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Systemic Cooling Poverty at the urban scale: evidence from Venice Provincial Area

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Abstract

The Copernicus Climate Change Observatory reports that 2024 has been the warmest year recorded since 1850, with global temperatures surpassing the 1.5 °C increase relative to pre-industrial levels - a threshold established during the 2015 Paris Agreement - reaching an observed increase of 1.60 °C. This escalation underscores the imminent and severe impacts of climate change, notably an amplification in the frequency and intensity of extreme weather events such as heatwaves (IPCC, 2023). In response, the European Commission's 2025 report on Summer Energy Poverty (SEP) highlights the multifaceted nature of SEP and explores strategies to enhance societal resilience. Heat stress constitutes a critical health threat, necessitating immediate, well-informed policy interventions that prioritize the assessment of population exposure to heat as a key step toward fostering equitable and inclusive resilience.

Recognizing a gap in existing literature concerning localized, multidimensional assessments of heat vulnerability - particularly within Italy - the present thesis aims to identify geographical hotspots and policy areas requiring urgent governance actions to enhance adaptive capacity to elevated temperatures and humidity. This is operationalized through the application of the Systemic Cooling Poverty Index, developed by Mazzone et al. (2023), at the Venice provincial level. The SCP Index consolidates socio-demographic, geospatial, climatological, infrastructural, and healthcare data within the R computing environment to evaluate the systemic factors influencing heat vulnerability across census areas.

The research aims to map areas within Venice where systemic characteristics of census tracts undermine residents' capacity to adapt to persistent heat. The SCP framework assesses five interconnected dimensions - Climate, Infrastructure and assets, Thermal justice, Health, and Education and work standards - each composed of specific sub-indicators. The findings reveal widespread cooling poverty, with approximately 80.6% of the population experiencing moderate to high deprivation in heat adaptation, and 13.6% suffering from severe deprivation, collectively affecting 94.2% of the inhabitants.

Certain municipalities, such as Cona, Mira, and Cavarzare, exhibit persistent vulnerabilities, particularly in the dimension related to Education and work standards and Health. Climatic conditions, characterized by high temperatures and humidity, significantly influence vulnerability levels, while deficiencies in educational attainment, unemployment, and poor air

quality exacerbate health risks and limit adaptive capacity. Accessibility issues to healthcare facilities further compound vulnerabilities in remote and insular areas. Infrastructural deficits - particularly inadequate public transportation networks and limited green spaces - also diminish resilience against extreme heat. The Thermal justice dimension, which accounts for the distribution of vulnerable socio-demographic groups, presents a less critical picture across the Province.

Despite some data limitations, the analysis provides a nuanced view of Venice’s resilience profile, emphasizing the necessity for systemic, multi-sectoral measures. Proposed policy strategies include implementing cooling shelters, increasing green infrastructure, improving access to healthcare and mobility services, and fostering social cohesion. Such interventions aim to fortify the community’s adaptive capacity, thereby mitigating the health and social impacts of escalating heat stress and climate-related challenges in the region.

0. Introduction

As far as we are living in a climate warming era, also defined as Anthropocene, and that, as outlined in the Summary for Policymakers from the Sixth Assessment Report released in 2021 by the IPCC (Intergovernmental Panel on Climate Change), anthropogenic activity is causing temperatures on Earth to rise at an unprecedented rate, human society needs to reorganize its structure towards a collective and substantial action.

Copernicus Climate Change Observatory, reports that 2024 has been the hottest year since 1850, breaking the record of 1.5 °C increase with respect to the pre-industrial era. During the last year, an increase of 1.60 °C has been observed, thus meaning that the first threshold established during the 2015 Paris Agreement has already been reached, exposing living beings to the severe consequences of climate change. In this perspective, episodes such as extreme weather events, among which heatwaves, intense rainfall and extended droughts, will be more acute and spread over the globe in the next decades (IPCC, 2021).

As a consequence, as reported by Becker et al. 2022 in their study about the analysis on the intensity of European heat waves between 1979 and 2019, the frequency and intensity of heat spells in this region of the world has been growing in the last 40 years. Other studies (Perkins-Kirkpatrick et al. 2020) offer further evidence of this phenomenon and predict it to become more frequent and intense in the near future (Papadopoulus et al. 2024).

Simultaneously to what outlined in the previous paragraph, attention should be directed to human health, which is exposed to a growing condition of risk in the face of rising temperatures (Ballester et al. 2023; Ellena et al. 2020; Zhang et al. 2024). In particular, specific categories of society result in being more vulnerable to climate extremes, due to physiological reasons, socio-economic factors and infrastructural conditions, other than the climatic characterization of the inhabited area and the orography of the same region. Heat stress represents a deadly threat to humans that needs to be dealt with informed and far-sighted decision making. In this context, measuring the population exposure to heat turns out to play a pivotal role towards a more just and inclusive societal environment.

Within this framework, the European Commission, in 2025, released its first report about Summer Energy Poverty (SEP), previously identified by Torrego-Gomez et al. 2024, where the complexity of SEP is brought to light and different resilience-enhancing strategies are explored. Until last year, the issue of energy poverty was explored preponderantly in the winter thermal comfort connotation and the attention was often focused only on the economic and infrastructural components of this phenomenon (e.g. OIPE 2023; Campagna et al. 2024), which is now recognised to have an intersectional, multidimensional nature. The issue has to be investigated redirectioning the attention to studying summer thermal comfort and its accessibility among different social categories. Recent studies oriented to dive deeper into the problem at multiple levels are presented by a multitude of scholars, among which Cole et al. in 2024, that focused the research on heat risk inequalities in London, and Mazzone et al. in 2023 in presenting the willingness to implement a novel multidimensional indicator for mapping the inequities in accessing thermal safety based on five dimensions, namely: Climate, Infrastructures and assets, Thermal inequalities, Health and Education and work standards.

Recent functional interventions in the field of local climate governance in the case study area of Barcelona have emerged in Amorim-Maia et al. 2024 and Estévez et al. 2025, suggesting a place-based and participatory approach could help downscaling the gap in accessing the optimal conditions for the population to achieve thermal safety.

Despite the existence of a body of research on the UHI (Urban Heat Island) effect and its social and infrastructural implications in the Italian context is found (Pappalardo et al. 2023; Maragno et al. 2021), there exist a lack of evidence underlying which are the additional systemic drivers exacerbating thermal stress across the Italian population and in which way they can directly shape the intensity of heat vulnerability.

Since a gap in the state of art of the literature emerges when looking for other studies oriented to map comprehensively the problem at the local level in Italy, the aim of this thesis to understand which are the geographical hotspots, in terms of reduced heat adaptive capacity, and policy areas urging immediate policy interventions tailored to address the necessities that will emerge through the application of the Systemic Cooling Poverty Index by Mazzone et al. 2023, at Venice metropolitan area level.

