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PhD in Economics and Quantitative Methods

Measuring Well-Being and Territorial Inequalities: Multidimensional and Non-Compensatory Approaches to Sustainable Development

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Introduction

In the past few decades, socio-economic inequality has become the focus of academic and public debate and a key factor for advanced and developing economies alike. Many contributions by now have emphasized that growing inequality is not just about fairness of distribution, but also has deep and lasting consequences for the way in which economic systems function, societies cohere, and long term development can be sustained.

So viewed, inequality is not just a transient or accidental consequence of economic growth patterns today.

The consistent effort to link the economic, social and environmental dimensions of development, while explicitly acknowledging the importance of reducing inequalities (Goal 10) and fostering inclusive solutions for sustainable growth models in a systematic way is embodied by Sustainable Development Goals (SDGs). The rapid adoption of this framework is, however, contrasted by many questions when it comes to empirical work and how to evaluate advances in relation to sustainability objectives.

One of the most controversial debates is over how to measure well-being and sustainable development. Classical macro-economic indicators, such as the Gross Domestic Product (GDP) while valuable for a long time still do not fully cover multi-dimensional phenomena or the disparities between societies and regions. Taking these assumptions, we have then that research line has emerged towards the construction of composite indicators and/or multidimensional indexes able to summarise a broad concept into a single, understandable figure.

In this investigation, there is evidence of the use of non-compensatory aggregation approaches, addressing one of the fundamental drawbacks when devising traditional composite indices – supposing that a high score on one dimension compensates for poor results in others. This further is especially pertinent when analysing inequality and sustainability, due to the way it makes structural disproportions explicit which runs the risk of being concealed by average aggregate values. So the move to non-compensatory measure is a reaction to the requirements of measuring in a way (apparently) more in accordance with sustainable development, and inter- and intragenerational equity.

Territory is also a key factor to consider in the analysis of inequalities and well-being. Several works have shown that the chances of having access to services, levels of education, environmental quality and socioeconomic conditions vary greatly across space, leading to pronounced territorial inequalities. Territoriality is more than an empty shell of physical space within which economic activities function but rather, an elementary cause having a bearing upon individual and institutional feature that powerfully impacts aspects of human well-being.

In this light, a multi-scalar analysis also seems particularly relevant when it comes to characterise the type and strength of inequalities. The dynamics that unfold at the level of a city, such as in mobility service provision, have specific outworkings which will not be properly understood outside of its environment. These dynamics are often shaped by larger processes connected to economic and social structures at the regional, national, or international scale.

In view of these considerations, this thesis is located at the intersection of three main research lines: the analysis of socioeconomic disparities, multidimensional well-being and sustainable development approach and territorial analysis field. The general purpose is to explore the way in which inequalities are built and reproduced at multiple territorial scales affecting well-being and sustainable development trajectories, and how advanced analytical tools can help to comprehend them better as well as the design of more efficient public policies.

A deliberately focused empirical strategy characterizes the thematic scope of the research questions attempted in this dissertation across chapters. Each study operationalizes the dimensions of inequality, well-being and sustainability in terms of their respective analytical context and at the same time all are embedded within a shared conceptual and methodological framework. Accordingly, the originality of this dissertation is to be found mostly in its collective - and comparative interpretation of the separate contributions, rather than in the novelty of its individual applications considered individually.

This doctoral dissertation builds upon a set of peer-reviewed publications, extending and integrating previously published findings within a unified analytical framework.

Nature and structure of the dissertation

The work presented in this doctoral thesis is also set forth in authored or co-authored publications and/or published submitted for publication scientific articles. More than being a monographic work, the thesis organises and develops works previously published in the existing literature under an analytical approach of methodological unity.

Every chapter can be read as a single piece, with its own origin, motivation and audience dealing with separate dimensions of inequality, well-being, sustainability and policy evaluation in different empirical contexts. The manuscript as it stands here is an attempt to bring these original articles together by juxtaposing the theoretical suppositions, data bases and methodological decisions in a way that a merged optic of comparing and interpreting was out of reach for each paper along.

The dissertation value added lies in the coherent synthesis of the published works, the development of empirical analyses when relevant also and explicit reflection about methodological convergence and evolution between analytical tools used – most particularly with reference to composite indicators, non-compensatory aggregation rules, multidimensional evaluation frameworks.

By situating the individual studies within a shared conceptual architecture, the thesis contends that it may serve to indicate both the internal coherence of the research programme and the candidate's cumulative contribution to science and a wider interpretative synthesis in relation to contemporary discussions about sustainable development and socio-economic inequality.

Outline of the chapters

The thesis is structured around three empirical contributions dealing with education from different angles of analysis and scope levels, using a range of methodological approaches.

The first paper is at the urban scale and explores inequalities in access to public mobility services, with a focus on socio-demographic characteristics as well as the role of AI tools in transport planning. This article is located within the literature on sustainable mobility and urban equity and argues that access to transport services constitute a fundamental vector of urban well-being and an important means for reducing regional disparities.

The second is more national oriented toward gender and territorial disparities of education in Italy, using the frame of the Equitable and Sustainable Well-being (BES) developed by ISTAT. There is a positive concept of education as it's valued as an important aspect of well-being and a critical element in determining individual opportunities. The study raises the dimensions of educational inequalities and their connection with overall well-being, that calls for targeted education policies by region are emphasized.

Finally, the third contribution is at international and temporal level: it investigates the paths of sustainable developments which emerging countries have identified in the light of a longitudinal analysis performed on as non-compensatory composite indicators. This research enables us to see that in even contexts of rapid economic growth, there are still massive imbalances between the economic, social and environmental dimensions of development and raises concerns as to whether the growth models pursued are sustainable into the future.

Overall, the three contributions provide an integrated way of reading inequalities and sustainability in that they illustrate how these phenomena assume various contours depending on the level at which we operate. Also, from a methodological point of view, this thesis participates in the discussion about how to measure well-being and sustainable development by underlining the benefits of a multidimensional and non-compensatory perspective for addressing territorial disparities. From a public health policy perspective, our results show that there is a requirement for multi-level interventions to harmonize urban planning tools, educational policies and sustainable development strategies as components of an integrated strategy dedicated to equity.

Chapter 1: Urban Public Transport Use and Socioeconomic Inequalities: Empirical Evidence from Genoa and the Role of Artificial Intelligence in Sustainable Mobility

Abstract

The social dimension of cities is more and more being influenced by people's capability to benefit from basic services, including urban mobility, one of the most important ones. Socioeconomic and demographic disparities may lead to inequalities in access to public transport and hove significant implications for social inclusion, quality of life and environmental sustainability. This paper examines the effect of some selected sociodemographic variables on public transport use in Genoa (Italy) using an ordered logistic regression approach.

Residential location and sex are found to be the most important determinants of public transport use in the empirical results. Residents of suburban areas show a consistently lower tendency to use the public transit, and women tend to be the users more frequently than men. Such patterns reveal the structural mobilities of access in which inequalities in social well-being are produced across urban space.

In this scenario, the inclusion of AI in urban transportation systems is examined as a possible policy 'lever' for reducing mobility inequalities and promoting collective well-being. AI solutions – including predictive demand analysis, dynamic scheduling and personalised routing – could increase efficiency and access to services in areas of weaker transport provision. In promoting more reactive and inclusive mobility systems, such technologies could potentially promote not only environmental sustainability but also equity in urban living.

In summary, this study demonstrates the importance of considering sociodemographic in shaping accessibility to mobility as a primary dimension of social well-being and fosters evidence-based use of data-driven and AI-enabled tools for urban transport planning. Discussion The results feed into the wider debate about how selective mobility policies might be used to counter social inequalities and contribute to more sustainable and inclusive urban development.

1.1 Introduction

In recent discussions of social well-being, more and more emphasis is placed on the circumstances under which people are able to function effectively in their economic and social roles within community life. Well-being, in a multidimensional sense is the result not only of the economic resources Har life chosen character inherently depends on such nature to preserve physical and mental health. Under this perspective, urban mobility is a pivotal factor due to its nature as an enabler for the realization of many other aspects of well-being. Efficient, safe and accessible travel has a direct impact on the quality of life experienced daily and how much one 'belong' in their city.

This chapter belongs to the thesis at large and is centred on social well-being, investigating urban mobility choices as a concrete realization of sociodemographic disparities.

The users of public transport are not only individual choices, but the interaction with the characteristics of individuals, their socioeconomic condition and territorial structure of service supply. In this sense, sex, age, income and place of residence are essential dimensions that configure who is well and who is not in the city.

The scholarship has shown in great detail that mobility choices are shaped by very different constraints and opportunities within social groups. And, of course, some people have a panoply of travel choices available to them whereas others are very reliant on mass transit and hence more exposed to system failures. These inequalities are not neutral with regard to well-being: low mobility capacity translates into limitations on access to employment, education, health and social relationships that produce various forms of exclusion which build up day by day, almost imperceptibly in the sum of statistics.

In this regard, the urban environment is an optimal observatory for studying the association between sociodemographic indicators and social well-being. Cities bring opportunities, however they also amplify inequalities, above else when the territorial organization and the service delivery are matched incoherently. It is on this reflection that the case of Genoa, which I employed as an empirical demonstration in this chapter, responds. The physical framework of the city, the existence of stark contrasts between centre and periphery, and a population with an elevated average age explain how public transport accessibility may be quite different according to people's socio-demographic characteristics.

We will not attempt to address such a question in the present chapter, and instead aim to identify here the main sociodemographic determinants of PT use considering that we run an ordered logit model using data obtained from a sample survey. The aim is not simply to report on the factors influencing public transport demand but also to explain these results in terms of the wider concept of social well-being. These differences in mobility practices are considered to signal the presence of urban patterns of inequality that affect quality of life and opportunities for inclusion.

As a corollary to this analysis, the chapter proposes a meditation on how technology-based innovation—namely of artificial intelligence and with it–offers prospects for policymakers and other stakeholders as a means to tackling problems of mobility injustice. This thesis does not treat AI as a neutral or purely technical 'answer', but rather as a possibly strategic level for the improvement of the collective well-being, only if it is contextualized within a policy vision capable to consider relevant social processes. When it comes to urban mobility, AI can contribute on structurally reshape the public transportation system, which becomes more flexible and adjust better concerning different population segments, such as people who are living in geographically isolated locations or ones that have a higher level of moving restrictions.

So the chapter part is essentially and fundamentally fulfil its introductory role in thesis. It demonstrates how sociodemographic factors are related to a specific.

From this perspective, the chapter plays a crucial role as part of thesis introduction. It demonstrates how sociodemographic characteristics impact a specific, practical aspect of social quality and inform other analyses conceptually and empirically. By investigating urban mobility, well-being is perceived in its most material form, a product of structural factors, lifestyle choices and public policies. This tactic shows that inequalities are not something abstract but unfold through everyday practices, and opens for a more general consideration of strategies to advance an equitable and inclusive urban development.

1.2 Urban Mobility, Sociodemographic Factors and Social Well-Being

Urban mobility is a primordial dimension of social well-being, since it impacts directly on people's access to key services and the opportunity to partake in economic and social life as well as engage with urban space. In modern cities, movement is not purely a technical or infrastructural problem but a structural condition that shapes daily possibilities and limitations, and therefore mirrors wider social and territorial inequalities. That is why dimensions of mobility may be a particularly relevant perspective to examine the impact of sociodemographic variables upon individuals' social well-being, particularly in urban areas marked by spatial discontinuities and non-uniform availability of services.

Urban mobility is a key aspect for planning future sustainable cities, and it is one of the most important challenges for policy, due to the growing urbanization and climate change [1]. The increasing attention for smart cities and urban sustainable environments underlines the necessity of understanding how people interact with the system of public transport. During the last century, the share of vehicle owners has grown, and this has caused a change in mobility habits [2]. This large property and use of private vehicles has contributed to creating serious problems like congestion, emissions and victims of road accidents. In this context, it assumes a relevant role in the promotion of public transport; in fact, compared to private vehicles, this guarantees lower emissions and costs and permits to reach the environmental sustainability.

In 2023, Isfort registered a gap between the use of public transport and the use of private one in Italy [3]; this disequilibrium in favor of private mode of transport is very significant [4]. It is therefore clear that there is a need to reverse the trend. So, the analysis of the determinants of demand for public transport assumes particular importance. Studies investigate how choices relating to the adoption of public transport are influenced by sociodemographic factors [5, 6, 7].

In this chapter, the effects of these variables have been analysed across an ordered logistic regression model. In parallel, the growing development of AI offers new possibilities to optimize the management of public transport services and improve the efficiency of the system [8, 9]. Better access to the transport service and an increased efficiency of it could change people's mobility habits. Also, the introduction of advertising campaigns and target rates is an effective way to motivate people, and this policy is quite widespread at this time in transport companies. In Genoa, starting from 2021, it is possible to take the metro and elevators for free at some hours of the day. Since 2024, AMT (Azienda Mobilità e Trasporti S.p.a), which is the local company that provides public transport services, has extended this policy, so metro and elevators are free all day, and for people over 65 years, it became possible to travel also by bus for free. AI allows us to explore innovative and improving solutions in the management of public transport services, both on the supply side, increasing the efficiency, accessibility and sustainability of companies involved in the production of the service, and on the demand side, through targeted advertising campaigns or subsidized pricing systems, for example. AI applications, such as predictive route planning, dynamic management of traffic flows and offer personalization, could help improve user experience and adapt services to real-time needs. This work therefore aims not only to investigate the sociodemographic determinants in the use of public transport but also to explore how the integration of AI can transform the management of the urban mobility system, promoting more efficient and sustainable planning. This chapter is made up of seven sections, after the introductory part, which presents the theme and objectives of the research. The second section contains a review of the reference literature to contextualize the contribution of this chapter. In the third section, the methods of data collection and sample creation for conducting the ordered logistic regression are presented, which is described in detail at a mathematical level. In the fourth section, the results are reported and in the fifth, they are discussed and investigated. The sixth section is dedicated to the introduction of AI in the public transport sector. Finally, the conclusions summarize the main contributions of the article and suggest potential future developments.

Public transport is a central element of urban mobility, and different studies have examined how socioeconomic and demographic factors influenced models of mobility but also the potential of AI in the improvement of this sector.

Gender, age, income and place of residence have consistently been identified as key determinants of mobility choices. A study conducted in Colombia highlights how factors such as costs, time, safety, comfort and personal security are perceived differently depending on socioeconomic characteristics [10]. It is well documented that women tend to rely more on public transport than men [11]. At the same time, age is an equally important determinant of public transport use, strongly related to accessibility—difficult to capture in quantitative terms [12]—and to perceived safety [13].

Income level is another crucial factor, which directly affects the demand for public transport also through the effect on car ownership [14, 15]. However, accessibility is still a challenge, particularly for residents of suburban and outlying areas, where transportation services are often less frequent and efficient [16]. Recent advances in AI have opened new possibilities for improving the efficiency of public transport through data management, algorithm selection, system architecture and governance. Not only these tools but also the introduction of self-driving vehicles is a turning point in terms of safety and efficiency [17]. Applications of AI in transportation include demand forecasting, route optimization and dynamic scheduling, all contributing to a more efficient and sustainable mobility system [9].

Furthermore, AI-powered route optimization algorithms help reduce travel times and congestion [18], helping both operators and users. AI applications in fleet management can also optimize the regularity of frequencies, thanks to real-time analysis and thus improve the quality of service and passenger satisfaction [19]. The implementation of new AI tools also allows us to significantly reduce emissions, pursuing the goal of environmental sustainability [20]. This study contributes to broadening the topic through an analysis conducted in Genoa and aims to analyse how the implementation of AI can be integrated with the sociodemographic variables that most influence the use of public transport.

1.3 The model

This analysis is based on a survey that was conducted in 2024. The statistical approach uses an ordered logistic regression to investigate the influence of variables, gender, age, income and place of residence, on the use of public transport. The statistical sample is formed by 1,210 people, and all of them are adult residents of the wide area of the metropolitan city of Genoa. In Table 1.1, all the questions, the possible answers and the number associated with the answer chosen are presented.

The variables collected are of a nominal qualitative type but present an intrinsic logical ordering, which allowed them to be classified for the purposes of the analysis, as can be seen from the third column of the table. To ensure the reliability of the dataset, anonymity and confidentiality were strictly preserved throughout the data collection and analysis process. In addition, a thorough examination of anomalous values was carried out. Specifically, descriptive statistics and distributional checks (such as boxplot inspection and standard deviation thresholds) were employed to identify potential inconsistencies or extreme values. These were carefully assessed to distinguish genuine extreme cases from data entry or measurement errors, in order to retain only reliable observations in the final analysis.

