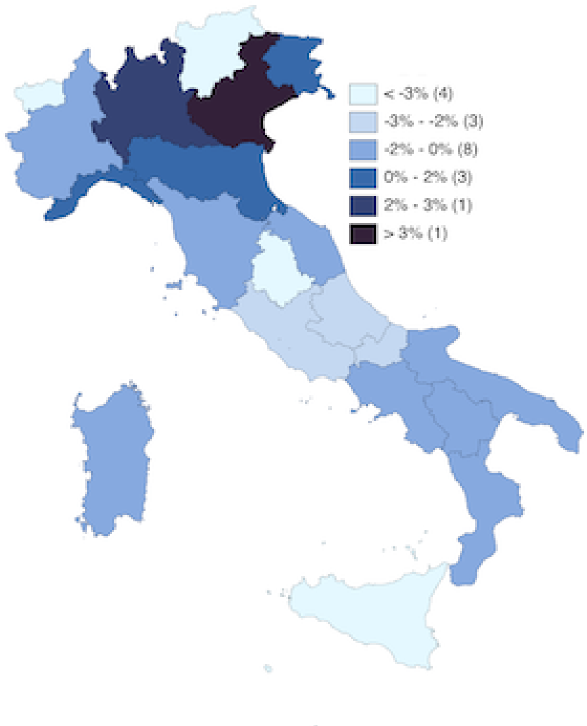

Figure 2.18.: Italy regional change in GDP per capita (2013-2017, % of national average). For each class, the number of regions is reported in brackets. Our elaboration with Istat data.

Table 2.2.: Number of firms per economic sector (%) in 2018. CRENoS elaboration on Info-Camere data.

Sectors (Ateco 2007)	**Sardinia**	**Mezzogiorno**	**Center-North**	**Italy**
agriculture	24.0	20	11.6	14.4
manufacturing	7.5	8.2	10.8	9.9
construction	13.7	12.1	15.5	14.4
trade	26.4	32.2	24.4	27
hotels and restaurants	8.8	7.4	7.7	7.6
other services	19.5	20.1	30.1	26.8
total	100	100	100	100

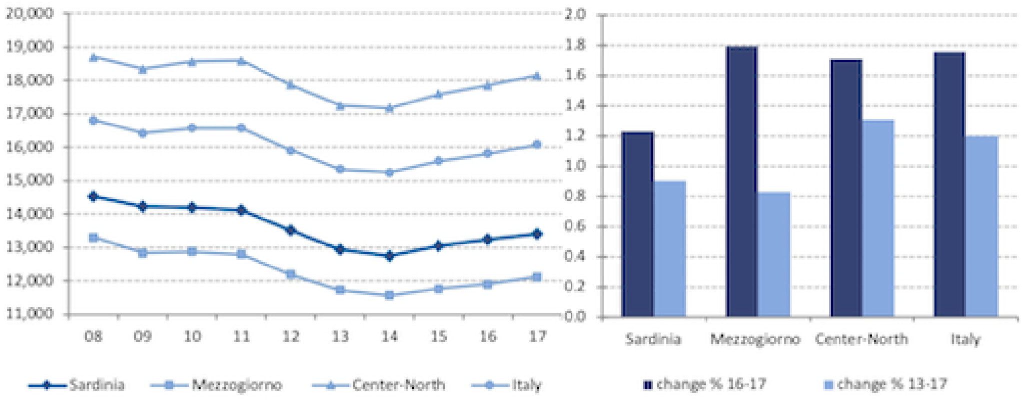

Figure 2.19.: Family consumption per capita (2008-2017, euro), change (2016-2017, %) and annual average change(2013-2017, %). CRENoS elaboration with Istat data.

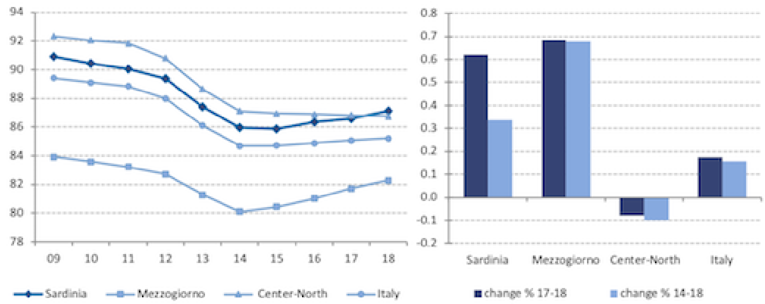

Figure 2.20.: Entrepreneurial density (2009-2018, number of enterprises per 1000 people), change (2017-2018, %) and annual average change (2014-2018, %). CRENoS elaboration with Istat data.

corresponding average in the Mezzogiorno area.

Importantly, as emerges from figure 2.23, the unemployment rate of Sardinia has been declining in the post-crisis period ($2014-2018$) and reached 15.4% in 2018, which was 3% lower than the figure for the Mezzogiorno but still 5 percentage points above the national rate. The total number of unemployed people was $105,741$ in 2018, with a reduction of approximately 10,000 people with respect to 2017. This significant overall reduction was mainly driven by the decrease in the unemployment rate of low-skilled women (high school diploma) (-25%) and low-skilled men (-13%) with respect to 2017. In contrast, the unemployment rate of skilled people has remained stable over the last five years at approximately 8.4% for men and 11.2% for women.

In 2018, the unemployment rate of people aged 15-24 was approximately 35.7%, 3 percentage points higher than the national average (33.8%; see figure 2.24).

Figure 2.25 shows the percentage of people aged 30-34 with tertiary education (university

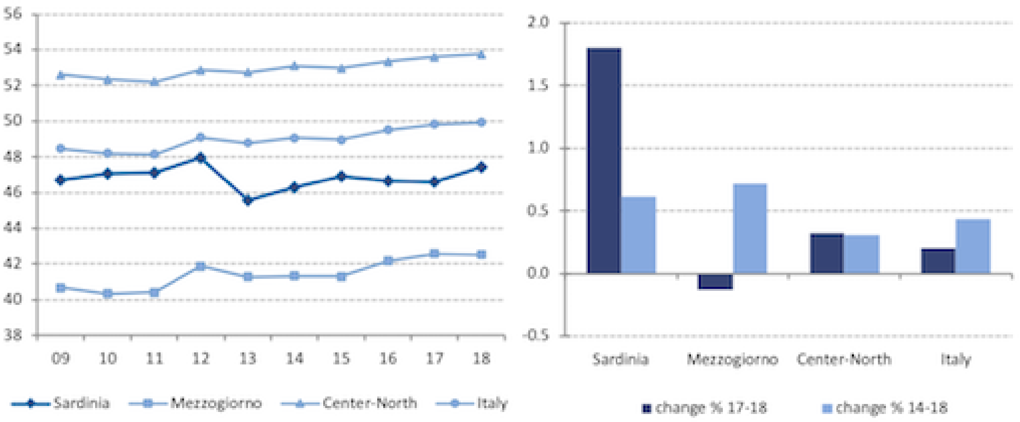

Figure 2.21.: Employment rate of people aged 15 and older (2009-2018, %), change (2017-2018, %) and annual average change (2014-2018, %). CRENoS elaboration with Istat data.

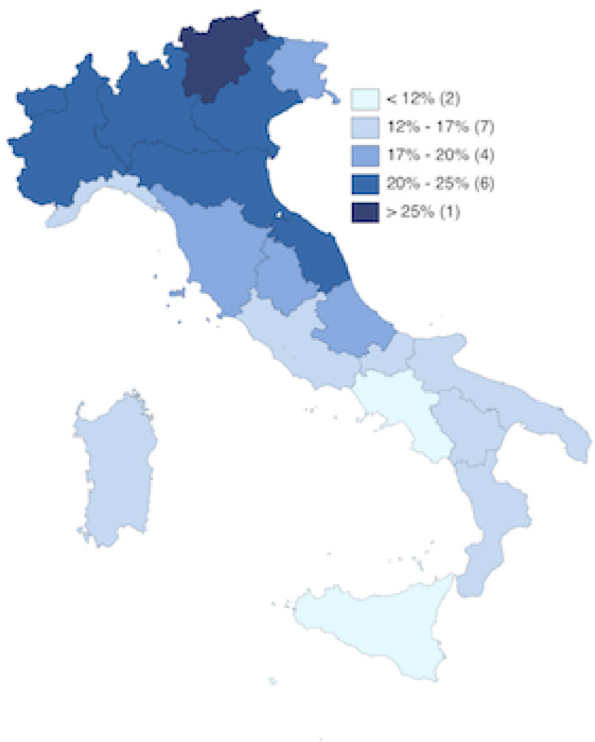

Figure 2.22.: Italy regional employment rate of people aged 15-24 (2018, %). For each class, the number of regions is reported in brackets. Our elaboration with Istat data.

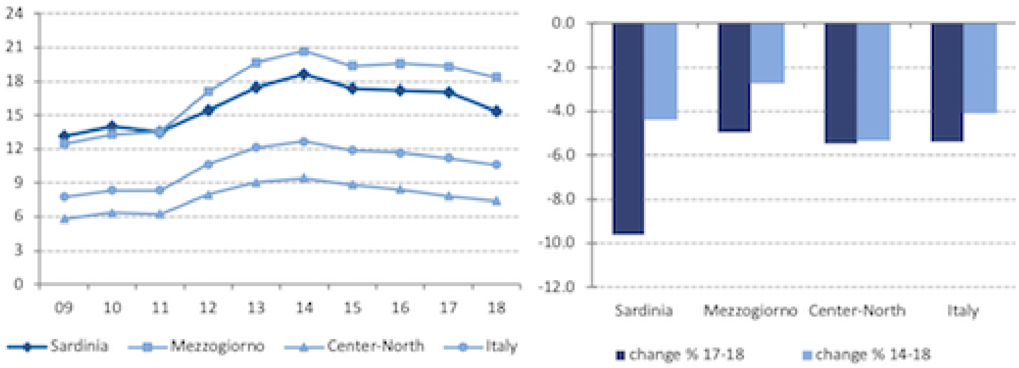

Figure 2.23.: Unemployment rate of people aged 15 and older (2009-2018, %), change (2017-2018, %) and annual average change (2014-2018, %). CRENoS elaboration with Istat data.

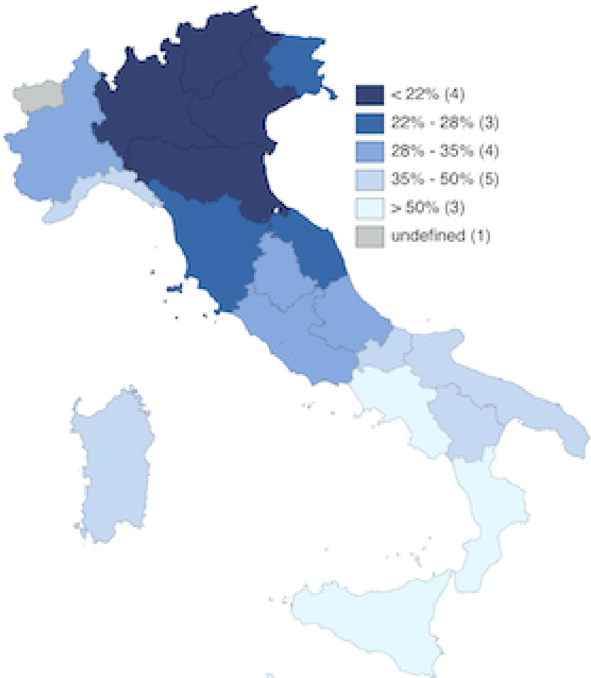

Figure 2.24.: Italy regional unemployment rate of people aged 15-24 (2018, %). For each class, the number of regions is reported in brackets. Our elaboration with Istat data.

education) in the Italian regions in 2018. All regions are far below the European Commission's 40% goal. In Sardinia, 21.5% of people aged $30-34$ hold a university degree, which is somewhat below the national average (27.2%). It is important to note that the percentage of individuals with a university education grew by 4 percentage points over the 2014-2018 period.

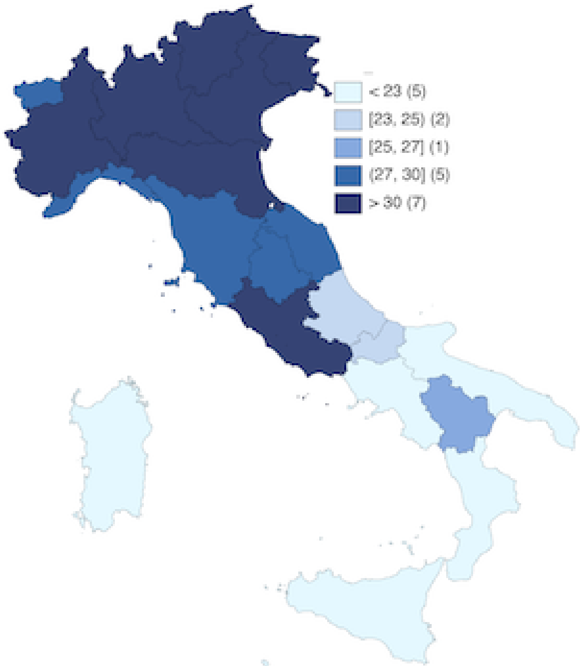

Figure 2.25.: Italy regional educational attainment of people aged 30-34 (2018, %). For each class, the number of regions is reported in brackets. Our elaboration with Istat data.

2.3. The province of Nuoro compared to other European provinces

In this section, we describe the main characteristics of the province of Nuoro, which will host the ET infrastructure, in a comparison with other EU counterparts. To do so, we employ micro data at the disaggregation level NUTS3, which corresponds to the provincial level in the case of Italy. It is worth noting that the OECD classifies NUTS3 regions (equivalent to the TL3 classification of the OECD) into three main groups: (i) predominantly urban (when the share of the population living in rural local units is below 15%); (ii) intermediate (where the share of the population living in rural local units is between 15% and 50%); (iii) predominantly rural (where the share of the population living in rural local units is higher 50%). Figure 2.26 shows that the province of Nuoro (Nuoro hereafter), where the ET will be located, can be considered predominantly rural. Figure 2.27 compares EU NUTS3 regions in terms of GDP per capita with respect to the EU28 average. In 2016, Nuoro had a GDP per capita that was 36 points lower than the EU average indexed to 100. Nuoro is among the 256 areas whose GDP per capita is between 60% and 80% of the EU average. As figure 2.28 illustrates, between 2012 and 2016, Nuoro was among the EU NUTS3 regions with the weakest GDP per capita dynamics

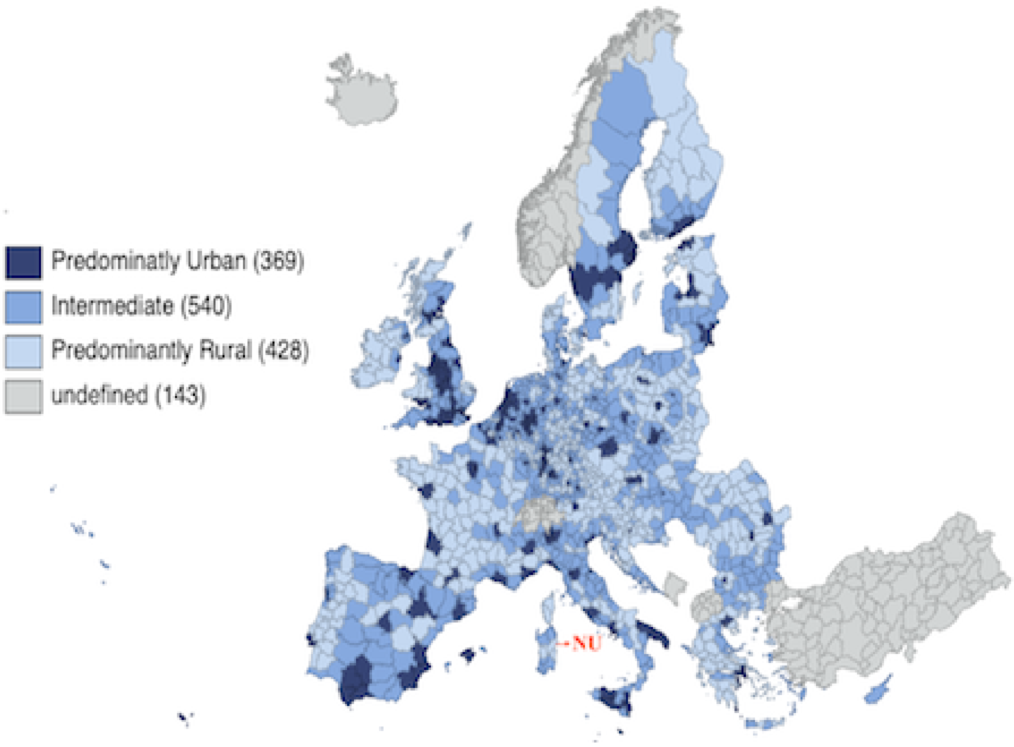

Figure 2.26.: EU classification of rural-urban regions (2015). For each class, the number of regions is reported in brackets. Our elaboration with OECD data.

with respect to the EU average measured in real terms.[5] The province was unable to keep pace with overall EU GDP growth.

2.4. The province of Nuoro in regional context

Figure 2.29 shows that only northern Sardinia (the provinces of Sassari and Olbia-Tempio) and southern Sardinia (the province of Cagliari, where the capital of the region is located, and the provinces of Carbonia-Iglesias and Medio Campidano) are considered intermediate regions (between rural and urban), while the rest of the provinces, including Oristano, Ogliastra, and Nuoro, are predominantly rural. According to the National Institute of Statistics (ISTAT), the population of the province of Nuoro as of 1 January 2018 consisted of $210,531$ individuals, equal to 12.8% of the whole regional population. With respect to 2017, despite the negative change registered at the regional level (-0.3%), the population of the province increased by $54,435$ individuals (+34.8%) simply because of a change to provincial borders that added more municipalities and thus more population to the province. In regards to the demographic

[5] More specifically, GDP per capita decreased by 5 points in five years with respect to the EU average indexed to 100.

