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Geo-spatial accounting for the socio-economic impacts of megaprojects: Towards operationalization of Megaproject Social Responsibility

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ABSTRACT

Megaprojects are crucial to address the current challenges of climate change and sustainability. Despite the growing interest in Megaproject Social Responsibility, there is still a lack of accounting protocols, standards and frameworks so widespread to monitor the short, medium, and long-term impacts megaprojects may generate both on local territories and communities. This work presents an original geospatial accounting protocol for megaprojects to monitor and assess the generated impacts during all the life cycle phases, from the initial planning and design to the construction and use phase. The proposed protocol includes a three-step methodology - definition of relevant indicators and aspects, 2) identification of a counterfactual territory, and 3) comparison of trends - and six macro areas - from socio-economic impacts to cultural identity preservation or the governance of sustainability. The protocol has then been applied to a relevant highly contested megaproject, i.e., the Turin-Lyon high-speed railway in Italy, to highlight the pros, cons, and limitations of such protocol. This work represents a first development and test of a geospatial accounting application for megaprojects and it can support future policies and managerial decisions, as well as it represents a highly scalable and reproducible operationalization approach for Megaproject Social Responsibility.

1. Introduction

Megaprojects, defined as *"large-scale, complex ventures that typically cost US$1 billion or more, take many years to develop and build, involve multiple public and private stakeholders, are transformational, and impact millions of people"* by Flyvbjerg (2014, p.6), represent the backbone of every developed society. However, their construction, management, and operations could generate unprecedented impacts on societies and on the environment (Thacker et al., 2018). Such construction works can last for decades, greatly impacting the affected areas and generating potential problems for local populations. In many cases, megaprojects can be part of the infrastructural territorialization of a country (Lesutis, 2021), as a state-imposed form of order and organization-making through infrastructural development, which however does not come free of tensions and struggle. Moreover, the mapping, measurement, and evaluation of the social and economic impacts generated by the construction of megaprojects are activities less-known and explored in the literature than the processes needed for measuring environmental impacts (Vanclay et al., 2015). At the same time, the dissemination of methods of socio-economic impact assessment of megaprojects is also quite fragmented in professional practice, in addition to the unevenness within regulatory systems, which shows a great discrepancy among different countries. Furthermore, there is no unique protocol or framework on how to monitor and account for impacts on large geographical areas and for a long period of time (up to several decades), including what impacts should be monitored and how to responsibly communicate these effects, all adding to the open debate. Specifically, studies presenting cases where the functioning and effectiveness of social impact assessment is actually demonstrated are still rare. Building on this, in this paper we present the development and application of an experimental methodology for assessing and measuring economic and social impacts, in the context of a highly contested transportation megaproject, which sits at the core of the future European sustainable mobility network. This megaproject is currently under construction after a long stalemate, and its construction should last for at least another decade.

In the last decade, megaprojects gained momentum in the academic debate, both in terms of pure project management (Turner and Xue, 2018; Flyvbjerg, 2017b; Pollack et al., 2018; Wang et al., 2022), but also for the extent and the responsibility of the generated impacts on the societies involved (Zhou and Mi, 2017; Lin et al., 2017). The process of

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determining proper stakeholder management and accounting strategies during all project life-cycle phases - from the planning, design, and construction to the use and End of Life (EoL) phases - is essential to reduce large negative impacts on local communities and territories, as well as to avoid the upsurge of conflicts (Corazza et al., 2022a; Olander, 2007; Winch, 2017). According to Vanclay et al. (2015), the process of social impact assessment should be open, reliable, and should follow a multistakeholder orientation. This especially holds true for projects with a high degree of complexity. Megaproject management, indeed, is intrinsically a multistakeholder, multilevel, and multidimensional activity, with very high complexity (Nyarirangwe and Babatunde, 2019), which still needs to be disentangled. First, it must involve a large variety of (affected) stakeholders, whose interests must be taken into account (Kariyawasam et al., 2019). Stakeholders may range from local communities and citizens (Di Maddaloni and Davis, 2017), up to large public bodies, such as the European Commission (Esposito et al., 2022). Second, it is multilevel, as it refers to the scale and lifespan (time) that vary from the local to the international level, and from short-term impacts during the construction phase, to long-term impacts and effects during the use phase (Zidane et al., 2016; Sierra et al., 2017). Finally, it is multidimensional, because the generated impacts, whether positive or negative, include the three pillars of sustainability, as well as other relevant aspects related to megaproject governance (Thacker et al., 2018). Thus, project complexity should necessarily be addressed from the planning and earlier phases (Collard et al., 2023) to the operating and dismantling phases (OECD, 2019).

On top of these premises, in recent years the concept of Megaproject Social Responsibility (MSR) is emerging globally to address potentially large negative impacts generated by megaprojects, especially during the construction phase (Ma et al., 2020). Such negative megaproject outcomes typically represent the root of citizens' protests and consequent delays during the construction phase (it must pointed out that protests represent one of the main reasons, albeit not the unique one, for the famous *"iron law of megaproject"* of Flyvbjerg (2017a)).

Therefore, this study aims to fill this research gap, namely the lack of a robust accounting protocol for the socio-economic impacts of megaprojects, by addressing the following research questions:

1. How can the social responsibility of megaprojects be operationalized? What are the main characteristics and methodological steps of a socioeconomic impact accounting protocol to assess the impact of megaprojects at the geospatial level?
2. How can the infrastructural territorialization effect of megaprojects be assessed?

Hence, this study applies a social and environmental accounting and reporting logic, a perspective that is herein the business and management scientific field (Gray, 2001), and proposes a novel and original accounting protocol for megaprojects, also discussing its application to a relevant and purposefully chosen cross-border case study (Stake, 1995) between France and Italy, the Turin-Lyon high-speed railway (HSR) megaproject (Esposito et al., 2022). The proposed methodology is based on three main steps (1. the definition of indicators and areas, 2. the identification of a counterfactual territory, 3. a comparison of trends) and a general protocol (it includes six macro areas, from the governance for sustainability to socio-economic aspects and local cultural identity preservation). The protocol represents a novel approach to support decision- and policy-makers to transparently account for current and future impacts, as well as how to wisely involve and engage local communities during earlier phases (i.e. planning and design phase).

In this work, we discuss the methodological steps adopted to evaluate the impact of a megaproject over time on a local geographical area, also by comparing the affected territory with an ad-hoc chosen counterfactual territory, which acts as a control group. Then, a trends comparison is performed on a core set of selected indicators, with the aim of identifying the main features of the analyzed areas, and how these characteristics can be impacted by a megaproject. This step is done by looking at the affected territory against the counterfactual area. The framework is programmatic, and looks at megaprojects longitudinally, collecting and analyzing data during the *ante operam*, *inter operam* and *post operam* phases. Coupled with the counterfactual analysis, this is crucial to account for impacts that signal how the megaproject affects the area over time, and how certain phenomena are instead endemic to the territory.

The novelty of this work is two-fold, as the concept of social responsibility in megaprojects is somewhat still in its infancy. First, it represents one of the first applications of sustainability accounting in representing ecosystem impacts generated by a megaproject with a geospatial reference. Second, the study accounts for the socio-economic impacts of the Turin-Lyon high-speed railway in Italy, a megaproject that has been, and still is, under a fierce debate and strife since the early 1990s. Specific findings and results from the case study are discussed, to highlight the positive features of the proposed methodology, as well as its limitations.

The rest of the paper is structured as follows. Section 2 presents and summarizes current literature on megaprojects and sustainable infrastructure, the environmental and social impacts of megaprojects, and the emerging trends related to MSR. In section 3, the originally developed protocol and methodology are presented in detail, focusing on the methodological steps and implications, as well as on the description of the selected and analyzed case study. In sections 4 and 5 the findings and results are summarized, highlighting pros, cons, and limitations of the methodology. Section 6 closes the papers presenting future trends for further studies.

2. Background and literature review

2.1. Megaprojects and sustainable infrastructure

Megaprojects are a subset of all infrastructures necessary for the development of every society, and represent the cutting edge of innovation in the construction sector. Despite raising great interest from both academics and practitioners, most studies related to megaprojects focused on their critical success factors and performance (Cepeda et al., 2018; Rolstadås et al., 2014), and on how to deal with their managerial complexity (Nyarirangwe and Babatunde, 2019) through the development of ad-hoc and innovative project management approaches (Sandhu and Khan, 2017; Randeree, 2014). Strictly speaking, megaprojects include a wide range of temporary projects - e.g., Olympic Games (de Lima et al., 2022) - or fixed large infrastructures - e.g., new airports, railways or highways, industrial facilities (Damayanti et al., 2021) - and, due to their critical role in society, they are experiencing the *"biggest boom"* in the last decades (Ma et al., 2020). The OECD (2019) estimated that in the next two decades more than 90 USD trillion will be invested in infrastructure (which is more than the total investment recorded to date). However, despite the growing debate on sustainable development and sustainability practices in general, megaprojects and sustainable infrastructures, until now, have only touched each other tangentially (Corazza et al., 2022a). This has likely happened because megaprojects still seem to remain closely tied to the "iron triangle", to innovation and the four sublimes - technological, aesthetic, political and economic - as defined by Flyvbjerg (2014).