Converting the age variable into a sortable one makes it possible to define how this influences the use of public transport and evaluate whether there is a greater or lesser propensity as age increases. The choice to exclude adults from the analysis is dictated by the need to evaluate individual choices, since those who are below this age threshold are often constrained in their choices, both due to lack of driving license and parental decisions, it was preferred to exclude them from the count. Furthermore, the bands were segmented considering the travel passes offered by AMT Genoa.

Similarly, in the answer to question 3, the response options are arranged according to increasing income range, creating a proxy for income through employment. As regards the residence variable, a dummy was created that considered the location within the urban or suburban context.

The variables generated by the questions on transport habits are ordered following an increasing scale, both in terms of use, frequency and travel title.

The sample analysed reflects the composition of the Genoese population, according to International Society of Transport Aircraft Trading data [21].

In the ordered logarithmic regression of this analysis, term Y, the dependent variable, refers to the use of public transport, and it is measured on an ordered scale of j values (j = 3), where the highest corresponds to a total use of public transport for urban travel. The model assumes that there is a continuous latent variable Y* that governs the choice of the observed category of Y. The model is defined as:

$$Y^{*} = X\beta + \varepsilon$$

Table 1.1: Questions, Answers and Value of the Variable.

Question	Answer	Value
1 What is your gender?	Male Female	0 1
2 What age group do you belong to?	18–26 years 27–46 years 47–64 years 65+ years	1 2 3 4
3 What is your professional status?	Student Unemployed Retired Employee or similar Self-employed or similar	1 2 3 4 5
4 Which municipality do you live in?	Genova Other	0 1
5 Do you use the service provided by AMT for your urban travel? (exclude trips made on foot or by bike)	No Yes, partially Yes, for all	1 2 3
6 How often do you use AMT public transport?	Never Occasionally, less than once a month At least once a month At least once a week Daily or almost	1 2 3 4 5
7 Which type of ticket do you use on AMT transport network?	Nothing Ordinary ticket or other Weekly pass Monthly pass Annual pass	1 2 3 4 5

Source: Author

where X is the vector of regressors (*gender, age, income, residence*), b is the vector of coefficients and e is the error term, distributed as a standard logistic distribution $e \sim$ Logistic (0, 1).

The observed variable Y is determined by the latent variable Y^* and a series of estimated thresholds $\tau_1, \tau_2, \ldots, \tau_{j-1}$ which represent the separation points between one category of the dependent variable and another one, such that:

$$Y = \begin{cases} 1 \quad if & Y^* \leq \tau_1 \\ 2 \quad if & \tau_1 < Y^* \leq \tau_2 \\ . & \\ . & \\ . & \\ . & \\ j \quad if & Y^* > \tau_{j-1} \end{cases}$$

The latent equation Y^* in the model is represented as:

$$Y^* = \beta_0 + \beta_1 \text{Sex} + \beta_2 \text{ Age} + \beta_3 \text{Income} + \beta_4 \text{Residence} + \varepsilon$$

Regression return coefficients b_k are associated with the explanatory variables X_k, and they are the effect of the independent variables on the log-odds of the cumulative outcome.

1.4 Results

The application of the ordinal logistic regression model highlighted the following correlations between the use of public transport and the sociodemographic variables analysed.

The regression was conducted using the STATA18SE software, which proposes the analysis in Table 1.2. Here number of observation = 1,210; LRchi^2 (4)

= 306.71; Prob. > chi^2 = 0.000; pseudo R^2 = 0.1157.

The odds ratios, OD, are shown in Table 1.3; they are useful for a complete and deep comprehension of the model [22]. Odds ratios give indications on the probability, like coefficients, but they show the factor of change.

The analysis of multicollinearity through the variance inflation factor (VIF) confirms that there are no significant collinearity issues among the independent variables. The 1/VIF values are all close to 1, indicating that the explanatory variables are not highly correlated with each other. This ensures that the regression coefficients remain stable, and the model does not suffer from distortions due to multicollinearity.

Likelihood Ratio test, LRchi^2 (4), compares the model analysed with a null one. The null hypothesis is rejected with a value of LRchi^2 (4) = 306.71, so that at least one of the sociodemographic variables is considered significant with Prob. > chi^2 = 0.000. The data pseudo R^2 = 0.1157 show how much of the variability on the variable *Usept* is explained by the model, so the model constructed in this way explains instead the 12% of the variability.

The variable *gender* is the one with the higher positive coefficient in the model. This variable is significant because it has a p = 0.000, and its value of 0.08545 implies that as *gender* increases, the probability of a higher level on *Usept* also increases. Looking at the OD value equal to 2.35, it is possible to affirm that a woman has 2.35 times more probability to use the public transport often than a man.

Table 1.2: Logistic Regression ($p < 0.05$).

Usept	Coefficient	Standard Error	z	$p > \|z\|$	[95% Confidence Interval]
Gender	0.8544	0.1144	7.46	0.0000	[0.6300, 1.0788]
Age	0.7153	0.0602	11.88	0.0000	[0.5973, 0.8333]
Occupation	−0.4402	0.0570	−7.71	0.0000	[−0.5521, −0.3283]
Residence	−1.2566	0.2489	−5.05	0.0000	[−1.7446, −0.7687]
/cut1	0.0814	0.2637			[−0.4354, 0.5982]
/cut2	1.6081	0.2680			[1.0827, 2.1334]

Source: Author

Table 1.3: Odds Ratio ($p < 0.05$).

Usept	Odds Ratio	Standard Error	z	$p > \|z\|$	[95% Confidence Interval]
Gender	2.3501	0.2690	7.46	0.0000	[1.8777, 2.9414]
Age	2.0449	0.1231	11.88	0.0000	[1.8172, 2.3011]
Occupation	0.6438	0.0367	−7.71	0.0000	[0.5757, 0.7201]
Residence	0.2845	0.0708	−5.05	0.0000	[0.1747, 0.4635]
/cut1	0.0814	0.2637			[−0.4354, 0.5982]
/cut2	1.6081	0.2680			[1.0827, 2.1334]

Source: Author

The other sociodemographic variables are also significant; all have a value of $p = 0.000$, but only *age* has a positive effect on *Usept*. *Age* with a coefficient of 0.7153 suggests that an increase in age causes an increase also in the probability of higher *Usept*.

Income and *residence* have the inverse effect on *Usept*; in fact, both have negative coefficients, respectively, −0.4402 and −1.2566, which correspond to a lower probability of belonging to high classes of public transport use.

In the image, there are also the threshold values, /cut1 and/cut2, and they are the values that separate the categories of the ordered outcome, defining the boundaries between the levels of the dependent variable.

In the output of ordered logistic regression, the Z-test is statistic, and if

$|z| > 2.58$, the coefficient is highly significant. In this case, all the coefficients are highly significant, suggesting a strong association between the use of public transport and the sociodemographic variables [23, 24].

Another interesting measure is the standard error; the smaller it takes on values, the more precise the estimate of the coefficient is. In the model, the highest standard error refers to the residence variable with a value of 0.2489, and this suggests that the estimated effect of the variable on the use of public transport is more uncertain than the error estimated for the occupation variable of 0.0570.

The last aspect to consider is the confidence interval, which contains the value of the coefficient in 95% of cases. Since for none of the variables the confidence interval includes value 0, all of them can be said to be significant.

1.5 Discussion

The results of the analysis confirm that individuals' mobility choices are not random, but respond systematically to sociodemographic factors. In particular, gender emerges as a determining variable in the use of public transport. This result is consistent with previous studies highlighting that women tend to make more fragmented and complex journeys, often combining work-related travel with family care and other daily activities [11]. At the same time, this greater dependence on public transport can lead to increased vulnerability, especially with regard to safety during evening hours and on peripheral routes [25]. The issue of safety for female passengers has been extensively discussed in the literature, including analyses based on victimization reported by women [26]. These findings suggest that cities should focus on the development of gender-sensitive public transport service plans and policies that explicitly take into account the specific needs of women and girls in public transport systems [27].

Age also emerges as a determining factor; the elderly appear to be the main users of public transport, partly because of the composition of the Genoese population. Added to this is the possibility that AMT Genova offers residents over 65 the chance to travel for free. However, this propensity of the elderly is not given and strongly depends on some characteristics, such as convenience, availability, accessibility and acceptability [28], but safety also plays a fundamental role in their mobility choices [13]. One of the most relevant aspects that emerged from the analysis is the role of income: as the economic level increases, the use of public transport decreases. This phenomenon is well documented in the literature, and it has been analysed that this behaviour depends on the accessibility of the service. A more accessible service would increase the use for both high-income and low-income groups [29]. Income directly influences the demand for transport also depending on the ownership of a private vehicle [14]; therefore, those with a higher income are more likely to own a car and therefore make different transport choices compared to those who have a lower income. Another central element is the strong impact of residence on the use of public transport: those who live on the urban outskirts or in suburban areas tend to use it much less than those who live in urban centres; here, the proximity of public transport plays a crucial role [16]. The lack of effective connections between the centre and the periphery creates a barrier to access to work, educational and social opportunities, contributing to widening territorial inequalities. These findings suggest that mobility choices cannot be analysed exclusively in terms of transport efficiency but must be understood in the broader context of social and economic inequalities. Public transport plays a crucial role in accessing services and opportunities, but to be truly inclusive, it must be designed considering the specific needs of the population groups. Technological innovation, particularly the use of AI, could help reduce these inequalities through more flexible and personalized solutions, such as real-time route optimization and improved demand forecasting. However, for technological innovations to be truly effective, it is essential that they are accompanied by mobility policies with social and environmental justice as goals. However, for these improvements to be equally distributed among different segments of the population, it is necessary to integrate technological tools with an inclusive political vision that is attentive to social inequalities. One of the main advantages of AI in public transport is the ability to analyse large volumes of data to predict demand in real time. Thanks to machine learning tools, it is possible to analyse massive quantities of data without being programmed. These algorithms allow the processing of historical data on passenger flows, weather conditions and city events and allow forecasts to be made on changes in transport demand. Machine learning tools also allow the automation of decision-making processes, improving resource allocation and operational efficiency. The optimization of the frequency of vehicles and the location of stops [30] reduces the problem of overcrowding during rush hours, improving the efficiency of the system and user satisfaction. In cities like London, Transport for London (TFL) uses predictive algorithms to adapt subway and bus frequencies based on changes in passenger traffic, avoiding overcrowding and improving service punctuality [31]. A specific part of machine learning called neural networks enable road planning, traffic accident detection and traffic conditions [8]. Another tool is natural language processing which allows us to improve communication with citizens, which is particularly useful for people with disabilities or for those with specific mobility needs, as it allows us to reduce barriers in accessing public transport. Through these tools, it is possible to obtain greater feedback from marketing campaigns and improve the accessibility of the service in terms of information. The use of chatbots can make citizens more oriented toward public transport than private vehicles, and this leads to important reductions in con gestion, delays and environmental pollution [32]. For example, the AI-based platforms adopted by the Tokyo Metro automatically translate announcements and signs into multiple languages, making the system more inclusive for tourists and foreign residents [31]. One of the key implications of the introduction of AI in public transport is the reduction of environmental impact. The optimization of routes and resources allows us to minimize fuel consumption and so emissions, which can also be controlled through information on best speeds or charging times for electric vehicles. One of the most relevant applications concerns the intelligent management of urban traffic: machine learning algorithms and neural networks analysing data from sensors, cameras and global positioning system (GPS) in real time to predict and decongest traffic, thus reducing greenhouse gas emissions resulting from the inefficient circulation of vehicles.

In Oslo, the implementation of electric buses with AI-based management made it possible to reduce energy consumption by 30% and improve service coverage in peripheral areas [33]. Vehicle energy management and alternative fuel technologies, such as hydro gen fuel cells and biocarbons, also offer significant opportunities to improve environmental sustainability [34]. These tools have a powerful effect when applied to public transport but can also be implemented on private electric and autonomous vehicles. Furthermore, public transport fleets benefit from AI-based systems that optimize routes and vehicle frequencies based on demand, avoiding energy waste and improving service for citizens. A concrete example of the integration of AI into transport systems is represented by the SUTRAC technology, which was tested in Pittsburgh (USA). Advanced systems analyse vehicle flows in real time, adapting the duration of traffic light signals to reduce traffic jams and reduce CO2 emissions. The Scalable Urban Traffic Control (SURTRAC) system was developed by Carnegie Mellon University and implemented to improve urban traffic management through AI and machine learning algorithms. The experimentation was carried out on nine intersections, each of which was independent of the others with respect to the green time. Through the management of intersection flows and real-time calculation, the system allows the management of multiple traffic flows [35]. The improvements recorded are numerous: the average travel time has been reduced by 25%, the average speed has increased by 34%, the average waiting time has decreased by 40% and stops have been reduced by 31%, with important environmental implications. Overall emissions were reduced by 21%, with estimated daily emissions reductions of 2,253 metric tons [35]. This model could be exported to other metropolises to improve urban mobility in an intelligent and ecological way. It is also possible to identify the areas of the city that are less satisfied with the service through user reports and plan new infrastructures that improve user perception or implement security systems on the network to guarantee accessibility even to the segments of the population most exposed to risks. In Barcelona, for example, the municipality used AI to reorganize the bus network, ensuring better access to transport for the most vulnerable segments of the population [33]. Lastly, the automation of numerous processes significantly reduces management costs for companies, allowing a different and waste-free use of economic resources. Despite these advantages, AI-driven transport solutions must be implemented with an equity-focused approach to avoid exacerbating existing disparities. If not carefully managed, AI-based optimizations might prioritize efficiency at the expense of accessibility for marginalized communities. Therefore, policies must ensure that AI technologies are deployed to enhance inclusivity, ensuring that all citizens regardless of socioeconomic status or place of residence benefit from improved mobility services. Ultimately, AI has the potential to revolutionize public transport, but its success depends on its integration with policies that prioritize fairness, sustainability and social well-being. If accompanied by inclusive mobility strategies, AI can transform public transport into a fundamental pillar for building more connected, equitable, and environmentally sustainable cities.

In conclusion, this study confirms that mobility choices are shaped by a complex interaction of sociodemographic characteristics, territorial conditions and technological factors. While the empirical analysis focuses on the specific case of Genoa, the findings highlight dynamics that are relevant to other urban contexts. Future research could expand the analysis to different spatial and temporal settings, integrate qualitative approaches to capture cultural factors, safety perceptions and individual habits, and further examine the environmental impacts of transport policies. Artificial intelligence represents a powerful opportunity to transform public transport into a more efficient, accessible and sustainable system, but its success depends on its integration within comprehensive policy frameworks that prioritize social well-being, equity and environmental sustainability.

1.6 Conclusions

In sum, the analysis in this chapter revealed that urban mobility constitutes a core aspect of social well-being, deeply marked by persons' sociodemographic characteristics and the local environment where they reside. Then mobility decisions are not made in isolation, nor entirely personal, they express structural limitations and uneven possibilities, reflecting wider inequalities based on gender, age, income and place of residency. So, in this way, the availability of public transportation assumes importance that transcends mere efficiency of moving from point-to-point: it becomes a quality-of-life issue and part of the ability to participate fully in a city's society, economy and culture.

The results show straightforward to what extent a social well-being cannot be grasped by economic or infrastructural indicators alone": it necessitates targeted action on the conditions that make people effectively capable of concretely exercising them. Mobility as a driver It is because mobility is an enabler that it influences access to basic services, employment, education facilities, health care and social networks; and thus helps to constitute sequences of inclusion/ exclusion along the life course. The inequalities in mobility behaviours which we observe are thus not isolated but rather form part of cumulative processes of car strengthening or weakening previous advantages and disadvantages.

This is the stance that enables us to understand how what happens in this chapter trough our dynamics above are directly related to what takes place in the next one on education. Indeed, access to education is another important dimension of social well-being and similarly to mobility it is largely affected by socioeconomic features and territorial setting. The lack of public transport, especially in peripheral areas, can constitute real didactic obstacles for access to education, with a consequent reinforcement of territorial and gender gaps throughout the adult lifespan. In this regard, mobility and education are not just two separate fields, but mutually constitutive components of well-being that determine individual opportunities.