The thesis study focuses on the Venetian province, in the north-eastern area of Italy, representing the capital city of Veneto region. Venice is known for being a critical area, due to its amphibious nature, with respect to environmental issues, in relation to climate change exacerbation, leading to more frequent high tides and the depletion of salt marshes and other lagoon-associated ecosystem services (Giupponi et al. 2024, Lionello et al. 2021, Maragno et al. 2023, Sambo et al. 2023, Zanchettin et al. 2021). Socioeconomic stressors, such as over tourism and gentrification, represent one other major threat to local inhabitants' wellbeing, as described in recent studies (Del Chiappa et al. 2021, Lopez et al. 2022, Salerno et al. 2022, Tedesco et al. 2024), and to social cohesion and sense of belonging.

In light of these phenomena, the aim of this study is to provide a first measure of the geographical distribution over Venice province of the systemic conditions leading the population to have scarce possibility of adapting to extreme heat conditions in the present days, through the application of the Systemic Cooling Poverty Indicator by Mazzone et al. (2023).

The thesis is articulated into four main sections delineating the process of study. The first section introduces a description of the summer energy poverty issue and presents the Systemic Cooling Poverty framework. The second section describes the characteristics of the data employed for the analysis and the methodology adopted for the measurement of the indicators, dimensions and Index. The third section moves to the analysis of the results produced from the computation of the SCP Index. Concluding, the final section presents a discussion over the results in a decision-support perspective.

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1 Literature and background

1.1 Literature

In recent years, concerns about energy poverty have received a renewed interest due to climate change and rising energy prices. Globally, numerous impediments to fuel poverty alleviation persist, encompassing pervasive inequality, political instability and violence, the impacts of climate change, the ongoing recovery from the COVID-19 pandemic, and escalating living costs. Recent geopolitical conflicts, notably the Russia-Ukraine war, have precipitated a decade-high surge in oil and gas prices, thereby disrupting global energy markets (Al Kez et al., 2024; Burguillo et al., 2025).

As outlined in Mazzone et al. (2023) and Charlier et al. (2021) the history of fuel poverty literature begins with its first definition, in 1983, by Bradshaw and Hutton, mainly referring to the inability of families to achieve residential thermal comfort during the coldest months of the year. Thermal comfort is considered (Teixeira et al. 2024) as the psychological state in which an individual perceives satisfaction with the prevailing thermal conditions of the environment. After the first interpretations of energy poverty, an enlarged body of literature was developed over the topic and different approaches to the issues were proposed. In particular, Boardman in 1991, released an expenditure-based definition of fuel poverty that identified households deprived from the capacity to reach thermal comfort during winter when households' energy expenditure was higher than the 10% of their income. Instead, Callan et al. (1993) propose that a household can be considered energy poor when it lacks access to basic utility needs and is living in dwellings presenting damp walls, floors, roofs or does not have energy or electricity access. Many indicators for the quantitative measure of fuel poverty in the consequent years, in different regions of the world, have been designed and implemented. In the past, fuel poverty has been preponderantly studied in an economic perspective, where the most vulnerable would be the ones suffering from economic instability and low-income (Gouveia et al. 2019, Krstic et al. 2017), indicators that were representative just for that dimension of scarce adaptive capacity to climate extremes were designed, leaving behind all the other drivers of vulnerability. It has later been recognized that there exist multiple drivers of energy poverty and relevant studies started attributing fuel poverty also to lack of adequate infrastructural components. Nevertheless, as described by the European Commission in 2016 with their report among the selection of energy poverty indicators, the causes driving households to be energy poor are multifold, not only economical or infrastructural. Energy poverty has been subsequently defined in the 2023 Social Climate Fund Regulation and the revised Energy Efficiency Directive as 'a household's lack of access to essential energy services that provide basic levels and decent standards of living and health, including adequate heating, hot water, cooling, lighting, and energy to power appliances, in the relevant national context, existing social policy and other relevant policies, caused by a combination of factors, including but not limited to non affordability, insufficient disposable income, high energy expenditure and poor energy efficiency of homes.' (European Parliamentary Research Service, 2023). This new conception of thermal comfort deprivation has been largely explored by a multitude of scholars. In 2012, Nussbaumer et al. released MEPI, the Multidimensional Energy Poverty Index, a measurement comprehensive of different pillars. Cooking is one of these, since it constitutes a fundamental human necessity, requiring energy in the form of heat to prepare food. To assess aspects of energy poverty related to cooking, the study by Nussbaumer et al. considers the type of fuel utilized. Additionally, indoor air pollution resulting from incomplete combustion of these fuels poses substantial health risks. Consequently, the type of stove employed - specifically, whether it is equipped with a hood or chimney- has been used as a proxy to capture these health and convenience-related dimensions of energy poverty in MEPI design. After the first implementation of the multidimensional indicator, covering the African region, different measurements, based on the same framework, have been applied to different world nations as in the case of Laldjebaev et al. (2021) applying it to Tajikistan and Sokolowski et al. (2019) employed it to Poland. Nussbaumer et al. in 2013 applied the MEPI framework on the global scale highlighting how the issue remains of particular concern in the African continent. The Multidimensional Energy Poverty Index has been further studied in other contexts as in the case of Bezerra et al. 2022, that explored the issue in Brazil from an historical perspective. Overall, MEPI's application to Brazil demonstrated notable improvements over the observed periods (from 2002 to 2017). Despite these advancements, approximately 11% of the population continued to experience energy poverty conditions. The study highlights that in urban areas, these conditions are primarily driven by issues related to affordability while, in rural regions, where 16% of households are still classified as energy-poor, multiple dimensions collectively contribute to these findings.