Due to their scale and size, megaprojects may affect, both in the short- and in the long-term and both positively and negatively, entire regions and large communities (Lesutis, 2021), as well as potentially impacting on climate change globally. OECD (2019) estimated that about 60 % of global greenhouse gas emissions derive from the infrastructure and construction sector). While the "iron triangle" of budget, scope and schedule has been one of the most adopted frameworks against which megaproject success (or, in many cases, failure) should be assessed (Lehtonen, 2014), several studies have then focused the attention on other issues, especially concerning the *social* aspect of megaprojects. Lehtonen (2014) argues that megaproject evaluations have suffered from 'pathologies' deriving from failing to stick to the iron triangle and calls for more reflexivity and learning-oriented evaluation approaches. To do so, Lehtonen invites us to look at the conditions under which projects can actually succeed, instead of pointing fingers to why they might fail. The scholar stresses that diversity in megaprojects might also mean that the iron triangle is not applicable in the same way on every project. Dimitriou et al. (2013) echo this by suggesting that success should be defined holistically, by taking into account the various forces at play during all phases of megaprojects' life-cycle, therefore looking at 'social, political, economic and institutional aspects' (p.4). Volden and Welde (2022) contend that evaluations should be conducted *ex ante* and *ex post,* and that the same criteria should be used for determining the success or failure of the projects. While stressing again the narrow focus of the iron triangle, they also emphasize the difference in perspectives among various stakeholders for what determines a successful (public) megaproject, calling for valuation perspectives such as sustainability (all three pillars. social, economic, and environmental aspects), good value for money and how the decision maker sees the projects in terms of its goals. Turner and Xue (2018) assess megaproject success in terms of short-term outputs and outcomes and long-term impacts, including all three pillars of sustainability.

According to the Inter-American Development Bank (2018), sustainable infrastructures are not simply green infrastructures, but they should be defined within the framework of the sustainable development concept; in other words, they should be *"planned, designed, constructed, operated, and decommissioned in a manner to ensure economic and financial, social, environmental (including climate resilience), and institutional sustainability over the entire life cycle of the project"* (p.11). In this sense, it seems clear that, for environmental impact assessments, it is necessary to also consider socio-economic impacts, although these are very different from those on the natural/ecological environment (Thacker et al., 2019). Considering impacts not only as potential risks or to ensure appropriate compensatory measures, but also as aspects to be monitored for the creation of positive impacts, requires that those implementing megaprojects feel institutionally responsible. The concept of MSR will therefore be discussed below.

2.2. Megaproject social responsibility

As briefly mentioned, the concept of developing sustainable infrastructures (Corazza et al., 2022a) is embedded in the formal recognition of social responsibilities within the different life stages of a megaproject (Ma et al., 2020). Taking into account the scale and the potentially dramatic and permanent impacts of megaprojects (Lin et al., 2017), the concept of Megaproject Social Responsibility (MSR), has gained importance among academics and practitioners in the last decade. According to Zeng et al. (2015), it consists in the *"policies and practices of the stakeholders through the whole project life cycle that reflect responsibilities for the well-being of the wider society"* and integrate the three pillars of sustainability. Strictly speaking, MSR is the straightforward evolution of Corporate Social Responsibility (CSR), from an organizational level to the (mega)project scale (Corazza et al., 2022b).

While CSR provides a solid theoretical basis for assessing the social responsibility of major infrastructures (Zeng et al.,2015), Ma et al. (2017) contend that, so far, there is still a wide discrepancy in focus between CSR and MSR, with the latter being a more intricate subject, affected by the complexity and dynamism of megaprojects, as well as by the different levels of social responsibilities that megaprojects carry. MSR is therefore more dynamic than CSR, because megaprojects evolve considerably during their life-cycle, in terms of participants and social and environmental issues. Zeng et al. (2015) call for such issues to be addressed systematically, rather than focusing on just one aspect of social responsibilities. Zhou and Mi (2017), after reviewing the existing megaproject literature, list six main responsibilities within MSR: ecological, economic, environmental, ethical, legal and political. Similarly, Ma et al. (2020) provide different dimensions to MSR: economic and quality, legal and regulatory, environmental and ethical, political and communal. In both cases, the scholars emphasize the central role of stakeholder involvement and engagement towards a sustainable development of the megaproject.

Thus, similarly to most recent CSR practices, recent MSR literature posits that the boundaries of the generated and analyzed impacts should be expanded to, first, all primary stakeholders - e.g. contractors, subcontractors, suppliers, private or public local institutions and organizations - and, secondly, to all other stakeholders, including all local communities and citizens directly, or indirectly, affected by a megaproject. This is particularly relevant because, as said above, MSR is not only a matter of financial performance (hence simply related to an economic accounting practice), but it includes a wider set of social responsibilities. This is generally the case, as the organization in charge of the construction of a megaproject is usually directly commissioned by public funding (from national governments or the European Union for instance) (Scherer and Palazzo, 2011). Therefore, accounting activities should be planned not only with respect to short- and medium-term financial and economic outputs and performance, but also including long-term impacts, both at the local and the national/international scale (since most megaprojects have an international outlook and scope). However, although scholars generally agree on the need for geo-spatial accounting protocols, there are still few research studies proposing effectively an operationalization of such protocols or standards for megaprojects. Within the MSR framework, for instance, Lin et al. (2017) proposed an indicator system that first traces, akin to other literature, the main dimension of MSR (legal, social, ethical and environmental, economic and political responsibility), but then provides a large list of indicators considering aspects, among others, such as quality and safety of workers, protection of the local community environment and technology innovation and progress. Zidane et al. (2016) put forward a project evaluation framework, acting at the strategic, tactical and operational levels, and differentiating project success and impacts in output, outcome and long-term impacts (similarly to Turner and Xue (2018)). Mostafa and El-Gohary (2015) develop a semantic system for transportation megaproject and infrastructure by mapping dozens of different stakeholders and the corresponding potential social, economic and environmental benefits for them.

Several studies conducted previously, also analyzed megaprojects' stakeholders with an *outside-in* (in contrast with an *inside-out* approach, as previously described) point of view (i.e. the impact of stakeholders on megaproject performance) by looking at, for instance, how NGOs counter-accounting activities may affect megaprojects' performance (Hamman, 2016). In this sense, the concept of *double materiality*, also recently introduced by the European Union as a fundamental concept in non-financial reporting and in CSR, should be central in future studies regarding MSR and megaprojects' impact assessment. The concept of *double materiality*, namely the impacts generated by a megaproject (*inside-out*) and the relationship between external stakeholders and a megaproject (*outside-in*) recalls for an analysis of the existing interlinkages existent among a megaproject, its place-based boundaries and the actual and potential impacts of that work on the short and long run over the entire area. For that reason, it could be argued that mapping and accounting for impacts at a territorial level could be fundamental in representing the *infrastructural territorialization* (Lesutis, 2021) invoked for sustainable megaprojects.

2.3. Towards a geo-spatial accounting approach

Geo-spatial accounting is widely used for a broad range of analysis, such as the evaluation of GHG emissions and carbon accounting (Adams and Opoku, 2020; Barrett et al., 2013), the sustainable development of a territory (Musa et al., 2019), or population dynamic (Bhaduri et al., 2007). The mapping, measurement, and evaluation of the social and economic impacts generated by the construction of megaprojects are activities less-known and explored in the literature than the processes needed for measuring environmental impacts (Vanclay et al., 2015). In Vanclay et al. (2015), the so-called social impact assessment management cycle covers a wide timeframe spectrum of the project development, clearly starting from the identification/exploration stage, to the end of the work. According to this view, assessment and monitoring are crucial in the feasibility, construction and operations phases (Esteves and Vanclay, 2009; Franks and Vanclay, 2013). Current literature is presenting studies on the identification of typology of impacts (Lin et al., 2017), and on the applicability of management systems, such as the social life cycle assessment framework on large-scale transportation infrastructure (Yang et al., 2022). Other studies are emerging on the role of stakeholders in weighing indicators (Collard et al., 2023) related to short and long-term impacts (Sierra et al., 2017).

Regarding megaprojects and methodologies for the quantitative assessment of impacts, recent studies propose a few experimental methodologies, which mainly focus, but not exclusively, on environmental impacts. For instance, Nourelfath et al. (2022) use the Input-Output tables to assess the socio-economic impact on the national economy of a new large oil and gas power plant in Kuwait. Cristiano and Gonella (2019) propose a system thinking and energy analysis to evaluate the environmental impact generated by the expansion of a highway in Italy. Destyanto et al. (2017) assess the *social cost of carbon* of a new power plant in Jakarta, Indonesia. Although various past studies applied different methodologies to account for the environmental, social, and economic impacts of megaprojects, previous studies show a lack of specific protocols (despite the large lists of indicators already existing, as described in previous paragraphs), and their operationalization (in terms of a robust and standardized methodological approach), for geospatial accounting of such impacts. Moreover, due to the intrinsic complexity and the required effort, there are no comparable studies that develop and test a method for the assessment of the socio-economic impacts of megaprojects, which show their impacts over the different life-cycle phases (including, potentially, depicting the situation before the planning phase of the megaproject, to the end of the construction works and the decommissioning). Regarding the scientific literature on megaprojects, the work of Coskun et al. (2023) goes in a similar direction, but the intent of their paper is more on managing sustainability risks than accounting for real impacts. The only similar experience recently extended to megaprojects is the Envision certification system, which could represent a way to guarantee a proper level of sustainability for complex projects that is not always applicable, especially for ongoing constructions (Diaz-Sarachaga et al., 2016).