The examination of urban mobility therefore provides a first empirical indication of the way that sociodemographic inequalities are materialised in daily practices by means of different access opportunities. The chapter on education will extend this view to the way in which these inequalities are re-inscribed through educational and cultural processes over time, at both micro (skills and jobs) and macro (quality of life) levels. In both situations, the local area appears as an important factor mediating the effect of sociodemographic variables in such a way that it reinforces or attenuates inequality depending on contextual circumstances.

In this sense (and in several cases also relevant to the urban mobility) becomes a smaller matter compared with the role played by technological innovation and artificial intelligence, which will be developed in this chapter/problem beyond it being referred not only to just one sector. The possible contribution of AI based technology for enhancing accessibility, personalizing services and improving system efficiency may be seen as transversal tools to foster social well-being if embedded into equity-based public policies. Nevertheless, the analysis demonstrates that embracing new technologies is insufficient in terms of tackling inequalities: indeed, without an inclusive understanding or direct focus on sociodemographic differences, a sort of reproduction or amplification loop might arise where existing unbalances are rolled-out.

Thus, the chapter has helped develop the wider structure of our thesis by establishing both a theoretical and empirical basis for more extensive investigations into the determinants of quality of life. In the investigation of urban mobility well-being is experienced in its most direct and concrete way, as a product of individual features, territorial settings and policies. Transition to the next chapter on education will give us an opportunity to explore these dynamics further in a medium-to long-term perspective, and to show how sociodemographic inequalities are embedded within educational trajectories and help shape wellbeing trajectories over the life course.

Through locating an examination of inequality and well-being within a tangible empirical site, this chapter demonstrates how differences are produced though visible social effects. Building on these results, the next chapter turns to a more structural aspect, exploring educational inequalities and well-being in national perspective.

Chapter 2: Educational Inequalities, Gender Disparities and Social Well-Being in Italy: A Multidimensional Territorial Analysis

Abstract

This chapter examines gender and regional disparities in education in Italy, viewing it as a key aspect of social well-being. It relies on data from the 2021 Equitable and Sustainable Well-being (BES) system of ISTAT, which are analysed through two different but complimentary empirical strategies in order to investigate the robustness of results and represent the multilayered complexity of educational gaps.

For the comparability of men and women a standardization to the variables was made by means of the stacking procedure, whereby also equal measurement scales were constructed. The indices were then summed to form composite education indices for each gender and region, and the gender gap was measured as the difference between aggregated values for women and men, with a synthetic measure of educational inequality at regional level.

In a preliminary step, these gaps were investigated by the k-means clustering algorithm. Italian regions were classified into five homogeneous clusters in terms of gender inequalities in intensity and structure. The pattern of the mean educational gaps was then further explored from a graphical perspective, identifying themes within their average metrics in different domains of education. In a second analysis, the robustness of the outcomes was tested using alternative aggregation and ensemble methods (MPI, arithmetic and geometric means, min–max normalization to 0–1 scales) and PCA to enable a systematic comparison with different methodological approaches.

In general, the results of the analyses are robust and coherent: a marked North-South education gap endures and women exhibit a structural advantage across the various educational dimensions, regardless of analytical choices.

The chapter has implication on the global discussion on gender equality, educational disparities and social well-being by including observational evidence towards achieving Sustainable Development Goals – such as SDG 4 (Quality Education), SDG 5 (Gender Equality) and SDG 10 (Reduced Inequalities).

2.1 Introduction

Gender disparities persist as one of the most enduring and systemic barriers to sustainable and inclusive development in today's world. Although considerable advances have been made in many fields, differences between men and women are being perpetuated for access to resources, opportunities and life capacity, frequently reproducing social and economic inequality generation after generation. Education is one of the key areas in which such gaps are laid bare, and occupies a specific ambivalent position. Firstly, on the one hand education is an area where inequalities can be produced and reproduced whereas it is also a fundamental means for social redistribution, individual empowerment and long-term enhancement of well-being.

Education is not just a technique of accumulation of human capital but an inherent aspect in forming individuals' capabilities, empowerment and social engagement. Differences in ability to access education, level of educational attainment and opportunities for learning therefore have implications which reach well beyond the confines of the educations systems themselves as they will affect individuals' labour market experiences, potential income levels, degree of civic engagement, and individual's sense of subjective well-being. From this standpoint, gender discrepancies in education attain significance not just because of the absence of fairness or equality of opportunity they imply, but also because they are a principal factor that shapes more general patterns of social development and quality of life.

The exposure to the Italian context provides a very interesting and complex opportunity to analyze educational inequalities. Italy is also a country with deep and enduring territorial imbalances still shaping social and economic outcomes. Continuing north-south and city-country gaps also impede the quality of educational provision, access to learning opportunities, and elasticity in education systems supporting social mobility. These territorial inequities are compounded by gender relations, which generate a differentiated educational pathway, in relation to the wider cultural, institutional and economic structure of society. Therefore, gender disparities in education cannot be properly understood without taking into consideration the territorial contexts where they take shape.

An expanding literature shows that educational disparities in Italy are not homogenous across the country, featuring substantial geographic differences stemming from distinct levels of economic development, infrastructure endowment, labor market characteristics and cultural settings. These differences play a role in maintaining spatially differentiated gradients of well-being thereby reinforcing cumulative advantages and disadvantages across the life course. In this sense, education operates as a mirror and also an engine of regional disparity, framing the symbiosis between sociodemographic features and individual life courses.

And education also factors into subjective well-being and life satisfaction. The overwhelming evidence is that the greater the education (especially for women), the higher the empowerment, autonomy and perceived quality of life. Education increases people's aptitude for informed decision making, engagement in society and politics, resilience in uncertain economic climates. Therefore, the examination of gender and territorial disparities in educational attainment provides important clues about how well-being is generated and distributed within societies.

Within this broader theoretical and empirical framework, the present chapter also addresses to specific aims by providing a detailed investigation of multidimensional educational inequalities in Italy. This chapter analyses (with the most recent 2021 ISTAT Fair and Sustainable Well-being – BES) a series of ten education- and learning-related indicators, broken down by gender and region. These indicators try to capture various aspects of the educational experience, including how well people learn and progress through formal education systems or move between them, their lifelong learning (both formal and non-formal), cultural participation and digital skills. This more holistic view allows for a broader and subtler analysis of inequalities in education than single indicator approaches.

"Comparability" is the methodological challenge in the analyses of gender, that is, about the comparability of outcomes for men and women across different dimensions. To resolve this problem, the chapter follows the "stacking" approach where to put male and female observations on a comparable measurement scale. The methodological decision to do so can be seen as a major contribution of the study, in that it ensures sex differences reported are indicative of real differences rather than artefactual ones. Based on these standardized indicators, composite education indices are created for each sex and region; the difference between male and female scores is then operationalized as gender gaps in educational attainment.

In addition to these multiple theories, the analysis is also enhanced with having multiple empirical strategies. Composite measures are exploited in combination with clustering algorithms to detect groups of regions sharing similar gender inequality profiles, and discovering convergence as well as divergence trends across Italian territory. We also use two types of aggregation methods (compensatory and non-compensatory) to examine sensitivity and impartiality of the results. In using an intersectional lens in this integrated manner the chapter does not only report on existing inequalities, but also critically consider methodological choices when it comes to measuring complicated and multidimensional phenomena like educational well-being.

The chapter also places the Italian case within an international and policy-focused framework of analysis, by discussing ongoing debates on gender equality, gender education equity and sustainable development. Consistent with the United Nations 2030 Agenda, the study deals also with three main objectives concerning Quality Education (SDG 4), Gender Equality (SDG 5) and Reduced Inequalities (SDG 10), underlining the relevance of multidimensional, gender-sensitive and territorially informed evaluation and design of education policies. In doing this, the chapter returns to one of the central argument that has travelled through the thesis: sociodemographic inequalities have a strong bearing on shaping variance in different aspects of social well-being across spaces and over time.

2.2 Literature review

The level of education is a crucial indicator of a country's social and economic development, directly influencing the quality of life, employment opportunities, and the competitiveness of the labour market. An efficient and accessible education system not only promotes individual growth but also contributes to collective progress, reducing social and territorial inequalities [36].

Cross-cultural research extensively documents the strong link between education, individual empowerment, and subjective well-being [37]. A plethora of studies exist that verify that women's education promotes greater personal freedom, economic independence, and happiness, thus better societal well-being [38]. OECD reports consistently confirm a positive correlation between women's educational attainment and overall social outcomes, including improved quality of life, increased life satisfaction, and narrowing gender gaps.

Women's education progress in European contexts specifically has been linked to enhanced resilience at the community level and increased collective well-being. In line with the United Nations 2030 Agenda [39], education represents a foundational pillar for sustainable development. This study contributes directly to SDG 4 (Quality Edu cation) by assessing the distribution and quality of educational outcomes; to SDG 5 (Gender Equality) by systematically comparing male and female educational performance; and to SDG10(Reduced Inequalities) by exploring territorial disparities in access and outcomes. Understanding these multidimensional gaps is essential for designing inclusive, effective, and evidence-based education policies that leave no one behind. Education is not only a right but also a driver of equity, economic resilience, and civic participation [40].

Reducing educational inequalities strengthens long-term social sustainability by empowering individuals, enhancing human capital, and fostering social mobility [41]. In contexts characterized by persistent territorial imbalances, such as Italy, promoting educational justice is crucial to mitigate systemic vulnerabilities and ensure sustainable regional development.

Gender disparities in educational attainment and enrollment at every stage of the education system have increasingly been recognized as an institutional trend, whereby women perform better than men across most aspects of education. The trend is well established across the world [42, 43], and has been confirmed in Italy by compound regional indicators [44].

Another significant methodological advancement in measuring educational inequality is the application of non-compensatory composite indices such as the Mazziotta–Pareto Index (MPI). These composite indices add multidimensional data without neutralizing imbalances among individual variables, making them particularly suitable to identify structurally embedded imbalances. MPI has been found to be effective in the Italian context in evaluating educational poverty and territorial wellbeing [40, 45].

Methodologically, another innovative element is the utilization of the stacking technique enabling combining observations of different groups—men and women—on a unique statistical axis and making it feasible to draw robust gender-based comparisons. In Italy, educational inequalities between different geographical areas and between genders are a structural issue, with significant impacts on social cohesion and economic growth [46].

Empirical evidence has long documented a significant gap between the Northern and Southern regions of the country: the former has higher education rates, while the latter records higher levels of school dropout and more limited access to tertiary education [47, 48]. This imbalance is also reflected in the labour market, generating differentials in terms of employment and remuneration. The causes of these disparities are multiple and attributable to economic, infrastructural, social, and cultural factors, which affect the quality of the training offered and educational opportunities [45].

In this context, the scientific literature has significantly deepened the analysis of educational inequalities, highlighting the importance of adopting methodological tools capable of synthesizing complex phenomena in a reliable manner.

The complex and multidimensional nature of socioeconomic phenomena requires the adoption of different measures to analyse and understand them. The measurement process in the social sciences is associated with the construction of systems of indicators, which makes it possible to measure phenomena that would not otherwise be measurable [49].

In this study, we use non-compensatory aggregate indices that allow different aspects of the phenomenon investigated to be included in a single variable. Composite indicators for the measurement of multidimensional phenomena have become very popular in various social, economic, and political fields [50]. Despite a growing body of literature on educational disparities, there remains a lack of studies that apply advanced aggregation methods—such as the stacking technique—to explore multidimensional educational inequality with gender disaggregation. Most existing works focus either on single indicators (e.g., dropout rates or tertiary access) or rely on traditional composite measures, without addressing the internal heterogeneity of gender-based educational performance.

This study seeks to fill this gap by offering an integrated approach that combines classical aggregation methods with the stacking procedure, allowing for a more robust comparison across population groups. Moreover, although regional disparities in Italian education have been widely documented, fewer studies have contextualized these patterns in relation to international com parisons.

Educational inequalities between regions—such as those observed in Spain [51], Germany [52], or the United States [53]—underscore the global relevance of spatial seg mentation in education policy. By situating the Italian case within this broader framework, this study contributes to the global discourse on regional equity and educational justice. Ivaldi and Ciacci [44] analyse the validity of the Gender Equality Index (GEI), proposed by the European Institute for Gender Equality, to measure gender inequalities in the Italian educational context, highlighting regional disparities in the period 2006–2014.

These inequalities can be traced back to multiple factors, including economic conditions, infrastructure, and spatial factors [47]. From a methodological perspective, Montorsi and Gigliarano [45] propose spatial composite indicators built through Bayesian latent factor models in order to assess the territorial well-being of Italian provinces, also integrating the spatial dimension in the measurement.

In line with this approach, Mazziotta and Pareto [50] introduce the non-compensatory indicator (MPI) of the same name, frequently adopted to summarize complex socioeconomic dimensions. This index has been applied in various contexts, such as the measurement of urban deprivation [54] and depopulation in Italian municipalities.

Numerous studies highlight how the choice of the summary index can significantly influence the results. For this reason, some authors have compared MPI with alternative methods, including principal component analysis (PCA), which is useful for the reduction of dimensionality [41] and the identification of latent patterns in educational variables

[47]. However, an appropriate measurement model must support a PCA-based composite index to function properly [50].

Similarly, cluster analysis represents a widely used technique to segment the territory into homogeneous groups, allowing for highlighting the dichotomy between the North and South and to identify areas with atypical educational performances [54, 55]. Studies such as Nardone et al. [48] have highlighted how the polarization between Northern and Southern Italy is not uniform but is articulated in sub-dynamics that also involve cultural, economic, and infrastructural factors.

A particularly relevant contribution is provided by Alaimo [49], who uses an adapted version of the MPI, called AMPI, to classify Italian regions according to different areas of well-being, including education, confirming the validity of these tools also for comparative analyses on a national scale.

Finally, the coherence between different aggregation methods can be assessed through Spearman correlation analysis, a tool that allows us to verify the solidity of the results and the non-dependence of the conclusions on the synthesis technique adopted [36].

This comparative approach guarantees greater robustness in the interpretation of the data and contributes to the validation of the methodological choices in the field of measuring educational well-being.

This study aims to analyse the education levels of the Italian regions in the year 2021, distinguishing between men and women, through the use of the Fair and Sustainable Well-being (BES) data published by ISTAT. The analysis involves a segmentation of the regions using cluster analysis techniques applied to a set of educational variables, followed by the calculation of the Mazziotta–Pareto Indicator (MPI) through the application of the stacking method in order to make the index values comparable between the two genders. Furthermore, to test the robustness and consistency of the results obtained, additional aggregation methods were applied: arithmetic mean, geometric mean, min-max normalization, and principal component analysis (PCA) [41, 50].

All techniques were adapted to the comparison between genders through stacking to ensure the methodological homogeneity of the approach. The consistency between the results obtained with the different methods was verified through Spearman correlation analysis [36].

The originality of this study lies precisely in the integration between classic aggregative approaches and the stacking technique applied systematically, to allow an accurate comparison between the education levels of the two genders.

This approach, in addition to offering an innovative methodological contribution, can support the formulation of educational policies aimed at reducing territorial and gender inequalities in the Italian education system. By employing multiple aggregation techniques and validating results across methods, this study offers a replicable framework for monitoring educational disparities.

This methodological robustness enhances the policy relevance of the findings, supporting data informed decision-making and the territorial targeting of educational interventions aligned with sustainable development principles.

2.3 Materials and Methods

2.3.1 Data source and indicators

The proposed analysis is based on the elaboration of a multidimensional set of educational indicators extracted from the ISTAT database of Fair and Sustainable Well-being (BES) for the year 2021 [53]. The BES system provides a comprehensive and multidimensional representation of social well-being in Italy, combining objective indicators across several domains, including education, work, health, environment, and social relationships. Its structure makes it particularly suitable for analysing territorial and sociodemographic inequalities within a well-being perspective. The unit of analysis is the Italian region, and all indicators are disaggregated by gender, allowing for a systematic comparison between male and female educational outcomes. The selected variables represent different aspects of the regional education level: a) population with at least a high school diploma (25–64 years), b) transition to university, c) early school dropout, d) young people studying or working, e) participation in continuing education, f) tertiary qualifications in the STEM field, g) cultural participation outside the home, h) reading books/newspapers, i) basic digital skills, j) graduates in the 25–34 age group.

Each of these ten variables was selected based on both theoretical relevance and empirical availability. For instance, “people with at least a high school diploma (25-64 years)” indicates the basic human capital and the minimum threshold for inclusion in skilled labor, a study related to the Chinese context uses this variable to analyze the state of the workforce and evaluate whether it is in line with the country's sustainable development goals [56].