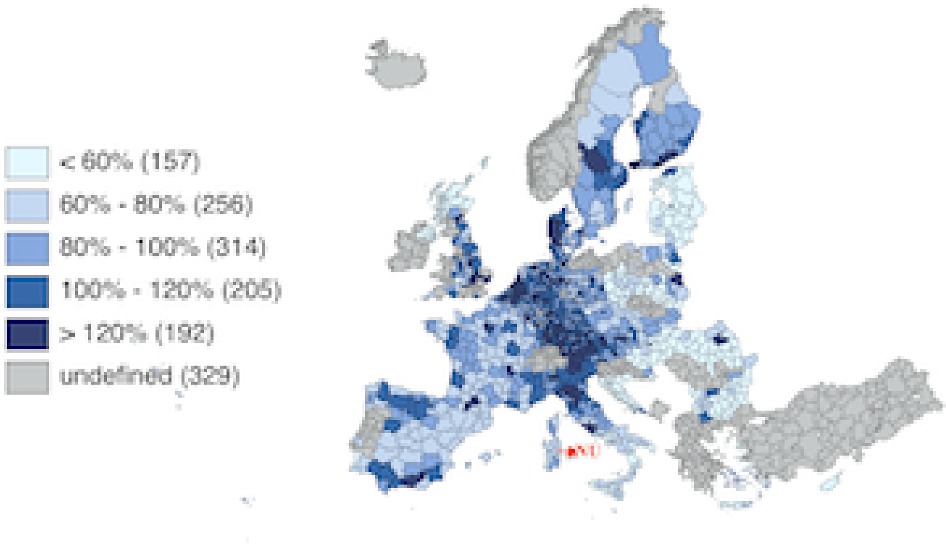

Figure 2.27.: EU regional GDP per capita in PPS (2016, % of UE28 average). For each class, the number of regions is reported in brackets.Our elaboration with Eurostat data.

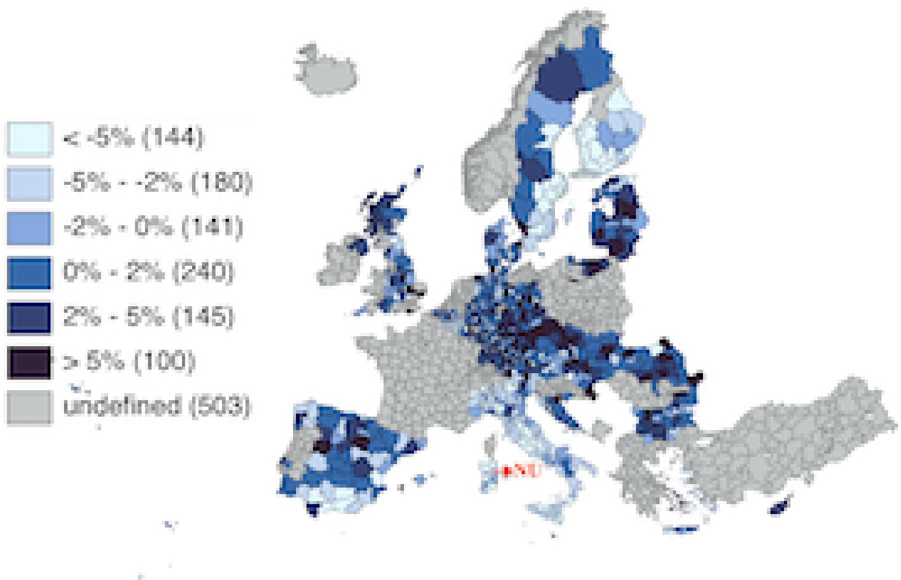

Figure 2.28.: EU regional change in GDP per capita in PPS (2012-2016, %, UE28 average=100). For each class, the number of regions is reported in brackets. Our elaboration with Eurostat data.

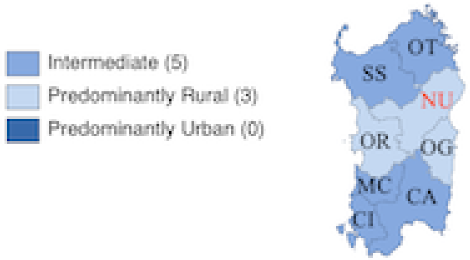

Figure 2.29.: Sardinia Classification of rural-urban regions (2015). For each class, the number of regions is reported in brackets. Our elaboration with OECD data.

dynamics (figure 2.30) of the 10 years from 2008 to 2017, the province showed a negative trend in terms of natural population growth due to the birth rate being lower than the mortality rate over that time span. The negative trend is exacerbated by the negative net migration flow over the same period, where the number of emigrants exceeded that of immigrants in all years, with the only exception of 2013.

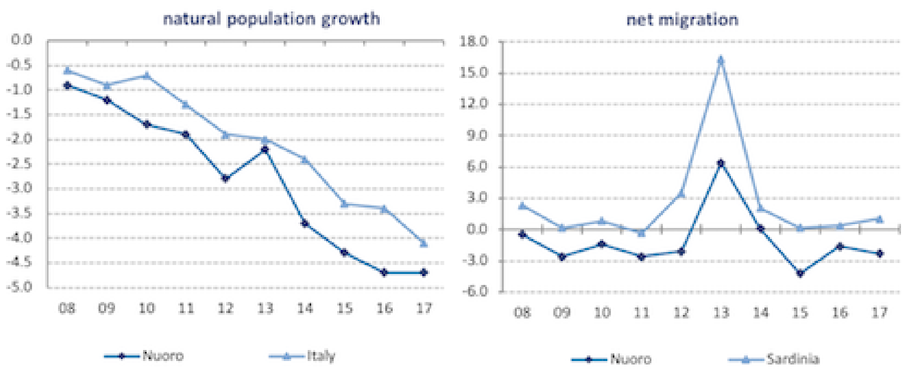

Figure 2.30.: Natural population growth and net migration (2008-2017, %). Our elaboration with Istat data.

Life expectancy at birth increased in the same 10-year period, in line with the regional average (table 2.3). For this time span, the average age of the population increased by 3.2 years, while in 2017, the average age was 46 years, corresponding to the regional trend. Table 2.3 shows that the structure of the population changes towards an inverted pyramid. This trend is evident when comparing the share of the young population with that of the elderly population.

In 2016, the overall GDP of Nuoro was approximately 2.9 billion euros, representing an increase over the previous year of 110, 000 €, corresponding to approximately +0.004% in

Table 2.3.: Indicators of structural demography, years 2008 and 2017. Our elaboration on Istat Data

	Nuoro		Sardinia	
	2008	**2017**	**2008**	**2017**
Life expectancy at birth	81.2	82.1	81.3	82.8
Average age of population	42.8	46	42.9	46.1
Young population rate	13.5	12	12.6	11.6
Elderly population rate	19.5	23.3	18.5	22.7
Structural dependency index	49.2	54.4	45.1	52.1
Elderly population index	144.2	195	148	196

growth terms. In the same year, GDP per capita was approximately 18,800 €. With respect to 2015, GDP per capita also increased in 2016, in line with the overall regional dynamic (figure 2.31).

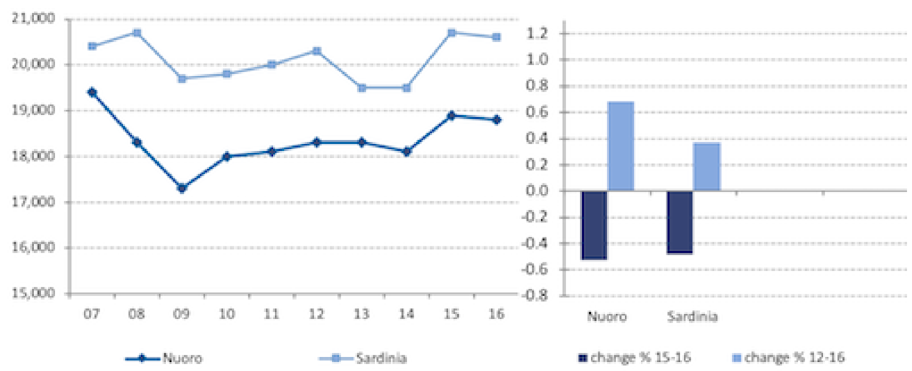

Figure 2.31.: GDP per capita (2007-2016, euros), change (2012-2016, %) and annual average change (2012-2016, %). Our elaboration with Eurostat data.

As figure 2.32 shows, in 2016, the GDP per capita of Nuoro was 8.7 points below the regional average (91.3 against the regional average indexed to 100), similar to the result of the province of Sassari (SS). Only the provinces of Cagliari and Olbia-Tempio have higher GDP per capita than the regional average; the others are all below the regional average level.

In 2016, the employment rate of Nuoro was 39.4%, one percentage point higher than the average of the whole region (37.3%). In the same year, the total number of employed people increased by 2.2% over the 2015 level. Moreover, in line with the trend of Sardinia, the variation over the 2013-2016 period is positive, with an inversion with respect to the significant fall in the employment rate experienced during the crisis period (figure 2.33). Additionally, as figure 2.34

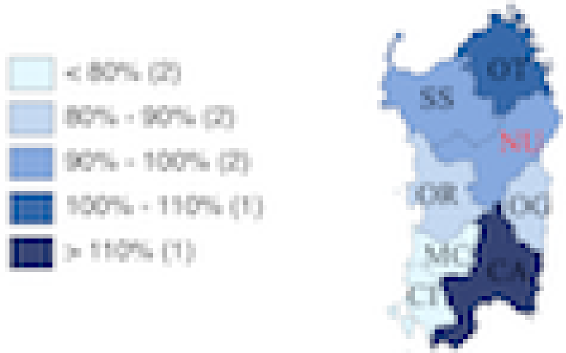

Figure 2.32.: Sardinia regional GDP per capita in PPS (2016, % of regional average). For each class, the number of regions is reported in brackets. Our elaboration with Istat data.

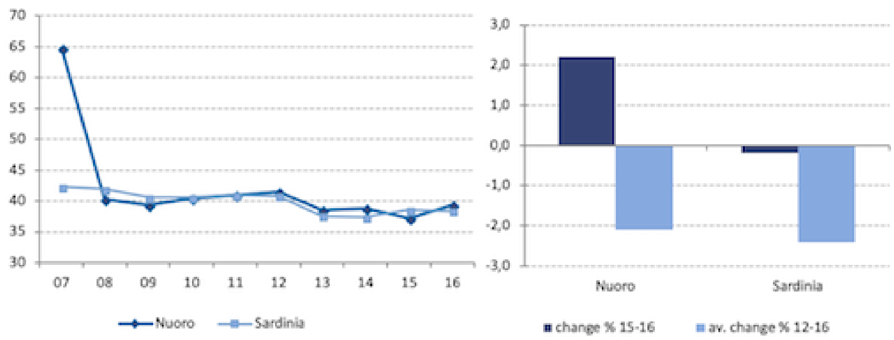

Figure 2.33.: Employment rate of people aged 15 and older (2007-2016, %) and change (2015-2016 and 2012-2016, %). Our elaboration with Istat data.

shows, in 2016, the employment rate of Nuoro (39.4%) was closer to that of the more dynamic provinces of Sardinia, such as Olbia-Tempio and Cagliari (41.2% and 41.7%, respectively), and it was significantly higher than that of the other three provinces, namely, Sassari, Medio Campidano and Carbonia-Iglesias, which were below 36%. In 2016, the unemployment rate

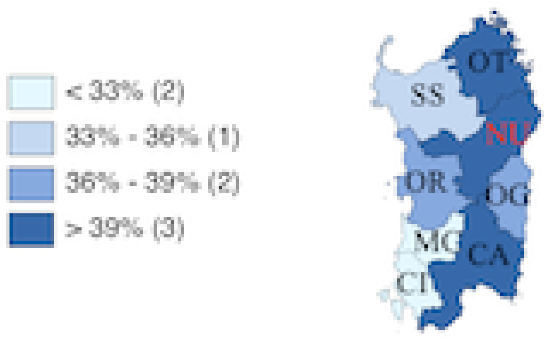

Figure 2.34.: Employment rate (2016). Our elaboration with Istat data.

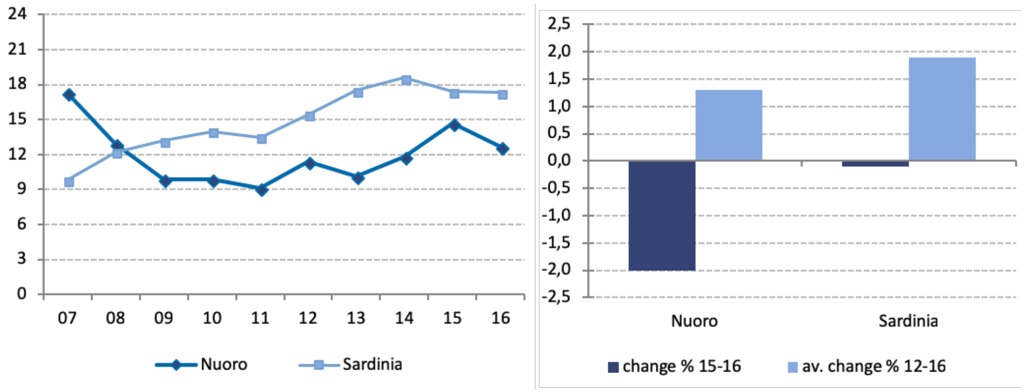

Figure 2.35.: Unemployment rate (2016). Our elaboration on Istat data.

was approximately 12.7%, below the regional level of 17.8% (figure 2.35). The total share of unemployed individuals decreased by 2 percentage points between 2015 and 2016. However, it decreased by only 1.3 percentage points over the period 2012-2016.

In 2016, with an unemployment rate of 12.7%, Nuoro was the province with the lowest rate, together with Olbia-Tempio. This figure is nearly the same as that for Cagliari and Olbia-

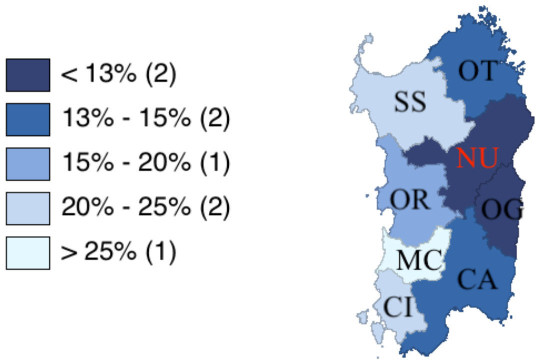

Figure 2.36.: Unemployment rate (2016). Our elaboration with Istat data.

Tempio (between 13% and 15%), and it is far below the high levels of Medio Campidano (27.8%), Sassari (21.9%) and Carbonia-Iglesias (20.6%) (figure 2.36).

2.5. Strategic features of the location

Among the important strategic features of a desired location are the distribution of firms across sectors and, more specifically, firm specialisation as well presence in sectors relevant to ET; the presence of a system of existing research infrastructures at the regional level; and the presence of transport and accommodation infrastructures. In this section, we provide a detailed analysis of such features at the regional level as well as at a more disaggregated level, especially for those aspects concerning logistics.

2.5.1. Firms

The overall number of active firms in Sardinia in 2018 is 143, 257 (table 2.4). The largest sectors – in terms of number of firms – are (i) wholesale and retail trade (37, 832) and (ii) agriculture, forestry and fishing (34, 350), which together account for 50% of all Sardinian firms (respectively, 26.4% and 24.4%). Sectors caracterized by a noteworthy number of firms also include (i) construction (13.7%), (ii) accommodation and food services (8.8%) and (iii) manufacturing (7.1%). Six sectors, including (i) transportation and storage, (ii) information and communication, (iii) financial and insurance activities, (iv) real estate, (v) professional,

Table 2.4.: Active firms per industry in 2018 in Sardinia. Our elaboration on InfoCamere data.

Code	Sector	Num. of active firms	% of active firms	Change 17-18 (17-18)
A	Agriculture, forestry and fishing	34,350	24.0	-0.3
B	Mining and quarrying	172	0.1	3.9
C	Manufacturing	10,127	7.1	0.8
D	Electricity, gas, steam and air conditioning supply	132	0.1	-3.1
E	Water supply; Sewerage, waste management and remediation activities	327	0.2	-1.6
F	Construction	19,676	13.7	0.0
G	Wholesale and retail trade; Repair of motor vehicles and motorcycles	37,832	26.4	1.3
H	Transportation and storage	4,064	2.8	1.0
I	Accommodation and food service activities	12,667	8.8	-2.5
J	Information and communication	2,723	1.9	-0.6
K	Financial and insurance activities	2,176	1.5	0.8
L	Real estate activities	2,504	1.7	-3.6
M	Professional, scientific and technical activities	3,018	2.1	-1.7
N	Administrative and support service activities	4,659	3.3	-3.1
P	Administrative and support service activities	662	0.5	-0.3
P	Education	662	0.5	-0.3
Q	Human health and social work activities	1,121	0.8	-3.2
R	Arts, entertainment and recreation	1,509	1.1	-4.2
S	Other service activities	5,538	3.9	-2.6
Total		**143,257**	**100**	**Average: -1.1**

scientific and technical activities and (vi) administrative and support service activities, have a number of firms between $2,000$ and $5,000$. The remaining sectors, which altogether account for 8.7%, have a lower number of firms and include mining and quarrying, education and other services. Most sectors register positive profitability. Most mature sectors are experiencing a reduction in the number of operating firms, which accompanies an increase in the typical firm's size.[6] Growing sectors include mining and quarrying (+3.9%), wholesale and retail trade (+1.3%), and transportation and storage (+1.0%). The reduction of the number of firms is, in general, associated with a persistent growth of profits over recent years, which is driven by medium- to large-firms. This seems to suggest that the reduction in the number of firms is mostly a physiological process in which mergers and acquisitions take place that result in increased firm size, while smaller and less efficient firms disappear as they are not fit for the challenges of global competition.