3. Methods

This work is based on a qualitative-quantitative mixed method (Johnson and Onwuegbuzie, 2004) and aims to propose and test an experimental geospatial accounting protocol for the socio-economic impacts of megaprojects, to further expand and improve existing methodologies and standards in terms of social and environmental impact assessment (SEIA), both for the academic community and practitioners. At the European level, for instance, existing Directives explicitly require an Environmental Impact Assessment (EIA) for several infrastructure types -including long-distance railway, among others - according to the directive 2011/92/EU (European Parliament and Council, 2011) and further amendments (European Parliament and Council, 2014). Although such Directives and European Guidances (European Union, 2017) already include compulsory steps for EIA, such as public consultations, mandatory assessments of alternatives, evaluation of mitigation and compensation, and monitoring measures, existing procedures are mainly focused on environmental and health aspects, rather than adding social and cultural aspects, and on the evaluation of alternatives, rather than comparison with similar territories. For these reasons, the expansions and improvement of existing approaches is necessary by including mandatory geo-spatial analysis, as well as counterfactual comparisons with territories not affected by the construction of an infrastructure, to be used as reference territory and basis for the evaluation of socio-economic impact of a large infrastructure. Hence, we propose a novel methodology for socio-economic impact accounting consisting of three main steps:

1. *The definition of relevant and material aspects and indicators*, aimed at identifying the most noteworthy and relevant socio-economic impact categories of the analyzed territory.
2. *The identification of a counterfactual territory* (not directly affected by the megaproject), necessary to compare the territory affected by a megaproject and to evaluate similar or dissimilar trends, common causes and to identify any possible impact category, aspect and dimension that is independent of the megaproject.
3. *A comparison of trends* between the affected and the counterfactual territory, aimed at specifically comparing the two areas with respect to a few composite socio-economic dimensions represented by several indicators.

In next subsections, first, the case study and, second, the protocols will be presented by explaining the details of each step, and then the details of the application to the case study will be provided. Since it is not possible to present and explain all the details of the present protocol, we refer the reader to the full explanation of the methodology submitted to the Italian Ministry for the Environment.[1]

3.1. Case study: The Turin-Lyon high-speed railway

3.1.1. A historical overview

The public debate about the construction of the Turin-Lyon High-Speed Railway (HSR), which aims to connect Italy and France more efficiently, started during the 1990s. The Turin-Lyon megaproject, as part of the Trans-European Transport Network (TEN-T) within the Mediterranean Corridor, specifically includes the longest tunnel in the world, 57.5 km (45 km in France and 12.5 km in Italy). At the beginning of the 1990s, a first technical Committee was formed by several public and private actors - from the Turin Chamber of Commerce and the Municipality of Torino to the Industrial Union of Turin or the FIAT group (today Stellantis) (Manfredi et al., 2015). The long-term aim of the Turin-Lyon HSR, as part of a larger European political vision, was, and still is, to reduce transportation carbon dioxide emissions, shifting the traffic of goods and people to trains, instead of less environmentally friendly means of transportation, such as trucks and planes (Marincioni and Appiotti, 2009). Since the beginning, the Turin-Lyon HSR megaproject has been highly debated and contested by local communities, public administrations and institutions (including local mayors) of the Susa Valley (the Valley affected by the construction) in Italy, for several reasons. Among others, the main issues were related to eventual wrong predictions in the increase of goods and commodities international transportation, and to environmental concerns on the construction of such a long tunnel. Specifically, criticism emerged at the end of the 1990s and at the beginning of the new millennium about the presence of toxic and radioactive materials, such as asbestos and uranium, below the mountains in the Susa Valley (Fornero et al., 2005). The megaproject also received political and economic criticism for the purported lack of real benefits and for wasting billions of euros of public funds, as well as for marginalizing local communities and institutions during the decisional process in the planning phase (Armano et al., 2013; Tartaglia, 2012; Marincioni and Appiotti, 2009). On top of these premises, the NO TAV (Italian acronym for high-speed railway, "Treno ad Alta Velocità") movement emerged (Leonardi, 2013). The social resistance grew especially in the first decade of the 2000s, to coincide with the first round of

[1] https://va.mite.gov.it/it-IT/Oggetti/Documentazione/7450/10766?pagina=3

land expropriations in Italy, and after the public declaration of the exploratory tunnel opening (and consequent expropriations), in the area of Venaus. On December 8th, 2005, more than 30,000 people reconquered the expropriated lands, leading to the megaproject plan being rediscussed at the national level (Leonardi, 2013). Moreover, the Italian Technical Observatory was created in 2006 as a multi-stakeholder observatory, with the aim of establishing a more democratic dialogue around the Turin-Lyon HSR, directly involving local stakeholders (Italian Government, 2020). During the first years, hundreds of audits were carried out, and in 2007 a new path and route for the HSR was proposed to obtain EU funding. Despite the creation of the Observatory, the proposal was contested once again, due to a lack of participation and joint public debate (Debernardi and Grimaldi, 2012).

3.1.2. The last decade

Although the establishment of the Observatory has helped restarting the dialogue with parts of the population (Marincioni and Appiotti, 2009), it is argued that, as early as 2008, it became a governance body, instead of an open forum (Ariemma and Burnside-Lawry, 2016). In 2009, it was declared that the new construction site would be set up in the town of Chiomonte, sparking a new wave of protests that peaked in 2011, when the No TAV movement occupied the site of La Maddalena, establishing the "Free Republic of the Maddalena". The occupancy of the site only lasted for a brief period, due to the consequent intervention of the Italian army and police forces (Ariemma and Burnside-Lawry, 2016). The construction site was consequently declared as a military area, patrolled and surveilled 24 h a day (Burnside-Lawry and Ariemma, 2015). Since then, and until 2021, a few evolutions occurred, in terms of social movements and construction progress. In 2015, TELT was founded as the new company in charge of the construction, and in 2018 the Italian government commissioned a Cost-Benefit Analysis for the megaproject, while in 2021, following a public announcement to open a warehouse and interport for the excavated materials in the small town of San Didero, protests began again.

At the time of writing this paper, the construction work is ongoing, but the social and environmental concerns of the local population are still underrepresented, and manifestations and soft riots still periodically occur.

3.1.3. A brief description of the valleys

The Susa Valley is the largest (over 80 km long and with a surface of 1200 km^2) and most populated (about 90,000 people) Piedmontese valley. The valley is in the west part of Turin, and it borders with France, whose connection is further facilitated by the Fréjus Rail Tunnel, as part of the Bardonecchia-Modane line. While the valley takes its name from the town of Susa (in the High Valley), its epicenter is Avigliana, with its famous lakes and industrial vocation. The High Valley is famous for winter tourism, and towns like Cesana, Sestriere, Sauze d'Oulx and Bardonecchia are attractive skiing locations, and have hosted numerous competitions during the 2006 XX Winter Olympic Games. On top of this, the valley has several lakes, parks and nature reserves.

The Chisone Valley, used in this study as the counterfactual territory, is another Occitan alpine valley in Piedmont and borders the Susa Valley to the north and east. It starts in Pinerolo and it ends in Sestriere, a town that is shared between the two valleys considered in this study. It is smaller than the Susa Valley, with a surface of 380 km^2 and a population just short of 20,000. The Chisone valley also gives its name to the main torrent that drains its waters: the Chisone, which runs through its entire length. The valley has its epicenter in Pinerolo and, like the Susa Valley, it is a ski destination, especially in Sestriere and Pragelato, which also hosted competitions during the aforementioned 2006 Winter Olympics. Tables 1 provides a list of all the towns considered in this study for each valley.

Table 1
Composition of the Susa and Chisone Valley.

Valley	Town
Susa Valley	Almese, Avigliana, Bardonecchia, Borgone di Susa, Bruzolo, Bussoleno, Buttigliera Alta, Caprie, Caselette, Cesana Torinese, Chianocco, Chiomonte, Chiusa di San Michele, Claviere, Condove, Exilles, Giaglione, Gravere, Mattie, Meana di Susa, Mompantero, Moncenisio, Novalesa, Oulx, Rosta, Rubiana, Salbertrand, San Didero, San Giorio di Susa, Sant'Ambrogio di Torino, Sant'Antonino di Susa, Sauze di Cesana, Sauze d'Oulx, Sestriere, Susa, Vaie, Venaus, Villar Dora, Villar Focchiardo.
Chisone Valley	Fenestrelle, Inverso Pinasca, Perosa Argentina, Pinasca, Pinerolo, Pomaretto, Porte, Pragelato, Pramollo, Roure, San Germano Chisone, Usseaux, Villar Perosa

3.2. Protocols and methodology

Fig. 1 shows the generic overview of the developed methodology, including details about the three main steps, while Fig. 2 shows the various methodological steps of the data collection process, by detailing the decision-gates necessary to select which indicators were relevant, which needed qualitative or quantitative measures and other aspects.

3.2.1. Definition of relevant aspects

The very first two steps (on the top-left box of Fig. 1), i.e., *"Review of scientific literature and Benchmark analysis of megaprojects"* and *"Definition of macro areas and indicators"*, consist of a literature review (both scientific and gray) and a benchmark process of relevant and similar megaprojects, aimed at identifying all relevant dimensions and indicators for the subsequent data collection and analysis steps. Before the data collection step, all indicators need to be labeled according to relevant aspects, such as the geographical area for the data (site, city/town, entire area), life cycle phase (ex-ante, construction phase, and ex-post), and main aspects (context, sustainability, socio- communication, construction site). Consequently, in the data collection and validation process, the initially identified indicators need to be tested and validated (prior to the data collection step itself) thanks to experts" interviews and focus groups (see last two boxes in top-row in Fig. 1). Details about the data collection process are provided in Fig. 2. Basically, it consists of a reiterative procedure where selected indicators were validated by experts' interviews and data availability. First, the materiality and relevance of the data need to be tested through interviews and/or focus groups, then the quantitative data need to be collected (if available). In the case that the corresponding quantitative data is not present, corresponding qualitative data have to be defined. For these steps, interviews must be intended as a participatory and engagement process where competent experts and stakeholders, both internal and external, must be engaged to obtain available datasets and to validate the collected data. In other words, stakeholders' opinions must be considered as a Boolean answer, i.e., yes/no, to evaluate if a particular indicator represents a meaningful criterion (See Fig. 2). A similar approach should be adopted both for internal – managers of the organization in charge of the megaproject – and for external indicators (primary or secondary stakeholders of the organization).