Against this literature backdrop, over the past few years, cooling poverty has become a growing issue due to climate change and energy prices. Indeed, in the past, the attention has been preponderantly posed on winter energy poverty, which is the inability to face low temperatures and keep the household adequately warm during cold periods, not considering the rising threat of elevated temperatures exposure, also at high latitudes, due to rising frequency, duration and intensity of heat waves, as pinpointed in (Perkins-Kirkpatrick, 2018). In this regard, different scholars have already shed light on the expected increase in the adoption of active cooling strategies, as in the case of air conditioning, causing the increase of energy demand across the world. As found by De Cian et al. (2023), household adoption of air conditioning is associated with a 34% increase in electricity consumption across the globe, though this effect exhibits substantial heterogeneity. The study reported that variation was evident across diverse weather patterns, income levels, and countries, highlighting the crucial role of individual behaviors, climate characteristics, and technological factors in shaping energy use. Furthermore, as highlighted by Falchetta et al. in 2024, access to and utilization of air conditioning are expected to remain markedly unequal both within and between countries and income groups, resulting in substantial regressive effects. Projections indicate that by 2050, as many as four billion individuals may still lack access to air conditioning. In the given context, passive cooling strategies emerge as a crucial factor, enhancing socio-economically vulnerable people's adaptive capacity to hot temperatures (Bach et al. 2023, Khosla et al. 2021). Chambers et al. (2020), in their global assessment studying the impact of hot temperature peaks among world population, found that even though heat waves impact nations regardless of their level of wealth, specific countries are at heightened risk of adverse effects due to the confluence of high heatwave exposure, limited medical services, and low income levels. These factors serve to intensify existing disparities among countries concerning the impacts of climate change. Indeed, a growing body of literature is investigating the issue of cooling poverty at the European level. From an econometric perspective, Gouveia et al. (2019) have been considering in their analysis both winter and summer energy poverty across 3092 civil parishes of Portugal considering the infrastructural component rendering households more fragile, posing the attention to their dwellings' energy performance, and the socioeconomic status of the population, taking into account the age and the educational and employment conditions of the inhabitants. The study revealed that the population living in the inland regions at the border with Spain were more exposed to climate extremes. Another study, by Torrego-Gómez et al. (2024a, 2024b), delved into the issue considering southern European countries, Spain, Italy, Greece and Bulgaria, for assessing whether a shared definition of summer energy poverty had already been released by European authorities, but different conception of heat vulnerability were proposed depending on the concerned country. In particular, while Italy had a propention to consider the economic and infrastructural component of deprivation from the capacity to deal with extreme temperatures, Greece and Spain contemplated also the social aspect of the issue. After that, in 2025, The European Commission released its first report on Summer Energy Poverty (SEPOV) bringing to light the multifaceted nature of this phenomenon across European countries. Very similarly to Systemic Cooling Poverty (Mazzone et al. 2023), the identified drivers of SEPOV are the infrastructural state, socio-economic and health conditions of the population. The guide released by the European Commission ends with a relevant section dedicated to good practices that can be considered when the objective is to increase the population's adaptive capacity to heat.

With respect to Italy, different scholars have already examined the issue of energy poverty (Bardazzi et al. 2021, Camboni et al. 2021, Fabbri et al. 2023) underlying the socioeconomic and built environment characteristics leading the citizens to a condition of disadvantage in achieving thermal comfort during periods of both elevated and low temperatures. As highlighted in Campagnolo et al. (2022), the impact of climate change and energy demand across the Italian population will have regressive effects in the coming decades: a novel emerging risk has been identified concerning households that will experience elevated temperatures and lack the capacity to bear the associated electricity costs necessary for adaptation. Additionally, Campagnolo et al. suggest considering the distributional implications of climate change impacts in the formulation of effective climate policies. In addition to these findings, an extended body of literature has already delved into the issue of heat vulnerability at the national level (Todeschi et al. 2022) and in particular at the urban level, investigating Urban Heat Island phenomenon across different municipalities (Drigo et al. 2025, Ellena et al. 2023, Maccabiani et al. 2025, Pappalardo et al. 2023, Vurro et al. 2022). These studies consider the effects on population's health and the major drivers contributing to enhancing thermal stress among the inhabitants: scarce infrastructure quality, minimal accessibility to green and blue spaces, social exclusion and low air quality conditions have been considered. In this framework, it is clear that the design of the indicators has a crucial role in shaping the urgence to plan a systematic governance procedure to tackle this multifaceted phenomenon across different world regions. After all, as reported by Pachauri et al. (2011) indicators are most effective when selected to assess particular impacts or dimensions, often aligned with specific thematic priorities. The discourse on indicators underscores the fundamental reality that energy poverty alleviation pertains to individuals, those who find themselves in circumstances that are difficult for many of us. Nevertheless, a study comprehensive of all the systemic drivers of heat vulnerability among the Italian population is still lacking and represents a crucial step in the light of recently produced climate projections, predicting heat waves to intensify and increase in duration and frequency among the European region over the next decades (Seneviratne et al., 2021).

1.2 Framework description: Systemic Cooling Poverty

The Systemic Cooling Poverty (SCP) Index designed in Mazzone et al., 2023, investigates the origins of the inability of households to adapt to high temperatures, where the economic implications of the phenomenon are omitted. SCP has the aim to overcome this unilateral and outdated perspective on energy poverty, and points to measure the interplay of five different dimensions that can increase the vulnerability to heat. This enlarged and more comprehensive conception of energy poverty has the objective to shed light on the systemic dimensions needing more attention in the policy agenda in order to give the possibility to the more fragile areas to increase their resilience to the rising threat posed by heat.

The pillars composing the multidimensional indicator have already been identified in Mazzone et al., 2023 and are represented by Climate, Infrastructures and assets, Social and thermal inequalities, Health and Education and working standards. Climate, in particular temperature and humidity, if intense and prolonged over time, are known for having important detrimental effects on human health. Infrastructural conditions of buildings and the development of the built environment can play a crucial role in enhancing or reducing people's adaptive capacity to heat. With regard to Thermal justice, the fundamental role played by social cohesion have widely been explored; with respect to heat adaptation patterns of urban and racial segregation can amplify heat related vulnerability. The dimension concerning health is at the core of the population's resilience to extreme temperatures: inadequate health care centers, unhealthy habits or non-communicable diseases have been identified as important drivers of susceptibility to heat extremes. Education and work standards are also affected by high temperatures: students' cognition capacity under relevant heat and humidity conditions are observed across world regions, and the workforce, mainly those involved in outdoor environments, is also impacted by these adverse climatic circumstances by decreasing workers' productivity and making them feel thermal stress. These five dimensions are further composed by specific sub-indicators and variables.