"Non-early school dropout" and "transition to university" capture the accessibility and continuity of the educational path, Asif and Searcy believe that evaluating the performance of higher education institutions can better guide the direction of funding in education [57]. While "STEM qualifications" and "basic digital skills" reflect the alignment of education with labor market demands which is based on digitalization and innovations [58]. "Cultural participation" and "reading habits" represent broader cognitive and social capital dimensions [59]. “Participation in continuing education” is aligned with SDG4.3 which is the goal of lifelong and sustainable learning.

Table 2.1: Variable, description, units of measure, statistical distributions, and sources (Year 2021).

Variable	Description	Units of Measure	Statistical Distributions	Sources
1	People with at least a high school diploma (25-64 years)	Percentage values	Percentage over population aged 25-64	Istat – Labour Force Survey
2	Transition to university	Cohort-specific rate	Rate of high school graduates entering university	Ministry of Education; Ministry of University and Research
3	Not leaving education and training early	Percentage values	Percentage of 18-24 year-olds not in education/training	Re-elaborations on Istat data – Labour Force Survey
4	Young people in employment and education (NEET)	Percentage values	% of 15-29 year-olds not in employment, education or training	Re-elaborations on Istat data – Labour Force Survey
5	Participation in continuing education	Percentage values	% of adults aged 25–64 in formal/non-formal education	Istat – Labour Force Survey
6	People who obtain a tertiary STEM qualification in the year	Per 1,000 residents aged 20–29	Absolute rate per 1,000 of the population 20–29	Istat – Ministry of University and Research data

7	Cultural participation outside the home	Percentage values	% of people participating in cultural activities	Istat – Survey Aspects of Daily Life
8	Reading books and news-papers	Percentage values	% of people who read at least one book or newspaper	Istat – Survey Aspects of Daily Life
9	At least basic digital skills	Percentage values	% of population with basic ICT skills	Istat – Survey Aspects of Daily Life
10	Graduates and other tertiary qualifications (25–34 years)	Percentage values	% of population aged 25–34 with a degree	Istat – Survey Aspects of Daily Life

Source: Author

Table 2.1 summarizes the variables, description, units of measure, statistical distributions, and data sources for each indicator during the year 2021. This detailed description ensures transparency in the construction of the composite index and allows for critical evaluation of its components.

Together, these indicators capture both formal and informal dimensions of education, extending beyond traditional measures of schooling to include cultural engagement and digital competencies. This multidimensional approach reflects the role of education as a key determinant of social well-being and individual capabilities, in line with the conceptual framework of the BES system

2.3.2 Gender comparability and stacking procedure

A central methodological challenge in the analysis of gender inequalities concerns the comparability of male and female outcomes across multiple indicators.

The adopted methodology of standardization through stacking and k-means clustering is best applicable to the detection of fine differences in academic accomplishments and how they contribute to regional welfare [60]. This comprehensive methodology enables investigation into how gender disparities can influence aggregate social happiness as well as self-reported well-being.

The selected methodology allows for precise measurement of subtle differences between genders across regions, lending more insight into their impact on general subjective well-being and happiness.

The first step involved the standardization of the variables, carried out according to the z-score formula:

$$z_{ij} = \frac{x_{ij} - \mu_j}{\sigma_j}$$

Where x_{ij} represents the value of variable j for observation i, μ_j is the mean and σ_j is the standard deviation of variable j, calculated on the stacked dataset. In order to guarantee the comparability between male and female values, the stacking method was adopted [61, 62, 63] following the approach adapted by Bartimoro and Ivaldi [64, 65], which allows comparative aggregation between distinct groups (males and females).

The formulation is as follows:

$$\mu_j = \frac{\sum_{i=1}^{n} x_{i,j,F} + \sum_{i=1}^{n} x_{i,j,M}}{2n}$$

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{n}(x_{i,j,F} - \mu_j) + \sum_{i=1}^{n}(x_{i,j,M} - \mu_j)}{2n}}$$

where i=1,2,...,20 are the Italian regions, j=1,2,....,10 are the explanatory variables of education and F and M are the two genders analysed.

This approach, instead of calculating mean and standard deviation separately for each gender, allows to obtain a common scale for both groups, improving the comparability between the two distributions. The stacking approach is consistently applied throughout the analysis, both in the construction of composite indices and in the implementation of alternative aggregation methods, ensuring methodological coherence and comparability across all analytical stages.

2.3.3 First analytical strategy: composite index and gender gap clustering

The first analytical strategy focuses on identifying territorial patterns of gender inequality in education through the construction of a composite education index and the subsequent analysis of gender gaps. Following standardization via the stacking procedure, the ten educational indicators are aggregated using an additive approach to obtain a composite education index for each gender in each region.

Subsequently, for each region r and for each gender g, a composite index was calculated by adding the ten standardized variables:

$$S_{rg} = \sum_{j=1}^{n} z_{rgj} \qquad n = 10$$

Where S_{rg} is the aggregate score for gender g in region r. The measure of gender difference for each region was then obtained by:

$$D_r = S_{r,female} - S_{r,male}$$

This difference summarizes the overall gap in favor of one of the two genders. Positive values indicate a female advantage, while negative values indicate a male advantage in educational outcomes. This gender gap indicator serves as the basis for the territorial analysis.

To classify the regions, the K-means clustering method was used [66], applied to the vector of D_r.

The number of clusters was set K=5, to ensure good granularity in identifying territorial differences. The choice of five clusters reflects a balance between interpretability and the need to capture meaningful territorial differentiation. Finally, for each cluster the averages of the standardized variables were calculated separately by gender, to represent the average educational profiles through a radar graph. This visualization allowed to synthetically observe the dimensions of the gender advantage/disadvantage in the various regional groupings.

2.3.4 Second analytical strategy: multidimensional aggregation and robustness analysis

The second analytical strategy complements the first by focusing on the robustness of the observed gender and territorial disparities to alternative aggregation methods. First, a cluster analysis was carried out, using the K-means algorithm with k=3, applied to the entire national sample (not distinguished by gender). The choice of k=3 was guided by both statistical and substantive considerations. We tested several values of k and found that the Calinski-Harabasz and Silhouette coefficients reached optimal values at k=3, indicating a well-defined clustering structure. Moreover, this solution aligns with the well-established North–Center–South tripartition commonly used in Italian territorial policy analysis, enhancing both interpretability and policy relevance.

The aim was to obtain a segmentation of the Italian regions into homogeneous groups based on the selected educational variables. This procedure made it possible to reduce the information complexity and identify recurring territorial patterns. The analysis was implemented using STATA 18 SE software.

The k-means algorithm minimizes the intra-cluster variance and maximizes the inter-cluster variance, optimizing the following objective function:

$$J = \sum_{i=1}^{k} \sum_{x_j \in C_i} \left\| x_j - \mu_i \right\|^2$$

Where:

k is the default number of clusters,

C_i is the i-th cluster,

x_j is the feature vector of region j,

μ_i is the centroid of the cluster C_i,

$\left\| x_j - \mu_i \right\|^2$ is the Euclidean distance between a point and the cluster centroid.

This first investigation allows us to assign each region to the cluster with the closest centroid and obtain a regional breakdown based on the totality of the explanatory variables of the level of education.

Subsequently, for each cluster the Mazziotta-Pareto Indicator (MPI) was calculated [67], in the decreasing version (MPI–), for the entire population and, separately, for each gender.

The MPI is a non-compensating composite index, used to aggregate multiple variables into a single synthetic value, maintaining the structure of the original distributions. This method is particularly useful when you want to avoid that extreme values of a variable compensate for low values of another. To calculate it, it is necessary to normalize the variables so that they have the same unit of measurement and can be compared with each other, after having performed correction of their direction that makes them all positively oriented. Among the available aggregation techniques, the Mazziotta–Pareto Index (MPI) offers a non-compensatory approach particularly suited for sustainability analysis, as it penalizes unbalanced performance across dimensions and prevents compensation between poor and strong values. This characteristic is especially relevant when measuring environmental sustainability, where trade-offs may mask systemic weaknesses [67, 68].

The synthetic index, for unit i at time t, is then calculated by applying the following formula:

$$MPI_{it}^{+/-} = M_{z_{it}} \pm S_{z_{it}} cv_{it}$$

Where: $M_{z_{it}} = \frac{\sum_{j=1}^{m} z_{ijt}}{m}$; $S_{z_{it}} = \sqrt{\frac{\sum_{j=1}^{m} (z_{ijt} - M_{z_{it}})^2}{m}}$; $cv_{it} = \frac{S_{z_{it}}}{M_{z_{it}}}$.

The aggregate MPI for each region was obtained by taking the arithmetic mean of the male and female values. The means of the aggregate values within each cluster were used to reorder the classes based on the overall level of education. The same ordering was repeated separately for the two genders, thus allowing direct comparison of the regional hierarchies within the same clustered structure.

A leave-one-out (jack-knife) sensitivity check was performed: the composite index was recalculated after sequentially removing each individual indicator to assess the influence of single variables on the overall result.

To ensure the robustness of the results, the procedure was replicated by adopting additional aggregation methods: arithmetic mean, geometric mean, min-max normalization, and PCA. In each case, the entire process was performed using the stacking methodology, thus ensuring analytical uniformity and comparability between genders. The simultaneous adoption of different techniques allows to verify the influence of the chosen methodology on the results obtained.

Finally, the Spearman correlation matrix was calculated between the indices obtained with the different aggregation methods, in order to assess the degree of consistency between the measures and identify any discrepancies. A high degree of correlation would confirm the stability of the results and the validity of the conclusions regardless of the aggregation approach used.

Similar studies investigate complex phenomena through a multidimensional approaches, Hassan explores the multidimensional nature of DEI (Diversity, Equity, and Inclusion) with practical measurement tools for cultivating fair, respectful, and inclusive environments across workplaces, educational institutions, and communities [69]. Educational disparities have also been analyzed to improve student success and retention in educational context, considering different factors as: clear student guidelines, integrating first-year transition coursework, intrusive academic advising to treat the nonacademic and personal factors, and traditional developmental education coursework and tutoring to address academic factors [70]. Also in Malaysian context trough a comparison of gender enrolment across three dimensions has been studied the gender disparity in higher education across different higher education institutions [71].

2.3.5 Summary of the methodological framework

In summary, the approach taken in this chapter combines both analysis methods as complementary strategies that serve for investigating a common dataset and concept. The former seeks to identify territorial gender inequality profiles using composite indices and clustering methods, whilst the latter ensures methodological robustness via the use of alternative aggregation techniques and consistency tests. These two methodologies serve as complementary measures that help to build an accurate picture of multidimensional educational inequality in Italy, consistent with the overall aim of examining how sociodemographic determinants contribute to social welfare.

2.4 Results

2.4.1 Gender educational gaps and regional clustering

The first analytical strategy provides a detailed picture of gender disparities in education across Italian regions by focusing on the composite education index and the resulting gender gap. To begin with, the Italian regions' assignment to the 5 homogeneous clusters identified by the K-means algorithm implementation is shown, and focus is put on the variable "difference" - the female-male aggregate score difference - being a synthetic measure of the two-sex educational gap. The areas were grouped into five homogeneous clusters such that similar repeat patterns of territory and systematic variations of the phenomenon's distribution can be derived. Table 2.2 shows the outcomes collected; the various clusters were ordered in ascending order by the intracluster mean value of the difference variable.

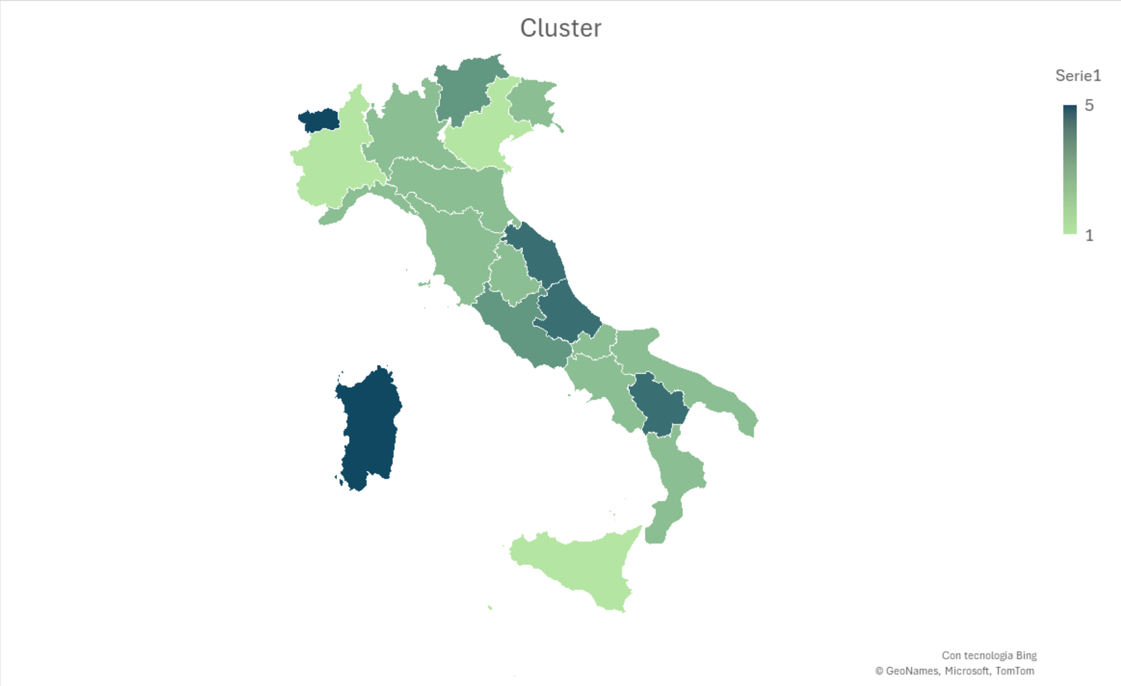
Table 2.2: *Systematic differences and Cluster for Italian Regions*

Regions	Differences (F-M)	Cluster
Piemonte	0.23	1
Sicilia	1.41	1
Veneto	0.77	1
Calabria	2.26	2
Campania	1.78	2
Emilia-Romagna	2.11	2
Friuli-Venezia Giulia	2.45	2
Liguria	2.10	2
Lombardia	1.63	2
Molise	2.14	2
Puglia	1.80	2
Toscana	2.43	2
Umbria	2.28	2
Lazio	3.65	3
Trentino-Alto Adige	2.88	3
Abruzzo	4.58	4
Basilicata	4.37	4
Marche	4.46	4
Sardegna	6.61	5
Valle d'Aosta	6.66	5

Source: Author

Fig. 2.1 shows the territorial subdivision into clusters. The number of clusters (K=5) was selected to ensure sufficient granularity in identifying territorial differences; however, future work could explore the robustness of this choice using cluster validation techniques such as the silhouette coefficient or the elbow method [66]. Higher cluster values correspond to a greater difference between the sum of the standardized female and male variables. The regions of Sardinia and Valle d'Aosta are those in which the difference in the level of education, in Favor of women, is more marked.

Fig. 2.1: Italian Regions into clusters



Source: Author

For each cluster, the mean values of the variable S_{org}, the sum of the standardized variables, for men and women were subsequently calculated, to reconstruct the mean educational profiles within each group. The results obtained are collected in Table 2.3.