3.2.2. Identification of a counterfactual territory

Although megaprojects are very diverse (Lehtonen, 2014), they often run the risk of instrumentalization and political demagogy by proposers and opposing parties. Hence, it is very important to assess trends across different areas and determine potential causality, as similar phenomena might not be necessarily associated with the megaproject. For instance, a decrease in tourism might occur across different areas, rather than being the (negative) outcome of the megaproject settlement in a territory. Therefore, testing the indicators counterfactually is a pragmatic and prudential way to act towards potential megaproject impacts, which might not be univocally attributable to it. Specifically, the *identification*

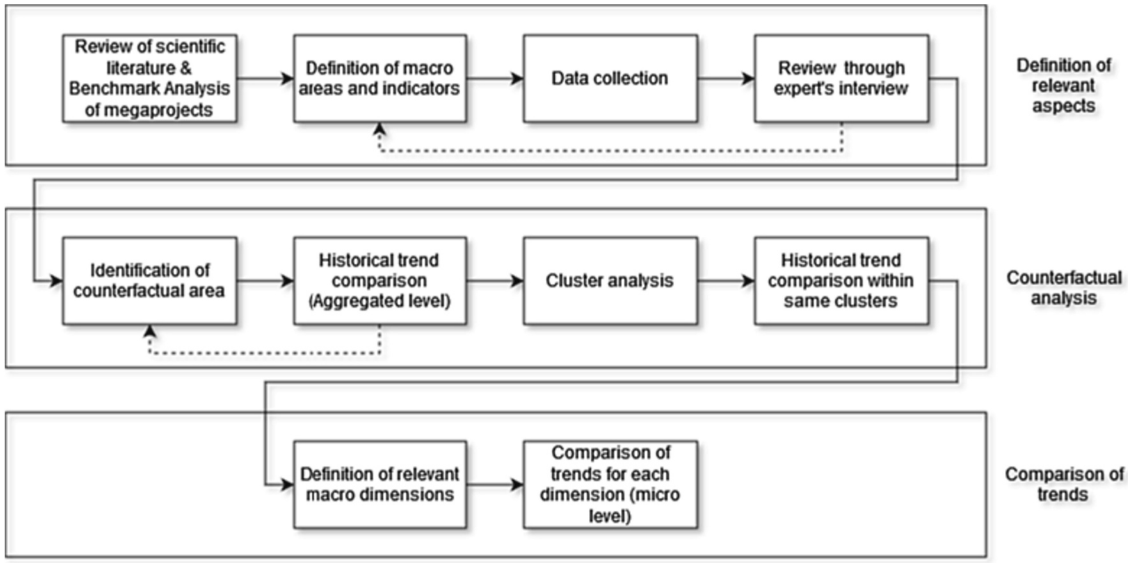


Fig. 1. Overview of the protocol and the methodology.

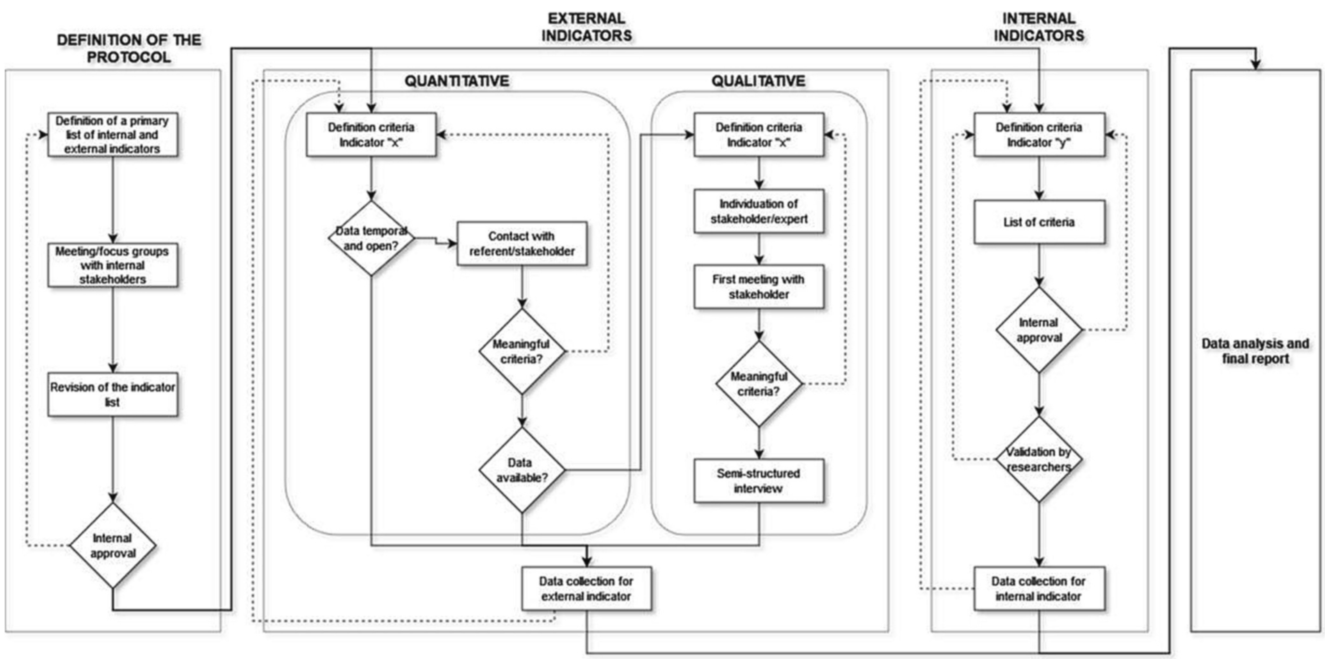


Fig. 2. Overview of the data collection process.

of a counterfactual territory step consists of a four-step process (see the central box in Fig. 1). First, a few proposals for similar geographical areas (similar to the one affected by the analyzed megaproject) need to be qualitatively revised, in terms of generic socio-economic characteristics, to identify the most proper and similar ones. Second, the two areas - i.e., the affected and the counterfactual ones – should be compared in terms of trends with respect to the identified indicators, by considering different granularities (depending on the indicator, data availability, relevance, and/or other considerations) from the whole affected area to sub-areas such as small towns, neighborhoods, etc…). The goal of this step is not to find a perfect counterfactual area, but rather to analyze any potential difference and similarity between the two selected areas and to, eventually, dismiss certain specific aspects in the analysis. Third, once a proper counterfactual area is identified, a cluster analysis should be performed at the most relevant scale and level (e.g. town, neighborhood, km2, …) including the affected and the counterfactual territory and all the identified indicators. For instance, for a megaproject that affects an entire geographical area (e.g. a valley) of dozens or hundreds of square kilometers, the counterfactual analysis may be performed at the level of single small towns; on the contrary for a smaller megaproject (e.g. an airport or a stadium) that may impact smaller areas, the right granularity may be up to a single neighborhood, or even smaller area. Such considerations may vary and change according to the megaproject under analysis.

3.2.3. *Comparison of trends*

Finally, the trends (e.g., *ante operam* or *post operam*) for single entities belonging to the same cluster, should be analyzed to identify similarities and differences between the affected territory and the counterfactual one(s), aiming to figure out potential impacts of a megaproject. After the identification of different clusters of areas (e.g. cities, neighborhoods), all those falling within the same cluster (e.g. the most similar cities) need to be compared both in terms of slopes (past growth or decrease), to evaluate eventual existing trends for certain indicators, and in terms of macro socio-economic phenomena through, for instance, a multi-criteria decision analysis, to evaluate specific snapshot in time (at a specific year). To do so, first, "macro dimensions" should be defined to aggregate different indicators and variables under the same group (e.g., social capital, vocation of the territory), and second, for each group of indicators, a comparison between the territory affected by the megaproject and the counterfactual one should be performed. The analysis could be done by adopting different approaches and methodologies, such as a multi-criteria decision analysis (Norese et al., 2021; Coskun et al., 2023), linear regression analysis or any other combination of most proper techniques.

3.3. Application to the case study

3.3.1. Definition of relevant aspects

The very first two steps represented on the top-left box of Fig. 1, drawn on Corazza et al. (2022b), consist of the analysis of 44 scientific articles and 11 megaproject reports, worldwide distributed. The review process output was the definition of two main sections (socio-economic and socio-communication), ten macro-areas[2] and more than one hundred indicators. Then, the indicators were labeled according to the geographical area for the data (construction site, city/town, entire area), life cycle phase (ex-ante, construction phase, and ex-post), and main aspect (context, sustainability, socio- communication, construction site). After this preliminary phase, *ante operam* data - i.e. data referred to the planning phase - were collected, for a period of ten years before the initial year of construction, according to the procedure shown in Fig. 2. The same process is adopted both for external (external to the company in charge of the construction) and internal indicators.

At the end of the elaboration process, the final phase of the development of the experimental protocol has included a consultation, during which the researchers shared with the extended community of stakeholders the structure and the rationale of the work done. This step provided the chance to get feedback on the main process, from the community beyond the scientific one. Table 2 showsthe list of the events and main participants included.

Once the data collection process was finalized, the second step is related to the identification of a counterfactual analysis.

3.3.2. Identification of a counterfactual territory

According to Fig. 1, the first step for the counterfactual analysis is the identification of a proper geographical area with similar size, socio-economic characteristics and composition (in terms of numbers of cities and their size). As already briefly introduced, the need to compare the variables used on a valley with similar socio-economic characteristics to the one on which the megaproject construction work stems from determining the causality of the impacts to the megaproject itself. Some socio-economic phenomena are not directly attributable to the megaproject or cannot be confined within the perimeter of the construction sites. Therefore, at this stage of the method, a comparison with a counterfactual valley was employed to increase the degree of judgment about causality, i.e., the imputation of a phenomenon to the generating cause, i.e., the megaproject. For example, the loss of real estate value of houses in an area may have depended on the inconvenience of residents caused by construction work, or it may be completely disassociated.