2.5.2. Presence of ET-related sectors

Here, we focus on the sectors that include potential suppliers of goods and services relevant for the ET at both the construction and operating phases. We refer to such sectors as ET-

[6] Twelve sectors out of eighteen register a negative change in the number of operating firms between 2017 and 2018, with an average change of -1.1%. The highest negative change is found in arts, entertainment and recreation (-4.2%); real estate activities (-3.6%); human health and social work activities (-3.2%); electricity, gas, steam and air conditioning supply; administrative and support service activities (-3.1%) and accommodation and food service activities (-2.5%).

related sectors. The number of active firms pertaining to ET-related sectors was 43,878 in 2018, which corresponds to almost one-third of the overall number of active firms (table 2.5). In terms of the number of firms, the most relevant sectors are (i) accommodation and food services, which accounts for 28.9%; (ii) construction of buildings (23%) and (iii) specialised construction (21%). Other relevant sectors include (iv) land transport (7.2%); (v) manufacture of fabricated metal products (4%); (vi) information services (3.3%); (vii) manufacture of wood and of wood and cork products (3%); (viii) manufacture of other non-metallic mineral products (2.2%); (ix) repair and installation of machinery and equipment (1.9%) and (x) computer programming, consultancy and related activities (1.6%). The number of firms in ET-related sectors increased by 0.4%, on average, between 2017 and 2018. This positive change was driven by the 7.9% increase in the number of active firms in the remediation activities and other waste management services sector as well as the increased number of firms operating in the manufacture of computer, electronic and optical products and in the manufacture of machinery and equipment, which account, respectively, for 6.6% and 5% of total active firms in ET-related sectors. Sectors experiencing a reduction in the number of firms include (i) accommodation; (ii) repair and installation of machinery and equipment; (iii) computer programming, consultancy and related activities; and (iv) manufacture of basic metals. However, these sectors, as well as the others, registered an increase in profitability in recent years.[7] Therefore, as mentioned at the beginning of the section, in many cases, the negative change in the number of firms is due to a physiological process by which stronger firms – those that are able to compete at the global level – become medium- and large-sized firms at the expense of some of the smaller and less productive firms that cannot survive in the global market, with an overall efficiency gain.

Among the 43,878 firms in ET-related sectors (table 2.5), 330 of them are among the top 1000 firms, which are defined as those firms that generate a sales volume higher than 2 M€ per year (table 2.6). Most of these firms operate in (i) transport and storage (83); (ii) construction of buildings, civil engineering and specialised construction activities (81), and (iii) accommodation and food service activities (60). These 330 firms generate overall sales of 3,600 M€. Thirty-five percent of the total sales are produced by firms operating in transport and storage, while accommodation and food service activities, construction of buildings, civil engineering, specialised construction activities, telecommunications and computer programming and related activities account for 15.1%, 13.8% and 7.5% of the overall sales of the 330 firms, respectively. The firms with the highest profitability – a *ROS* index between 7 and 13 – are those operating in leasing, architectural and engineering activities; industrial laundries; waste

[7] The median firm among the largest 1000 Sardinian firms registered an increase of 30% in profits in 2017 with respect to 2016. Among these firms, the median firm among medium-sized firms registered the highest growth in profits (+40%) between 2016 and 2017.

Table 2.5.: Active firms of ET related sectors in 2018. Our elaboration on InfoCamere data.

Code	Sector	Num. Of active firms	% of active firms
C 16	Manufacture of wood and of products of wood and cork, except furniture	1,314	3.0
C 20	Manufacture of chemicals and chemical products	99	0.2
C 22	Manufacture of rubber and plastic products	118	0.3
C 23	Manufacture of fabricated metal products, except machinery and equipment	950	2.2
C 24	Manufacture of basic metals	45	0.1
C 25	Manufacture of fabricated metal products, except machinery and equipment	1,742	4.0
C 26	Manufacture of computer, electronic and optical products	183	0.4
C28	Manufacture of machinery and equipment n.e.c.	248	0.6
C33	Repair and installation of machinery and equipment	849	1.9
E38	Waste collection, treatment and disposal activities; materials recovery	223	0.5
E39	Remediation activities and other waste management services	35	0.1
F41	Construction of buildings	10,101	23.0
F42	Civil engineering	339	0.8
F43	Specialised construction activities	9,236	21.0
H49	Land transport and transport via pipelines	3,143	7.2
H50	Water transport	156	0.4
H51	Air transport	5	0.0
H53	Postal and courier activities	142	0.3
I55	Accommodation	1,444	3.3
I56	Food and beverage service activities	11,223	25.6
J61	Telecommunications	141	0.3
J62	Computer programming, consultancy and related activities	685	1.6
J63	Information service activities	1,457	3.3
Total		**43,878**	**100**

collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services; construction of buildings; civil engineering; specialised construction activities; accommodation and food service activities; telecommunications; computer programming; and consultancy and related activities. It is worth noting that most sectors have a positive level of profitability. The above evidence suggests that the industrial structure of Sardinia guarantees a favourable environment for construction and operating activities related to a large research infrastructure project such as the ET. The region already hosts some large and innovative infrastructure, and other projects are under construction.[8] The construction of the ET would increase the presence in the region of clustering innovative and high-tech firms.

2.5.3. Accommodation capacity and logistics

In 2018, the overall number of official accommodation establishments in Sardinia was $5,149$ (camping sites not included), which corresponds to an overall number of $156,325$ bed places (table 2.7). Seventy percent of the bed places are provided in hotels and 30% in other types of accommodations, corresponding to $109,499$ and $46,826$ bed places, respectively. Hotels account for 18% of all establishments that correspond to 919, while other accommodations, including

[8]See, for example, the Sardinia Radio Telescope (http://www.srt.inaf.it) and the ARIA project (https://wpress.ca.infn.it/?page$_i d = 590$).

Table 2.6.: Biggest firms of ET related sectors in 2017. Our elaboration on InfoCamere data.

Code	Sector	Num. of active firms	Total sales (M€)	Total sales (%)	ROS index
16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	5	42.7	1.2	3
20	Manufacture of chemicals and chemical products	7	200.8	5.7	-148
22	Manufacture of rubber and plastic products	6	59.2	1.7	5
23	Manufacture of fabricated metal products, except machinery and equipment	14	70.6	2.0	4
24 25	Manufacture of basic metals; Manufacture of fabricated metal products, except machinery and equipment	20	250.3	7.1	7
26 28 33	Manufacture of computer, electronic and optical products; Manufacture of machinery and equipment n.e.c; Repair and installation of machinery and equipment	14	152.5	4.3	4
30 39	Waste collection, treatment and disposal activities; materials recovery; Remediation activities and other waste management services	19	137.7	3.9	9
41-43	Construction of buildings; Civil engineering; Specialised construction activities	81	483	13.8	9
49-51 53	Transport and storage	83	1,229	35	5
55 56	Accommodation and food service activities	60	528	15.1	9
61-63	Telecommunications; Computer programming, consultancy and related activities: Information service activities	12	264.1	7.5	7
77 71	Leasing; Architectural and engineering activities; Industrial laundries	9	91	2.6	13
Total		**330**	**3,600**	**100**	

Table 2.7.: Accommodation capacity in Sardinia in 2018. Our elaboration on ISTAT data.

Indicator	**Hotels**		**Other accommodations**		**Total**	**Change 17-18**
Establishments	919	18%	4,230	82%	5149	8.3%
Bed-places	109,499	70%	46,826	30%	156325	1.4%

hostels, resorts, and bed and breakfasts, account for 82%, for a total of 4,430 establishments. In 2018, the overall number of accommodation establishments registered an increase of 1.3% over its level in 2017, which translates to a 1.4% increase in bed places within the region.

The province of Nuoro hosts 16.5% of Sardinian establishments (camping sites excluded), which correspond to 850 establishments and 21,598 bed-places (table 2.8). Hotels account for 20% (171) of the establishments while other types of accommodation cover the remaining 80% for a total of 679 hostels, camping sites, resorts and so on. Regarding the number of bed-places, 16,128 places are offered by hotels and 5,470 in other accommodations. The annual change of both indicators of both number of establishments and bed-places is significant. In 2018 the overall number of establishments increased by 12% respect to 2017, which implied a 3.4% relative increase in the bed-places available within the province.

Table 2.8.: Accommodation capacity in the province of Nuoro in 2018. Our elaboration on ISTAT data.

Indicator	**Hotels**		**Other accommodations**		**Total**	**Change 17-18**
Establishments	171	20%	679	80%	850	12%
Bed-places	16,128	75%	5,470	26%	21,598	3.4%

2.5.4. Accommodation capacity in the surroundings of Sos Enattos

We define the surroundings of Sos Enattos, the potential location of the ET, as the area including locations within a reasonable driving distance (between 15 and 40 minutes; see figure 2.37). The surroundings of Sos Enattos have a notable accommodation capacity. This area includes 14 towns and villages [9] and offers accommodation services of different types (hotels, resorts, BBs, houses for rent, and others). As table 2.9 shows, the area accounts for 399 accommodation establishments (campsites not included), of which 78 are hotels and 321 are other accommodations. Hence, overall, the area would potentially be able to host 11,385 people per day, 76% in hotels and 24% in resorts, bed and breakfasts, guest houses, and so on. There are 15 establishments that can host 152 people per day within a 15-minute driving distance. Within a 30-minute driving distance, there are 159 establishments, which can accommodate 6,140 people per day. Within a 40-minute driving distance, there are 225 establishments, which are able to host 5,093 people per day.

2.5.5. Connectedness

From a logistic point of view, Sos Enattos is well connected to urban areas, ports and airports by means of roads and trains. Moreover, Sardinia is a region of significant commercial and touristic activity that relies upon the efficient regular transport of goods and people from around Europe and the rest of the world.

The "SS73" road is the main access to Sos Enattos, and it connects to the two main highways, "SS131dcn" and "SS389", within approximately 15 to 20 minutes by car (respectively 25 km and 16 km). Both highways connect to the main cities to the east, north and south of the region, which lie at a distance of less than 2 hours by car. Precisely, Nuoro – the closest and capital city of the province – is a 35-minute drive; Olbia is a 1-hour drive; Sassari is reachable in 1 hour and 40 minutes by car; Oristano is at 1 hour and 20 minutes; and Cagliari is about 2 hours by

[9] Lula, Onanì, Bitti, Orune, Buddusò, Lodè, Orosei, Nuoro, Galtellì, Irgoli, Posada, Torpè, Siniscola and Dorgali.

Table 2.9.: Accommodation capacity within of Sos Enattos surrounding area in 2018. Our elaboration on ISTAT data.

Driving time	Indicator	Hotels	Other accommodations	Total
15 min.	Establishments	1	14	**15**
	Bed-places	40	112	**152**
30 min.	Establishments	36	123	**159**
	Bed-places	4,997	1,143	**6,140**
40 min.	Establishments	41	184	**225**
	Bed-places	3,655	1,438	**5,093**
Total	Establishments	78	321	**399**
	Bed-places	8,692	2,693	**11,385**

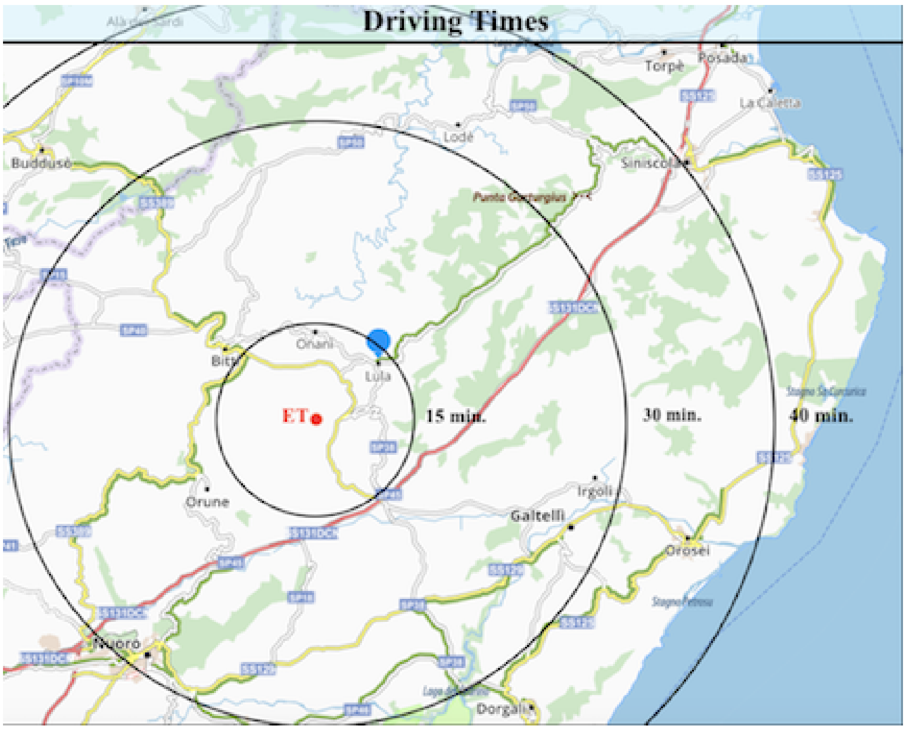

Figure 2.37.: Accommodation facilities [10] within driving distance of Sos Enattos. Our elaboration with Micheline maps.

car from Sos Enattos.
All these roads are suitable for a low-loader carrying a railway wagon-sized load and have the highest national load classification, that allows a maximum gross weight of 60 t (in accordance with EU regulations). Permits for special transport on these three roads – due to weight or size – are obtainable from the national transport authority (ANAS). Moreover, the Sos Enattos area is easily reachable by means of public busses from the closest town of Lula (15 minutes by car from the ET site). There are many daily busses, run by the company ARST, arriving to Nuoro from Lula and leaving from Nuoro for the main destinations of the region, including ports and airports.
The "SS131dcn" highway connects Sos Enattos to the closest airport and ports, approximately 1 hour away by car (70 km), of Olbia and Golfo Aranci (north-east). The port of Arbatax, at a drive of approximately 1 hour and a half (100 km), is connected to the ET site by the "SS389" highway. The "SS131dcn" highway also connects Sos Enattos to the Alghero-Fertilia Airport and the port of Porto Torres (north-west) within 2 hours' drive (respectively, 140 km and 150 km). The airport and the port of Cagliari (south) – both at approximately 200 km away from Sos Enattos – can be reached within approximately 2 hours by car via the "SS131dcn", as can the port of Porto Torres (north-west), which is located at a similar distance.
Sardinian ports are all suitable for receiving the heavy equipment and machines required for the construction and operating activities of the ET, and they offer a good network of direct connections mainly between the island and the mainland of Italy, as well as some direct connections to other EU countries such as France and Spain. There are daily ferries by six different shipping companies connecting the five ports mentioned above to 7 different national destinations (Civitavecchia (Rome), Genoa, Livorno and Piombino (Tuscany), Naples, Palermo, and Trapani) and approximately 5 international destinations between France and Spain, including Barcelona and Marseilles. The national and international ports to which Sardinia is connected are pivotal hubs of the Mediterranean and global shipping trade.
The region is accessed by air through the three airports of Olbia, Alghero and Cagliari. These airports serve in total 161 direct connections worldwide, 40 domestic and 121 European and international. Domestic destinations can be reached within an hour's flight time, while most European destinations are reachable in less than 3 hours. A large number of airline companies operate in Sardinia: 66 in Olbia, 18 in Alghero and 24 in Cagliari.
The railway covers the whole region from north to south, with daily trains to the main cities and towns. The train station of Nuoro is the closest to Sos Enattos, and it is connected to the main destinations in the north (Sassari and Olbia) and south (Cagliari), which are all reachable within approximately 2 hours.

2.5.6. Services and recreational activities

The area that surrounds the site of Sos Enattos, as well as the whole region, is well served with healthcare, education, and recreational infrastructure and services.

Hospitals and emergency medical centres are quite close to the ET site. Nuoro hosts 3 public hospitals – open 24 hours a day – and several private and public medical centres with specialised units and cutting-edge departments of first aid, surgery, cardiology, radiology, orthopaedics, gynaecology, paediatrics, and others. Emergency medical centres are also operative at a smaller distance in the towns of Lula, Bitti and Onanì.

Regarding kindergartens and schools, there are 3 public kindergartens for children aged 3 to 6, respectively, located in the nearby towns of Lula, Bitti and Onanì, as well as 2 primary schools and 2 secondary schools located in Lula and Bitti. Moreover, Nuoro offers several private and public kindergarten, primary and secondary schools and high schools: 13 kindergartens, 8 primary schools, and a total of 19 high schools with different courses that include classic literature, languages, sciences, music and arts, accounting, finance and marketing, design, information technology and computer science, tourism management and agriculture.

Nuoro – as well as many other cities and towns in Sardinia – is a very cultural and creative city. It is the hometown of the 1926 Literature Nobel prizewinner Grazia Deledda, to whom the "Museo Deleddiano" is dedicated. Other museums in Nuoro host a variety of expositions that include arts (the MAN museum); Sardinian traditional cloths, masks, musical instruments and jewels (Museo del Costume); and archeology (Museo Archeologico Nazionale G. Asproni). Various festivals of cinema, literature and music take place every year, such as the IsReal Festival and the international Festival Nuoro Jazz. The city also has one multi-screen cinema and two theatres, Teatro Eliseo and Teatro San Giuseppe, which host numerous performances, concerts and plays by national and international artists.
Sports and open-air activities play a key role in Nuoro's citizens and Sardinians' lives. The city is well served with sports centres, gyms, parks and swimming pools where residents practice a wide range of activities. Moreover, the Sardinian countryside as well as the surrounding areas of Sos Enattos, Lula and Nuoro offer the opportunity to enjoy clean and fresh air in a wild and stunning landscape where one can practice open-air activities that include horseback riding, trekking, canyoning, climbing, biking, rowing, and so on. Moreover, on the beaches of the east coast of Sardinia – easily reachable within 30 to 40 minutes by car – it is possible to practice water sports – surfing, wind surfing, kite surfing, and sailing – in spring and summer.

2.5.7. Innovation and research environment

Sardinia promotes smart growth, sustainable development and social inclusion in line with the 2020 Europe Strategy.[11] This goal is key to the Smart Specialisation Strategy (S3) of Sardinia, within the EU Cohesion Policy 2014-2020, which aims at identifying and promoting key local research and innovation competences that are relevant to enhancing economic and social growth. The strategic sectors identified by Sardinia within the S3 framework are the following[12]:

1. Developing the ICT sector
2. Healthy living care services and products (Life sciences)
3. New technologies and materials for the aerospace industry
4. Providing healthy and safe food (agri-food)
5. Smart networks for efficient energy management
6. ICT and new technologies for tourism and cultural industries

A more competitive, sustainable and inclusive growth-oriented regional system is fostered by allocating investments in research and innovation that positively impact the entrepreneurial environment across Sardinia as well as citizens' quality of life. As mentioned in section 2.2, the regional economic system is moderately innovative and competitive; however, Sardinia makes considerable public investments in research and innovation. In 2016, the share of financial resources allocated to research and innovation investments was 0.7%[13] of GDP, which is higher than the national average of 0.5%. Moreover, Sardinia is among the most efficient Italian regions in terms of allocation of European structural funds.[14] More precisely, Sardinia has been assigned, for the period 2014-2020, 930.9 M€ by the FESR and 444.8 M€ by the FSE. To date, 26.77% of the whole budget has been assigned to projects, higher than the national average of 26.6%. The actors involved in the innovation process of the six sectors listed above are firms, research institutions and universities. In particular, research institutions and universities play a key role in this process.