Table 2.3: Results of each cluster

Cluster	Mean female S_{rg}	Mean male S_{rg}
1	12.24	11.43
2	14.62	12.52
3	20.29	17.03
4	16.58	12.11
5	16.67	10.04

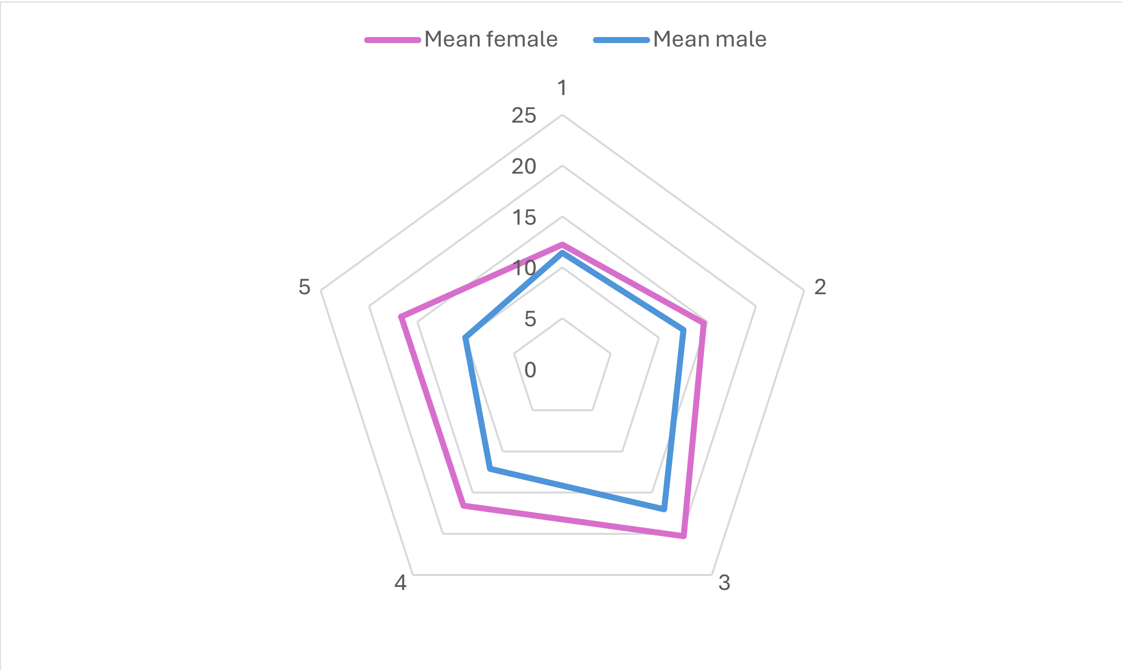
Source: Author

The non-monotonic trend in Table 2.3 means values with reference to the clusters is consistent with Table 1, while in Table 2.3 variable sum of standardized means in the two sexes are grouped and in Table 1 mean differences between clusters are mentioned.

Figure 2.2 below provides a graphical representation of the difference in mean values between the women and men across the various clusters obtained. The blue line represents the female mean, and the pink line represents the male mean. One also observes how the magnitude of this difference varies across different clusters.

These numerical data highlight that jurisdictions in which women possess a good record over men on educational indicators can be expected to record higher levels of well-being at the community level, empowerment, and subjective well-being, bearing in mind the established relationship between schooling and life satisfaction.

Fig 2.2: Differences in the mean values between men and women in the various clusters



Source: Author

2.4.2 Robustness of educational inequalities across aggregation methods

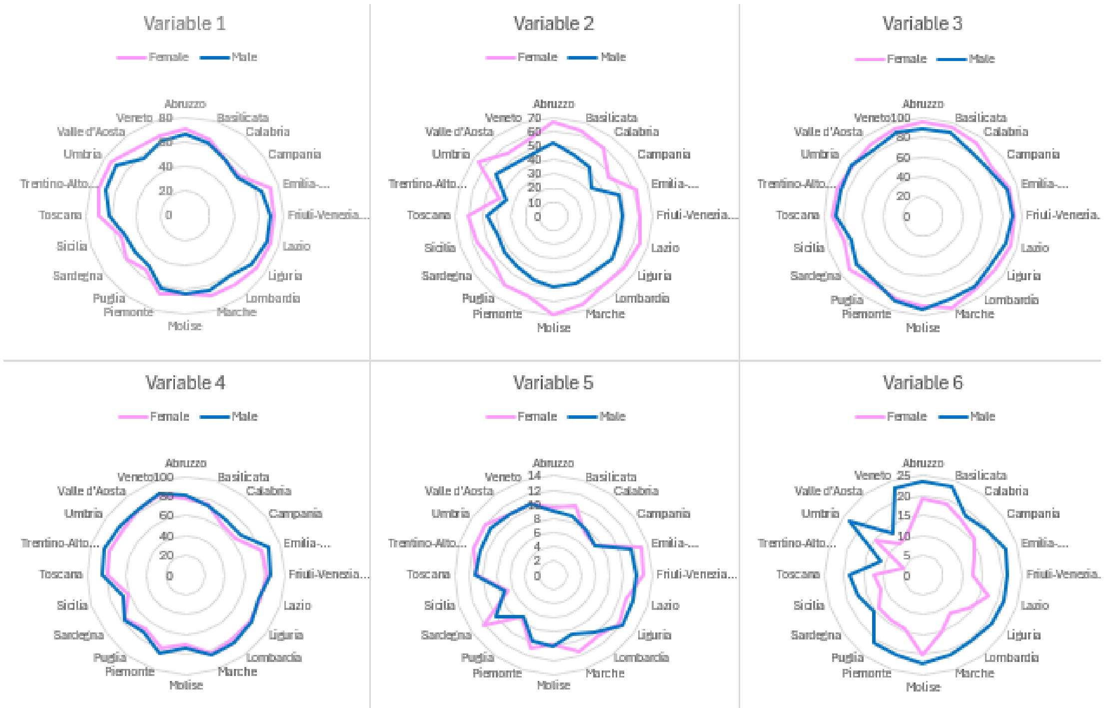
This section presents the results obtained from the analysis of Italian regional educational data for the year 2021. The elaborations were carried out by distinguishing by gender and applying the stacking method to make the indicators comparable between the two components of the population.

First, figure 2.3 and figure 2.4 presents the radar graphs for the ten educational variables and MPI in Italy by region, comparing them by gender. The pink lines indicate the values for females, while the blue lines indicate the values for males.

This visualization allows you to immediately grasp the territorial and gender differences in the variables.

The radar graphs also highlight the degree of homogeneity: more regular polygons indicate a more uniform distribution among the regions, while marked deformations suggest specific critical issues in the variable.

Figure 2.3: Education variables (from variable 1 to variable 6) in Italian regions by gender (Year 2021)



Source: Author

Figure 2.4: Education variables (from variable 7 to variable 10) and MPI in Italian regions by gender (Year 2021)

Source: Author

After that, the classification of the Italian regions into three homogeneous clusters is reported, obtained through the K-means algorithm, based on the set of educational variables considered. The ordering of the clusters was established on the basis of the average value of the Mazziotta-Pareto indicator (aggregate MPI), calculated as the arithmetic mean between the MPI of females and that of males (Table 2.4).

We decide to label clusters in increasing order as: “Low-performing”, “Intermediate-performing” and “High-performing” based on the aggregate MPI values, so in cluster “Low-performing” the aggregate MPI values vary between a minimum of 86.07 (Sicilia) and a maximum of 97.60 (Molise). In cluster “Intermediate-performing”, the range is between 96.90 (Sardegna) and 101.03 (Trentino-Alto Adige). Finally, cluster

“High-performing” records the highest values, with a range from 102.31 (Piemonte) to 107.00 (Friuli-Venezia Giulia), as summarized in table 2.4.

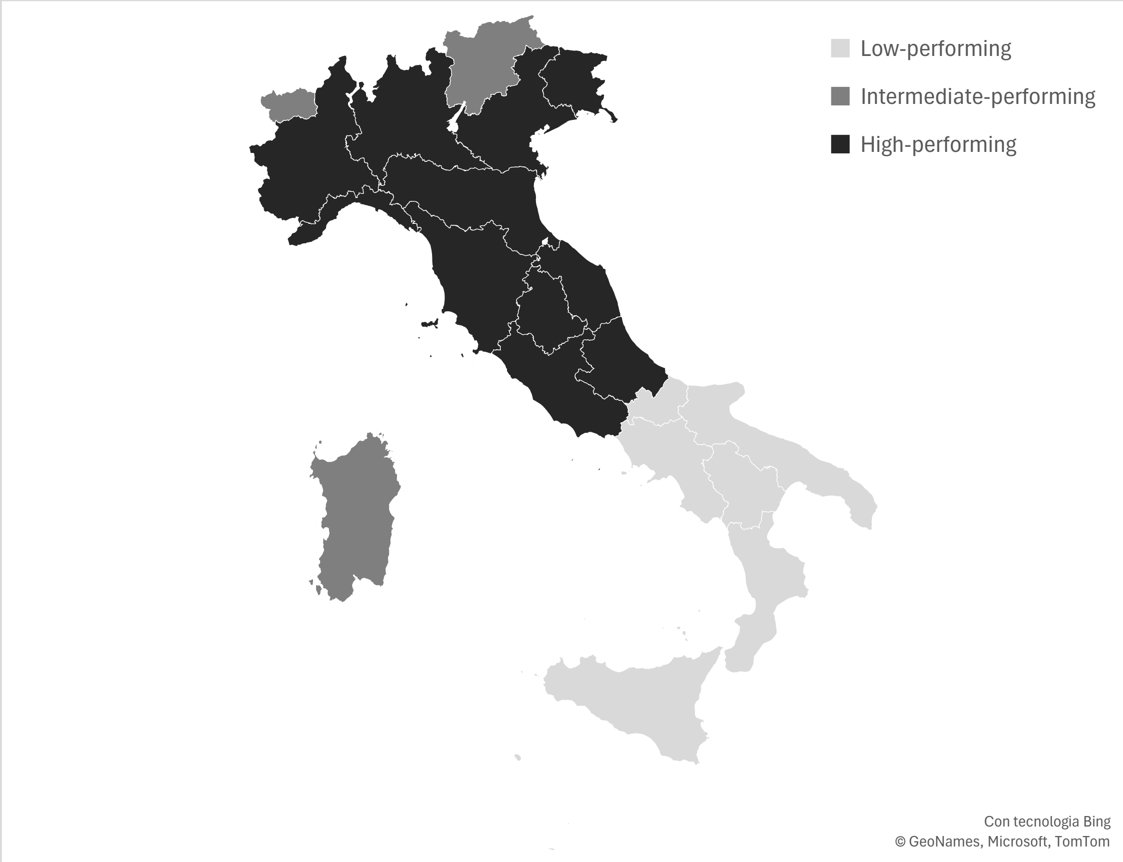
Table 2.4: Total MPI and Cluster

Region	Cluster	Aggregate MPI
Abruzzo	High-performing	100,79
Basilicata	Low-performing	95,92
Calabria	Low-performing	89,42
Campania	Low-performing	88,02
Emilia-Romagna	High-performing	106,16
Friuli-Venezia Giulia	High-performing	107,00
Lazio	High-performing	106,42
Liguria	High-performing	103,24
Lombardia	High-performing	102,84
Marche	High-performing	102,32
Molise	Low-performing	97,60
Piemonte	High-performing	102,31
Puglia	Low-performing	89,69
Sardegna	Intermediate- performing	96,90
Sicilia	Low-performing	86,07
Toscana	High-performing	102,90
Trentino-Alto Adige	Intermediate- performing	101,03
Umbria	High-performing	104,04
Valle d’Aosta	Intermediate- performing	100,64
Veneto	High-performing	103,97

Source: Author

For visual support, a map of Italy is presented that graphically highlights the distribution of the regions in the three identified clusters, Figure 2.5.

Figure 2.5: Cluster sorted on the average of the aggregate MPI.



Source: Author

Subsequently, all the indicators calculated with the stacking method are reported in Table 2.5, separately for gender. In particular, the following are presented: the Mazziotta-Pareto indicator (MPI), the geometric mean, the arithmetic mean, the normalized value through min-max scaling and the score of the first principal component obtained by PCA.

The leave-one-out test confirmed the robustness of the index: omitting any single indicator changed the composite scores by less than 2 % and did not alter the regional ranking.

Table 2.5: Composite Indicator Values by Gender: MPI, Geometric and Arithmetic Means, Min-Max Normalization, and PCA Scores

Region	MPI female	MPI male	Geometric mean female	Gometric mean male	Min-max female	Min-max male	Arithmetic mean female	Arithmetic mean male	PCA female	PCA male
Abruzzo	97,76	94,08	29,17	28,46	0,63	0,49	42,52	38,65	0,35	-1,10
Basilicata	90,11	88,73	26,08	25,82	0,27	0,23	37,69	35,91	-1,16	-2,08
Calabria	88,93	87,11	26,81	25,61	0,21	0,10	36,23	34,60	-1,68	-2,49
Campania	98,48	96,71	31,44	29,46	0,57	0,53	43,27	40,55	0,30	-0,38
Emilia-Romagna	90,64	88,75	27,32	26,54	0,16	0,02	38,15	36,12	-1,30	-2,27
Friuli-Venezia Giulia	86,72	85,43	25,39	25,24	0,18	0,05	35,62	34,16	-1,87	-2,80
Lazio	100,36	93,44	32,88	29,13	0,38	0,00	43,50	38,84	0,31	-1,42
Liguria	102,20	99,85	32,89	32,50	0,94	0,72	45,73	43,25	1,02	0,01
Lombardia	103,96	97,33	35,40	31,58	0,72	0,30	46,32	41,61	1,02	-0,62
Marche	102,94	98,64	34,02	30,87	0,84	0,68	45,68	42,43	1,10	-0,37
Molise	107,19	105,12	37,10	36,08	0,93	0,62	47,67	45,61	1,70	0,57
Piemonte	108,28	105,72	37,89	35,91	0,93	0,78	48,59	45,97	1,88	0,69
Puglia	108,35	104,49	38,15	36,20	0,97	0,80	48,13	44,89	1,72	0,53
Sardegna	104,37	102,11	35,16	34,36	0,88	0,70	46,29	44,10	1,08	0,12
Sicilia	103,66	102,03	34,81	34,59	0,78	0,47	46,09	44,07	1,01	0,01
Toscana	104,42	100,23	34,42	32,66	0,77	0,57	46,14	43,28	1,39	-0,20
Trentino-Alto Adige	102,54	102,07	34,71	34,34	0,69	0,49	45,00	43,79	0,64	0,03
Umbria	104,12	101,67	35,34	33,95	0,81	0,46	45,85	43,60	1,04	0,04
Valle d’Aosta	105,04	103,04	35,96	34,32	1,00	0,76	47,12	44,19	1,39	0,30
Veneto	104,34	103,60	34,84	35,30	0,74	0,55	46,33	44,82	1,17	0,30

Source: Author

In female MPI values, the range extends from 86.72 (Friuli-Venezia Giulia) to 108.35 (Puglia); for men, the corresponding range goes from 85.43 (Friuli-Venezia Giulia) to 105.72 (Piemonte). The female geometric mean varies between 25.39 (Friuli-Venezia Giulia) and 38.15 (Puglia), while the male mean varies between 25.24 (Friuli-Venezia Giulia) and 36.20 (Puglia). The min-max scaling values ranges from 0.16 to 1.00 for women and from 0.00 to 0.80 for men.

The female arithmetic mean values range from 35.62 (Friuli-Venezia Giulia) to 48.59 (Piemonte), while the male values range between 34.07 (Friuli-Venezia Giulia) and 45.97 (Piemonte). Finally, the PCA scores range between –1.87 and +1.88 for women and between –2.80 and +0.69 for men.

Table 2.6 shows the averages of each indicator within the clusters, again broken down by gender. This allows us to observe the average behaviour of the indicators within each regional group and verify any systematic patterns between the clusters.

Table 2.6: Average Values of Composite Indicators Within Each Cluster, by Gender

Cluster	MPI female	MPI male	Geom mean F	Geom mean M	Min max F	Min max M	Arithm mean F	Arithm mean M	PCA F	PCA M
Low-performing	92,11	90,13	27,70	26,86	0,34	0,24	38,91	36,67	-0,89	-1,85
Intermediate-performing	102,17	96,87	33,72	31,07	0,68	0,34	45,18	41,23	0,79	-0,68
High-performing	105,02	102,61	35,67	34,42	0,85	0,63	46,63	44,25	1,28	0,18

Source: Author

In cluster low-performing, the female MPI average is 92.11 against 90.13 for male; in cluster intermediate-performing the averages are 102.17 (females) and 96.87 (males); finally, in cluster high-performing the values are 105.02 (females) and 102.61 (males). For the geometric average, the values vary from 27.70 to 35.67 (females) and from 26.86

to 34.42 (males). In the min-max, women range from 0.34 to 0.85, men from 0.24 to 0.63. The female arithmetic mean grows from 38.91 to 46.63, while the male arithmetic mean grows from 36.67 to 44.25. Finally, the average PCA values rise from –0.89 to +1.28 for women and from –1.85 to +0.18 for men.

Tables 2.7 and 2.8 present the Spearman correlation matrix calculated between all the composite indicators considered. This matrix allows to evaluate the coherence and robustness of the measures adopted, providing an indication of the convergence between the different aggregation techniques applied.