1.2.1 Climate

For gaining a comprehensive picture of the intensity of SCP, the four complementary dimensions of the index have to be put in relation with the local climate condition, for understanding the thermal discomfort distribution and intensity over the case study area. For this reason, the first dimension of the Systemic Cooling Poverty indicator has the objective to capture the population condition of thermal discomfort when exposed to extended periods of intense heat and humidity. According to current literature (Ebi et al. 2021, Faurie et al. 2022), when the human body is exposed to elevated temperatures its thermoregulatory capacity decreases sensibly, leading to fatal outcomes. The human body exposed to elevated temperature remains incapable of cooling due to reduced physiological heat stress responses. Moreover, while the majority of heat-related hospitalizations occur within the first 24 hours of exposure, the resulting cognitive and organ dysfunctions may have long term effects, with affected individuals facing a two to threefold elevated risk of mortality that can persist for several decades following the initial injury. Furthermore, humidity plays a crucial role in shaping the adaptive capacity to heat of the human body: an association between hot temperatures and elevated humidity rates in the atmosphere are linked to a decreased evapotranspiration capacity of the body (Baldwin et al. 2023, Grundstein et al. 2024, Zhang et al. 2023). In this perspective, the Discomfort Index by Thom et al. (1959) has been selected for the analysis following the recent dynamical downscaling of ERA5 reanalysis computed by Raffa et al. in 2021. The discomfort index has been designed specifically to quantify the thermal discomfort of people according to temperature and moisture content in the air at the superficial level both considering dry and wet bulb temperatures. The climatic indicator has been applied in different climatological regions of the world (Ekra et al. 2024, Fotso-Nguemo et al. 2022, Maftei et al. 2017, Nurmaya et al. 2022, Yin et al. 2023, Yousif et al. 2013) including the Mediterranean area (Angouridakis et al. 1982, Pantavou et al. 2011, Poukou et al. 2011, Stathopoulou et al. 2005) and in the Italian context (Drigo et al. 2025, Monforte et al. 2022), that is usually characterized by warm temperate weather, fully humid (Cfa) or summer dry precipitations (Csa), depending on the latitude, and hot summer climate in accordance to Köppen-Geiger classification (Kottek et al. 2006).

1.2.2 Infrastructures and assets

The second dimension of the index aims to identify the gaps in physical structures rendering census tracts more fragile with respect to extreme temperatures. In this perspective, the degree of urbanization, green and blue infrastructures accessibility, residential buildings' year of construction, buildings' thermal insulation and the accessibility to public transports have been identified for this analysis as possible drivers contributing to shaping the population's exposure to heat. Passive cooling strategies can play a pivotal role in preventing people from experiencing thermal stress. Many studies have already shed light on the capacity of urban green spaces to reduce UHI effect, considering different case studies in the Mediterranean region (Aboelata et al. 2021, Napoli et al. 2022, Olivieri et al. 2013, Zinzi et al. 2011) bringing consistent contribution to the field of research. As reported by Kharachaliou et al. in 2016, in

Athens, a green roof is estimated to reduce the annual cooling load of the building where it is installed by 19%, while in Cairo (Aboelata et al. 2021) implementing green roofs above buildings of 12 m in height is proven to lower the building's cooling energy by 3.2-4% on a typical summer day. At other latitudes the phenomenon has been investigated (Kijung et al. 2019, La Roche et al. 2014, Moss et al. 2019, Quaranta et al. 2021, Santamouris et al. 2014, Susca et al. 2011, Zhang et al. 2014) for urban green spaces, water bodies (Oertli et al. 2023) and within the presence of both solutions (Zhang et al. 2014). The majority of the studies explore whether cool or green roofs represent the best option for increasing buildings' energy efficiency, not considering that it implies the affordability to implement these passive adaptation strategies by private actors, living behind the more vulnerable layers of society. Two studies at the Italian national level (Quaranta et al. 2021, Zinzi et al. 2011) consider the social inequality issue that often arises from the uneven distribution of passive cooling strategies among the population. The two aforementioned research give importance to green spaces considering the complexity of implementing such measures in socio-politically compromised hotspots of Italy. Nature-based solutions can be implemented as effective passive cooling adaptation strategies for the more fragile layers of the population that suffer from the deprivation of cooling solutions, in the context of a warming climate, increasing the rate of accessibility to these measures. Nevertheless, as explained here (Kijung et al. 2019), also at different latitudes, green and blue urban spaces can contribute to exacerbate thermal inequity amplifying green gentrification, that happens when the provision of multifold ecosystem services, produced by the greening of urban spaces, causes the prices of housing in the considered urban area to rise, making it difficult for socio-economically jeopardized households to afford living close to these spaces and benefitting from them. Urbanized areas, in this perspective, can play a critical role in amplifying climate-related risks (Marcotullio et al. 2022), particularly in the context of high temperatures. On one hand, the extensive presence of built environment, leading to loss of green spaces and thus, of fundamental ecosystem services, can render cities more prone to land degradation and intensified UHI effects (Shahfahad et al. 2022). On the other hand, the concentration of people coming from different socio-economic conditions can lead to unequal exposure and adaptive capacity in facing extreme weather events (Mazzone et al., 2024). This combination can make urban spaces act as threat multipliers, magnifying the impact of climate stressors by exacerbating existing vulnerabilities related to infrastructures conditions, energy access, and socio-economic disparities. As pinpointed in Anguelovski et al. (2022, 2024) and in Rodgman et al. (2024), urban segregation is an emerging issue in the face of climate change and unequal access to green and blue infrastructures can contribute to fuel patterns of green gentrification. In this framework, the diffused presence of built environment, the inaccessibility to green and blue infrastructures and the inability to take advantage of public transportation services (Candipan et al. 2021, Moro et al. 2021, Tammaru et al. 2023, Xu et al. 2025) can contribute shaping the degree of urban segregation, further enhancing means of maladaptation and decreased adaptive capacity to heat extremes.

One other key factor to be considered when measuring adaptive capacity to heat is the thermal insulation of residential buildings (Banassiadi et al. 2022, Calama-González et al. 2023, Paneru et al 2024, Samuelson et al. 2020, Wang et al. 2022), that can have an important influence in shaping the passive cooling adaptability of the citizens with respect to climate extremes and weather shocks.

1.2.3 Social and thermal inequalities

The geographical concentration of marginalized households can lead to further thermal justice concerns. Social inequality determined by intrinsic characteristics of all individuals such as gender, sexual orientation, ethnicity, race and disability often lead people to live in situation of segregation, rendering it more difficult for them to access basic services capable of lowering the exposure to high temperatures as described in Cole et al. 2024, Karagiannaki et al. 2020, Mazzone et al. 2023, Mazzone et al. 2024, Pappalardo et al. 2023.