Sardinia is home to a system of relevant research centres and institutions that are geographically distributed across the region. The key players are as follows:

[11] http://www.sardegnaprogrammazione.it/index.php?xsl=1384s=278012v=2c=12950
[12] http://s3platform.jrc.ec.europa.eu/regions/itg2/tags/itg2
[13] http://www.sardegnastatistiche.it/index.php?xsl=1954s=12v=9c=10288nc=1gl=1c1=10288httphst=www.regione.sardegn
[14] https://temi.camera.it/leg18/post/OCD25-320.html

1. **SarGrav**. SarGrav is a research centre set up by a collaboration of the University of Sassari, the National Institute for Nuclear Physics (INFN), the Sardinia Regional Government (RAS), IGEA SpA and the National Institute for Geophysics and Vulcanology (INGV). It is an underground research infrastructure that has operated since the beginning of 2019, when the first underground labs were inaugurated. It is located in the old mining sites of Sos Enattos (Lula), which is also the candidate site for the ET. The regional government of Sardinia granted the University of Sassari 3.5 M€ to develop the research centre. The infrastructure consists of a laboratory hall (120 m^2 x 4.75 m) that is excavated at 110 m underground, with a 200-m^2 surface building designed to host the control room, offices, services, and electronic and mechanical workshops converted from an existing building of the old mine of Sos Enattos. Moreover, the Consortium GARR – the ultra-broadband network dedicated to the Italian research and education community – announced it would design and build a high-speed internet connection at Sos Enattos, and the project is supported by the regional Government (RAS), which financed it with 1 M€. The regional government has also granted 500 K€ to the Department of Engineering of the University of Cagliari to design a high-quality and stable electricity infrastructure for Sos Enattos. The research activities carried out at SarGrav aim to study the physics of gravity, and they will also contribute to developing ET technologies, as they will host experiments requiring low noise and a controlled environment, providing an ideal site for the R&D of technologies for 3^rd-generation GW detectors. One of the first experiments to be hosted is the Archimedes, funded by INFN-CSN2, which will study the interaction between vacuum fluctuations (Casimir effect) and gravity.
   This project, due to the specific research activities, its location and the development of relevant infrastructures, is considered the first module of the Einstein Telescope project and specifically the first vertex station.

2. **ARIA Project**. This is a research infrastructure project located in the old mine of Monte Sinni (south-west) and inaugurated in September 2018. The scientific promoter of the project is the National Institute of Nuclear Physics (INFN) together with Princeton University, the Autonomous Region of Sardinia (RAS) and the Carbosulcis SpA, a subsidiary company of the RAS that manages the mining plant. ARIA[15] brings cutting-edge science and technology to the region as it arises from basic research, in particular from fundamental physics, to answer an experimental need: to have available large amounts of argon, currently obtained only from Colorado gas wells, in the United States, for the research of dark matter. However, in the future, argon could also be used for the distilla-

[15] https://wpress.ca.infn.it/?page$_id = 1799lang = en$

tion of other isotopes increasingly used in medicine, both in advanced diagnostics and in cancer therapy, as well as in environmental and agricultural sciences. The project consists of the construction of a cryogenic distillation tower for the production of very high-purity stable isotopes. The plant will be the first of its kind in Europe and the first in the world realised with an innovative technology that should allow the achievement of previously unprecedented performance. At the moment, the infrastructure is under construction and the INFN has already invested 6 M€, the RAS has contributed 2 M€ and 700 K€ and Carbosulcis SpA has already contributed to the adaptation of the mining infrastructure at a cost of over 1.5 M€ and has made an investment of over 2 M€ for the installation of the plant in the Seruci well. The goal of the project is the separation of the air in its fundamental components, elements that find their usefulness in different areas of research and application. In particular, one of these components, argon-40 (40Ar), will allow the development of an innovative technique for the research of dark matter at the National Laboratory of Gran Sasso (LNGS) (L'Aquila) of INFN, designed and realised by the scientific collaboration of the DarkSide experiment.

3. **Sardinia Radio Telescope (SRT)** Since 2012, the National Institute of Astrophysics (INAF) has operated the SRT[16], which is a 64-meter single-dish radio telescope with state-of-the-art technological capabilities located in San Basilio (Cagliari). It is a versatile instrument for radio astronomy, geodynamic studies and space science, which can be operated in either single dish or very long baseline interferometry mode. Its strengths include a large collecting area (a steerable parabolic dish with 64 meters of diameter) combined with state-of-the-art technology, allowing for a high efficiency up to 115 GHz. The commissioning activities, performed by the astronomical validation team, have transformed the SRT into a world-class radio astronomical facility that delivers outstanding scientific results. Among the many research activities at the forefront of radio astronomy and space science, it is worth mentioning the Sardinia Deep Space Antenna project (SDSA)[17]. The project consists of a new research unit at the Italian Space Agency (ASI) located at the SRT, which is in charge of providing services to interplanetary and lunar missions. The SDSA has recently become part of the NASA Deep Space Network project, but it will also be part of European activities carried out by the European Space Agency (ESA) within the ESTRACK network.

4. **Space Propulsion Test Facility (SPTF)** This technological and space infrastructure project – unique in Italy and Europe – will be set up in Villaputzu (south-east). The

[16] http://www.srt.inaf.it
[17] https://www.asi.it/lagenzia/le-basi/sardinia-deep-space-antenna-sdsa/

project allows the carrying out research activities in the field of solid propulsion and space tests as well as the development of internal and external thermal shields for the family of Vega Italian launchers. The infrastructure is set up by the partnership of the Italian company Avio, which operates in the aerospace industry, the ASI, the Sardinia Aerospace District (DASS), and the RAS and Villaputzu municipality. The company SpaceLab, which is an ASI-Avio subsidiary, will be in charge of the operating phase of the infrastructure. The project partners have already allocated 26 M€ for the establishment of this facility, which will employ 25 highly qualified technicians, including engineers, chemists and computer specialists.

5. **Sardinia AeroSpace District (DASS Scarl)** The DASS Scarl[18] was established in October 2013 to underpin the collaboration among research centres, universities and space companies based in Sardinia, as well as to take advantage of significant business opportunities and suitable occasions for growth and innovation in the space segment. The district is composed of 29 shareholders, which include companies and public institutions, namely, Accademiasapr Srl, Aermatica SpA, Aeronike, Avio SpA, Centro Italiano Ricerche Aerospaziali ScpA, RINA Consulting, Centro Sviluppo Materiali SpA, Fondazione di Sardegna, Gem Elettronica Srl, Geodesia Tecnologie Srl, Innovative Materials Srl, Karalit Srl, Lion Consulting Srl, MR8 Srls, Nemea Sistemi Srl, Nurjana Technologies Srl, Oben Srl, Opto Materials Srl, Poema Srl, Soliani Emc Srl, Space SpA, Spacearth Technology Srl, 3D AEROSPAZIO Srls, UavItalia Srl, Vitrociset SpA, Consiglio Nazionale delle Ricerche (CNR), CRS4 Surl, Istituto Nazionale di Astrofisica (INAF), the University of Cagliari and the University of Sassari. The RAS believes that the technological aerospace district represents a key element towards the realisation and management of an industrial network able to develop competitive solutions for national and international customers. As a new model of development, the challenge taken up by the DASS Scarl is linked to the consolidation and integration of the competences of all expertise in the aerospace sector, already developed at the regional level. The ability of DASS Scarl to integrate all the regional players of the technological and productive supply chain together with research institutions is made possible by the adoption of an innovative model of governance able to ensure the representation required by each member and at the same time to use a collaborative system of design and knowledge management on which all partners work independently, while considering an integrated view. In addition, the transversal actions implemented by the district to focus on and address the regional strategy in the aerospace field include vocational training and higher education, technology transfer and

[18] http://www.dassardegna.eu

communication and internationalisation.

6. **Consiglio Nazionale delle Ricerche (CNR)**. CNR is the largest public research institution in Italy. Its mission is to (i) promote innovation and competitiveness of the national industrial system, (ii) foster the internationalisation of the national research system, (iii) develop technologies and solutions from emerging public and private needs, (iv) advise the central government and other public bodies, and (v) contribute to the development of human resources. Sardinia hosts six centres that belong to the CNR, which are located in Sassari, Oristano, Lanusei, Cagliari and Pula. This institution promotes studies and research in several fields, such as engineering, ICT, energy, transportation, physics and matter, chemistry and materials technology. More precisely, the research centre based in Sassari hosts the Institute of Biometereology (IBIMET), the Institute of Biomolecular Chemistry (ICB), the Institute for Genetic and Biomedical Research (IRGB), the Institute of Ecosystemic Studies (ISE), the Institute of Sciences of Food Production (ISPA) and the Institute for the Animal Production System in the Mediterranean Environment (ISPAAM). The centre of Oristano hosts the Institute for the Coastal and Marine Environment (IAMC), and the one located in Lanusei hosts the Research Institute of Genetics and Biomedics (IRGB), whose Immunogenetics labs are also hosted in Pula.

7. **Sardegna Ricerche**. Sardegna Ricerche has operated since 1989 as the regional agency supporting the regional government's policies for research, innovation and technology development and coordinates the two technology parks of Sardinia, which are located in Pula and Alghero. The agency operates in four locations: Pula, Cagliari, Uta and Nuoro. The headquarters are at the technology park in Pula (Cagliari). The technology park in Alghero is operated by the research centre Porto Conte Ricerche. Sardegna Ricerche supports research programmes related to ICT, biotechnologies, RES and other sectors.

8. **CRS4**. CRS4[19] is an interdisciplinary research centre founded by the regional government of Sardinia in 1990 and whose sole shareholder is the regional agency Sardegna Ricerche. The centre promotes the study, development and application of innovative solutions for natural, social and industrial environments. Since 2003, the centre has been located in Pula (Cagliari) at the science and technology park. Today, approximately 150 people work at CRS4. The mission of the centre is to help Sardinia build and support high-tech industries as key factors for economic and cultural development. CRS4 collaborates with industries, universities and scientific laboratories in technological development and scientific research related to state-of-the-art computational technologies and their application

[19] https://www.crs4.it

to several fields, such as biosciences, information society, energy and environment.

9. **Porto Conte Ricerche**. Porto Conte Ricerche[20] is one of the pivotal players of the science and technology park based in Alghero (Sassari). It is active in complementary areas of technology: biomarker discovery, diagnostic systems and biotechnologies applied to nutrition and health. For over 15 years, the research centre has been developing and delivering high-tech services to companies engaged in the innovation of their production systems through industrial research and experimental development activities.

10. **Universities**.
Sardinia hosts two universities, the University of Sassari and the University of Cagliari.

    i. **University of Sassari**. The University of Sassari (UNISS), opened in the XVI century, is the first university ever founded in Sardinia, with more than 450 years of history. The main campus is located in the city of Sassari (in the north-west of the island). Other campus sites include Alghero (north-west), Nuoro (centre), Olbia (north-east) and Oristano (north-west). The university consists of 10 departments, approximately 600 professors and 500 administrative staff, and a population of over 13,600 students. Programmes are available for a wide range of fields, such as agriculture, veterinary science, computer science, architecture, humanities and arts, sciences, and social sciences, including economics, political science and law. The university offers 59 programmes, both graduate and post-graduate, including international masters and PhD positions. Its infrastructure includes 40 research centres and labs and 12 libraries. It has cooperation agreements with approximately 500 international programmes that participate in the European Erasmus Exchange Programme. Regarding the research, 460 researchers operate at UNISS. The majority of them, 232 researchers (45%), operate in life sciences. Social sciences and humanities researchers, 200 people, account for 38.8% of the academics at the university, while researchers in physical sciences and engineering number 83 (16.12% of the total).

    ii. **University of Cagliari**. The University of Cagliari (UNICA) was founded in 1620. The main campus is located in the south of the city of Cagliari, which is the largest city of the region as well as its capital. Other campus sites include Nuoro (centre), Iglesias (south-west) and Oristano (north-east). The university consists of 16 departments and 6 faculties, approximately 900 professors and researchers, and 24,600 students. Programmes are available for a wide range of fields, such as electrical and electronic engineering, civil and environmental engineering, mechanical, chemi-

[20] http://www.portocontericerche.it/en

cal and materials engineering, physics, mathematics and computer science, history, architecture, humanities and arts, sciences, social sciences and law. The university offers 140 programmes, both graduate and post-graduate, including international masters and PhD positions. Its infrastructure includes a wide number of research centres, labs and libraries. It has cooperation agreements with 960 international programmes that participate in the European Erasmus Programme and other overseas programmes.

11. **Startups**. In 2018, the number of innovative startups operating in Sardinia was 163. Many of these firms cluster in the south and north-west in the provinces of Cagliari and Sassari where there are, respectively, 18.7 and 13.5 startups per $100,000$ inhabitants – figures that are close to the national level (16.1 firms per $100,000$ inhabitants). The services sector, as in the rest of Italy, generates the majority of the innovative startups (106 firms), and among these, 38% operate in the ICT industry, 13% in the information industry, 9% carry out R&D activities and the remainder offer other services.

3. Economic impact

The construction and operation of the ET will generate a long-lasting economic impact on a large community of stakeholders at different geographical levels. First, suppliers of raw materials, technologies and services located in Sardinia, Italy, and abroad will be affected by the activities of the construction of this unique research infrastructure. In turn, this demand effect will affect other suppliers of intermediate goods and services along the supply chain. Similarly, at the operation stage, a stock of highly qualified workforce, including administration staff, especially researchers, technologists and technicians from Sardinia, Italy and abroad, will work for the ET and will live in the surrounding area. This includes both workforce employed by the ET as well as research visitors from other institutions and external providers of goods and services. The operational activities carried out at the observatory, including routine operations, use of research facilities, maintenance and upgrading of the research infrastructure and the tailoring of research instruments for specific experiments, will require highly specialised and high-tech instrumental goods and services supplied by local, national and international providers. The demand effect associated with such activities will therefore have potentially substantial economic effects at the local, regional and international levels.

To correctly assess the economic impact of the ET, we need to quantify both the initial increase in demand that stimulates production (direct impact) and the multiplier mechanism according to which such initial demand generates further demand for goods and services along the supply chain (induced impact). More precisely, we need to estimate the following effects:

1. The **direct impact** associated with the value of goods and services, including labour, supplied by the constructors contracted by the agency responsible for the construction of ET (construction phase), and the value of hired labour, as well as goods and services demanded by the agency managing the ET (operational phase);

2. The **induced impact** associated with the value of intermediate goods and services (IGS), including labour, demanded by firms contracted by the agency managing the ET or by any subcontractor along the supply chain (at both the construction and operating stages) and by the labour force working for/at the ET (see figure 3.1).

Following the literature, the economic impact of the construction and operation of ET will be evaluated according to the following dimensions (Miller and Blair, 2009):

1. Total output
2. Value added
3. Employment

The total output effect captures the overall increase in the level of economic activity due to the demand of goods and services (including labour) generated by the ET. The value-added effect captures that part of the increase in the level of production due to the demand effect generated by the ET, which refers to final goods and services and therefore corresponds to an increase in the value added or gross domestic product on an annual basis. The value added effect so defined is necessarily smaller than the total output effect, as the latter includes some duplications of value along the supply chain.[1] Finally, the additional production of goods and services stimulated directly and induced by the ET requires the use of additional labour; accordingly, another important dimension of the economic effects generated by ET is the potential employment effect.

Finally, since all these effects are generated over a significant period of time, when evaluating the economic impact of the infrastructure, we choose a reference point in time with respect to which we evaluate the present value of such impact by discounting future flows of value.

3.1. Direct and induced economic effects: The input-output method applied to ET

Consider an economy consisting of N industrial sectors plus a household's labour sector. Households produce labour services and consume goods and services, while industries produce final and intermediate goods and services using other goods and services as inputs. By definition, for each sector, ex post supply and demand of goods and services must be equal. Accordingly, the yearly flow of production (supply) and demand satisfy:

$$X = Z \times I + F \tag{3.1}$$

where X is an $N \times 1$ vector containing the production, x_i, of each sector i, with $i = 1, .., N+1$, Z is a $N+1 \times N+1$ matrix containing the demand, z_i, of goods and services produced by

[1] Total output effects include both costs and revenues of each sector firm, while the value added captures the value that is added by a sector in engaging in production – the difference between a sector's total output and the cost of its intermediate inputs.

sector i and used in sector j, for all i and j, F is the vector containing the final demand, f_i, of goods and services produced by each sector i, and I is an $N+1 \times N+1$ identity matrix.[2] Now let

$$a_{i,j} = \frac{z_{i,j}}{x_j} \tag{3.2}$$

be the technical input-output coefficient that describes how much input from sector i is needed to produce a quantity of output x_j in sector j, so that

$$a_{N+1,j} = \frac{z_{N+1,j}}{x_j} \tag{3.3}$$

tells us the amount of labour necessary to produce a unit of good/service j. Then, (3.1) can be rewritten as

$$X = A \times X + F \tag{3.4}$$

where A is the $N+1 \times N+1$ containing all technical input-output coefficients. It then follows that, given the flow of final demand of goods and services F, the total output generated in the economy is given by

$$X = [I - A]^{-1} \times F = L \times F \tag{3.5}$$

where L is the Leontief inverse. Note that the marginal effect on production in sector i due to a change in final demand of sector j is given by

$$\frac{\partial x_i}{\partial f_j} = l_{i,j} \tag{3.6}$$

where $l_{i,j} \in L$. The above model delivers a method to estimate the impact of an exogenous flow of demand F on total production, i.e., on total output, X. Accordingly,

$$x_{i,j} = l_{i,j} f_j \tag{3.7}$$

is the value of goods/services produced by sector i, associated with the increase in production of good/service i necessary to meet the flow of additional demand of final goods and services from sector i, $l_{i,j}$ due to an exogenous increase in demand in sector j. Clearly,

$$m_j^O = \sum_i^{N+1} l_{i,j} \tag{3.8}$$

measures the overall output effect of an additional nominal unit of expenditure in goods and services produced by sector j. Note that, as fully explained in the appendix, subsection A.1, $l_{i,j}$ captures both the direct effect of an increase in the demand for good/service j on the production of good/service i as well as the related induced effects produced through a multiplier effect

[2] Note that x_{N+1} represents the value of labour services produced by households.

according to which the initial exogenous increase in demand in sector j stimulates production in sector j, which, in turn, stimulates demand of goods and services in all sectors of the economy, and so on. Accordingly, we call m_j^O an output multiplier.