Table 2
Events organized with external stakeholders to validate the protocol.

Date of the event	Main representatives	Duration	Number of participants
21 July 2020	Istituto Superiore per la Protezione e la Ricerca Ambientale, Ministry of Environment and Energy Security, Regional Agency for environmental protection, Prefecture of Turin area	1,50 h	14
21 December 2020	Piedmont Region, Regional Agency for environmental protection, Chamber of Commerce, National Bureau for Statistic (ISTAT), Politecnico di Torino, Entrepreneurial associations, Bocconi University	3 h	91
25 January 2021	Piedmont Region	1,50 h	65
24 March 2022	Italian Rectors' Conference (President), TELT, University of Turin (representatives)	1 h	10
18 May 2022	Piedmont Region representatives, Italian Technical Committee for Environmental Impact Assessment, Representative of the Italian Ministry of Environment and Energy Security	1 h	20

Having a comparison area is helpful in assessing the rapidity, magnitude, and size of any recorded phenomenon.

The identified counterfactual area is the Chisone Valley, a geographically bounded Valley in Piedmont with similar socio-economic features. Following the methodology described in the previous sub-section, the two areas (the affected one and the counterfactual area) are compared in terms of *ante operam* trends with respect to 27 indicators (context and construction site indicators). The comparison is done considering the whole area, as well as two sub-areas, the high and low valleys, to give a better overview and to highlight the different vocation of the two territories (mainly touristic and rural the medium-high valley, mainly industrial and with bigger towns the low valley). The full list of indicators is provided in Table 1 in Appendix A.

The two areas, then, are compared and analyzed, with respect to each indicator, according to the following procedure:

1. R^2 coefficient was calculated to verify the eventual linear trend (if any)
2. A linear regression was carried out with corresponding calculation of the angular coefficient (positive, stationary, or negative)
3. t-student test with null hypothesis H0 to check if an effective positive/negative trend (not constant) was present
4. Comparison of the two identified slopes (one per area) via t-student test with null hypothesis H0 to check the statistically significant difference between the two slopes.

A significance level of $p = 0.05$ is adopted in both t-student tests. The test is carried out for every aspect reported in Table 3 and for several normalized/weighted indicators (e.g., No of students / No of high schools, No of agricultural enterprise / Agricultural usable land area, …). All considered and evaluated normalized indicators, and their corresponding rationale, are summarized in Table 2 in Appendix A.

Among others, the following aspects are investigated: well-developed tourism in the high valley (mainly related to skiing activities), small-medium size towns in the medium valley (related to forestry and agriculture), and medium-large size towns with a propensity to industrial activities. To check for similarities between the two valleys (Susa and Chisone), the historical trends for the past 10 years (from 2012 to today) are compared and analyzed, as described in the methodological section. Table 4 in Appendix B summarizes the linear trends (if any) and the main considerations for several indicators and aspects.

[2] 1. Health and safety in the workplace and for the local population, 2. Relational capital with the territory, 3. Governance of sustainability, Economic impact on the territory, 5. Impact on population mobility, 6. Promotion of the territory and its cultural and identity capital, 7. Civic culture, 8. Information sources, 9. Social representations, 10. Values associated with the work

Table 3
Indicators analyzed at the city level.

Dimension	Sub-dimension	Indicator and Description
Economic	Economic Vocation of the territory	usable agricultural area
		vineyard area
		forest companies / total companies
		No. of tourists
	Economic health	company turnover / total companies
		net profit / company turnover
		new VAT activations
		active companies / total registered companies
		registered companies / total population
Social		% indigent (income less than 10,000€)
		real estate value (residential housing)
		total associations / total population
		population 65+ / total population
		population 0–6 / total population
		Population Density

Data without a historical trend are evaluated on the basis of the situation in 2020, according to available data, highlighting in absolute terms (e.g., number of start-ups created) or in relative terms (normalizing or weighing other considerations) any difference between the two valleys. As it emerges from the comparison, the two valleys present similar socio-economic trends. In either valley, the number (and the percentage) of low-income people constantly decreased over the last ten years, while the number of active NGOs (proxy of the relational capital of a territory), both civil protection and social and health NGOs, increased over time. Regarding specific productions, instead, the two areas present a decreasing number of enterprises and agricultural land, related to the wine sector, while the wood industry activities increased over time. With respect to construction site indicators, namely aspects that may be directly affected by the megaproject, unemployment decreased in both valleys, while the number of registered companies increased over the whole period. Similarly, the agricultural enterprises and usable agricultural areas (UAAs) increased in Susa Valley, while the trend in the Chisone Valley is not linear. On the contrary, the company turnover decreased in both valleys, while the real estate value (for civil houses and luxury ones) constantly increased (following a more general national trend). Finally, in terms of population and age composition, the population and its density constantly increased. Concluding, the two compared territories present similar historical trends, with minimal differences, mainly due to non-linearity in certain trends. The general overview can be summarized into a generalized improvement of wealth (decrease in unemployment, increase in the number of enterprises) and relational capital (increase in the number of civil protection and socio and health NGOs) of both areas. On the contrary, the economic vocation has shifted from agriculture to the wood industry, while the cultural capital (the number of cultural associations) is decreasing over time.

Once the counterfactual area is identified, a cluster analysis at the level of the individual towns is performed by using two clustering algorithms, the k-means (Sinaga and Yang, 2020) and the hierarchical k-means (Qi et al., 2017) to provide robustness of results. The cluster analysis, at this stage, aims at identifying the counterfactual towns for every city directly affected by this megaproject. When the identified clusters are too big (more than 10 cities), a second cluster analysis is performed on the results derived from the first cluster algorithm. The right number of clusters is identified by using the elbow plot (Syakur et al., 2018). The elbow plot is a widely adopted technique in cluster analysis that qualitatively shows the optimal number of clusters by evaluating the "*Total Within Sum of Square*", i.e. the distance between points belonging to the same cluster (that must be minimized). Cluster analysis is performed according to the specific indicators summarized in Table 3 in the Supplementary Materials. Only data and indicators with a historical continuity in both areas are chosen. To perform the cluster analysis, absolute indicators and variables are used (e.g. total population, enterprise turnover), rather than weighted/normalized ones (e.g. enterprise turnover / No of enterprises), to allow the clusterization of cities with a similar size, and to avoid false-positive results (e.g. a cluster with medium-large cities and smaller ones but with similar economic performance).

3.3.3. *Comparison of ante operam trends*

The socio-economic phenomena are defined according to Table 3, to highlight specific territorial aspects, such as local production and tourism or economic growth and wealth. In this case, the phenomena are defined, among others, with normalized and weighted indicators, to highlight specific aspects. Three main phenomena are analyzed: 1) economic vocation of the territory, 2) economic health, and 3) social aspects (i.e., population and relational and social capital). The procedure adopted to compare linear trends among different cities is the same described in the previous section, for the comparison of the entire area. Due to the limited number of indicators, the multi-criteria comparison is done by giving priority to single indicators and excluding a direct comparison (when the classification based on top-ranked indicators was unclear). Whenever a specific type of production (e.g., wine production) is different between two cities, the result is highlighted and described to policymakers, but not considered in the overall comparison.

4. Results

4.1. *Identification of a counterfactual territory*

Fig. 3 shows the results of the first clusterization based on the indicators defined in Table 3 of the Supplementary Materials for the year 2020. Similar results for the year 2012 (the starting period for our historical analysis) and for the hierarchical k-means clustering algorithms are reported in the Supplementary materials in Appendix C (see Figs. 3, 4, 5, 6, 7, 8). The right number k of clusters is identified by using the elbow plot (See Fig. 1 in Appendix C). The different compositions for different values of k are reported in Fig. 2. From the cluster analysis six main clusters are identified. The main cluster composition is summarized in Table 4. Basically, two outliers, the towns of Pinerolo and Avigliana, are correctly separated from the others because of their larger size, both in terms of population and industrial activities. The other four clusters, instead, are grouped according to the territory's vocation and economic wealth. First, the higher valley towns, with a tourist vocation (predominantly skiing areas) and without a large number of agricultural activities, are grouped together. Second, the medium-high valley towns focused on tourism, wood and agricultural activities, but without a stronger vocation in a specific sector. Third, the medium valley towns, with a strong vocation towards agricultural and wood industry activities, but without a relevant touristic presence, and finally the lower valley towns, which focus on industrial activities with a larger population. Finally, a second clustering algorithm is run by selecting only the municipalities within cluster 4 (yellow), i.e., the one which includes the small town of Chiomonte.[3] Thanks to the second clusterization, the corresponding counterfactual town - i.e., Pomaretto - in the Chisone Valley is identified. The economic vocation of Chiomonte, in fact, is strongly linked to the wine and forestry sector, with little tourism. Pomaretto is similar in terms of tourism, in terms of the number of farms (although with little UAA available per enterprise) and it has a wine supply chain (which also characterizes Chiomonte, although on different specific productions).