Racialized communities, as explored by different scientists (Clark et al. 2024, Leap et al. 2024, Monteiro Dos Santos et al. 2024, Sejo et al. 2024) both in foreign countries and at the Italian national level (Alioni et al. 2025, Drigo et al. 2025, Drigo et al. 2024), are reported to experience more often thermal discomfort and heat related issues. In particular, a correlation between the presence of non-white communities and a decreased welfare and wellbeing conditions of the same population has been observed (Pappalardo et al. 2023, Van Selm et al. 2025). Additionally, elderly people are at greater health risk when exposed to high temperatures due to physiological reasons and more prone to develop heat stroke, ischemic heart diseases, heart failure and arrhythmia, pulmonary diseases (Fastl et al. 2024, Ou et al 2023). The phenomenon needs to be taken into consideration particularly in the face of the aging of Italian society (Baniassiadi et al. 2023, Carr et al. 2023, Falchetta et al. 2024, Midões et al. 2025) and in the face of recently published climate projections (Seneviratne et al., 2021). A further age group needing specific attention when considering heat extremes is that of children. As reported in different studies (Lala et al. 2023, Uibel et al. 2022) children exhibit slower physiological acclimatization to elevated ambient temperatures compared to adults. Furthermore, their perception of thirst and voluntary fluid intake differs from the one of the adult population, increasing their susceptibility to dehydration under heat stress conditions. Profuse sweating in response to elevated temperatures can result in dehydration and may progress to exhaustion. Moreover, exposure to hot temperatures can exacerbate underlying medical conditions. A relevant association was found in the literature between the younger population and heat-related illness, dehydration, diarrhea and digestion disorders, infectious diseases, asthma and wheeze during periods of extreme heat exposure (Niu et al. 2023, Oh et al. 2024, Uibel et al. 2022). Consequently, preventive strategies should prioritize early identification, appropriate treatment, and effective management of heat-related illnesses in pediatric populations.

It must be noted that not every socially fragile group could be considered for the quantification of the thermal discomfort of all citizens through the application of the SCP index, as in the case of transexual people (Mazzone et al. 2024), of elderly living in nursing homes (Klenk et al. 2010, Van den Wyngaert et al. 2021) and of people deprived even of basic human rights, e.g. people living in jails (Brunn et al. 2025, Colucci et al. 2023, Skarha et al. 2022, Tuholske et al. 2024) and in immigration detention centers (Pellow et al. 2019). Nevertheless, for the study, the concentration of foreigners, elderly and children over the inhabitants has been measured.

1.2.4 Health

One further systemic dimension that has been identified and measured considering heat-related phenomena in view of weather risks is the contribution of non-communicable diseases, including heart disease, stroke, cancer, diabetes and chronic lung disease in enhancing human vulnerability to hot temperatures. As reported in Zhang et al. in 2024, between 1990 and 2019, the global mortality associated with non-communicable diseases attributable to elevated ambient temperatures increased more than six times, indicating a substantial rise in heat-related health impacts, over the three-decade period. One other recurrent characteristic of intensified and prolonged hot temperatures is that of affecting psychologically vulnerable individuals, further exacerbating poor mental health conditions and depression by altering fundamental neurological functions. For this reason, the mortality rate for cause of death was considered for this study, specifically the mortality rate linked to chronic illnesses was examined. Moreover, irritability, aggression and violence become more frequent under severe weather conditions, as much as that related to alcohol or substance abuse (Kubo et al. 2021, Liu et al. 2021, Zhou et al. 2023). Additionally, as reported in Fritz et al. 2022 in a case study among hospitalization rates of people affected by non-communicable diseases in Indonesia under particularly hot days, although this country experiences consistently how weather and residents are generally acclimatized to both heat and humidity, the association between elevated temperatures and morbidity remains a significant determinant of health care-seeking behavior. Utilizing district-level daily medical visits and meteorological data, this study demonstrates that primary health care visits for both all cause and non-communicable diseases increase sensibly on days when the mean temperature surpasses the long-term average. Notably, on days with mean temperatures exceeding 30°C, the number of daily visits rises by 8% for all causes, 25% for people with diabetes, and 14% for the population affected by cardiovascular diseases, relative to reference days with mean temperatures ranging from 25.5°C to 27°C.

In the framework of heat-related morbidity and mortality, the time needed to reach the closest health care facility from the dwellings located in the area of interest results in playing a crucial role in mapping the vulnerability of the population to health risks (Kelly et al. 2016, Weiss et al. 2020), also when exacerbated by heat. It is widely recognized (Marasini et al. 2024, Sandroni et al. 2021, Zhang et al. 2021) that in cases of heatstroke, cerebral hypoxia can lead to neuronal cell death, with irreversible brain damage typically occurring within 6 to 10 minutes following the onset of cardiac arrest, and that is the reason why this study aims also to map the most isolated places with respect to access to healthcare facilities in the area of interest.

One additional systemic factor that is capable of decreasing people's resilience to heat is scarce air quality (Austin et al. 2020), which is capable of causing the health conditions of the local population to fall, further expanding the fertile terrain for the development of non-communicable diseases over people. As reported by the European Environment Agency, air pollution is currently the largest environmental risk in Europe and represents a major cause of premature death and diseases (EEA, 2024). Exposure to air pollution, whether in the short or long term, has been associated with a broad spectrum of adverse health outcomes, including stroke, chronic obstructive pulmonary disease, cancers of trachea, bronchus, and lungs, exacerbation of asthma, and lower respiratory tract infections (Breitner-Busch et al. 2023, Lelieveld et al. 2023). Furthermore, evidence provided by the World Health Organization (WHO) indicates significant associations between air pollution exposure and an increased risk of type 2 diabetes, obesity, systemic inflammation, Alzheimer's disease, and other forms of dementia. Consequently, WHO in 2021 released the Global Air Quality Guidelines to regulate and define standards for a healthy environment for the population in the concentration of particulate matter, including PM2.5, PM10, ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide, at the atmospheric ground level. It has further been revealed that the intersection of heat exposure, racial segregation, green gentrification and air pollution converge in areas where vulnerable communities live, strengthening the bundle of environmental injustice (Di Fonzo et al. 2022, Drigo et al. 2025, Josey et al. 2023, Rentschler et al. 2023 Venter et al. 2023). For these reasons, the mean concentration of nitrogen dioxide in the atmosphere in the last years (2018-2022) was taken into consideration for the scope of the analysis over the case study area.

1.2.5 Education and work standards

As outlined in Mazzone et al. 2023, education represents a fundamental pillar in increasing people's adaptive awareness to intensified heat. Traditional and vernacular knowledge can broaden the employment of passive cooling strategies, necessary when the population is unable to access active cooling technologies like air conditioning and fans (Khoja et al 2025, Kumar et al. 2023, Leal et al. 2022). At the same time, a higher level of education can enhance the perception of the threats posed by hot temperatures and render more comprehensible different means of information on how to get protected individually and collectively from heat-related risks (He et al. 2022, Shortridge et al. 2022, Torriani et al. 2023). It is important to consider that extreme heat conditions in school can have a negative impact on the cognition level of students and can lead them to exhaustion, determining lower academic achievements (Brink et al. 2021, Park et al. 2021). This factor is of relevant importance when periods of high temperatures exposure in a geographical area are particularly prolonged over time: in this case, local policy makers should consider the development of active or passive cooling strategies in order to render students more receptive to the cognitive stimuli (Ye et al. 2024, Zhou et al. 2025).