Finally, the period t flow of the output effect of the building or operation of a large infrastructure project such as the ET is measured by

$$TO_t = \sum_{j=1}^{N+1} m_j^O f_{j,t}^{ET} = \sum_{j=1}^{N} m_j^O f_{j,t}^{ET} + m_{N+1}^O f_{N+1,t}^{ET} \tag{3.9}$$

where $m_{N+1}^O f_{N+1,t}^{ET}$ measures the overall effect generated by the demand for labour services, and $\sum_{j=1}^{N} m_j^O f_{j,t}^{ET}$ measures the effect generated by the demand for goods and services other than labour. Clearly, these effects result from the initial demand effect F and additional demand effect triggered by F according to the multiplier mechanism (see also figures 3.1 and 3.2).

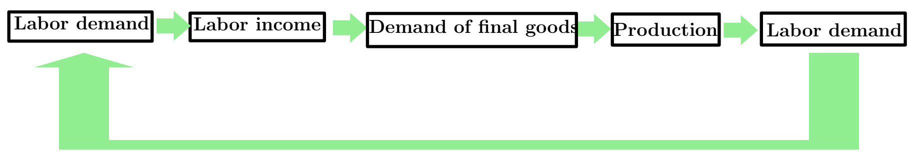

Figure 3.1.: Impact due to exogenous demand for intermediate goods and service (IGS)

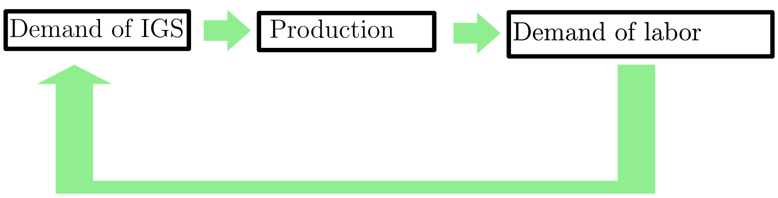

Figure 3.2.: Impact due to exogenous demand for intermediate goods and service (IGS)

According to the above discussion, we can explicitly distinguish between direct effects and induced effects that lead to the total output effect, TO_t. Let D_t^{TO} be the direct effect on total output, which by definition measures the overall initial exogenous increase in demand of goods and services. Therefore,

$$D_t^{TO} = \sum_{i=1}^{N+1} f_i \tag{3.10}$$

while the induced effect is

$$I_t^{TO} = TO_t - D_t^{TO} \tag{3.11}$$

The same reasoning applies to other types of effects, including value added and employment. For instance, to compute the employment effects, we just need to convert the marginal effect of demand from sector j on production in sector i, $l_{i,j}$, in an effect on the quantity of additional labour services produced by the household sector to meet the additional labour demand generated by producers in sector i. Such a labour effect is given by $a_{N+1,i}l_{ij}$. Correspondingly, the labour multiplier is given by

$$m_j^L = \sum_{i=1}^{N} a_{N+1,i}l_{ij} \tag{3.12}$$

Finally, the employment effect associated with the construction or operation of the ET is measured by

$$E_t = \sum_{j=1}^{N+1} m_j^L f_{j,t}^{ET} \tag{3.13}$$

Following the same logic, the annual flow of the value added effect of the construction/operation of ET is measured by

$$VA_t = \sum_{j=1}^{N+1} m_j^{VA} f_{j,t}^{ET} \tag{3.14}$$

where m_j^{VA} is the value added multiplier that measures the value added generated by a unitary increase in final demand in sector j. Clearly, also for the employment and the value added effects, we can disentangle direct and induced impacts, and we can distinguish the impact of the demand for labour from the demand for intermediate goods and services.

3.2. From theory to practice: Estimation of the economic impact of the ET

To estimate the impact of the construction and operation of the ET, we need to estimate (i) the demand for goods and services associated with the construction phase and the operation stage; (ii) the input-output multipliers for output, employment and value added; and (iii) the time span of construction and the operating life of the infrastructure.

Estimates of goods and services in the construction phase are based on two sources of information: (i) experts' opinions and (ii) the ET's conceptual design study (CDS). The CDS provides estimates of the annual costs for 5 macro systems: (i) site, (ii) vacuum, (iii) cryogenics, (iv) suspensions, and (v) optics. These estimates have been revised and integrated with the support of a panel of experts from INFN and the ET-Sardinia group that works on the ET project with a focus on the Sos Enattos site.

Estimates of the operational demand for goods and services are obtained by combining experts' opinions with data from two existing large research infrastructure facilities based in Italy, which share key features with the ET. The two reference infrastructure sites are the European Gravitational Observatory (EGO), located in Cascina, and the Laboratori Nazionali del Gran Sasso (LNGS), located in L'Aquila. Like the ET, the EGO is an observatory of gravitational waves, so it shares similar technologies with the ET. For the LNGS, the similarity with the ET stems from the fact that the LNGS is also an underground infrastructure site. However, the dimensions of the ET are much larger than those of the two reference research infrastructure facilities. Significant differences might also characterise the set of activities being carried out at the various research sites. To reduce the possibility of measurement and quantification errors, the estimates of the operating costs of the ET – obtained from the analysis of operating costs of EGO and LNGS – have been validated and integrated by collecting the relevant experts' opinions via questionnaires administered to a pool of physics researchers from the INFN. For the N industrial sectors, sector-specific multipliers are estimated by applying the methodology discussed in section 3.1 to the input-output tables of Italy for 2014, the most recent ones that are publicly available. These tables contain information on 63 industries. We decided not to use the regional input-output tables of Sardinia because the economic impacts of large research infrastructure projects spread beyond regional boundaries; therefore, we believe that national sector-specific multipliers are a better proxy.

3.2.1. ET: economic impact of its construction

The total output effect of the construction phase is found by adding up the annual flows of total output generated by construction over the construction period.

$$TO^{ET} = \sum_{t=1}^{9} TO_t \tag{3.15}$$

Similarly, the value added effect and the employment effects are

$$VA^{ET} = \sum_{t=1}^{9} VA_t \tag{3.16}$$

$$E^{ET} = \sum_{t=1}^{9} E_t \tag{3.17}$$

Tables 3.1-3.3 report the estimates for the TO, VA and E effects, which respectively amount to $6,184.2$ M€, $2,263.5$ M€, and $36,085$ workers FTE. Since the economic effects are generated over a significant period of time, we also provide estimates of the present value of the economic effects generated by the ET, discounting the annual flows of value by a positive discount factor,

$r > 0$. We set $r = 2.57\%$, using the average interest rate of the Italian BTP (Buoni del Tesoro Poliennali) in 2018, as our estimate of the cost for the public provision of financial resources. These present values are computed according to the following equations:

$$PV_{TO}^{ET} = \sum_{t=1}^{9} \beta^t TO_t \tag{3.18}$$

$$PV_{VA}^{ET} = \sum_{t=1}^{9} \beta^t VA_t \tag{3.19}$$

where $\beta = 1/(1+r)$ amounts to $5,497.8$ M€ and $2,011.8$ M€, respectively.

Table 3.1.: Total output effect of ET at construction phase (M€).

Source of impact	**In 2019 euro**	**Present Value**
Direct Impact	1,736	1,543
Induced Impact	4,448.2	3,954.8
Total	**6,184.2***	**5,497.8*** **

* Obtained by summing annual flows without discounting.

** Obtained by discounting to year 2025 the annual flows before adding them up. Discount rate, 2.57%.

Table 3.2.: Value added effect of ET at construction phase (M€).

Source of impact	**In 2019 euro**	**Present Value**
Direct Impact	633.8	563.5
Induced Impact	1,629	1,448.3
Total	**2,263.5**	**2,011.8**

Table 3.3.: Employment effect of ET at construction phase (worker FTE).

Source of impact	**Value**
Direct Impact	10,104
Induced Impact	25,981
Total	**36,085**

In the next two sections, we explore direct and induced impacts in some detail.

a. Direct impact of the construction of ET

The direct impact, in terms of total output, value added and employment, results from the annual flows of demand of goods and services necessary for the construction of ET associated with the 5 macro-systems. These annual flows are reported in table 3.4, which reports the distribution of the disaggregated flow of demand for goods and services directly related to the construction of the infrastructure over the 9-year construction period. Table 3.5 reports the corresponding flows measured in present value terms in 2025.

Table 3.4.: Annual flows of for the five macro systems (M€).

System/Year	2025	2026	2027	2028	2029	2030	2031	2032	2033	TOTAL
Site	9.9	22.6	149.0	188.0	188.0	255.8	158.4	22.0	8.5	1,002
Vacuum	16.8	22.8	19.9	29.9	32.1	89.4	111.4	111.4	63.3	497
Cryogenics	0.0	0.0	0.0	2.6	14.1	9.6	9.6	12.1	0.0	48
Suspensions	0.0	0.0	0.0	0.0	8.0	10.4	14.5	10.8	8.3	52
Optics	0.0	0.0	5.1	16.8	13.3	33.3	28.9	21.5	17.9	137
Total	**26.6**	**45.4**	**174.0**	**237.3**	**255.4**	**398.5**	**322.8**	**177.8**	**97.9**	**1,736**

Table 3.5.: Direct Impact of ET construction, annual flows for the five macro systems in Present Value terms (M€).

System/Year	2025	2026	2027	2028	2029	2030	2031	2032	2033	TOTAL
Site	9.9	22.0	141.6	174.1	169.8	225.3	136.0	18.4	6.9	904.0
Vacuum	16.8	22.2	18.9	27.7	29.0	78.7	95.6	93.2	51.6	434
Cryogenics	0.0	0.0	0.0	2.4	12.8	8.5	8.2	10.1	0.0	42
Suspensions	0.0	0.0	0.0	0.0	7.3	9.1	12.4	9.1	6.7	45
Optics	0.0	0 .0	4.8	15.6	12.0	29.3	24.8	18.0	14.6	119
Total	**26.6**	**44.3**	**165.4**	**219.9**	**230.7**	**350.9**	**277.1**	**148.8**	**79.9**	**1,543**

"Site" and "Vacuum" are the two most relevant macro-systems in terms of flows of demand. "Site" refers to costs of providing infrastructure to the observatory site, which are estimated at $1,002$ M€ over the nine years (904 M€ in PV terms). The costs include the value of transactions associated with the supply of materials and services for underground civil facilities, electricity and water distribution, and buildings and surface construction (ET Design Study, 2011). The costs linked with the Vacuum macro-system are expected to be equal to 497 M€

over the construction period (434 M€ in PV terms). This includes the value of technologies provided for the propagation of laser beams along the 10 km arms, such as vacuum pipes, pumping and control towers, and valves. The value of Cryogenics-related provisions is 48 M€, and it involves international providers of cryogenic technologies and equipment. The Suspensions system yields a total value of 52 M€, which measures the revenues generated for companies providing suspension technologies and systems and payload transport services. Finally, the Optics macro system has a direct impact of 137 M€, which measures the value of the procurements of high-quality optics, auxiliary optical systems, mechanical and electrical support systems, and laser systems.

Tables 3.6 and 3.7 give us the distribution of the other dimensions of the impact, i.e., value added and employment, over the construction period.

Table 3.6.: Time distribution of direct impact on Value Added (M€)

Year	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**TOTAL**
Impact in 2019 euro	9.7	17.0	63.0	86.0	93.3	145.4	117.5	65.4	36.4	**633.8**
Present Value in 2025 euro	9.7	16.5	59.9	79.7	84.3	128.0	100.9	54.8	29.7	**563.5**

Table 3.7.: Time distribution of the direct impact on employment (workers FTE)

Year	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**TOTAL**
Impact	155	270	1005	1372	1488	2318	1874	1043	580	**10,104**

b. Induced impact from the construction of the ET

According to the definition provided on page 43, the induced impact is defined as the value generated by two effects: (1) the increase in consumption of goods and services by the workforce employed by the contracted firms and (ii) the demand for intermediate goods and services by the contracted firms that will be met by other firms along the supply chain. Over the 9-year time span of the construction process, the estimates of the values of the two effects on TO sum up to 464.3 M€ and $3,983.9$ M€, respectively, where the first amount is the value of the impact induced by labour demand, and the second is the value of the impact induced by the transactions in goods and services other than labour, as reported in table 3.8. However, also in this case, since the induced impact is spread over a 9-year time span, we need to discount the annual flows (table 3.8), which leads to 412.8 M€ and $3,542$ M€ as the present values of the two above mentioned effects.

Table 3.8.: consruction on Total Output Overall Induced Impact of ET(M€)

Source of impact	In 2019 euro	Present Value
Labor	464.3	412.8
Goods and services other than labor	3,983.9	3,542.0
Total	**4,448.2**	**3,954.8**

Figure 3.3 shows how the induced impacts are distributed over the 9-year construction period. The effect is relatively moderate in the first two years; it rises above 10% from 2007 to 2009 and reaches a peak in 2030. From 2031 to 2033, the impact decreases as the construction process approaches its end.

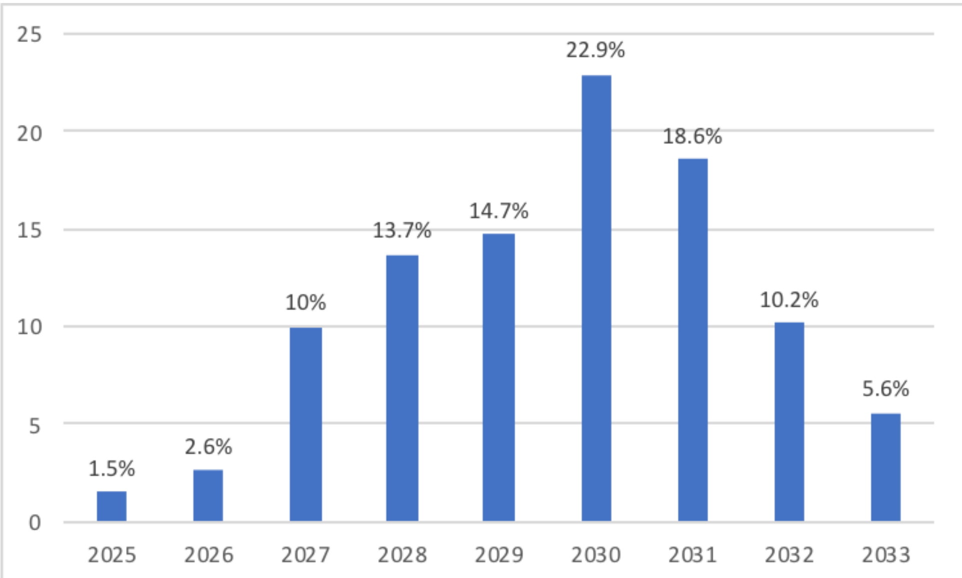

Figure 3.3.: Time span distribution of the induced impact (%)

b1. Induced impact from the construction of the ET: The role of labour income

To estimate the effects induced via the consumption of goods and services by workers, we proceed as follows. Data on labour income are derived from the estimates of construction costs provided by the ET conceptual design study. Specifically, the panel of experts consulted, as well as the experts of the construction company SWS, estimate 252 M€ of labour costs for the site macro-system (see appendix A.4). Accordingly, we take 252 M€ as the estimated value of the labour income earned by the workforce employed by the firms contracted for the construction of the ET. Costs for social security and labour taxes are estimated to be approximately 30%.

Moreover, labour income is partly spent on consumption and partly saved to finance future consumption. The estimated consumption marginal propensity rate of Italian families is a reliable proxy of workers' marginal propensity to consume. The most recent data available on the ISTAT website place this figure at 92.2% in 2018. When this value of the marginal propensity to consume is applied, the flow of overall aggregate consumption associated with the labour income generated by the construction phase equals 163 M€. Then, we assume that the value of consumption is distributed over different varieties of final goods and services according to the official basket of twelve goods and services provided by ISTAT, which allows us to estimate the level of consumption for each industry i of the twelve corresponding branches of economic activity (see appendix A.5). Industry multipliers are estimated by applying the Leontief I-O model to I-O tables. For the purpose of this study, the I-O tables used are those provided by ISTAT from 2014 national accounts that contain information on 63 industries (see appendix A.3). Then, by applying the multiplier to the consumption first order, we estimate the yearly gross-induced impact on each branch of economic activity. Finally, the sum of all these induced impacts across the 12 branches of economic activity determines the overall yearly gross induced impact on output produced by labour income generated during the construction phase. The overall sum of all these yearly effects net of first-order aggregate consumption delivers the estimate of the net or effective induced output effect of labour, which is equal to 464.3 M€.

Tables 3.9-3.11 show how the induced impacts associated with labour – in terms of total output, value added and employment – are distributed over time during the construction phase. When applicable, we also produce the estimates in present value terms to account for the fact that the effects are spread over the 9 years of the construction phase.

Table 3.9.: Time distribution of induced impact of labor on Total Output (M€).

Year	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**TOTAL**
Impact in 2019 euro	7.1	12.4	46.2	63.0	68.4	106.5	86.1	47.9	26.6	**464.3**
Present Value in 2025 euro	7.1	12.1	43.9	58.4	61.7	93.8	73.9	40.1	21.7	**412.8**

Table 3.10.: Time distribution of induced impact of labor on Value Added (M€)

Year	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**TOTAL**
Impact in 2019 euro	2.6	4.5	16.8	23.0	24.9	38.9	31.4	17.5	9.7	**169.4**
Present Value in 2025 euro	2.6	4.4	16.0	21.3	22.5	34.2	27.0	14.6	7.9	**150.6**

Table 3.11.: Time distribution of the induced impact from labour demand on employment (workers FTE).