[3] Chiomonte hosts the first and main construction site for the Turin-Lyon HSR

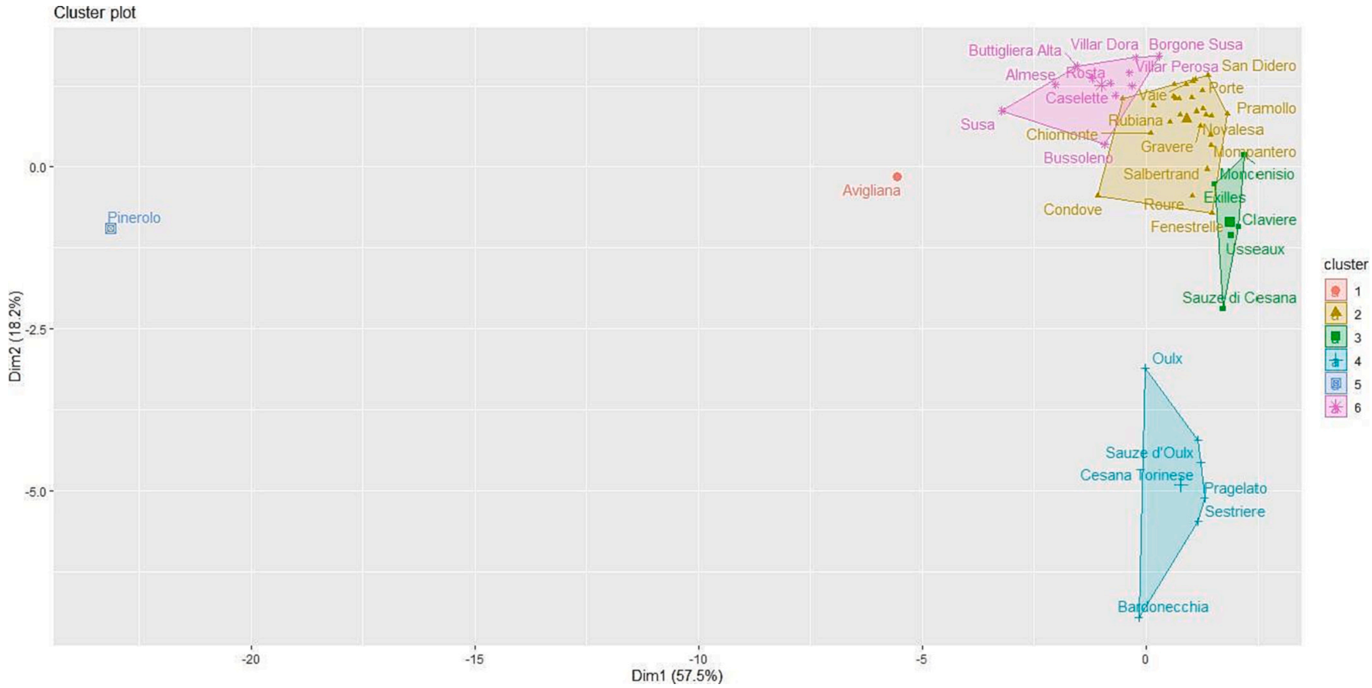


Fig. 3. Cluster analysis for the year 2020 considering all the 49 cities in the Susa Valley and the 15 in the Chisone Valley.

Table 4
Cluster description. Six clusters were identified representing higher, medium and lower valley and largest industrial cities.

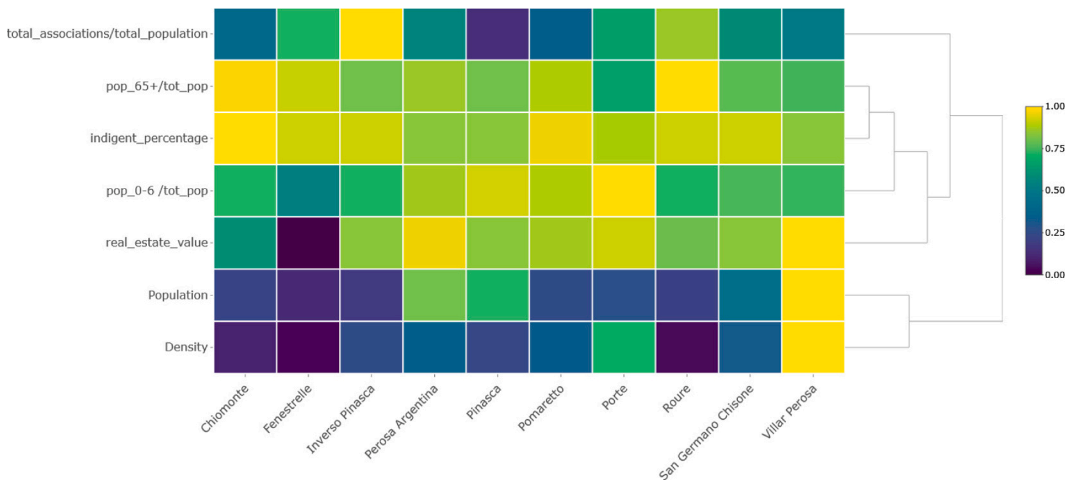
Cluster ID	Color	Description
1	Blue	Consisting of the municipality of Pinerolo alone, which cannot be compared with any other municipality in the two valleys due to its high industrial vocation;
2	Light blue	Made up of 6 municipalities (Sauze d'Oulx, Sestriere, Cesana Torinese, Pragelato, Bardonecchia and Oulx) representing the two high valleys, i.e., municipalities with a strong tourist pull and vocation and little agricultural land;
3	Green	Made up of 3 (in 2012) and 5 (in 2020) municipalities (Claviere, Sauze di Cesana, Usseaux, Moncenisio, Exilles) in the medium-high valley, where the territorial vocation is more focused on agricultural activities and tourism is on average low;
4	Yellow	Composed of the largest number of municipalities in the middle valley. An agricultural vocation predominates here, and tourism is almost non-existent (with a few exceptions);
5	Red	Consisting of the municipality of Avigliana alone. Like Pinerolo, Avigliana is not comparable to any other municipality as it has a strong dual vocation (both tourist and industrial);
6	Purple	Made up of 14 municipalities, mainly located in the lower Susa Valley (with the exception of Susa, which can be considered in the middle valley) and with a high population density and a predominantly industrial and entrepreneurial vocation and little agricultural land.

4.2. *Comparison of ante-operam trends*

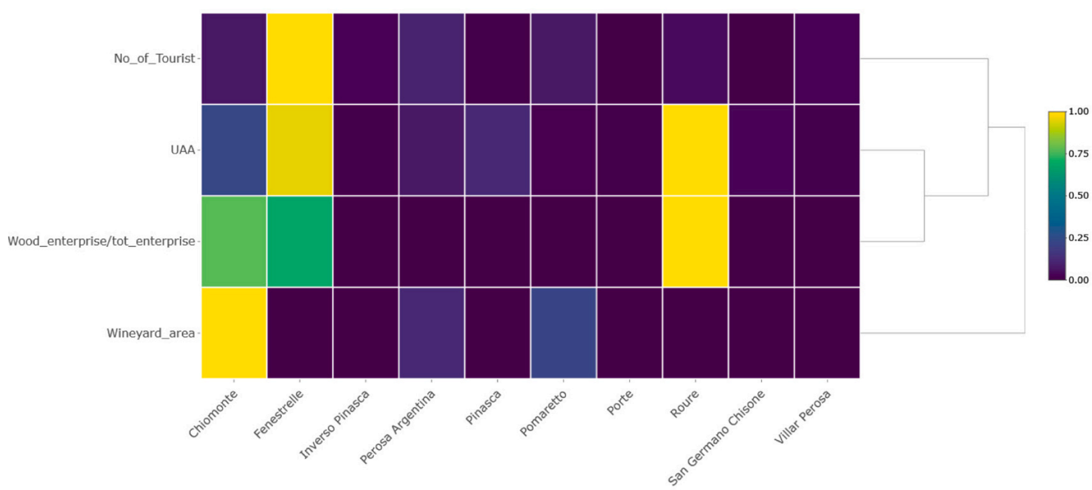
The comparison between the two areas (the affected and the counterfactual ones) is performed considering the normalized and standardized indicators summarized in Table 1. The aim of this last phase iss to identify specific socio-economic phenomena as described in the methodological section. Three aspects are considered: economic vocation of the territory, economic health and social aspects. Precise results in terms of specific and single indicators are shown in Supplementary materials in Tables 6, 7 (economic vocation), 8, 9 (economic health), and 10, 11 (social aspects) in section D for the year 2012 and 2020 (to allow historical comparability). Fig. 4 shows the three analyzed socio-economic phenomena for the selected towns (Chiomonte + counterfactual cities). The plotted values are normalized over the maximum value for each indicator. Details for the year 2012 and 2020 are provided in the Supplementary Materials in Appendix D.4. For the sake of simplification, due to the low number of indicators for each aspect, a descriptive analysis based on multiple criteria (and not a proper and full multiple-criteria decision analysis) will be provided in the next subsections.