On the other hand, in the perspective of work standards, it is relevant to consider the conditions of workers when exposed to extreme heat, specifically in the case of outdoor activities. In particular, prolonged heat is demonstrated to decrease workers' productivity, safety and wellbeing. As reported in Morrissey et al. in 2021, the ability to sustain physical activity in high-temperature environments is determined by three primary factors: the metabolic heat generated by the intensity of the task being performed, the thermal insulation and transpirability characteristics of clothing or personal protective equipment worn by the individual, the surrounding environmental or workplace conditions, including temperature, humidity, and ventilation. Emerging research (Flouris et al. 2018, Ioannou et al. 2021) indicates that elevated ambient temperatures can have a direct negative impact on economic output by reducing labor productivity and reported that approximately 30% of workers experienced declines in work performance under heat stress conditions, with an estimated 2.6% reduction in productivity for each degree Celsius increase above 24°C in wet bulb temperature, a composite measure that accounts for both temperature and humidity. Furthermore, other studies (De Lima et al. 2021, Valenti et al. 2024) brought to light an estimate of the economic impact of heatwave exposure on individual income. Heatwaves are generally defined as periods of more than two consecutive days with maximum temperatures exceeding either the 95th percentile of the local historical distribution or an absolute threshold of 30°C. The results indicate that each additional day meeting these criteria leads to a reduction in personal monthly earnings by approximately 0.51% under the relative threshold definition, and by 1.47% when using the absolute threshold. These considerations ulteriorly underline the importance of mapping the educational level and working standards when interested in the study of intense heat vulnerability. As reported in Slesinski et al. 2025 and Ye et al. 2018, unemployment represents an ulterior factor capable of rendering the population belonging to a lower socioeconomic status more exposed to the threats posed by intensified heat. For the considerations made in this paragraph, in the research, both the educational level of the population and its unemployment rate distribution over the geographical area have been taken into account.

1.3 Venice as a case study

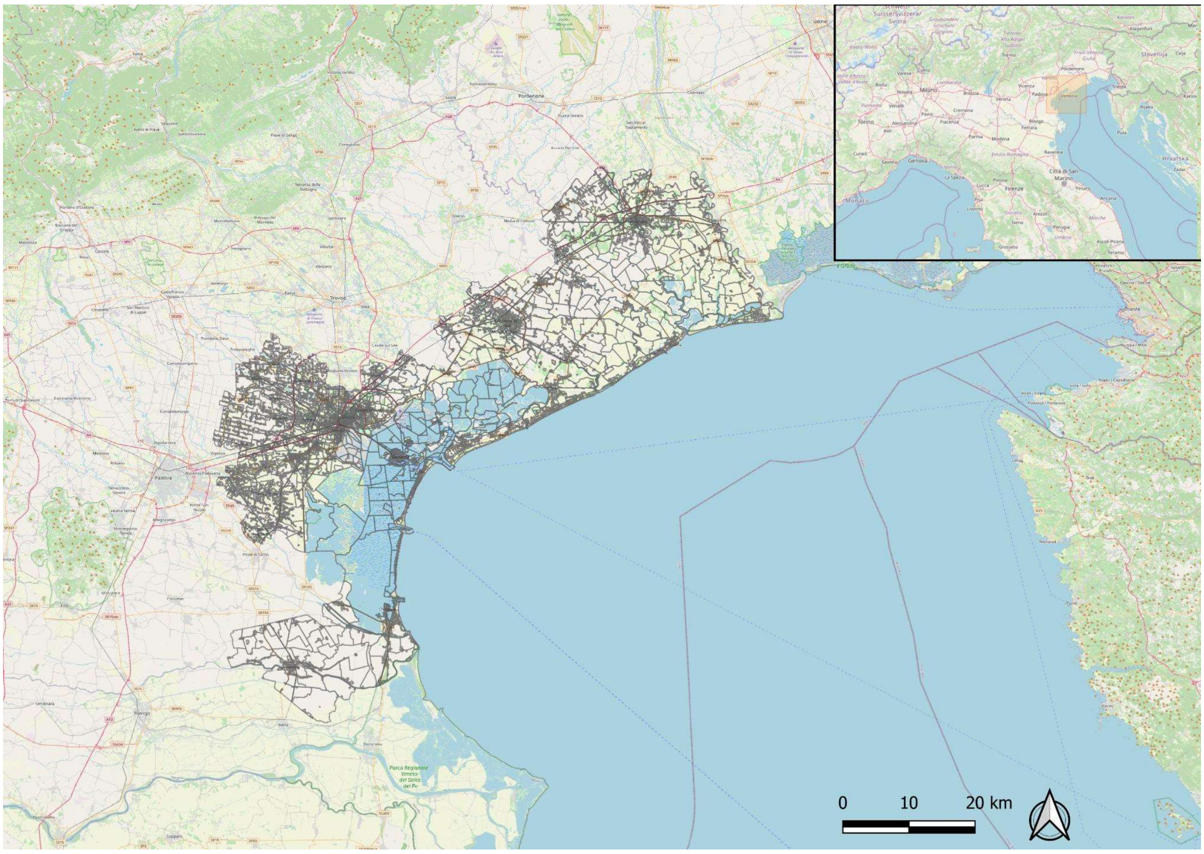

Figure 1 – Case study area: The map shows Venice Province area, and its census tract boundaries according to the 2021 census by ISTAT, over the surrounding territory depicted by OpenStreetMap (OSM).

The area that has been considered for the analysis is located in the Northern Eastern part of Italy. More specifically the Province of Venice is one of the 7 provinces of the Veneto region, and its territory covers a surface area of 2,274.57 square kilometers, approximately 600 square kilometers of which consist of the lagoon waters of Venice and Caorle-Bibione. Geographically, the province extends longitudinally for about 110 kilometers along the coastal strip, from Chioggia to Bibione. Its boundaries are delineated to the south by the Adige river system, to the east and southeast by the Adriatic Sea, to the north-northeast by the Tagliamento River, to the northwest by the Province of Treviso, to the west by the Province of Padua, and to the south by the Province of Rovigo. The Province comprises 44 municipalities. Among these, the largest by land area are the Municipality of Venice (457.47 km²), Chioggia (185.19 km²), Caorle (151.39 km²), Cavarzere (140.34 km²), San Michele al Tagliamento (112.28 km²), and Portogruaro (102.31 km²) (Emergency Action Plan of the Venice Province, 2008).