Year	2025	2026	2027	2028	2029	2030	2031	2032	2033	TOTAL
Labour	41	72	269	367	398	620	501	279	155	**2702**

b2. Induced impact from the construction of the ET: the role of goods and services other than labour

The contracting of construction firms by the ET agency determines a ripple effect, as these firms demand intermediate goods and services themselves. The result is an increase in output, i.e., revenues, for a wide number of firms located at both the local, regional, national and international levels. Similar to the effect induced by labour income, this ripple effect is an induced economic impact. As before, the sector-specific multipliers are estimated by applying the Leontief I-O model to national input-output tables provided by ISTAT from 2014 national accounts with information on 63 industries (see appendix A.3). In this case, we expect that the procurement of raw materials, goods and services involves construction-related supply companies from 24 different industries. Since we do not have information on the composition of expenditure in each of the four macro-systems, we need to apply a more parsimonious model than that using 63 industries. Specifically, we estimate a "general" multiplier, which is the average of the 24 economic activities' multipliers chosen among the estimated 63 economic activities' multipliers from the input-output table (see appendix A.6). The 24 economic activities are selected on the basis of the information about the varieties of goods and services that the construction of the ET would require according to the 5 macro-systems described in the conceptual design study.

The average value of the multiplier across these industries is equal to 3.63 (see appendix A.6). Multiplying by 3.63 the annual flows of the direct effect net of goods and services, we obtain the yearly flow of induced impact, which is equal to $3,983.9$ M€. For the direct impact and the induced impact from labour, the induced impact from goods and services is also spread in the future over a 9-year time span. Hence, it is important to calculate the present value of the estimates in 2025 Euro – the first year of construction activities – and it is $3,542$ M€ (table 3.12).

Tables 3.12-14 show the time distribution of the induced impact from the demand for goods and services other than labour on total output, value added, and employment.

Table 3.12.: Time distribution of the impact of the demand of goods and Services other than labor on Total output (M€)

Year	2025	2026	2027	2028	2029	2030	2031	2032	2033	TOTAL
Impact in 2019 euro	60.9	106.6	396.1	540.8	586.5	914.1	738.9	411.3	228.5	**3,983.9**
Present Value in 2025 euro	60.9	104.0	376.5	501.1	529.8	804.9	634.3	344.2	186.4	**3,542.0**

Table 3.13.: Time distribution of of the impact of the demand of goods and services other than labor on Value Added (M€)

Year	2025	2026	2027	2028	2029	2030	2031	2032	2033	TOTAL
Impact in 2019 euro	22.3	39.1	145.1	198.1	214.9	334.9	270.7	150.7	83.7	**1,459.6**
Present Value in 2025 euro	22.3	38.1	137.9	183.6	194.1	294.9	232.4	126.1	68.9	**1,297.7**

3.3. ET: Economic impact at the operational stage

As in the case of construction, the operation of ET generates significant economic impacts through direct and induced effects associated with the demand for labour and for intermediate goods/services other than labour in terms of total output, value added and employment. The yearly flows associated with these effects are reported in tables 3.15-3.17. The corresponding overall values referring to an estimated operating life of 30 years are reported in table 3.18.

3.3.1. Direct impact of operation

According to the definition, the direct impact of the operating phase of the ET observatory is the effect on economic output associated with transfers of financial resources to pay employees' salaries (in exchange for labour services) and taxes as well the value of transactions associated with the demand for goods and services other than labour. The complexity and the highly specialized technologies that characterize the observator's daily activities are key determinants of the skill composition of human resources employed at the operating stage. Certainly, the infrastructure requires a consistent number of employees and highly skilled professional profiles. Therefore, labour costs constitute an important element of the annual budget of ET at the operating stage as well as one main element in determining the overall direct economic impact of the ET in the operational phase. As already mentioned, the estimated overall direct impact

Table 3.14.: Time distribution of of the impact of the demand of goods and services other than labor on Employment (workers FTE).

Year	2025	2026	2027	2028	2029	2030	2031	2032	2033	TOTAL
Labour	356	623	2.315	3,160	3,427	5,341	4,318	2,404	1,335	**23,279**

Table 3.15.: ET operating phase Total Output Impact per year (M€).

Source of impact	**Value**
Direct Impact	36.2
Induced Impact	91.3
Total	**127**

Table 3.16.: ET operating phase Value Added Impact per year (M€).

Source of impact	**Value**
Direct Impact	14.9
Induced Impact	33.4
Total	**45.3**

Table 3.17.: ET operating phase Employment Impact per year (Workers FTE)

Source of impact	**Value**
Direct Impact	188
Induced Impact	525
Total	**713**

Table 3.18.: ET Overall Impacts and present value (TO, VA, E) over the operating phase period 2034-2064.

Type of impact.	**Value**	**Present Value**
Total Output (M€)	3,824	2,711
Value Added(M€)	1,358	1,045
Employment (FTE workers)	21,390	

is 36, 2 M€ per year. The impact due to salaries amounts to 10.9 M€, while taxes contribute 330 K€ (table 3.19-3.20).

Table 3.19.: ET Employees Salaries per year. Our elaboration from EGO and LNGS data (€).

Professional profile	**Units**	**Average Salary per Unit**	**Impact**
Administrative	16	63,127	1,010,031
Researcher	18	63,614	1,145,059
Technologist	51	79,857	4,072,700
Technician	60	56,944	3,416,654
Associate Researcher	6	116,612	699,674
Temp - Technician	9	40,636	365,720
Temp - Researcher	3	66,200	198,600
Total	**163**		**10,908,438**

Table 3.20.: ET annual taxes. Our elaboration from LNGS data.

Taxes	
VAT and Taxes on imported goods	81,071.6
Stamp Duty	8,163.5
Vehicle ownership tax	3,362.0
Council Tax	2,268.0
Tax on waste	62,551.2
Tax on companies	61,793.6
Regional tax	88,496.1
Other taxes	22,264.3
TOTAL	**329,970**

The estimates shown in table 3.19 are inferred based on data from the two operating research infrastructure facilities based in Italy, the EGO and the LNGS. More precisely, the estimation of salaries is obtained by merging the available information about these two research facilities. The merging is conducted based on the expert opinion of physicists from the INFN to account for differences and similarities between these two existing infrastructure projects and the ET project.

For instance, in terms of professional profiles, the ET staff structure is likely to be similar to that of the EGO due to the analogies between the two research infrastructure facilities in terms of technologies being used and the research-related activities. However, the ET will be much larger than the EGO and located underground, which implies the need for a larger number of employees for the conduct and management of several daily activities. The structure of the staff that the ET will employ at the operating stage, in terms of skill composition and number of employees, is predicted by combining information based on experts' opinions and the EGO staff structure. Specifically, we use employment data from the EGO for the four years spanning 2014-2017. Since the facilities of the ET are larger than the EGOs', a scale factor is applied to the EGO to identify the size of the ET. The scale factor of each professional profile unit was estimated by using the information provided by the experts through the ad hoc designed questionnaire administered to the staff of the EGO, LNGS and INFN. Table 3.19 shows the outcome of the ET's employment structure estimates. The site is expected to employ approximately 163 people per year. The majority consist of highly qualified holders of human capital, such as researchers, technologists and technicians. For each professional profile, the annual salary is estimated according to the EGO's data. Since data were provided for four years (2014, 2015, 2016, 2017), the expected salary of ET staff is measured as the average salary of the mentioned years. The annual impact that ET employees' remuneration has on the economy is therefore quantified by multiplying the number of employed units from each professional profile by the average annual salary of the respective professional profile. The resulting overall impact is 10.908 M€ (table 3.19).

Taxes are the second effect of the direct economic impact associated with the operation of ET. They have a positive effect on public administrations' tax revenue, which then, in turn, has more financial resources to allocate for public services and investments. Table 3.20 summarises annual taxes that ET would pay according to the Italian tax system. The overall impact on administrations' revenue is approximately 330 K€. The estimate is based on the EGO data on annual taxes multiplied by a scale factor to produce the ET volume of taxation. For the employee salaries estimates, the applied scale factor is the outcome of an ad hoc designed questionnaire administered to the staffs of the EGO, LNGS and INFN.

The annual overall economic output effect of goods and services procurement is estimated from the LNGS and EGO accounting data on annual expenses in goods and services. A specific scale factor is applied to each value of the expense item of the combined data by the panel of experts from the EGO, LNGS and INFN to whom the ad hoc questionnaire was administered. For the estimation of salaries, the idea is to predict the volume of procurement transactions of the ET by using the information of the two research facilities that share similar technologies (the EGO) and facilities (the LNGS) to those that will characterise the ET. The resulting estimated impact is 25 M€ per year (see tables 3.21-3.22).

Table 3.21 lists the main categories of services that are required for the operating ET. Twenty-nine percent of the whole budget allocated for services is assigned for the maintenance of both buildings and equipment. The procurement of electricity, water and communication services is also a considerable source of expenses, with a share of 18.5%. Employee training and the refund of their missions expenses (travel and accommodation costs) account for 15% of annual services expenses, while the share of insurance and social security services for staff is 11%. Ten percent is spent on security and cleaning services. Other services include legal and technical consultancy services, canteen services, bank and post office services, and leasing of software and machinery.

Among the expenditures on goods, the largest portion relates to (i) materials needed for projects (29%), (ii) materials for maintenance (24%), (iii) materials for the functioning of machinery (19%), (iiii) IT equipment (13%), and (iiiii) new technological equipment (10%). The rest of the expenses cover the procurement of stationery, fuel heating, office furniture and expenses for events (table 3.22).

Table 3.21.: ET estimated services procurement transactions. Our elaboration from EGO and LNGS data (M€ and %).

Staff missions and training expenses	3.1	15.12%
Buildings and equipment maintenance	5.9	28.85%
Insurance and social security	2.3	11.27%
Legal and technical consultancy	0.9	4.54%
Security and cleaning	2.1	10.07%
Canteen	0.4	1.90%
Utilities	3.8	18.55%
Bank and Post Office	0.006	0.03%
Leasing of equipment and software	0.2	1.02%
Other services	1.8	8.60%
Total	**20.5**	**100%**

3.4. Induced impact

According to the definition provided on page 43, the induced impact at the operation stage is associated with the value of intermediate goods and services (IGS), including labour, demanded

Table 3.22.: ET estimated goods and materials procurement transactions. Our elaboration from EGO and LNGS data (K€ and %).

Machineries' materials	842	19%
Stationery	23	1%
IT Equipment	584	13%
Maintenance Materials	1,092	24%
Fuel Heating	112	3%
Office Furniture	3	0.10%
Expenses for events	62	1%
Expenses for projects	1,313	29%
Machineries	446	10%
Total	**4,478**	**100%**

by firms contracted by the agency or by any subcontractor along the supply chain and by the labour force working for/at the ET. For the construction phase, the induced impact of the operation phase is estimated using the Leontief input-output model. As shown in table 3.23, the overall estimated impacts on TO, VA and E are equal to 91.3 M€, 33.4 M€, and 525 FTE workers, respectively, per year.

Table 3.23.: Annual impact on TO, VA and E from Labour and Goods and Services.

Source of Impact	**Total Output (M€)**	**Value Added (M€)**	**Employment (workers FTE)**
Labour	20.1	7.3	116
Goods and Services	71.2	26.1	409
Total	**91.3**	**33.4**	**525**

The effect induced by labour is caused by the increase in the consumption of final goods and services due to ET employees' consumption. The majority of the employees of the ET, as well as their families, are expected to permanently live in nearby towns, such as Lula or Nuoro. They are likely to consume a large part of their labour income to buy commodities and services, thereby demand for various economic activities via a multiplier effect. This effect mainly impacts the economy at the local and regional levels. It is measured with input-output multipliers, which are estimated by applying the Leontief input-output (I-O) model. The annual aggregate income (Y) of ET employees equals 10.9 M€. Costs for social security and labour taxes are estimated to be approximately 30%. As previously mentioned, families tend to save a share of their income and allocate the remaining part for purchasing goods and services. The estimated marginal propensity to consume of Italian families is a reliable proxy for employees' marginal propensity to consume. We use the same estimate as for the construction phase, which is 92.2% according to the most recent data available on the ISTAT website, referred to 2018. Accordingly, applying this value of the marginal propensity to consume, the flow of employees' consumption, amounts to 7 M€. Industry multipliers are estimated by applying the Leontief I-O model to I-O tables. For the purposes of this study, the I-O tables used are those provided by ISTAT from 2014 national accounts that contain information on 63 industries (see appendix A.3). Then, we assume that the value of consumption is distributed over the official basket of twelve goods and services provided by ISTAT, which allows us to identify the level of consumption-driven demand induced in each of the twelve corresponding branches of economic activity (see appendix A.5). The sum of all the induced impacts across the branches of economic activity determines the overall gross induced economic impact produced by employee income generated during the construction phase. The estimated value is 27.1 M€. The effective net induced effect is calculated by subtracting workforce consumption from the gross induced economic impact. The overall estimate of this annual effect on TO is 20.1 M€, while it amounts to 7.3 M€ in terms of VA and 109 FTE workers in terms of employment.

The induced impact is also associated with the value of intermediate goods and services (IGS) demanded by firms contracted by the agency or by any subcontractor along the supply chain in relation to the operating activities. As we already discussed, the operating activities of ET, such as routine operation, use of research facilities, maintenance and upgrading of the infrastructure, require substantial procurement of goods and services. The economic impact of the related financial transactions constitutes the direct impact. This source of impact causes a further effect on the economy. The supplying companies – those directly involved in the procurement of goods and services for the operational activity of the ET – demand intermediate goods and services from other suppliers. This effect spreads along supply chains, thus generating an increase in the total economic output. This supply chain ripple effect triggered by the indirect impact constitutes the induced impact from the indirect impact and is measured with input-output multipliers, which are estimated by applying the Leontief input output (I-O) model.

The annual demand for intermediate goods and services of the ET operating phase aggregated across sectors amounts to 25 M€. Industries' multipliers are estimated by applying the Leontief I-O model to I-O tables as usual.[3] Then we assume that the value of consumption of goods

[3]The I-O tables used are those provided by ISTAT from 2014 national accounts that contain information on

and services is distributed over the related economic activities among the 63 industries in the national I-O tables. By multiplying the share of consumption of each economic activity by the respective estimated multiplier, we identify the level of consumption-driven demand induced in each of the 63 corresponding branches of economic activity. The sum of all the induced impacts across the branches of economic activity determines the overall gross induced economic impact produced by ET procurement of goods and services during the construction phase, which, net of the direct impact, amounts to 71.9 M€ in terms of TO, which corresponds to a VA of 26.1 M€. The annual employment effect amounts to 409 FTE workers.

3.5. Geographic distribution of impacts

The impacts generated by the construction process and the operation activities, expressed in terms of total output, value added and employment, take place at different geographic levels. To estimate the share of the impact for each geographic level – regional, national and international – we proceed by identifying the localisation of supplying companies that meet the demand for goods and services generated by the two phases of the ET project.

First, the construction activities would have a considerable effect on the hosting region of Sardinia. However, since they require specific high-tech inputs that are provided by only a few firms across Europe and overseas, the impacts should also spread beyond Sardinia at a global level. We expect that a share of $65\% - 75\%$ of the impact will mainly take place at the regional and national levels, which, over the 9-year construction period, corresponds to approximately $4,328$ M€ of total output and $1,584.5$ M€ of value added. This is mainly related to the impacts generated by the construction activities on the site that include the excavation and building of the tunnels as well as the construction of the surface civil facilities. We expect that a large part of these activities will be carried out by Sardinia-based contractors and sub-contractors that operate in the construction industry and related sectors, as seen in section 2. These activities are grouped within the Site macro-system of the conceptual design study and account for approximately 60% of the whole investment needed to build the ET; therefore, it is the main source of impact from the construction process. Moreover, the regional impact is also generated by the income consumption of the workforce employed in this process, as seen in section 3.2.2. The remaining ($25\% - 35\%$) part of the impact – about $1,855.3$ M€ of total output and 679 M€ of value added – is expected to spread globally, as mentioned above. This is related to the procurement and installation of the specific required technologies belonging to the Vacuum, Cryogenics, Suspensions and Optics macro-systems. The conceptual design

63 industries (See appendix A.3).

study mentions Australian and French companies as potential suppliers of the Vacuum system. Cryogenics providers are based in the USA, Japan and Switzerland, while inputs for the Optics macro-system could be provided by companies based in Germany.

Second, the operating activities will significantly affect the regional economy. The staff employed as well as the visiting researchers will, in large part, be formed by commuters from other Italian regions and abroad. Hence, a large part of their income will be spent outside Sardinia. Moreover, many goods and services required for daily activities will be purchased from companies based in Sardinia and a smaller part from companies located in Italy and abroad. Thus, we estimate that a share of $50\% - 60\%$ of the operating impact will remain within the hosting region of Sardinia, while the remaining $40\% - 50\%$ of the impact should spread across Italy and Europe. This means that Sardinia will benefit by approximately 70 M€ per year in terms of total output impact and approximately 25 M€ of value added per year, while approximately 60 M€ of output and 30 M€ of value added benefit other places in Italy and Europe. A large part of the regional impact is due to the procurement of goods and services – the direct impact, described in section 4.2 – and the related induced effect. Services that include utilities, canteen services, buildings and software maintenance, security and cleaning can be supplied by companies based in Sardinia, as shown in section 2. An important share of goods such as IT equipment, fuel, furniture and materials for maintenance can also be supplied by regional firms. We expect that hardware, software, technological machinery and the maintenance of such machinery will be provided by firms based in Italy or Europe. It is worth noting that these estimations aim to map the potential distribution of the economic impacts of the two phases, construction and operation, of the ET project. However, the geographic distribution of the economic impacts of investments in large research infrastructures usually varies according to political agreements between member states that support the project.

4. Social impact

The operational phase of large research infrastructure facilities also has an impact on social outcomes. In addition to its contribution to the advancement of knowledge in science and technology, the ET will represent an impetus to enhance innovative production processes. Moreover, research facilities may be pivotal to a process of technological transfer, innovation and human capital formation by generating systematic cooperation between research, education and businesses, fostering job creation and productivity enhancement.
Key to this process is the large international research community that the ET will attract to the area, which will include visiting scientists, associate researchers and PhD students, who will gravitate around ET and will use the research infrastructure to run their experimental programmes. In addition to the creation of a vast international scientific community, market spillovers may arise at the operating stage as well as during the construction phase to meet the required technical and scientific standards. The network of companies engaged in the provision of services along with the high-tech supply chain generates – as described in the previous sections - a multiplier economic effect, but it also promotes the build-up of new skills, with positive market spillover effects. Figure 4.1 represents the logical framework suitable to analyse the social impact arising from the operational activities of the Einstein Telescope observatory. Following the standard approach in the literature (Florio et al. 2016b; Florio and Sirtori, 2014), the evaluation of the social impact is carried out through proxies that account for the various activities carried out by the ET. These proxies are indicators of the technological externalities, human capital accumulation, value of knowledge, and services provided to external producers and consumers due to the existence of the ET.