Table 2.7: Spearman Correlation Matrix Among Composite Indicators (Female Population)

	Geometric mean female	Min-max female	MPI female	Arithmetic mean female	PCA female
Geometric mean female	1.0000				
Min-max female	0.8206	1.0000			
MPI female	0.9504	0.8447	1.0000		
Arithmetic mean female	0.9609	0.8394	0.9729	1.0000	
PCA female	0.8977	0.8770	0.9684	0.9474	1.0000

Source: Author

Table 2.8: Spearman Correlation Matrix Among Composite Indicators (Male Population)

	Geometric mean male	Min-max male	MPI male	Arithmetic mean male	PCA male
Geometric mean male	1.0000				
Min-max male	0.7248	1.0000			
MPI male	0.9774	0.7925	1.0000		
Arithmetic mean male	0.9820	0.7774	0.9970	1.0000	
PCA male	0.9624	0.8045	0.9910	0.9880	1.0000

Source: Author

For women, the highest correlations are between MPI and arithmetic mean (ρ = 0.9729), and between MPI and PCA (ρ = 0.9684). For men, the correlation between MPI and arithmetic mean is 0.9970, while that between MPI and PCA is 0.9910. These values indicate a high consistency between the different synthesis methods.

2.5 Discussion

The results presented in this chapter provide consistent and convergent evidence on the existence of gender and territorial inequalities in education in Italy, while also highlighting the robustness of these patterns across different methodological approaches. Taken together, the findings confirm that educational outcomes are not randomly distributed across the population, but reflect structurally embedded differences shaped by gender, territory, and broader socioeconomic contexts.

A first key result concerns the systematic female advantage observed across most educational dimensions and regions. Females in all the five clusters identified have higher mean scores than males for the sum of standardized education variables. This finding supports an established trend within international literature [43, 48, 72, 73, 74, 75, 76], in which the female gender is expected to obtain better performances in different areas of education, especially in highly educated environments and universalistic school systems [74]. Yet the feature that emerges strongly in this analysis is the spatial feature of the disparity: the female advantage is not uniformly spread, but is magnified in specific regions of the country, as picked out by clusters 4 and 5, where the gap between the genders assumes very high values.

The geographical education disparities identified may have significant implications not just for economic and labour market results but for subjective well-being and overall happiness. Regions with a high female education premium may experience broader social benefits, including improved family well-being, lower stress, and higher community satisfaction

Regions such as Sardinia and Valle d'Aosta are at the upper end of the distribution, indicating local, cultural, economic or offer-related educational determinants which contribute to increasing the female advantage. In clusters 1 and 2, including several regions in the North and Center, the gender gap is more restricted, yet still in favour of women. This framing suggests that policy and intervention into gender equality in education should not only be attuned at the national level, but also with sensitivity to regional specificities.

Finally, though a constant female advantage on average scores, it is notable that this does not preclude the existence of structural inequalities and barriers. In fact, there is an education gender paradox, whereby the more successful performances of women in the education system do not necessarily translate into equal opportunities in subsequent work, professional and salary paths [77]. The results reported in this research therefore pave the way for further reflections: on the one hand, on the need to secure women's achievements in the educational field, and on the other, on the need to remove the systemic barriers to the full valorisation of women's human capital in the labour market [77, 78, 79, 80, 81, 82, 83, 84, 85]. Policy interventions aimed at reducing gender disparities should not be limited to addressing educational access and attainment alone but should explicitly incorporate subjective well-being indicators to promote inclusive and sustainable societal development.

The educational gender premium observed in specific Italian territories is in line with trends described for Northern European countries, such as Sweden and Finland [74], where high educational attainment by women is linked very closely with enhanced well-being in the community, reduced stress, better health, and increased subjective happiness. These parallels point to the broader applicability of gender equality education policies as drivers of enhanced happiness and social sustainability across territories.

This pattern, is confirmed also by the second analysis. The cluster analysis, conducted with the k-means algorithm, allowed us to group the Italian regions into three homogeneous clusters based on ten educational variables extracted from the BES database. The clus ter with the highest scores of the aggregate Mazziotta–Pareto indicator (MPI)—above 102 points—mainly includes regions in the Centre-North, such as Emilia-Romagna (106.16), Friuli-Venezia Giulia (107.00), Lazio (106.42), and Marche (102.32). On the contrary, regions in the South, such as Campania (88.02), Calabria (89.42), and Sicilia (86.07), are placed in the cluster with the lowest values, highlighting a persistent

North–South fracture in the distribution of educational opportunities. This result is consistent with the existing literature, including the studies of Nardone et al. [48], which emphasize that the educational gap between north and south is not only expressed in school dropout or access to tertiary education but also in the quality and inclusiveness of the educational offer. These disparities directly impact the acquisition of cognitive and digital skills, undermining equitable human capital development [86]. From the perspective of the United Nations 2030 Agenda [39], these findings raise critical concerns for achieving SDG 4 (Quality Education) and SDG 10 (Reduced Inequalities). Territorial inequalities in education hinder the creation of inclusive and sustainable societies, weakening social cohesion and economic resilience in less advantaged areas. A second dimension of great importance is gender. The application of the stacking method made it possible to perform a direct and methodologically homogeneous comparison between men and women for each composite indicator. The results show that, across all methodologies used, women consistently score higher than men [42, 43, 72, 73, 75, 76, 77, 78]. For example, in the High-performing cluster, the female MPI average reaches 105.02, compared to 102.61 for men. Even in clusters with lower overall performance—such as the Low-performing cluster—women maintain an advantage: 92.11 versus 90.13. Similar trends are observed in other indicators—in geometric mean, PCA scores, and min-max normalization. Even in disadvantaged regions such as Calabria, female scores outperform male ones. This trend supports the goals of SDG 5 (Gender Equality) by evidencing a structural and persistent female advantage in educational outcomes, even in socioeconomically fragile territories. These findings resonate with the conclusions of Ivaldi and Ciacci [46], who demonstrate a long-term improvement in female educational performance across Italian regions. The observed resilience of the female segment in education highlights a paradox when contrasted with the more precarious position that women continue to hold in the labour market, emphasizing the need for integrated, cross-sectoral policies [78, 79, 80, 81, 82, 83, 84, 85]. Another relevant aspect concerns the consistency across the synthesis methods adopted. The Spearman correlation matrix, calculated separately by gender, reveals very high coefficients between indicators. For women, the correlation between MPI and arithmetic mean is 0.9729, and 0.9684 with

PCA. Among men, the MPI correlates 0.9970 with the arithmetic mean and 0.9910 with PCA. These values confirm the robustness of the analytical framework. As Alaimo and Maggino [36] suggest, strong correlations between results obtained through different techniques enhance the empirical validity and policy relevance of composite indicators. The integration of PCA, a compensatory method, with non-compensatory indices such as MPI is particularly useful in validating latent structures, as also noted by Mazziotta and Pareto [50]. In the context of sustainability, these methodological choices offer a replicable and robust framework for monitoring progress toward inclusive and equitable education, aligned with SDG reporting and local policy needs. The hybridization of classical and innovative approaches—such as stacking—enables more sensitive detection of regional and gender-specific patterns, enriching the decision-making process. Overall, the integration between traditional aggregation approaches and newer methodologies such as stacking has proven particularly effective in producing a robust, comparable analysis of educational inequality in Italy. This work not only offers an accurate picture of existing disparities but also a valuable methodological contribution for future research and sustainable policy design. As highlighted by Montorsi and Gigliarano [45], conventional well-being models risk overlooking spatial dynamics and latent heterogeneity. The application of hybrid methods, such as stacked MPI and PCA, can address this limitation, enhancing both analytical sensitivity and territorial equity—core principles of sustainable development. The policy implications of this study are closely aligned with the territorial clustering results. For low-performing Southern regions (Cluster Low-performing), policy makers should prioritize early intervention strategies, including investment in school infrastructure, expanded access to early childhood education, and targeted financial support for students at risk of dropout. For intermediate regions (Cluster Intermediate-performing), measures could focus on strengthening transitions from secondary to tertiary education and enhancing vocational pathways, especially in underdeveloped inland areas. In high-performing regions (Cluster High-performing), policy efforts may concentrate on consolidating existing strengths, such as promoting excellence programs, fostering lifelong learning, and addressing gender imbalances in STEM education. Moreover, the consistent female advantage observed across all indicators calls for integrated gender-sensitive strategies [87]. These should not only recognize women's educational achievements but also ensure that these are effectively translated into labour market opportunities. Gender mainstreaming in education policy, combined with labour-market reforms, is necessary to close the gap between educational performance and employment outcomes. While this study focuses on descriptive and comparative multidimensional analysis, future developments could incorporate inferential techniques to better understand the causal mechanisms behind regional and gender disparities in education. In particular, the use of regression models—both linear and multilevel—could allow researchers to test the impact of structural factors like household income [88–91], school infrastructure [71, 92], and urban–rural location, as well as psychological or individual factors such as field of study [71], academic self-esteem, and intrinsic vs. extrinsic motivation [90, 93, 94], on composite educational outcomes. Additionally, structural equation modelling (SEM) could offer a more integrated framework to explore latent constructs and indirect effects among educational determinants. These analytical extensions, while beyond the scope of the present study, would further enrich the explanatory power of the multidimensional approach presented here.

The integrated methodological approach adopted in this chapter also offers important insights for the design and evaluation of public policies. The combination of clustering techniques and robustness checks allows for the identification of regions characterized by similar inequality profiles, supporting the development of targeted and territorially differentiated policy interventions. Moreover, the use of the stacking procedure ensures that gender comparisons are based on a coherent and methodologically sound framework, addressing a critical issue in the measurement of gender inequalities.

In line with the United Nations 2030 Agenda, the findings of this chapter have direct relevance for several Sustainable Development Goals. The evidence contributes to SDG 4 (Quality Education) by highlighting disparities in educational outcomes and access; to SDG 5 (Gender Equality) by documenting persistent gender differences in educational performance; and to SDG 10 (Reduced Inequalities) by emphasizing the territorial dimension of educational disparities. Achieving progress in these areas requires policies that are simultaneously gender-sensitive and territorially informed, recognizing the multidimensional nature of educational inequality.

Finally, the results underscore the importance of adopting a holistic perspective in the analysis of social well-being. Education does not operate in isolation, but interacts with other domains such as labour market participation, mobility, and access to services, which are addressed in other chapters of this thesis.

2.6 Conclusions

This chapter aimed to analyse gender and territorial inequalities in education within Italy, through the lens of a multidimensional approach that is closely linked to the concept of social well-being in its wider sense. Instead of treating schooling as a simple end-state, the analysis conceptualized education as a fundamental capacity that organizes life chances and generates social inequality across generations. By combining both analytical strategies, which have been applied to the same dataset, in this chapter an overview of how educational inequalities are ordered regarding gender and region has been presented systematically, as well as why these inequalities matter for development other than just for education.

The first study undertaken appears to have demonstrated quite clearly and systematically that gender inequalities in education exist. At a general level this research, as well as indicating significant regional differences in gender educational outcomes in Italy, provides an extremely important contribution to the wider debate on world development, happiness and subjective well-being.

The primary strength of the study lies in its methodological rigour, and through constituting an original combination of standardization by stacking and k-means clustering it assesses the ability to pool inequalities and measure them from a regional perspective. Drawing on multi-categorical educational inequality indicators, we propose embracing policy frames that are holistic and well-being focused to drive sustainable development and happiness in cultural and geographic localities. Finally, relying on a theoretical account of the relationships between educational inequality, gender equality and SWB, this study yields crucial information for decision-makers to design more comprehensive and happiness-oriented policies of sustainable development that are sound both in a regional (the Italian one) context but most importantly in an international context.

However, the study has limitations. Descriptive analysis If/when the differences are not described in a very good manner despite being well documented in literature, we can't suspect explanation for them [95, 96, 97].

Second, the focus on 2021 BES data alone prevents us from estimating temporal trends or structural change. Third, the 2021 pandemic situation and some selection of variables could influence results as well, so over-interpretation of most extreme results should be taken with care.

With these attributes in mind, other reports can either extend the time horizon of the study or apply the analysis framework to the other BES dimensions (jobs, health etc.), thereby quantifying interdependence between subjective well-being and equity.

The case study selected for this work illustrates the potential of the multi-dimensional measures in advancing policy on gender equity and community well-being more broadly.

Educational equity is therefore seen as a precursor of subjective wellbeing, thus paving the way to a virtuous avenue where sustainable, inclusive and culturally directed-oriented development strategies could be constructed in Italy and beyond.

One of the most important findings one may possibly draw from this chapter, is related to these results' soundness. The second study was a clearly delimited and methodologically solid research on educational inequalities in Italy, illustrating the disparities which continued to persist in 2021 unpacking by region, and across sexes. The application of the cluster analysis and use of a more fine-grained version of Mazziotta-Pareto Indicator (MPI), sophisticated through a consistent exploitation of stacking, has endowed it with a reliable and comparable classification in relation to educational regional performance. The division of regional Italy into three clusters brought out the well-known divide based on the North-South that calls for "place-based" policy intervention capable of dealing with the structural weaknesses of the South and strengthening excellence in Center and North. One particularly notable feature is the consistently positive education gradient among women in all areas and for all methods of synthesis. This finding, which is a neglected fact of public conversation today, is structural rather than incidental. This implies that female human capital in Italy is already from an educational point of view at least stronger than male: some fundamental issues concerning the “gap” between achievement and labour market can be inferred.

Bridging this gap requires integrated and gender-sensitive policies, aimed not only at supporting education but also at ensuring the recognition and valorisation of women’s skills in professional and societal contexts. These conclusions speak directly to the objectives of SDG 4 (Quality Education), SDG 5 (Gender Equality), and SDG 10 (Reduced Inequalities). Ensuring equitable access to education, acknowledging the structural resilience of women in the educational sphere, and reducing territorial gaps are key priorities in the achievement of a sustainable, inclusive, and just society.

From a methodological standpoint, the study contributes to the growing literature on the use of composite indicators in educational research. By adopting and comparing multiple aggregation techniques—including arithmetic mean, geometric mean, min-max normalization, and principal component analysis—the analysis confirmed the internal consistency of the findings. The high Spearman correlations between indicators validated the reliability of the approach and its replicability across different territorial and temporal contexts. The application of the stacking method, originally employed in predictive modelling, proved effective in constructing composite indicators for non-overlapping population groups, reinforcing comparability and analytical clarity. The contributions of Alaimo and Maggino [36] have been particularly valuable in reframing educational well-being as a multidimensional and interconnected system rather than as a sum of isolated indicators. The empirical validation of hybrid aggregative methods consolidates their role as effective tools for evaluating complex phenomena in line with sustainability assessment principles. Despite its strengths, this study also presents some limitations.

Composite indices with a non-compensatory construction can mask internal imbalances between the indicators. While the application of Spearman correlations and repeated synthesis steps enhance robustness, a complete sensitivity analysis of indicator weights could be conducted in future research. Moreover, although stacking provides improved comparability, it cannot be used to address causality. This paper suggests that combining between regression models and SEM frameworks is also recommended for future studies to further illuminate the structural causes and mechanisms of educational inequality. Lastly, a future extension would be the investigation of spatially-aware composite measures (e.g., constructed from Bayesian structural latent factor models) to consider territorial contiguity and spillover effects. Finally, the study provides not only an accurate diagnostic of educational inequalities in Italy but also policy recommendations to establish fair and sustainable policy strategies. To narrow regional gaps it is necessary to invest more in the infrastructure, accessibility and quality of education in structurally less developed areas. Falling gender gaps require policies by which the educational products of women are fully valued particularly in the transition from school to work. Finally, the approach developed in this study is a replicable model that can be adapted to monitor educational equity over time and inform evidence-based planning. In future research the inclusion of spatially sensitive composite indicators such as the ones developed by Montorsi and Gigliarano [45] could be explored, which allow to use Bayesian latent factor models in order to capture territorial contiguity and diffusion dynamics. This line of investigation shows potential for enhancing the predictive power and local policy relevance of educational sustainability indicators.

Beyond the descriptive scope, however, the results suggest a reflection on the function of education in (social) differentiation and quality of life. Education is not merely an end product to be evaluated at a point in time. It has a significant impact on determining employment, income security, social participation and personal autonomy. Therefore, educational disparities are directly linked to the express of ranges of well-being among individuals and territories. From this viewpoint the educational inequalities described in this chapter should be viewed as one of the main mechanisms by which social inequality is transacted and sustained over generations.