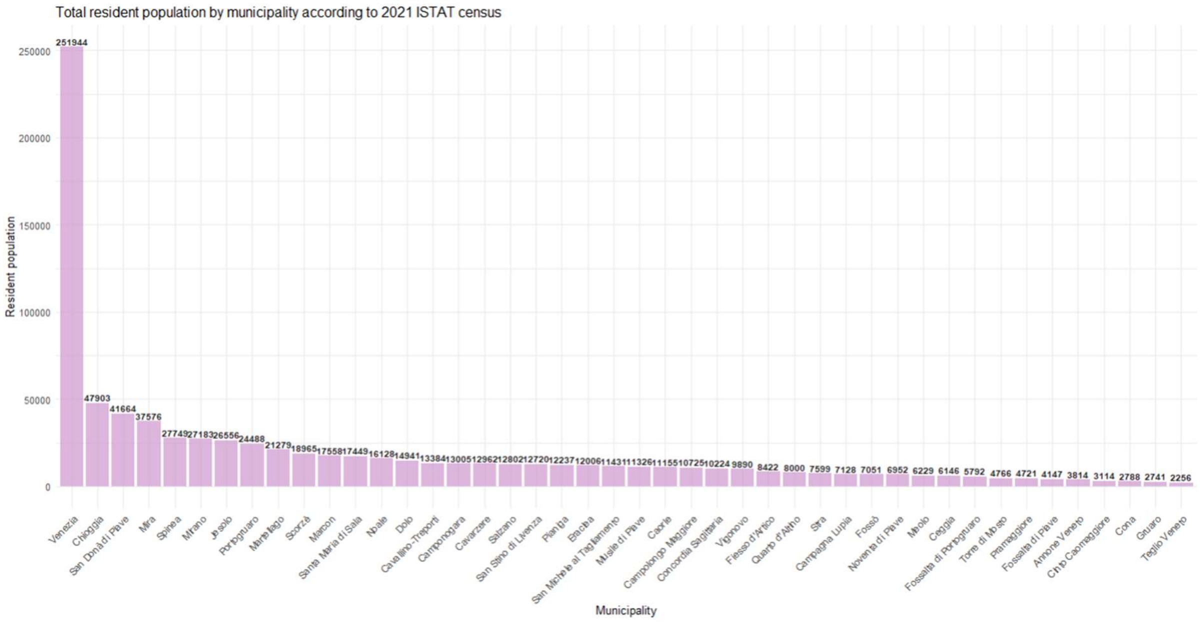

Figure 2 - Total population distribution across the 44 municipalities of Venice according to 2021 census by ISTAT.

The population, staying at the statistics of the year 2021 by ISTAT, is unevenly distributed over the area of interest with the majority of citizens living in Venice municipality, which comprehends also Mestre and Marghera, and in Chioggia, localized in the southern area of the province, and in San Dona di Piave, that conversely to the previous municipality, is located in the central-northern area of the province. Instead, the less populated municipalities are represented by Cona, in the southern-eastern part of the province, and Gruaro and Teglio Veneto, both lying in the northern part of the geographical area, at the border with Friuli Venezia Giulia region.

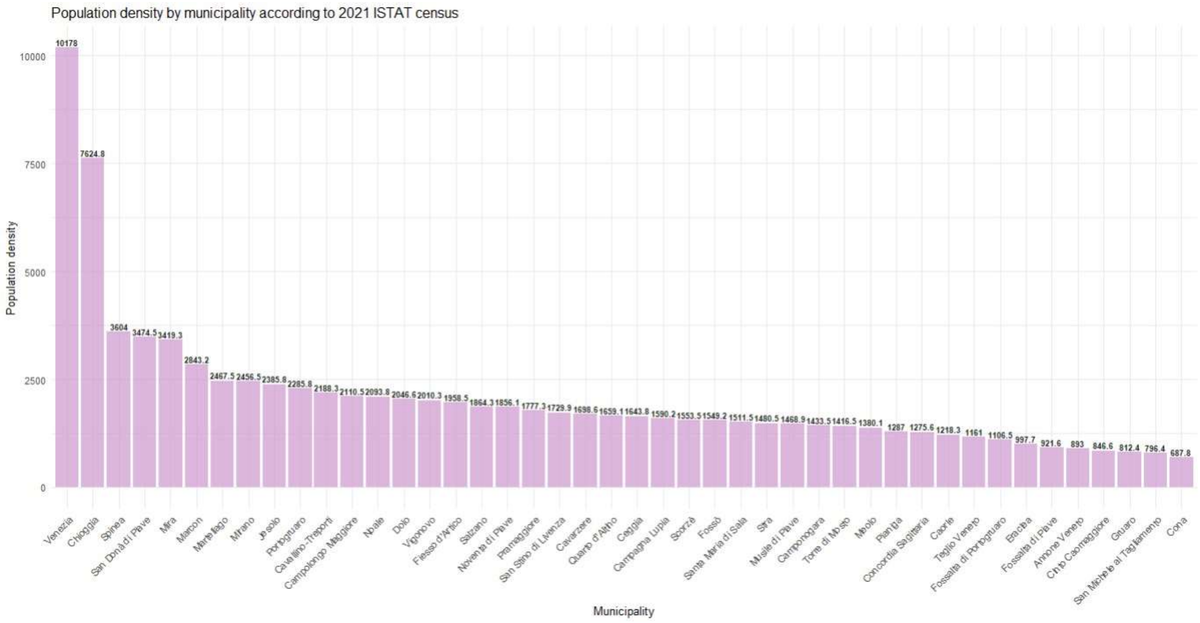

Figure 3 - Population density across the 44 municipalities of Venice according to 2021 census by ISTAT.

Instead, when considering the population density over the 44 municipalities of the Province, the places where a higher concentration of citizens is observed is in the municipalities of Venice, Chioggia and Spinea. In contrast, the least densely populated municipalities are Grauro, San Michele al Tagliamento, localized at the border with Friuli region, and Cona at the marginal southern boundary with Rovigo province.

The territory of the province of Venice is predominantly flat and gently slopes toward the sea, following a general northwest-to-southeast orientation. It belongs to the low Venetian plain and has been shaped over time by the combined depositional activity of major rivers, such as the Po, Adige, Brenta-Bacchiglione, Piave, Livenza, and Tagliamento, and the geomorphological action of the sea. The area encompasses the entire coastal zone of the Veneto region, with the exception of the Po Delta. It is distinguished by an extensive system of lagoon and deltaic environments, which includes the present-day lagoons of Venice and Caorle-Bibione, as well as vast expanses of reclaimed land that were historically characterized by marshes and coastal wetlands (Emergency Action Plan of the Venice Province, 2008).

A diverse range of economic activities characterizes the study area, encompassing sectors such as petrochemical manufacturing, primarily concentrated in the Mestre and Marghera districts, as well as tourism, maritime port operations, commercial shipping, and fishing, particularly in the island districts of Venice, Burano, Murano, and Lido (Sperotto et al. 2016).