4.2.1. *Economic Vocation of the territory*

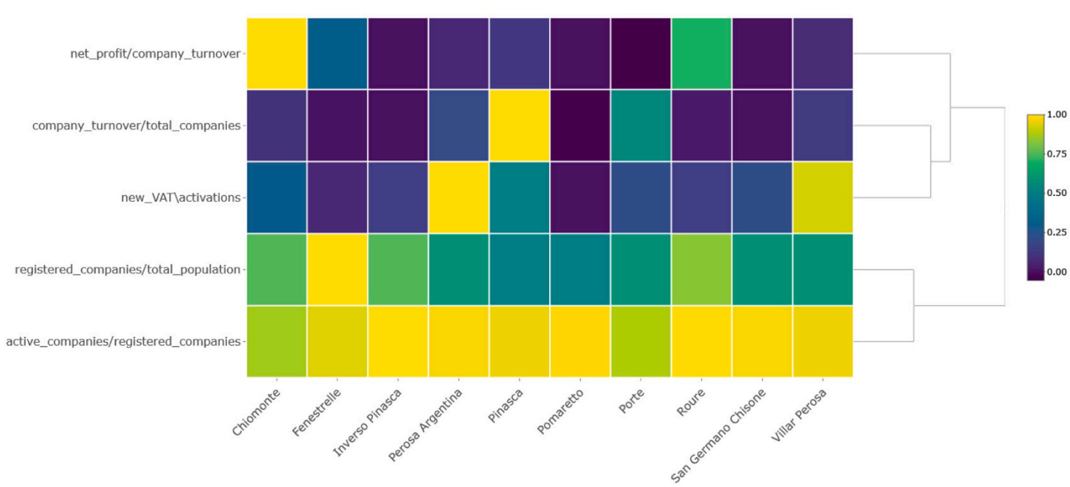
Concerning the “economic vocation of the territory” dimension in 2012 (see Table 6), there is not an exact match with the town of Chiomonte. The closest municipalities in terms of the number of tourists are Pomaretto, Roure and Inverso Pinasca (around 1000–1500 tourists per year), while in terms of usable agricultural area the nearest municipality is Pinasca, and in terms of vineyard areas we find Pomaretto and Perosa Argentina. Considering the wood industry activities, the only counterfactual towns comparable with Chiomonte are Fenestrelle and Roure. Concluding, in terms of “economic vocation of the territory”, the municipalities closest to Chiomonte turn out to be Roure and Fenestrelle (excluding municipalities without wood industry activities). Similarly, excluding municipalities that do not have a vineyard area, the closest municipality is Pomaretto. In conclusion, as far as the ‘Economic Vocation of the Territory’ is concerned, no precise counterfactual area can be identified, considering the four selected indicators. The year 2020 (see Table 7) presents a similar comparison. With respect to tourism, the most similar small towns are Pomaretto and Roure, while in terms of vineyard area and wood industry activities the most similar ones are, respectively, Perosa Argentina, Pomaretto (wine industry) and Fenestrelle and Roure (wood industry). The 2012–2020 comparison only shows a drastic reduction in the usable agricultural area for the municipality of Chiomonte (−44%), which loses almost half of its agricultural land (probably because of land expropriations and its collateral effects due to the construction site).



(a) Economic vocation of the territory



(b) Economic health of the territory



(c) Social components of the territory

Fig. 4. Socio-economic phenomena of the analyzed towns (year 2020). The color represents the normalized value (between 0 and 1) for each row where 1 represents the maximum value among all considered towns. Each row represents a different indicator as defined in Table 2. According to this representation, similar towns must have a similar color pattern for indicators under the same macro dimension.

4.2.2. Economic health

With regard to the economic sub-dimension "Economic health" (see Table 8 and 9), the new activation of VAT numbers, in absolute terms, are similar among various counterfactual municipalities (Fenestrelle, Inverso Pinasca, Pomaretto, Porte), with the lowest values for Roure and San Germano Chisone, and the highest values for Perosa Argentina and Pinasca. Both the number of active VAT numbers (out of the total number of registered VAT numbers) and the number of registered companies (out of the total population) are comparable among all the municipalities, with a minimum value of 0.85 for Fenestrelle and a maximum value of 0.97 for Inverso Pinasca. On the other hand, in evaluating the turnover of all companies (proxy to evaluate the presence of large companies) and the net profit on total turnover (proxy to identify the health of the active companies) the situation varies considerably in our sample. The turnover is similar for Porte and Perosa Argentina, with companies located in Porte performing better than those in Chiomonte. Regarding the net profit on total turnover, companies in all municipalities fluctuate with positive and negative values around 0, with the worst performance in Fenestrelle and the best performance in Roure. Concluding, for the reference year 2012, in terms of "economic health", the closest city for Chiomonte is Porte. The year 2020 does not show any major differences to the situation in 2012, although a few changes occurred. In particular, Chiomonte has the best profit/turnover ratio of all municipalities, followed by Roure, while in terms of turnover per number of companies, Chiomonte performs similarly to Roure and Villar Perosa.

4.2.3. Social dimension

Regarding the social dimension, the situation for the reference year 2012 is summarized in Table 10 in the Appendix D. Specifically, with regard to the percentage of low-income population (income lower than 10,000€), the percentages are quite similar among all municipalities (with a minimum value of 22% for Perosa Argentina and Villar Perosa). Similarly, the real estate value for civil dwellings ranges between a minimum of 875 €/m2 in Chiomonte and a maximum of 1525 €/m2 in Villar Perosa. Therefore, considering the two main aspects related to the economic situation of the municipalities, Chiomonte presents a social situation with more problems and little attractiveness for new residents (low real estate value). Considering the total associations per inhabitant (proxy for the relational capital of the territory), on average, there is less than 1 association per 1000 inhabitants (Chiomonte is in line with most of the other counterfactual municipalities, with 1 association per 1000 inhabitants). In terms of population composition, Chiomonte has a total population similar to Pomaretto, Porte and Roure, but a density that is similar only to Roure and Fenestrelle. It should be noted that for mountain municipalities, population density is not a particularly significant indicator, given the great variation in total area due to numerous factors (e.g., presence of natural parks, mountains). Finally, in terms of population composition, Chiomonte is in line with the Val Chisone municipalities, with a slightly older population (31%), but with almost the same population in the 0–6 age range (proxy for a 30–50 working class). Summarizing, the most similar counterfactual municipalities are Roure and Pomaretto. The year 2020 shows a slight decrease in the number of low-income people and a drastic reduction in property value. It is worth noticing that Chiomonte sees a reduction of almost 30% in real estate value (potential effect of the Turin-Lyon HSR construction site). However, the most similar town remains Pomaretto in terms of relational capital, while in terms of population composition the MCDA shows Roure as the closest counterfactual town.

5. Critical discussion

5.1.1. Theoretical considerations

This work demonstrates the application of the Megaproject Social Responsibility concept (Ma et al., 2020) using geo-spatial accounting to assess socio-economic impacts of megaprojects. The methodology is based on previous research, for instance Lin et al. (2017), and introduces a novel geo-spatial accounting protocol. This study addresses a gap in methodology, devising a robust three-phase approach - defining aspects, counterfactual analysis, and trend comparison. It is implemented on a prominent European megaproject, the Turin-Lyon HSR The presented accounting protocol fills a gap in megaproject socio-economic impact assessment by creating a replicable methodology, applicable in various contexts. It draws from social impact assessment literature (Vanclay, 2002; Esteves et al., 2012; Franks and Vanclay, 2013; Vanclay et al., 2015) and emphasizes specific indicators for economic and social phenomena. The protocol aligns with sustainability accounting (Baker et al., 2023), focusing on social and economic aspects, acknowledging that environmental impacts of megaprojects often are fully regulated by law.

An aspect of novelty of this project is represented by the sustainability perimeter identified in the protocol. Or, in other words, while usually sustainability accounting is centered on individual companies, this protocol considers megaprojects holistically, including the chain of contractors and subcontractors data in the analysis. A second innovative aspect, linked to the previous, is represented by the ecosystemic perspective adopted, that can be furtherly translated as examining economic and social impacts beyond the construction sites, affecting nearby populations and broader regions linked to the megaproject. While for environmental data the definition of the perimeter of the analysis that represents the impacted area, is often identified as the boundaries of construction sites or surrounding areas, for economic and social phenomena the geographical perimeter could be greater and complex. With this intent, this work wants to provide a contribution to the development of the literature on MSR and impacts of megaprojects presenting the operationalization of the protocol.

While the whole geo-spatial accounting protocol has been further discussed in Corazza et al. (2022b), with this paper the researchers want to show the operationalization of the protocol instead. This particular choice aims at tackling open challenges, is getting inspiration from and wants to contribute to the concept of "*infrastructural territorialization*" as defined by Lesutis (2021), but also previously debated by Marengo et al. (2015). For instance, in Marengo et al. (2015), the infrastructural territorialization is intended as some social and economic considerations, such as reducing working areas perimeters, avoiding base camps for workers, moving materials related to construction sites only by rail, developing closed and protected environments to work in, enhancing positive spillover effects on economy and labor market. As such, the methodology here presented could contribute to a better practical implementation of such a concept. Indeed, it is well-known by both scholars and policymakers how megaprojects could shape (positively and negatively) local communities and territories, especially in the case of transboundary megaprojects (European Commission, 2013), but until now researches on this field have been very limited and mostly focused on qualitative case studies (Camargo and Vázquez-Maguirre, 2021; Daye et al., 2020; Dogan and Stupar, 2017).

In fact, translating the relevant aspects of the concept of infrastructural territorialization in the context of the Susa Valley, has required researchers to conduct a deep analysis on different levels, such as historical, economic, sociological, anthropological, including in daily life, with occasional visits and field work. The research has been characterized by the constant confrontation with the relevant institutional stakeholders affected and directly involved in the development of this megaproject. Specifically, the involvement of the researchers in providing and receiving feedback from the regional and national environmental agency, the Piedmont Region, and the ministries involved, has been crucial to increase the level of impact of the research project. In addition, the researchers involved in the project have been subjected to a high level of scrutiny by different authorities, with different rules and regulations, ranging from agricultural production, mafia controls, or migrant regulations. For this reason, the development and the testing of the protocol has lasted for two years.