The examination of educational inequalities carried out in this chapter raises the complexity of well-being as a concept, and its reliance on institutional or territorial levels. It is this perspective that naturally serves as a stepping stone towards an even more extensive comparative and longitudinal expansion democratization trajectories in cross-country comparisons will be addressed in the following chapter.

Chapter 3: Sustainable Development Trajectories in the G7 Countries: A Multidimensional and Long-Term Analysis

Abstract

This work investigates the dynamics of sustainable development in G7 countries – Canada, France, Germany, Italy, Japan, United Kingdom and United States between 2000 and 2022. The analysis is based on a multifaceted approach, where the three pillars of sustainability (social-, economy- and ecology-development) form the foundation. The study enables a comparison over time of the sustainability performance of advanced countries by establishing an interdisciplinary framework that is underpinned with a number of indicators.

The social domain is reflected in indicators relating to poverty and education, the economic domain via GDP per capita and level of unemployment, with the environmental realm covered by CO_2 emissions and use of natural resources. By applying an integrative approach, we can examine how different dimensions of sustainability develop and interrelate through time within each national context. The findings point towards a relatively high heterogeneity among the G7, with a general trend towards beneficial economic growth at the same time as enduring social disparities and continued environmental aggression.

Therefore, the analysis also suggests that it has been considerable internal divergence in the path towards a sustainability innovation indicative of different policy priorities, long-term and consistency of institutional frameworks. Although in some countries there may be progress towards a balance between social inclusion, economic growth and environmental sustainability, others have more fragmented or uneven pathways. More specifically, the results call into question the ability of the G7 development model to foment sweeping and universally applicable sustainability initiatives.

Another contribution of the study regards renewable energy and energy efficiency, which appears as major drivers in determining the environmental performance and long-term sustainability consequences. In sum, the findings place the G7 experience in the

context of a wider discussion on sustainable development in advanced economies and offer empirical evidence regarding the obstacles and constraints faced by states aiming for sustainability under conditions of high economic development.

3.1 Introduction

Sustainable development has been an increasingly prevalent theme in international discourse since the release of the seminal 1987 United Nations report Our Common Future. That report defined sustainable development as the capacity to meet current needs without compromising the ability of future generations to meet their own [98]. This first set of definitions established a foundation for a shared vision of a more equitable and sustainable future and has since supported continued international efforts. The transition from the eight Millennium Development Goals (MDGs) to the more ambitious 17 Sustainable Development Goals (SDGs) was a key shift, emphasizing the interconnected nature of economic, social, and environmental challenges, and embedding the international community's aspiration for system change [99-102]

Within this global environment, it has become an urgent task not only for policymakers and international organizations but also for the academic community, responsible for providing both conceptual and operational orientation [103], to make sense of the multifaceted dimensions of sustainable development and to provide actionable frameworks for its attainment. The ecological footprint, as a rough estimate of the extent of human demand on nature versus the re-generative potential of the planet, is a useful metric to determine the sustainability of development trajectories [104]. Similarly, a country's energy mix, the breakdown of energy sources on which it relies constitutes a fundamental metric for both climate exposure and decarbonization potential [105].

The remaining key determinants of environmental sustainability are material productivity and resource intensity, which are increasingly recognized as being key levers in high-income economies such as the G7 economies. In these contexts, improvements in resource efficiency are likely to be linked with more advanced levels of technological maturity as well as with lower levels of environmental pressure [106]. The G7 countries, which include Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States, play a pivotal role in shaping both the global economy and environmental governance [104, 107, 108]. These older economies, characterized by mature urbanization, high levels of industrialization, and competent political authority, represent critical laboratories for experimenting with how sustainability may be operationalized at scale [109, 110, 111].

Empirical studies have traditionally tested the impact of economic activities on the environment based on economic growth and per capita income variables. Although the variables provide a simple economic indicator, they do not capture structural change in the economy and the direction of technological change [112-115]. Hidalgo & Hausmann [116] clarify that production requires not only labor and capital but also capabilities. Hidalgo & Hausmann originally developed the idea of economic complexity.

Although numerous composite indicators have been developed to measure sustainability performance at the global and national levels [117, 118], the scholarly literature reveals a critical methodological gap. Relatively limited research has carried out unified comparative assessments drawing on all three dimensions of sustainability economic, social, and environment within a single coherent analytical framework, much less from a temporal perspective. A great deal of the literature is biased either toward environmental or economic indicators, with too little regard for synergistic interlinkages with social ones, which limits the potential for capturing the dynamic of sustainability in practice.

Additionally, there is a lack of longitudinal studies that examine how sustainability performance changes over time, especially in high-income nations. However, recent research such as 119, 120, 121, 122] have observed the unemployment rate to have a positively correlated relationship with CO2e. These findings show that they tend to move in a positively linear fashion, highlighting the complexities of employment dynamics vis-a-vis environmental connections [123].

This paper seeks to bridge a gap in the literature by conducting a comprehensive temporal evaluation of sustainable development across G7 economies from 2000 to 2022. It needs a multi-faceted model using critical indicators across the three axes of sustainability: GDP per capita and employment rate (economic), poverty ratio and education (social), and CO_2 emission and natural resource depletion (environmental). By this integrated approach, the study attempts to gauge to what extent the G7 countries have achieved a balance among economic growth, social justice, and environmental management over time.

By providing a longitudinal and non-compensatory assessment, this work offers an innovative contribution to the empirical literature on sustainability measurement. It enables a more nuanced understanding of national sustainability trajectories within highly developed economies, highlighting both convergences and persistent disparities among G7 members.

The literature used today reflects the growing effort towards quantifying sustainability in terms of time, particularly focusing on mature economies' attempts to address concerns regarding maintaining long-term balance on the three dimensions of sustainable development.

Sustainability is envisioned as the sophisticated reconciliation between economic growth, social equity, and protection of the natural world has grown more and more at the forefront of intellectual interest and policy making, most significantly in high-income contexts such as the G7 [103, 106]. Much of this work has dealt with exploring the relationship between economic growth and environmental impacts, usually framed in terms of the Environmental Kuznets Curve (EKC) hypothesis. Empirical tests of the EKC hypothesis for G7 nations have produced different, sometimes inconclusive, outcomes [106, 122]. For instance, [122] re-investigated the CO_2 emissions versus income relationship with a new elbow regression approach, which offered better interpretations of the EKC. In the same vein, [106] employed the EKC to examine the environmental effects of material productivity indicators across G7 countries during 1970-2019, confirming the validity of the curve for the United States and Germany alone. Complementarily, [124] employed wavelet coherence analysis to further de-tangle dynamic interlinkages between carbon emissions and growth trajectories.

At the same time, the transition to renewable energy and pursuit of energy efficiency is central axes in the sustainability paradigm. Radmehr et al. [104] unraveled a two-way link between renewable energy consumption, income levels, and ecological footprints for 1990 – 2018 for G7 economies. Azimi and Rahman [123] provide empirical proof of the Environmental Phillips Curve in the G7 countries, and there is evidence that rising unemployment rates are associated with falling CO_2 emissions. Economic growth, economic policy uncertainty, and population size all have a positive long-term effect on emission levels, with the consumption of renewable energy and technological innovation resulting in long-term emissions decline. Dai et al. [105] emphasized the key role of energy structure in determining climate vulnerability profiles, whereas Liu [125] found a positive correlation between energy efficiency and indicators such as economic growth, energy prices, and the increasing share of renewables in G7 countries during 1990-2020.

The social sustainability dimension, while comparatively less concentrated, is manifested through studies on human capital, financial buffer, and inclusive growth. Lian and Li [103] associated human footprints, human capital formation, and financial inclusion with sustainability success, acknowledging that these play a mediating effect on sustainability success. Luo and Li [126] investigated the use of fiscal decentralization and human development indicators in shaping green innovation, affirming the underlying long-term contribution of education and human capital. Xiao and Tabish [127] further carried this train of thought by investigating green finance procedures, demonstrating how educational advancement, openness in trade, and management of natural resources affect G7 nations' practice of sustainable investment.

Environmental governance and regulation are another consistent theme in studies. Borozan et al. [128] tested the impact of high environmental and business regulations on foreign direct investment flows, both between G7 economies and BRICS economies. Dahmani [129] also explored the impacts of environmental tax systems and R&D-driven environmental technologies in driving ecological sustainability and the strategic policy architecture role in achieving sustainability goals.

Moreover, comparison with developing economies offers a context. Muguto and Muzindutsi [130] contrasted volatility in BRICS stock returns and the G7 market based on opposing structural differences of financial systems. Nasim et al. [131] examined determinants of banking efficiency in developed (G7) economies and developing (E7) economies and found mixed effects of institutions and regulatory systems.

Collectively, this literature highlights the multi-faceted nature of sustainability analysis in G7 economies, with dominant concern devoted to economic-environmental dynamics, renewable transitions, and policy responses. However, a comprehensively integrated, temporally harmonized approach that simultaneously records the evolution of economic growth, social justice, and environmental integrity is relatively under researched.

The present study seeks to fill this literature gap through an integrative temporal analysis of G7 nations' sustainability performance to contribute to improved understanding of how major economies address sustainable development's challenges.

The data used in this research, for the G7 countries' sustainability performance from 2000 to 2022, came from the SDG Transformation Centre database and is available on Kaggle.com. The same database was used to produce the Sustainable Development Report 2023 by Sachs et al. [132].

Measuring sustainable development requires an approach capable of integrating economic, social, and environmental dimensions into a single composite indicator. The Adjusted Mazziotta and Pareto Index (AMPI), which represents a variant of the original Mazziotta and Pareto Index (MPI) [61, 67, 133, 134], emerges as a robust non-compensatory approach for this purpose. It is adopted by the Italian National Institute of Statistics (I.Stat) for the analysis of complex phenomena over time [135, 136], but also across spatial dimensions [137, 138].

Its sequential construction process incorporates a penalty term, which contributes to its robustness, flexibility, and reproducibility. Consistently, the AMPI method offers a stable and reliable framework for constructing synthetic indicators in multidimensional assessment environments.

Mathematically, the index construction process is as follows: the raw data matrix X={xijt}, where xijt represents the value of the j-th indicator for the i-th unit at time t, is re-scaled to a normalized matrix R={rijt} through a constrained re-scaling equation so that all indicators are represented within a given range [70, 130]. The normalization is anchored to fixed benchmark values, referred to as goalposts, which are derived from the reference year 2000 (i.e., the initial year of data collection).

The formula used is:

$$r_{ijt} = \frac{x_{ijt} - Min_{xj}}{Max_{xj} - Min_{xj}} * 60 + 70,$$

The goalposts are determined using the formula:

$$Ref_{ijt} \pm \Delta, \text{with } \Delta = \frac{Sup_{xj} - Inf_{xj}}{2}$$

where Ref_{xj} denotes the reference value of the j-th indicator for unit i at time t, and Inf_{xj} and Sup_{xj} represent, respectively, the minimum and maximum values of indicator j across all units and time periods.

Under this setup, each basic indicator is rescaled so that the reference unit in the reference year assumes a value of 100, while all other values are expressed relative to this benchmark.

The final step concerns the aggregation of the normalized indicators into the composite AMPI index, calculated as:

$$AMPI_i = \mu_{ri} \pm \sigma_{ri} c_{vi}$$

Here, the AMPI score for each unit i is composed of two elements: the arithmetic means of the normalized indicators μ_{ri}, and a penalty term $\sigma_{ri} c_{vi}$, where σ_{ri} is the standard deviation and c_{vi} is the coefficient of variation. This penalty component captures the "horizontal variability" of indicators within each unit and penalizes those with greater internal imbalance, thereby rewarding more consistent profiles at the same mean level.

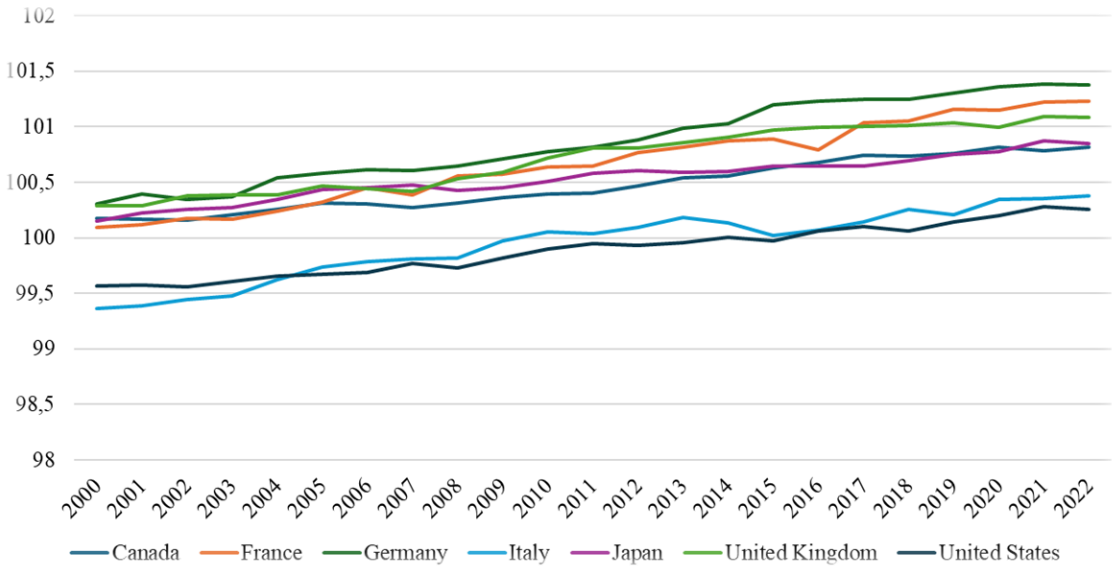
The AMPI was chosen not only because it can aggregate over one dimension into a unidimensional index, but also because it is non-compensatory. This feature makes it best suited for the measurement of sustainability, where a weak performance in one dimension (e.g., the environment) should not be offset by a strong performance in another (e.g., the economy). The internal penalty of imbalance in the AMPI allows for a more precise record of multidimensional well-being [54], and national statistical institutes such as ISTAT further confirming its methodological rigor [139] enhances it.

For multidimensional deprivation (MD), when the composite indicators are downward-oriented, i.e., larger values reflect worsening conditions, the correction is applied. That is, the standardized indicators is offset upwards by a positive penalty so that the index accurately reflects negative changes in the underlying phenomenon [136, 140, 141].

3.3 Results

Figure 3.1 shows the Adjusted Mazziotta and Pareto Index (AMPI) time series for all the G7 countries between 2000 and 2022. The index puts the three dimensions of economy, society, and environment together in one single measure of sustainability normalized on the scale 0-1. Larger values of the AMPI represent more balanced and sustainable performance across all dimensions. There is a clear convergence towards high mean values (above 0.7) for many countries since 2010, indicating a general rise in integrated sustainability. Disparities between members remain: Germany and France enjoy the most sustained and virtuous trajectories, while the United States and Canada exhibit greater volatility, especially in the post-crisis years (2008-2012) and the pandemic years (2020-2021), which indicates greater susceptibility to systemic shocks.

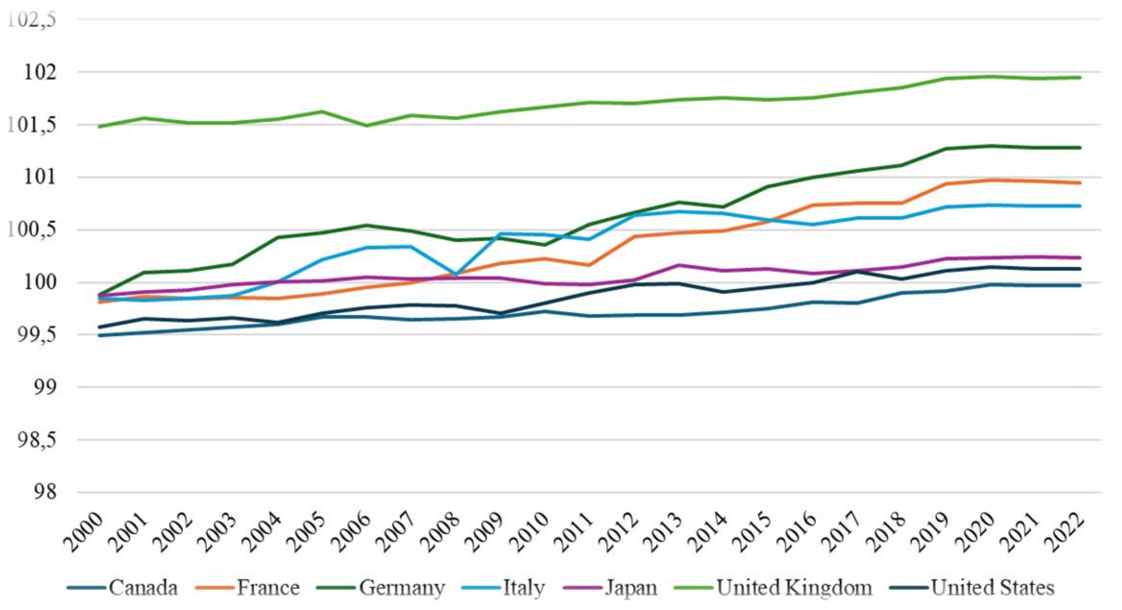
Figure 3.1: Trends in G7 countries' overall sustainability index from 2000 to 2022, combining economic, social and environmental dimensions.