Therefore, the overall assessment of the social impact emerges from the combination of quantitative and qualitative evaluation of the effects associated with the following dimensions (Rochow et al., 2011; JASPERS, 2013; Florio et al., 2016a; Florio and Sirtori, 2014; Dal Molin and Previtali, 2019; OECD, 2019):

i. Scientific impact

ii. Skills development

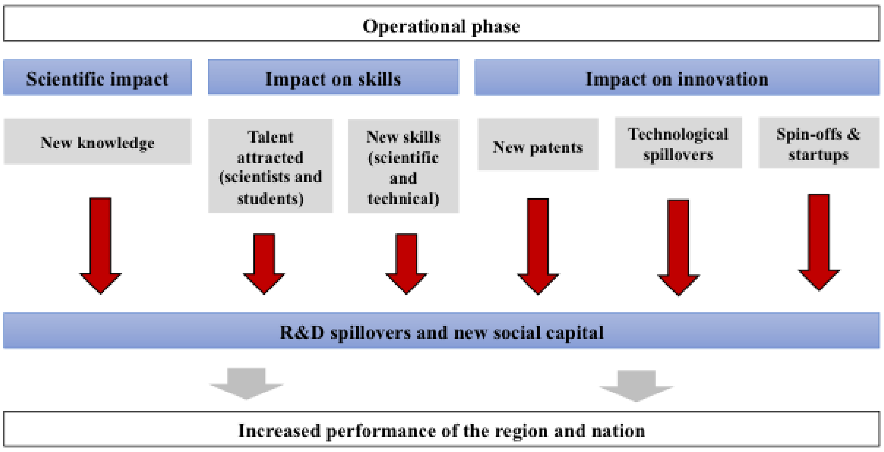

Figure 4.1.: Social impact breakdown

iii. Technological spillovers

iv. Scientific attractiveness

v. Other social impacts

For each dimension, excluding free local services, we provide a qualitative analysis as well as an estimate of the quantifiable part of the related social impact. Similar to the methodology we adopt for the valuation of the ET's economic impacts at the operational phase, we build our estimation of the social impact by taking into consideration the indicators acquired from the two operative Italian research infrastructure facilities (the EGO and the LNGS), as well as information gathered by administering a questionnaire to experts from the INFN. Table 4.1 shows the estimates of the part of the social impact that can be directly quantified using standard methodologies, as well as the level of each indicator, associated with the operating phase of the Einstein Telescope observatory.

In the following subsections, we provide an in-depth description of the key dimensions of the social impact and of the methodology used to estimate them.

4.1. Scientific impact

The ET will make a very significant contribution to the advancement of scientific knowledge in many related fields, as emerges from the qualitative and quantitative analysis we develop here. As the literature suggests (Martin, 1996; Pinski and Narin, 1976; JASPERS 2013; European Commission 2014), one empirical measure of scientific output is given by publications produced

Table 4.1.: Overall Social Impact over the period 2034-2064 (M€).

Type of impact	**Value**
Scientific Impact	147
Skills development	6.75
Technological spillovers	NA
Scientific attractiveness	92.5
Other social impacts	NA
Total	**246.25**

by research infrastructure researchers. A standard approach to evaluating the directly quantifiable part of the economic value of the contribution of the ET to new scientific knowledge is to estimate the number of scientific publications that will be produced at the observatory. It should be stressed here that this is only a fraction of the overall social value generated by scientific production related to the ET, as it represents a measure of the knowledge output and not the wider effects resulting from the publications' contents (Florio and Sirtori, 2014). Scientists and researchers will benefit from working at the observatory, as they will be able to access and elaborate new empirical data to contribute to the progress of scientific knowledge by producing reports, working documents and published scientific articles. The value of knowledge is comprised of two factors: the social value of a publication per se plus the "chain effect", i.e., the social value attributed the degree of influence of that piece of knowledge in the scientific community (Florio et al., 2016a).

Based on the information about the flow of scientific output generated by research infrastructure facilities that share similarities with the ET, such as the EGO, as well as from the panel of experts from the INFN, we estimate that over a time span of 30 years, the scientific community researching at the ET will generate a stock of scientific output equal to 13,500 publications.

In what follows, based on a standard approach in the literature, we estimate the part of value of the stock of scientific output of the ET related to the cost of the human resources employed to generate it. It must be stressed that this gives us a reference number that clearly significantly underestimates the overall economic value of scientific output, let alone its social value. This is because we do not consider the value of other inputs employed to produce the scientific output, and we only partially capture the externalities generated by the stock of new knowledge generated.

The time devoted by scientists to producing new findings and to publishing them in scientific

articles involves an opportunity cost because it could have an alternative application in other projects. We assume that this cost is equal to the hourly average remuneration of a scientist, which can be considered the marginal scientific cost born for scientific production. Accordingly, the directly quantifiable part of the social impact associated with scientific publication production is estimated by calculating the publications' marginal production cost, which includes the cost of labour involved in the production of scientific publications (Florio et al. 2016a). Because the quality of scientific output differs, it is necessary to weight the influence of a publication by multiplying its marginal production cost by an indicator that measures the influence of any given publication. The estimated average time spent by a researcher on a project is expected to be 60% of his work activity (teaching, administrative tasks, other research; Romano and Nicotra, 2016). According to expert opinions from the INFN members, the average annual productivity of a scientist is 15 scientific articles. The estimated annual average salary of a researcher employed at the ET will be 82.000 €. The marginal cost of a scientific article is measured by multiplying the average salary by the percentage of time dedicated to research activities, all divided by the annual average productivity of researchers.
To weight the degree of influence of a publication, we employ the average number of citations received by a publication. Taking the data on EGO and INFN researchers available on Google Scholar, we find that the average number of citations is 232. The same source of information is used to calculate the average number of cited articles in a publication, which is 100. The time needed to assess the publication and decide to cite it is estimated to be 1 hour. Therefore, the overall impact generated by scientific output is estimated at 147 M€ over the 30-year period of the operating activities (table 4.2).

Table 4.2.: Indicator of the Social Impact generated by Scientific Publication

Indicator		**Value**
A. Marginal cost of an article [(a1*a2)/a3]	a1. average gross salary per researcher	82,000
	a2. share of time spent on research activities	60%
	a3. average productivity of researchers (numbers of publications)	15
B. Number of publications ET 2034-2063		13500
C. Impact multiplier [c1*(c3/c2)]	c1. average of citations received	232
	c2. average of citations made	100
	c3. valuation time of a publication,(h)	1h
Total Impact (€) [A*B*(1+C)]		**147,009,600**

The above exercise captures part of the value of scientific output by focusing on the cost of the human resources devoted to scientific research at the ET. However, other inputs are involved in the research activity, including the value of all equipment and instruments used in experiments. Therefore, the estimates emerging from the quantitative analysis above do not reflect the full value of publications. Moreover, accounting for citations is not enough to capture all the externality effects that scientific output generated at the ET will have on the world-wide research community, as well as ultimately on the advancement of scientific knowledge. Hence, the true value of scientific output to society will be significantly larger than the quantitative value we estimate. It suffices to think of the contribution that research at the ET will have in terms of scientific progress in physics and astrophysics, as well as in terms of progress of the technologies used to operate the facility such as optics, data analysis software, laser machines, and control systems (from https://www.ego-gw.it/public/RD/list.aspx?ref=listyear=2003).

4.2. Skills development

Large research infrastructure facilities are considered fundamental boosters in human capital formation, as students and young researchers are directly involved in research activities, which offer them the opportunity to improve their competence. The ET will attract many PhD students, interns and junior researchers, often from abroad. These young researchers will acquire many skills during their stay at the ET, which will find practical application in careers outside scientific research. For instance, approximately 60% of students working at CERN eventually go into industry, according to Maiani and Bassoli (2012). There is evidence that research infrastructure facilities contribute to the training of young scientists and thus to the increase of human capital available to society (Florio et al., 2016). Several theoretical and empirical studies, such as those of Schulz (1961), Mincer (1974), Psacharopoulos and Patrinos (2004), and Blaug (1987), suggest that economic growth is enhanced by an increase in labour productivity due to education and training.

A standard approach to evaluating the effect of some policy on skills formation is to assess its impact on the wage schedule of treated individuals vs non-treated individuals. This is typically done by estimating the marginal effect of human capital formation on lifetime earnings with an econometric model, such as the one used by Mincer (1974), which takes into account schooling and training years.

In our case, we look at training only, and we assume that young researchers will gain additional salary thanks to their experience at the ET compared with their peers. The expected benefit for PhD students, interns and young researchers is represented by the premium obtained in their future salary due to the acquisition of new professional expertise during the stay at the ET.

The wage premium is given by two different components. The first is the effect generated by the marginal salary increase gained by a student who worked at the observatory over the counterfactual salary earned without the experience at the ET. The second effect is the increase in the probability of finding a position with a higher salary as a consequence of the training experience at the ET.

The social impact represented by the development of skills is thus defined as the wage premium gained by students who have work experience at the ET. According to the expert opinions from the INFN and EGO, the estimated annual average presence of students (PhD students, interns) is 100 people. On average, the categories considered spend 2 years at the facility, and we assume that they begin working as soon as they leave their position at the ET.
According to our estimates (see section 3.3.1), the annual average salary of a young researcher in Europe is 45,000 €. Based on Florio et al. (2016a), we expect the wage premium to be 5% for students who gain experience in a research infrastructure facility similar to the ET. Accordingly, the estimated social impact due to the training of human capital at the ET is 6.75 M€. Table 4.2 shows the methodology used to estimate this source of impact and the related estimates for the first 30 years of the operating phase. It is worth noting that 6.75 M€ is the effect on one year of salaries for each cohort of young researchers that will have work experience at ET over the 30 years in which we expect the ET to operate. Accordingly, the overall value should be obtained by multiplying 6.75 M€ by the expected duration of a lifetime career in physics, which should be no less than 30-35 years. Finally, this implies that the overall effect of ET on the development of skills for the part that is captured by the wage-premium effect should be over 230 M€.

Table 4.3.: Social Impact generated by the training of Human Capital. Our elaboration.

Indicator		**Value**
A. yearly N. students and postdocs at ET entering the job market		100
B. Annual salary premium [b1*b2]	b1. Avrage salary of young researchers (euro)	45,000
	b2. Salary premium	5%
C. Years considered (2034-2063)		30
Total annual impact (M€) [(A*B)*C]		**6,75**

It is worth noting that the above estimates do not capture the externality effects that skill formation has on society, as these positive externality effects do not translate into salary increases.

4.3. Technological spillovers

Since the seminal paper by Jaffe (1989), the existence of positive side effects stemming from collaboration between firms, research centres and universities has been empirically demonstrated. Positive spillovers of research infrastructures on other research centres and universities have also been documented in the literature. Recently, Helmers and Overman (2017) have found a positive correlation between the Diamond Light Source synchrotron in the U.K. and the productivity of academic research, together with a strong clustering of research-related activities near the infrastructure.

Concerning the ET, while the clustering effect is totally unpredictable and difficult to measure, we show that the share of the social impact represented by the benefit that high-tech providers experience by working and cooperating with ET employees is considerable. When a procurement contract for the research infrastructure facility is signed, it starts an intense collaboration process between the suppliers and the research infrastructure staff aimed at affectively designing, testing and manufacturing the required product or service. These efforts give firms the opportunity to learn something new (Florio et al., 2016b). Providers will have to find technical solutions to meet the demand of the observatory that contracts them. They will often provide ad hoc solutions not readily available in the market, customized to fit the exact needs of the contractor. Therefore, the opportunity for suppliers to work and cooperate with ET technicians and researchers generates an interaction that could greatly enhance their skills and knowledge and, therefore, their market value.

The learning-by-doing of suppliers benefits them through the improvement of existing equipment and machinery, production processes and the provision of new goods and services, which can also be demanded by other potential clients around the world. Such results were experienced by the companies that worked for the LHC project, as reported by Giudice (2010: 109). Moreover, knowledge spillovers, which allow firms to acquire new technologies and innovations, go beyond the providers affecting firms along the supply chain, as shown in the case of CERN (Florio et al., 2017).

Concerning ET, we expect that technological spillovers positively affect several dimensions that have already been studied for CERN by Autio et al. (2003), such as technological and market learning, international exposure, development of new products, openness to new markets, and establishment of new business units and new RD units. In this respect, a study on procurement effects on suppliers of large research centres (Dal Molin and Previtali, 2019) was carried out by the INFN, which administered a survey of 200 firms that provide goods and services for various research infrastructure facilities based in Italy. The results of the survey show that procurement favored three main dimensions: economic impact, learning and innovation, and the relationship with the market.

With respect to the economic impact, for $31,2\%$ of respondent companies, INFN procurement induced an increase in sales volume related to the new products or services developed. These sales increases may certainly come, at least partially, from the delivery of the order itself, but also likely originate from the sale of new products and services to other customers and in other

markets.
Regarding learning and innovation, the acquisition of new technical competencies represents the most significant benefit, followed by the improvement in market knowledge and the acquisition of managerial competencies. Thirty-eight percent of the suppliers reported developing new products since the collaboration with the INFN, and 44% recognized having experienced technological learning. For this specific case, the impact on patents, publications and the development of new products seems irrelevant.
Concerning the third dimension, i.e., the relationship with the market, it is clear that being an INFN supplier leads to an improvement of the company image and reputation, favors the acquisition of new clients, the entrance into new markets and the increase in market share. Forty-two percent of the respondents reported an increase in their international exposure, while 36% indicate an improvement in market learning and 17% an increase their openness to new markets.

4.4. Scientific attractiveness

Scientific attractiveness is an important element of the social value generated by large research infrastructure facilities. The geographic area where the observatory is located will attract a large number of people interested in visiting the facility, such as scientists, primary and secondary school students and university students. In addition, the site will likely host conferences, summer and winter schools, and public seminars as part of the program of outreach events and services, the aim of which is to inform the public of advances in science and technology. Moreover, the ET can be a destination for science tourism, with guided tours, special events, lectures and workshops. One of the standard approaches used to measure the social value of the attractiveness of research infrastructure facilities such as the ET is to measure the willingness to pay (WTP) to visit the site. The travel cost paid by each visitor to reach the infrastructure is the minimum WTP, as each visitor assigns a value that is at least as much as the value spent to reach ET (Florio et al., 2016a; Florio and Sirtori, 2014). Considering the average annual number of visitors to the EGO and LNGS, we estimate that the ET is expected to attract approximately 6,000 people per year as visitors for the aforementioned purposes. As shown in table 4.4, we also include travel costs by car for the visitors coming from Sardinia from a distance below 200 km (assumed to be 20% of total visitors) or by plane for those coming from outside the region, from more than 200 km away (80% of visitors). The estimated travel cost by car is 50 euros, while that by plane is 180 euros (table 4.4).[1]

[1]These costs have been estimated by administering a questionnaire to INFN researchers.

Table 4.4.: Differences in travel cost and % of visitors. Our elaboration.

Distance	**Transport**	**% of visitors**	**Cost of transport**
<200km	car	20%	50 euro
>200km	plane/ferry	80%	180 euro

Table 4.11 shows the methodology used to estimate the social impact of the attractiveness of the ET by using the amount of money spent on travel by the annual flow of visitors to the ET in Sardinia. The estimate is 92.5 M€ over the 30-year time span.

Table 4.5.: Indicator of the Social Impact generated by ET atractivity. Our elaboration.

<table>
<tr><th colspan="2">Indicator</th><th>Value</th></tr>
<tr><td colspan="2">A. number of annual visitors</td><td>6,000</td></tr>
<tr><td colspan="2">B. number of years (2034-2063)</td><td>30</td></tr>
<tr><td colspan="2">C. average number of days of stay</td><td>2</td></tr>
<tr><td colspan="2">D. daily average expense per visitor</td><td>180</td></tr>
<tr><td rowspan="4">E. annual expense on transport [(e1*e2)+(e3*e4)] = 924,000</td><td>e1. average travel expense by car per visitor</td><td>50</td></tr>
<tr><td>e2. number of visitors who travel by car</td><td>1,200</td></tr>
<tr><td>e3. average travel expense by plane per visitor</td><td>180</td></tr>
<tr><td>e4. number of visitors who travel by plane</td><td>4,800</td></tr>
<tr><td colspan="2">Total Impact (€) [(A*B*C*D)+(E*B)]</td><td>92,520,000</td></tr>
</table>

Moreover, it is worth considering that this cultural impact on the public also arises from participation in activities on social media, television audiences and website visits.

4.5. Other social impacts

In addition to the social impacts listed above, the literature also suggests some other effects that we have not estimated due to a lack of data or because they did not occur in similar research infrastructures such as the EGO and LNGS. However, it is worth mentioning them as they are related to the socio-economic context in which the research infrastructure is located, and therefore, they may occur in the case of Sos Enattos. More precisely, these effects include the increase of foreign direct investment (FDI), the production of spinoff firms, the value of patents, and free local services.

The construction and operating phases of a large research infrastructure facility can play a key role in the attraction of FDI to the region where the facility is located. The investments are mainly private and made by foreign company leaders in high-tech sectors that decide to open branches in proximity to the research infrastructure to exploit the market opportunities offered by the construction and operating activities (Romano and Nicotra, 2016). These companies' services and goods meet the research facility's needs that are not met by domestic suppliers, including the development of high-tech machinery and materials, communication systems, and so on.

Such projects are also pivotal in the creation of spinoff firms, thus increasing the social and economic value of the region. This effect is driven by both the market opportunities and highly innovative activities carried out at the research infrastructure facility (Rochow et al., 2011; Florio and Sirtori, 2014; Florio et al., 2016b; Romano and Nicotra, 2016; OECD, 2019).

The research activities conducted by scientists and researchers generate knowledge and innovation that can be protected by patents. This scientific output, as in the case of scientific publications described in section 4.1, widely affects the social dimension (Rochow et al., 2011; Florio and Sirtori, 2014; Florio et al., 2016b; Romano and Nicotra, 2016). The literature suggests that when a patent is registered, it produces a private return to the inventor and potential knowledge spillover to society. In the case of the ET, we do not have data on similar infrastructure facilities like the EGO (VIRGO) to estimate this impact. However, we cannot exclude this effect from occurring.