5.1.2. Case study considerations, dialogical intent and managerial implications

The proposed methodology and its application, hence, represent one of the first attempts in the literature to develop a scientifically based socio-economic impact assessment protocol for megaprojects, with a geo-spatial graphical representation. Visualizing impacts from a geo-spatial perspective can help policymakers in making informed decisions about the determination of impacts, which may require additional financial policies in terms of offsets, or other decisions about the development of a megaproject. The implicit goal of this methodology is for data to be released openly, and available to anyone who needs them, to foster further public participation (O'Faircheallaigh, 2010). It should be clarified again that, also in Vanclay et al. (2015), the emphasis on accounting for social and economic impact is described as less known and explored, if compared to environmental impact assessment processes and procedures. Within the specific context of the Turin-Lyon HSR megaproject indeed, the Italian national regulation has established a specific need for those megaprojects that are object of fierce contestations from local citizens and communities, to extend the environmental impact assessment to the so-called social and economic environment, To further exemplify,[4] this is justified by the underlying idea that a megaproject should not be exclusively intended as a technical system, but rather as a socio-technical system (referring to the legislations reported in the note). Specifically, a megaproject's “impact area” itself should be configured not only as pure physical territory or as a simple system, but also as a spatial social, economic and environmental system. The experimental nature of the work presented here is straightforward, simply because, although the legislation gently nudges the adoption of methods to evaluate the socio-economic impacts of megaprojects, no specific guidelines or frameworks are suggested. In particular, the existence of a strategic railway infrastructure plan is covered by the Objective Law no. 443/01 which invokes the adoption of social and economic impact assessment measures alongside the traditional environmental ones for such a specific type of megaproject. It should also be noted that the intention of this work is to accompany the development of megaprojects with data collection, suitable for assessing the impacts generated throughout development, execution and during the commissioning phase, to ensure the highest degree of objectivity of the analyses.

First, the modular and scalable approach represents its first strength, since the same approach can be applied to every megaproject, independently of size, type, and lifespan. Indeed, the initial phase - i.e., definition of relevant aspects as depicted in Fig. 1 - aims at collaboratively defining material topics for a local territory by engaging local communities and stakeholders. This is done by drawing on worldwide recognized approaches in sustainability accounting, like the determination of the materiality of the topics included, which should be done with the engagement of external stakeholders to obtain a collaborative validity of the issues included (Calabrese et al., 2019). In other words, the methodology has been drafted to be transversal, but its implementation on a specific territory could require a further level of application on the specific place-based features (for example, endemic production of a cultivar should be included according to the local economy vocation, while other endemic production could be excluded). Secondly, as demonstrated in the application phase, the methodology works independently of the number of aspects and chosen indicators, as the clustering algorithms used in the second phase - i.e. counterfactual analysis - can be applied to any number of towns (in this case it was done on 39 towns in the Susa Valley and 14 towns in the Chisone Valley) and indicators (in our case about 20 indicators, but many more can be used, if necessary). Finally, the last phase - i.e., the comparison of trends – could be useful to determine at its best the presence of a causal link between the megaproject and the impacts analyzed, adopting a geo-spatial perspective that could help the decision-maker to evaluate if a specific socio-economic phenomenon is happening on the site of the megaproject, on the surrounding area or if it is not linked at all to the megaproject.

In terms of the Turin-Lyon HSR case study, with this research a few counterfactual towns (depending on which socio-economic phenomena are addressed) have been identified for Chiomonte, the first and main town in the Susa Valley affected by the construction site. By applying the methodology presented in this study, it will be possible to determine the presence of other “counterfactual” cities, to be used as a control group, to understand the extent and causality of the analyzed phenomena. In particular, through this method, it will be easier to draw comparisons among different cities (those directly impacted and those not), even when site activities are operating on different sites simultaneously. Regarding the choice of a counterfactual geographical space, it should be noted that this methodology is accepted by social impact accounting literature, to evaluate the effectiveness of a specific action/project, and to clearly distinguish between association of factors and causation (United Nations Development Programme, 2009; Abadie and Cattaneo, 2018). The choice of using the Chisone Valley as a counterfactual area is justified by the fact that the culture, the origins and the territorial vocations of both areas are similar. However, the risk is that the geographical proximity will, in future, lead to an infrastructural interdependence between the two valleys, due to the changes in the mobility of the people and goods.

5.1.3. Methodological considerations

Regarding the first phase of our methodology, i.e. the definition of relevant aspects, future studies may take advantage of more robust participatory processes of stakeholder engagement, by organizing a higher number of focus groups with international experts and local communities not involved at this stage. With respect to the second phase, namely the application of a counterfactual analysis, this is not to be intended as a way of simply describing the socio-demographic composition or the economy of two valleys, but it mainly aims to assess the presence/absence or dynamism of a phenomenon, on the basis of the indicators examined, which could be used a proxy to assess the causality of the impacts to be attributed to the megaproject. This stems from the wish to clarify that researchers are aware that an endemic production of one of the territories (such as, for example, the production of chestnuts in Val Susa, or of a variety of apples in Val Chisone) cannot be found precisely in another valley (because of its endemic nature). Even with reference to the use of natural resources for economic and income-generating purposes, this can be very different even at small geographical distances, but it does not mean that an industrialized area, or a tourist area, cannot be comparable. Moreover, the selection of the counterfactual area may take advantage of a more in-depth statistical analysis, by looking at other geographical territories (including regions outside of Italy too). The adoption of counterfactual analysis in social impact assessment has been historically validated by Grieco et al. (2015), Kah and Akenroye (2020), and Perrini et al. (2021).

Concluding, some technical considerations and comments are needed for a few specific indicators. For instance, regarding the data

[4] According to the official document, the so-called “social and economic environment” has been included in compliance with the Legislative Decree No. 163, April 12, 2006 REV. 2 of July 23, 2007 of the EIA Commission (and its subsequent updates) and in compliance with Prescription 235 of CIPE Resolution 19/2015 (which approach cover also an impact assessment on safety).

collection, most data have been retrieved from open databases (*AIDA Bureau Van Dijk, national statistics database, Piedmont region database)* or regional open data platforms or other regional institutions data, such as the number of tourists and touristic structures, or the agricultural surfaces. Other data have instead been retrieved using other techniques, such as data scraping or direct interviews, as reported in Corazza et al. (2022b).

5.1.4. Limitations of the study

This study suffers from different limitations. A first limit is represented by a lack of connection between the pure environmental parameters and the socio-economic data used in this study. The choice of maintaining the data separated is justified by the lack of retrospective pre-operational data, the so-called *ante-operam*. Also the comparability of the environmental data and the socio-economic data could represent a limit of the study, but it should be noted that usually environmental data are subjected to strict data points (such as for a specific construction site), and not for the entire Valley or for other municipalities (as it has been used for socio-economic data). In addition, a further aspect of weakness of this study is represented by the data granularity required for the protocol, as such, a high level of significance is obtained only when data are available at a municipal level and in an open format. Finally, one of the main limitations of the study is that it focuses on the first stages of the construction works excluding, for instance, the design phase. The design phase, which is one of the most crucial in a megaproject, should include a section of data collection also for socio-economic phenomena, which in this case is evidently missing.

6. Conclusion

This work presents an original geo-spatial accounting protocol for megaprojects and its application to a well- known megaproject in Europe, the Turin-Lyon High-Speed Railway (HSR). Due to a lack of national or international legislation and regulation regarding the socioeconomic impact of megaprojects, the proposed protocol intends to address the current challenge in the accounting of social, and economic impacts, both in the short- and long- term.

The proposed methodology consists of three main steps: 1) definition of relevant aspects, 2) counterfactual analysis, and 3) comparison and multi-criteria decision analysis. The first stage aims at identifying the most relevant aspects and criteria for a specific territory and megaproject through a literature review (both scientific and gray literature) and a benchmark of the megaprojects process. The second step aims at selecting a proper counterfactual territory, to be used as a control group, similar to the area affected by the analyzed megaproject. In this stage, a comparison between the two areas is performed, at the level of the whole area, and, then, a cluster analysis at the level of single towns and cities: The purpose of this is to identify precise and specific counterfactual towns for the ones directly affected by the megaproject. Finally, in the last phase, a comparison and a multi-criteria decision analysis are conducted on the cities and towns belonging to the same cluster (identified in the previous step).

The described methodology is applied to a relevant and purposefully selected case study, the Turin-Lyon HSR megaproject, by, first, collecting dozens of different socio-economic indicators for the past ten years for almost forty towns in the Susa Valley (the valley affected by the Turin-Lyon HSR megaproject), and, second, by identifying the specific counterfactual towns for Chiomonte (the town where the main construction site was built) within the Chisone Valley (a very close - geographically - and similar - with the same feature - valley). What emerges from the case study, is that with respect to the *"vocation of territory"* no exact match exists, but the most similar towns are, among others, Pomaretto, Roure, or Perosa Argentina (depending on the priority given to the number of tourists, vineyard surface or wood industry). In terms of *"economic health"*, the closest town to Chiomonte is Porte, but also the towns of Roure, Villar Perosa and Perosa Argentina present similar features in terms of enterprise turnover, number of VAT and other economic indicators. Finally, regarding the *social* dimension, the closest municipalities are Pomaretto, Porte and Roure.

To conclude, although a perfect match cannot be perfectly identified, the present work developed and applied a robust, highly scalable and reproducible methodology, which can be extended to almost any megaproject. Further investigations may be necessary to devise a modular list of indicators (similarly to the work of Lin et al. (2017)) and to, for instance, test different multi-criteria decision analyses, in order to improve the counterfactual analysis. However, the work presents a few managerial implications, both considering the case study and in terms of future applications for other megaprojects. First, the identified Chisone Valley, and corresponding towns, can be used in the future as a reference basis to analyze how and how intensely the Turin-Lyon HSR affected Chiomonte and other involved towns. Second, from a general and methodological point of view, the proposed methodology lays the foundation for an accounting protocol for socio-economic impacts of megaprojects that can be easily applied in future studies and other case studies.

CRediT authorship contribution statement

Dario Cottafava: Conceptualization, Visualization, Writing – review & editing, Methodology. **Laura Corazza:** Conceptualization, Methodology, Writing – review & editing. **Daniel Torchia:** Conceptualization, Methodology, Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Dr. Laura Corazza reports partial financial support was provided by TELT sas.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eiar.2023.107288.

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