Source: Author

The second graph (Fig. 3.2) divides the environmental aspect of WAPI, considering CO_2 emissions and the use of natural resources. In this case, important divergences emerge: the United Kingdom and France have consistent improvements, likely because of energy transition and effective decarbonization policies. On the contrary, the United States and Japan show unstable performance, with recent improvement but not offsetting the high environmental cost of previous decades. Of particular concern is the slowdown of progress in Canada and Italy since 2015, highlighting potential structural limits to energy efficiency and resource utilization.

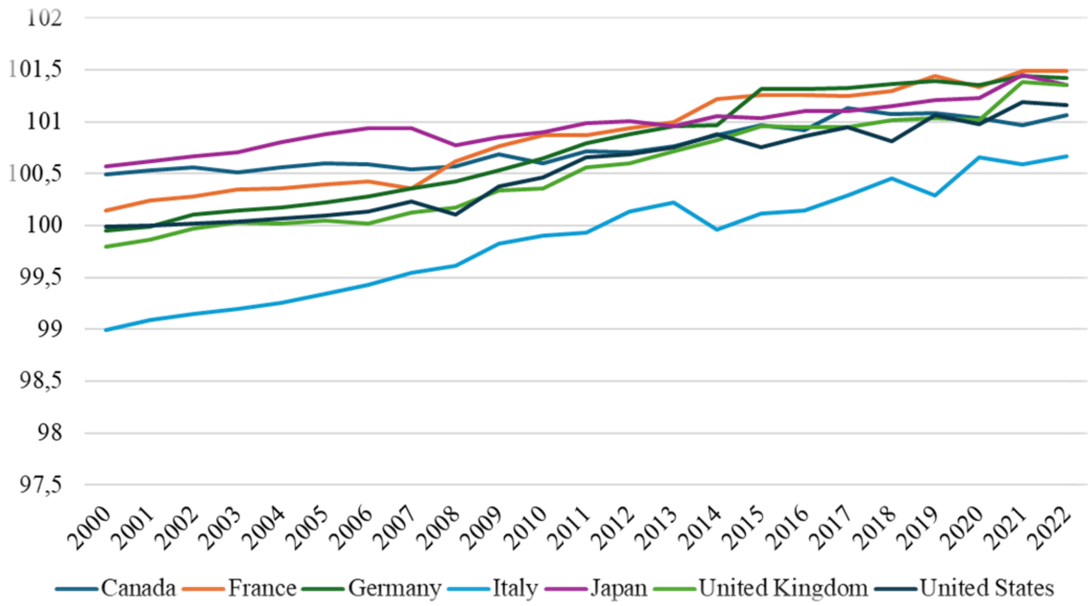
Fig. 3.2: Trends in the environmental sustainability index for G7 countries (2000–2022)



Source: Author

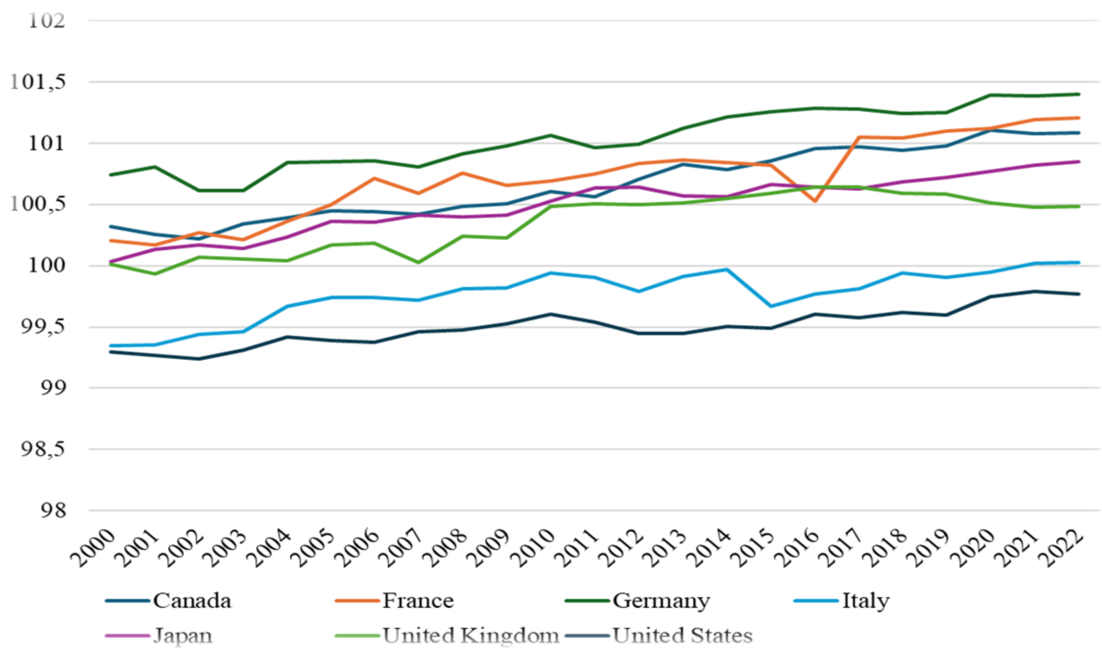
Figure 3.3 shows the economic factor, e.g., GDP per capita and unemployment rate. All G7 countries show values that are moving upwards, historically with interruptions brought about by world financial crises. The United States and Germany show resultant indices that are above average, showing resilience and economic strength. Italy is the only country to remain continuously below the group average, having structurally poor growth with concomitant high, long-term unemployment. This result validates Italy's inability to convert economic growth into inclusiveness and long-term sustainability.

Fig. 3.3: Trends in the economic sustainability index for G7 countries (2000–2022)



Source: Author

Fig. 3.4: Trends in the social sustainability index for G7 countries (2000–2022)



Source: Author

Finally, the fourth figure analyzes the social component, addressed by indicators such as poverty and schooling. The advancement is general, with emphasis for Germany and the United Kingdom, where significant improvement in social performance since 2010 can be registered. France's is more incremental but steady, while the United States and Italy stand out for a relative decline in recent years, mainly because of increasing inequality and polarization of access to services. Japan, while at a high-medium level, shows an alarming deceleration after 2015, possibly reflecting demographic and intergenerational inclusion issues.

3.4 Discussion

To measure the transforming relationship between economic growth, social welfare, and environmental sustainability in G7 countries, a wide correlation between four composite indicators - overall, economic, social, and environmental - and GDP was conducted employing Spearman’s rank correlation coefficient. As it is a non-parametric test that optimally identifies monotonic relationships without assuming normality and therefore suitable for multi-dimensional development indicators, it has been employed. The results display consistently high and statistically significant positive correlations between GDP and the overall index, with coefficients greater than 0.95 and often very close to 0.99 for all G7 countries in 2000-2022. This implies that economic growth has been followed by more general improvements in quality of life, although the force of this connection may partly be an artefact of the employment of overlapping variables in the construction of indices. The economic index data show a nearly perfect correlation with GDP trends, decelerating slightly in pandemic years, showing temporary shocks from global crises. The strong correlation between GDP and the economic aspect can partly be attributed to partially structural overlaps in the variables included in both. While this is good for internal consistency, it also demands caution in interpretation. The green index features extremely high correlation coefficients, with minimal recent divergence pointing to emerging stresses in balancing growth and environmental resilience. The people index, if similarly, highly correlated with GDP, is more sensitive to external shocks and exhibits a marginally worsening coherence since 2015, suggesting social well-being lags economic recovery. Longitudinal design also facilitates pattern detection and structural change for resilience, providing critical knowledge upon which to ground joined-up policy interventions. It thus helps to reconceptualize development in terms other than the purely economic and map a multidimensional definition of progress in the developed world.

A second component of the study involving the initial aggregate analysis of the relationship between GDP and composite economic, social, and environmental welfare indicators included a dis-aggregated analysis at the national level for G7 members. Spearman correlation coefficient was used once more as it is applicable in identifying monotonic relationships without assuming a normal distribution. The reasoning behind this approach stemmed from the need to uncover country-specific patterns hidden in aggregate data so that structural and policy-related differentials across countries could be identified more clearly. Spearman correlations for all the G7 members (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States) provided data on how much GDP relates to improvement in the general well-being index (OVER) as well as the economic (EC), social (SOC), and environmental (ENV) areas.

Results revealed that there existed consistently high and high and meaningful positive correlation ($p < 0.01$, two-tailed) between GDP and OVER index in all countries, with a range from 0.95 to 0.99. This reveals an extremely tight relationship between economic growth and multifaceted developments in quality of life.Sectoral decompositions also confirmed that the economic index (EC) most closely correlated with GDP in all countries ($r > 0.96$–0.98), suggesting almost perfect correlation between macroeconomic performance and sectoral indicators such as employment and income. The environmental index (ENV) also had high correlations with GDP ($r = 0.90$–0.97), but slightly lower than for EC, especially in Japan and the UK. This means that while economic growth generally benefits environmental progress, these kinds of relationships are not as strongly linked and may be affected by other national environmental policies or outside ecological pressures.

There was even more heterogeneity in GDP relative to the social index (SOC). Canada, Germany, and the United States had high correlations ($r = 0.90$–0.96), whereas

Italy and the UK had lower but still significant correlations ($r \approx 0.80–0.82$), indicating a less direct relationship between economic growth and social well-being in those cultures. These imbalances underscore the importance of policies that are country-specific to guarantee that economic growth is converted into social development that is inclusive and equitable.

Generally, the country-level results reinforce the robustness of the initial aggregate results yet also reveal large national differences with implications for sustainable development policy. States such as Canada, Germany, and the US appear to have achieved a superior balance between economic expansion and improvement in the quality of life, whereas the weaker social links in states such as Italy and the UK suggest potential for gaps in economic performance to be converted into greater societal welfare. These tendencies highlight the significance of policy measures aimed at the social dimension of sustainability alongside economic and environmental priorities.

3.5 Conclusions

The comparative analysis of the sustainability performances of the G7 nations offers a multi-dimensional view of the shifting priorities and policy orientations of the world's major economies. The evidence suggests that while the G7 group reflects a shared interest in sustainable development, there are substantial national variations along social, economic, and environmental axes. These variations are not merely the product of divergent institutional arrangements and policy choices, but also the product of the impact of historical legacies, socioeconomic structures, and political will.

Thematic convergence on some fronts, such as macroeconomic stability and technological progress, is juxtaposed with deep divergence on others, i.e., environmental and social. These findings argue for a more cohesive, longer-term-oriented public policy that is sensitive to the extremely interdependent interaction among the dimensions of sustainability. In that case, internal heterogeneity within the G7 can be appreciated not as a weakness but as a wellspring of strength. Differing national trajectories can be fertile soil for cross-learning and experimentation, with the construction of adaptive and context-specific policy.

Policy-wise, the findings imply the need for coordinated yet differentiated policies, with a priority on systemic integration along with multi-level governance. Greater policy coherence, underpinned by international benchmarking and standard measures, could hold the secret to speeding up sustainability transitions. Second, the witnessed variability in sustainability trajectories across G7 nations underscores the scope for more integrated and forward-looking public policies. Countries can benefit from having national sustainability frameworks that are both internationally coherent and nationally distinctive, thereby fostering greater resilience, legitimacy, and effectiveness. Policymakers are therefore recommended to adopt flexible governance models facilitating innovation and experimentation together with accountability and long-term commitment.

Based on these results, policymakers in G7 countries should consider adopting sustainability strategies that explicitly balance all three pillars: economic, social, and environmental, rather than focusing on economic performance alone. The strong correlation of GDP with sustainability indicators is a signal that economic growth may be channeled into sustainable development only if supplemented with certain investments into social welfare and environmental resilience.

Future studies could explore how regional or urban uses of AMPI reveal additional inequalities or combine this index with qualitative as-assessments to better understand local sustainability dynamics. Comparative studies with G20 or EU countries could also extend the scope of temporal benchmarking.

The research is subject to limitations that should be noted. First, the application of composite indices, while facilitating cross-country comparisons, can obscure key intra-country variations and institutional complexities. Second, the choice of indicators, while guideline-prescribed, entails inevitably normative subjective judgment that may bear on interpretability. Third, since the study is founded on a cross-sectional design, it remains limited in following temporal dynamics and causal processes. Longitudinal designs must be the focus of future studies and encompass qualitative methods to enlighten us about institutional determinants of performance and contextualize observed trends. More intense inclusion of bottom-up approaches, including stakeholder interviews and participatory assessments, would also deepen the image of how sustainability is implemented at the local level and how citizens view it. Finally, while the AMPI provides a robust and justifiable structure, it also has some limitations of method. The construction draws upon normative decisions like indicator choice, normalization cut-off points, and penalization policy. While such decisions are justified, they can impinge upon comparability across countries and must be justified. In addition, the fixed benchmark values taken from the base year may short-change the more recent change in absolute performance.

Concisely, the study adds to the knowledge of sustainability governance among high-income economies and provides a valuable analytical framework for guiding evidence-based policy transformation. Convergence should not be an objective, but a shared normative consensus on the construction of resilient, inclusive, and forward-looking strategies. A consciousness of the differentiated sustainability pathways within the G7 can allow for more integrated and foresight-capable policies that can deal with both global problems and national specificity. This report contributes to the necessity of making sustainability a cross-cutting theme of all major policy domains, including fiscal policy, innovation systems, labor markets, and education, rendering the transition to sustainability both fair and sustainable in the long run.

This chapter concludes the analytic trajectory of the dissertation by taking this empirical inquiry to an international and historical level. The overall conclusions reflect and summarize the evidence across all of the chapters, providing a coherent explanation of the findings and synthesizing the combined methodological and substantive contributions of the research.

Conclusion

The analyses developed in this doctoral thesis have highlighted the profound connection between socioeconomic inequalities, well-being, and sustainable development, highlighting how these phenomena manifest differently across regions and significantly impact individual and collective opportunities. Through a multidimensional and territorial approach, the research has shown how well-being cannot be understood solely as an economic condition, but as a complex set of factors—including access to services, education, mobility, environmental quality, and social participation—that interact with people's sociodemographic characteristics and the context in which they live. The three case studies presented, while operating at different scales, converge in underscoring the structural nature of inequalities. Overall, the thesis suggests that effective policies to reduce inequalities and promote sustainable development must be based on an integrated understanding of phenomena, capable of capturing their complexity and interconnections. In this sense, the territorial dimension and the use of advanced analytical tools—such as non-compensatory composite indices and clustering techniques—are crucial.

This thesis has presented a collection of articles directly published in peer-reviewed journals and developed within a coherent conceptual and methodological framework with the goal of contributing to an accumulated, meta-theoretical view on inequality, well-being, sustainability, and policy analysis. Even if every single chapter is based on a specific empirical contribution, the fragmented studies are combined into an overall research trajectory and not just left as discrete analyses in space.

The integrated nature of this thesis has enabled comparison across domains, spatial scales and analytical settings providing patterns as well as methodological insights that are not gained within the frame of single publications.

Apart from the particular empirical results, the main achievement of this thesis is a methodological unification. By allowing the assumptions, constraints, and complementarities of used analytical frameworks to be critically scrutinized, an attempt is made to demonstrate that sound methodological coherence and transparency matter in the joint measurement of inequality and sustainable development.

In sum, this collection of work collectively speaks to the importance of integrated research design in pushing forward empirical knowledge and interpretative clarity, as well as providing a launching-off point for future research set on further extending multidimensional evaluation frameworks into new policy domains, datasets and comparative settings.

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