The last effect worth considering is that produced by free local services (Rochow et al., 2011; Florio and Sirtori, 2014; Florio et al., 2016b; Romano and Nicotra, 2016). This effect arises when the research infrastructure itself or the activities provide free services to the local area and community. In the ET's case, the construction of high-speed internet connections and high-quality electricity infrastructure (see section 2.5.7) will allow people and companies in the surrounding area to freely benefit from these infrastructures.

To conclude, it is worth mentioning that the local schools and regional universities will most likely be affected by the presence of the ET, thus having an impact on students, the scientific community and the skill level in the region. We expect that – as in the case of the EGO (VIRGO) in Tuscany – international schools will be set up for the children of the international employees of the ET that can also be attended by local students. The physics scientific community in the two Sardinian universities will surely increase, allowing the establishment of physics departments and programmes.

5. Environmental impact

The environment is the third dimension affected by the ET project. Both the construction and operating phases produce effects on the environment that need to be taken into account in our analysis. However, the negative externalities on the environment generated by the construction process as well as the operation activities are low, and above all, they are actually positive. In this section, we outline these effects for both phases of the ET project at Sos Enattos in Sardinia.

The construction phase of the ET, as mentioned in the previous section, involves large-scale activities mainly required to build the underground facilities (excavation and building of tunnels, caverns, shafts and roads) and, to a smaller extent, the overground facilities.

The underground facilities, which include tunnels, caverns, shafts and portals, are of large scale and will have an impact on the environment. However, the effects are moderate due to the specific features of the Sos Enattos site. The largest effect is produced by the excavation of tunnels that are 30 km long in total. According to the technical project of the ET-Sardinia team, the already existing underground infrastructure at Sos Enattos – mainly tunnels and caverns of the decommissioned mining site – are planned to be used as part of the infrastructure of the ET by restoring them. However, due to the size of the tunnels and their shape (see figure 5.1), a significant portion has to be excavated from scratch. This implies a large consumption of soil that actually will not significantly alter the environment, as the tunnels are approximately 200 meters below the ground level, and thus, the impact will not be negative. The main "issue" of this phase is represented by the high amount of soil to be removed during the excavations of the tunnels that has to be stocked or used. The team of engineers and geologists who worked on the technical design of the ET at Sos Enattos expects that the volume of soil extracted during tunnel excavation will be approximately 5.5 Mm^3. The composition of the materials of the excavations is not considered risky or dangerous by geologists because it is mainly formed by barren rocks of granite, quartzite, orthogneis, and mica schist. Consequently, the excavation materials (mainly sand, gravel, and small/medium blocks) can be used at the construction site to build roads and access tunnels as well as sold in the construction sector if refined or used for landscape restoration in nearby areas where the quarrying industry has a presence. The engineers and geologists expect that approximately 2.5 Mm^3 will be used in the construction of roads and tunnel accesses, while the remaining part (approximately 3 Mm^3) can either be sold in the market or used for quarries' restoration. We consider the last option as an opportunity to reclaim the surrounding area of Sos Enattos, where the quarrying industry is significant and changed the topography by damaging the hills of many areas, such as the important granite quarrying districts of Buddusò and Alà dei Sardi. Figure 5.1 shows the quarries (in red) located in the surroundings of Sos Enattos. Some of them are operative, but many no longer are, and deep excavation voids were generated during the period of maximum exploitation. We computed the volume capacity of the inoperative quarries that are located within a short travel distance to minimize the costs of transport as well as the emissions of trucks. At a maximum driving time of 50 minutes from Sos Enattos, there are 13 quarries that are not active, and their overall volume capacity equals 3.2 Mm^3, which is the total volume of spare materials produced by the excavation of the ET tunnels. These quarries are located to the north and east of Sos Enattos, precisely at Buddusò, Alà dei Sardi and Siniscola. As already said, we consider this impact to be an opportunity because the material is not risky, according to geological studies, and it is free, imposing no costs on those who will restore the quarries. Moreover, restoration works would have an economic impact that is mainly located in the area surrounding Sos Enattos. At this stage, we can estimate the direct economic impact related to the restoration of the closest dismissed quarries at approximately 64 M€. This estimate – which has already been included as part of the ET's economic impact in section 3 – is actually the estimate of the transport and restoration activity costs. The transport costs are estimated considering the fact that 70% of the excavation material is expected to be taken to the quarries of Buddusò and Sinscola (approximately 40 km from Sos Enattos) and the remaining 30% to the quarries of Alà dei Sardi (50 km from Sos Enattos). This information allows us to estimate the overall emissions caused by the trucks that will take the material to the quarries. We estimate that to deliver the whole amount of excavation material (mainly sand and gravel), approximately $204,000$ trips of one truck are required. This number is doubled to take into account the return to the construction site at Sos Enattos, that is, $408,000$ trips and $17,372,000$ km in total, considering that 70% will be to Buddusò and Siniscola and 30% to Alà dei Sardi. According to the information contained in the database of the 2017 Sardinia car fleet of the Ministry of Transport, the average CO2 emissions of a truck in the province of Nuoro is approximately 180 g/km. Therefore, the overall CO2 emissions are equal to 3.1 billion grams (that is, $3,127$ tons). To quantify these emissions in economic terms, we refer to the price of CO2 European Emissions Allowances[1], which is approximately 25€ per ton of CO2, on average, in 2019. Hence, the overall estimate of the cost of the CO2 emissions generated by the excavation material activi-

[1]https://ec.europa.eu/clima/policies/ets/auctioning$_i t$

ties is at approximately 79 K€ which shows that the environmental impact caused is negligible.

The overground infrastructure requirements are significantly smaller in comparison with the underground ones. The project does not require huge facilities and infrastructures at the ground level, as mentioned in the conceptual design study (control buildings, roads, access to tunnels and caverns). Moreover, at the Sos Enattos site, there are existing roads and facilities that used to be part of the now-inactive mining site. These facilities are planned to become part of the surface buildings and roads of the ET. Hence, the ET project aims to refurbish the old facilities, located at the chosen site, thus keeping the environmental impact at the surface low and actually producing positive externalities due to the restoration work on the roads and infrastructure of the area.

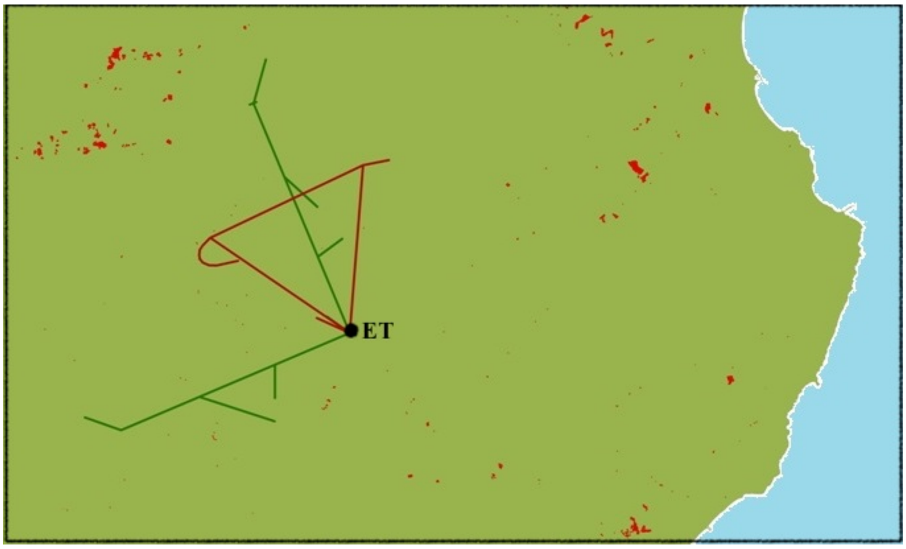

Figure 5.1.: Quarry sites in the surrounding area of Sos Enattos and the two potential configurations of the ET (triangular and L-shaped)

The environmental externalities caused by the operation phase of ET are considered very low and positive. The specific activities carried out at the ET and the machines used do not produce any kind of emission that damages the environment or the life of the nearby population. Moreover, the specific requirements of the technology used – low seismic activity including traffic and industry noise – will impose constraints on the whole surrounding area, thus preserving its environmental integrity from future projects (for instance, the building of certain factories or roads). These environmental constraints are certainly a positive externality that is line with the main economic activities of the area (agriculture and farms). These activities will not be negatively affected by the operation of the ET; in contrast, the environmental constraint described above protects their activities from future negative externalities.

A. Appendix

A.1. Interpretation: Power series representation and multipliers, m_j

The matrix A is a non-negative matrix with $a_{ij} < 1$, since we know that $\sum_j a_{ij} < 1$, because the sum of the nominal value of inputs from other industries used to produce one unit of nominal product in sector j cannot exceed one, as all production sectors produce non-negative added value, and they all use labour services aside from goods and services from other sectors. These two characteristics imply that

$$L = \lim_{n \to \infty} (I + A + A^2 + A^3 + ...A^n) \tag{A.1}$$

so that

$$X = I \times F + (A + A^2 + A^3 + ...A^n) \times F \tag{A.2}$$

which provides a meaningful economic interpretation in terms of the direct and induced impacts of an exogenous flow of expenditure F. This exogenous flow of expenditure F generates a direct effect on production measured by $I \times F$ and an induced impact measured by $(A + A^2 + A^3 + ...A^n) \times F$. This induced impact stems from the fact that the additional production due to the direct impact, $I \times F$, generates a corresponding flow of new demand of goods and services measured by AF, and so on according to a multiplier mechanism. Assuming we have only one aggregate sector, a flow f of additional expenditure generates an overall output effect equal to

$$x = \lim_{n \to \infty} (1 + a + a^2 + a^3 + ...a^n) f = \frac{1}{1 - a} f \tag{A.3}$$

A.2. List of sectors involved in the construction of the ET

1. Manufacture of wood products of wood cork, except furniture
2. Manufacture of fabricated metal products, excluding machineries
3. Manufacture of computer, electronic and optical products
4. Manufacture of electrical equipment
5. Manufacture of machinery and equipment n.e.c
6. Manufacture of motor vehicles, trailers and semi-trailers
7. Manufacture of other transport equipment
8. Repair and maintenance of machineries and devices
9. Electric power generation, transmission and distribution
10. Water collection, treatment and supply
11. Sewerage
12. Construction
13. Wholesale and retail trade and repair of motor vehicles and motorcycles
14. Wholesale trade, except of motor vehicles and motorcycles
15. Retail trade, except of motor vehicles and motorcycles
16. Water transport
17. Land transport services and transport services via pipelines
18. Warehousing and support activities for transportation
19. Financial service activities, except insurance and pension funding
20. Insurance and reinsurance, except compulsory social security pension funding
21. Legal activities; Accounting, bookkeeping and auditing activities; tax consultancy
22. Architectural and engineering activities; Technical testing and analysis
23. Rental and leasing activities
24. Security and investigation activities; services to buildings and landscape activities

A.3. Total output multipliers

Table A.1.: Total Output Multipliers per economic activity (1 - 32)

Output Industries Multipliers (1 - 32)					
Num.	**Economic Activity**	**Multiplier**	**Num.**	**Economic Activity**	**Multiplier**
1	Crop And Animal Production, Hunting And Related Service Activities	3.07	**17**	Manufacture Of Computer, Electronic And Optical Products	3.99
2	Forestry And Logging	3.37	**18**	Manufacture Of Electrical Equipment	4.52
3	Fishing And Aquaculture	3.55	**19**	Manufacture Of Machinery And Equipment N.E.C.	4.31
4	Mining Activities	2.94	**20**	Manufacture Of Motor Vehicles, Trailers And Semi-Trailers	4.53
5	Manufacture food products, drinks and tobacco	4.19	**21**	Manufacture of other transport equipment	4.23
6	Manufacture Of Textiles, Wearing Apparel, Leather And Related Products	4.17	**22**	Manufacture Of Furniture, and Other Manufacturing	4.10
7	Manufacture Of Wood & Products Of Wood & Cork, Except Furniture; Manuf. Of Articles Of Straw	3.96	**23**	Repair and maintenance of machineries and devices	3.80
8	Manufacture Of Paper And Paper Products	4.45	**24**	Electric power generation, transmission and distribution	3.97
9	Printing And Reproduction Of Recorded Media	3.92	**25**	Water Collection, Treatment And Supply	3.34
10	Manufacture Of Coke And Refined Petroleum Products	4.46	**26**	Sewerage	4.33
11	Manufacture of chemical products	4.53	**27**	Construction	3.82
12	Manufacture Of Basic Pharmaceutical Products And Pharmaceutical Preparations	3.97	**28**	Wholesale And Retail Trade And Repair Of Motor Vehicles And Motorcycles	3.62
13	Manufacture Of Rubber And Plastic Products	4.33	**29**	Wholesale Trade, Except Of Motor Vehicles And Motorcycles	3.30
14	Manufacture of glass, refractory, clay, porcelain, ceramic, stone products	4.07	**30**	Retail Trade, Except Of Motor Vehicles And Motorcycles	2.95
15	Metallurgy activities	4.99	**31**	Land transport services and transport services via pipelines	3.27
16	Manufacture of fabricated metal products, excluding machineries	4.20	**32**	Water Transport	4.09

Table A.2.: Total Output Multipliers per economic activity (33 - 63)

Output Industries Multipliers (33 - 63)					
Num.	**Economic Activity**	**Multiplier**	**Num.**	**Economic Activity**	**Multiplier**
33	Air Transport	4.96	**49**	Other Professional, Scientific And Technical Activities; Veterinary Activities	2.57
34	Warehousing And Support Activities For Transportation	3.53	**50**	Rental And Leasing Activities	2.94
35	Postal And Courier Activities	4.26	**51**	Employment Activities	4.13
36	Accommodation; Food And Beverage Service Activities	3.41	**52**	And Other Reservation Service And Related Activities	4.19
37	Publishing Activities	3.96	**53**	Activities; Services To Buildings And Landscape Activities	3.63
38	Motion Picture, Video & TV Programme Production, Sound Recording & Music Publishing Activities & Programming And Broadcasting Activities	3.65	**54**	Office Administrative, Office Support And Other Business Support Activities	3.14
39	Telecommunications	3.14	**55**	Education	3.51
40	Consultancy And Related Activities	3.36	**56**	Human Health Activities	3.35
41	Financial Service Activities, Except Insurance And Pension Funding	2.79	**57**	Residential Care & Social Work Activities	3.81
42	Insurance and reinsurance, except compulsory social security & Pension funding	2.98	**58**	Creative, Arts And Entertainment Activities; Libraries, Archives, Museums And Other Cultural Activities	3.43
43	Activities Auxiliary To Financial Services And Insurance Activities	2.74	**59**	Sports Activities And Amusement And Recreation Activities	3.64
44	Real estate services	1.38	**60**	Activities Of Membership Organisations	3.95
45	Legal activities; Accounting, bookkeeping and auditing activities; tax consultancy	2.55	**61**	Repair Of Computers And Personal And Household Goods	3.07
46	Architectural And Engineering Activities; Technical Testing And Analysis	2.52	**62**	Other Personal Service Activities	2.71
47	Scientific Research And Development	3.51	**63**	Activities Of Households As Employers Of Domestic Personnel	4.84
48	Advertising And Market Research	3.78			

A.4. Labour incidence in construction costs

Table A.3.: Labour Income incidence on overall construction phase costs (SWS colloquium)

Labour cost incidence on system Site costs (M€)			
Item Description	**Total cost**	**Incidence min/max**	**Average Cost**
Main Tunnel excavation	320	15%-30%	72.1
Auxiliary Tunnel excavation	126	15%-30%	28.2
45 pumping/bake-out areas	120	15%-30%	27.1
Shafts	177	15%-30%	39.8
Main Caverns	28	15%-30%	6.4
Satellite Caverns	59	15%-30%	13.3
Control buildings	109	30%-40%	38.2
Roads	9	30%-40%	3.2
Cooling and ventilation	53	40%-50%	24.0
TOTAL	**1002**		**252**

A.5. Families' consumption distribution: Sector data

begintable[h!] Families consumption distribution

Families consumption distribution in 2018, ISTAT (%)		
Categories of goods and services purchased by families	**Families expenses distribution**	**Matching Economic Activity**
Food and beverage	17,8%	5
Alcohol and cigarettes	1,8%	5
Clothes and footwear	4,7%	6
Accommodation, water, electricity, gas	35,0%	24
House forniture	4,3%	22
Health services	4,8%	56
Transport	11,3%	31- 32-33
Communication	2,5%	39
Leisure and cultural activities	5,1%	58
Education	0,6%	55
Hotels and restaurants	5,1%	36
Other goods and services	7,1%	42 - 18 - 43 - 44 - 45 - 46
TOTAL	**100%**	

1.6. Average multiplier related to induced impact from goods and services: sector-level data

Table 1.4.: Average Multiplier relative to Induced Impact from Goods and Services

Num.	Economic Activity	Multiplier
7	Manufacture Of Wood & Products Of Wood & Cork, Except Furniture; Manuf. Of Articles Of Straw	3.96
16	Manufacture of fabricated metal products, excluding machineries	4.20
17	Manufacture Of Computer, Electronic And Optical Products	3.99
18	Manufacture Of Electrical Equipment	4.52
19	Manufacture Of Machinery And Equipment N.E.C.	4.31
20	Manufacture Of Motor Vehicles, Trailers And Semi-Trailers	4.53
21	Manufacture of other transport equipment	4.23
23	Repair and maintenance of machineries and devices	3.80
24	Electric power generation, transmission and distribution	3.97
25	Water Collection, Treatment And Supply	3.34
26	Sewerage	4.33
27	Construction	3.82
28	Wholesale And Retail Trade And Repair Of Motor Vehicles And Motorcycles	3.62
29	Wholesale Trade, Except Of Motor Vehicles And Motorcycles	3.30
30	Retail Trade, Except Of Motor Vehicles And Motorcycles	2.95
31	Land transport services and transport services via pipelines	3.27
32	Water Transport	4.09
34	Warehousing And Support Activities For Transportation	3.53
41	Financial Service Activities, Except Insurance And Pension Funding	2.79
42	Insurance and reinsurance, except compulsory social security & Pension funding	2.98
45	Legal activities; Accounting, bookkeeping and auditing activities; tax consultancy	2.55
46	Architectural And Engineering Activities; Technical Testing And Analysis	2.52
50	Rental And Leasing Activities	2.94
53	Security And Investigation Activities; Services To Buildings And Landscape Activities	3.63
Average Multiplier		**3.63**

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