The Province is located in the Padana plain, which has been recognized as one of the most critical European regions for its poor air quality, particularly with respect to elevated concentrations of particulate matter, PM2.5 and PM10, (Gea et al. 2023, Robotto et al. 2022) and nitrogen dioxide, NO_2 (Serio et al. 2022). This region accounts for approximately 60% of the total annual exceedances of the PM10 daily limit value recorded nationwide (Gualtieri et al. 2025, Mastronardi et al. 2022).

The burden imposed by the orography of the region and industrial sites aggregation, leading to dangerous air pollutant concentration, combined with the hot and humid summer climate of the area of interest render Venice an interesting case study for assessing the systemic conditions that can render the local population vulnerable with respect to extreme heat.

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2 Methodology

In order to proceed with the empirical analysis, R computing environment (available at the following link: https://cran.r-project.org/bin/windows/base/) has been used for the Systemic Cooling Poverty (SCP) index calculation. For each dimension of the index a set of indicators have been extracted from different databases according to the availability of information at the local level.

2.1 Data description and variables extraction

2.1.1 Climate

For the computation of the climatic dimension, the Discomfort Index (DI) by Thom et al. (1959) has been selected as a reference indicator. It comprehends both air temperature and humidity and it has been developed following Equation 1, with T_d standing for dry-bulb temperature and T_w for wet-bulb temperature (originally calculated in Fahrenheit degrees).

Equation 1: $DI = 0.4 \times (T_d + T_w) + 15$

The Discomfort Index comprehends both dry and wet bulb temperatures and that renders it an optimal measure to capture summer thermal discomfort over the population. The database has been downloaded from the Euro-Mediterranean Center for Climate Change (CMCC) Data Delivery System (DDS); general information about the database can be observed in Table 1. The Discomfort Index database covers the Italian territory with a climatology spanning from 1989 to 2021, the data have an hourly or daily temporal resolution and a spatial resolution of 2.2 km. For the scope of the analysis, the time window taken into consideration was from 2000 to 2020 with a daily resolution, in order to build a robust climatology capable of capturing recent climate anomalies, with respect to intensified heat, induced by anthropogenic activities. The data were produced downscaling ERA5 data, previously at a spatial resolution of 31 km available at a global scale, to a 2.2km spatial resolution over Italy by Raffa et al. (2021).

DIMENSION	VARIABLE	DATASET	SCOPE	SPATIAL RESOLUTION	YEAR OF PUBLISHING	REFERENCE TIME FRAME	FORMAT
Climate	Discomfort Index (°C)	CMCC DDS: Wellbeing Indicators using ERA5 downscaled	Italy	2.2 km	2021	2000-2020 (selected temporal resolution: daily)	NetCDF (Network Common Data Form)

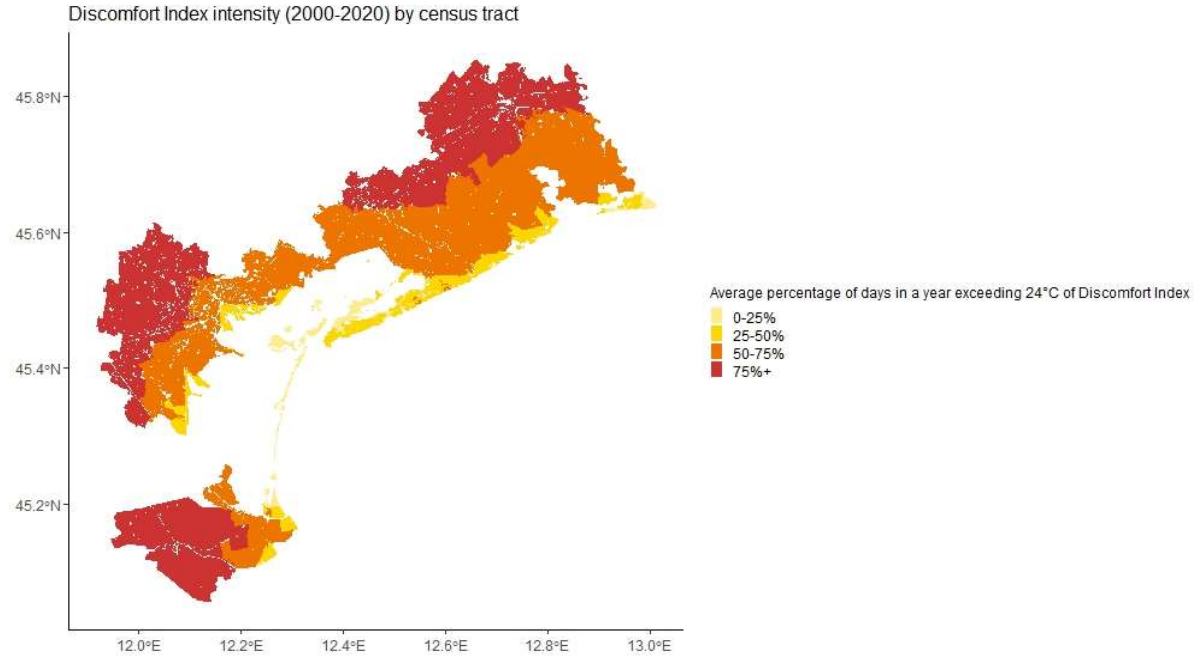
Table 1 - General databases information for Climate dimension of SCP index

Consequently, for capturing the intensity of the climatological indicator over the area considered, the sum of days for each year having a maximum temperature that exceeded 24°C of DI has been computed for each census tract. In this way, the average percentage of days in a year exceeding 24°C can be considered for every census area over the time frame spanning from 2000 to 2020. The threshold value of 24°C DI has been selected since it implies that more than half of the population is in a condition of thermal discomfort (Table 2).

DISCOMFORT INDEX (°C)	POPULATION UNDER THERMAL STRESS
DI<21	No discomfort
21<DI<24	Less then 50% feels discomfort
24<DI<27	More then 50% feels discomfort
27<DI<29	Most of the population feels dicomfort
29<DI<32	Everyone feels severe stress
DI>32	State of medical emergency

Table 2 - Discomfort index intensity and relative thermal discomfort level over the population

In the delineated context, Map 1 shows the geographical distribution of the intensity, in average percentage of days exceeding the threshold, of Discomfort Index in every census tract over Venice provincial area. It can be observed that the population level of thermal stress is higher in the inland area, while it remains lower on the seaside, particularly in the southern region, along Lido and Pellestrina islands, the two subtle land stripes expanding from the southern proximities of Venice's historical center towards the south of the lagoon.



Map 1 - Average percentage of days in a year of Discomfort Index exceeding 24°C (2000-2020)

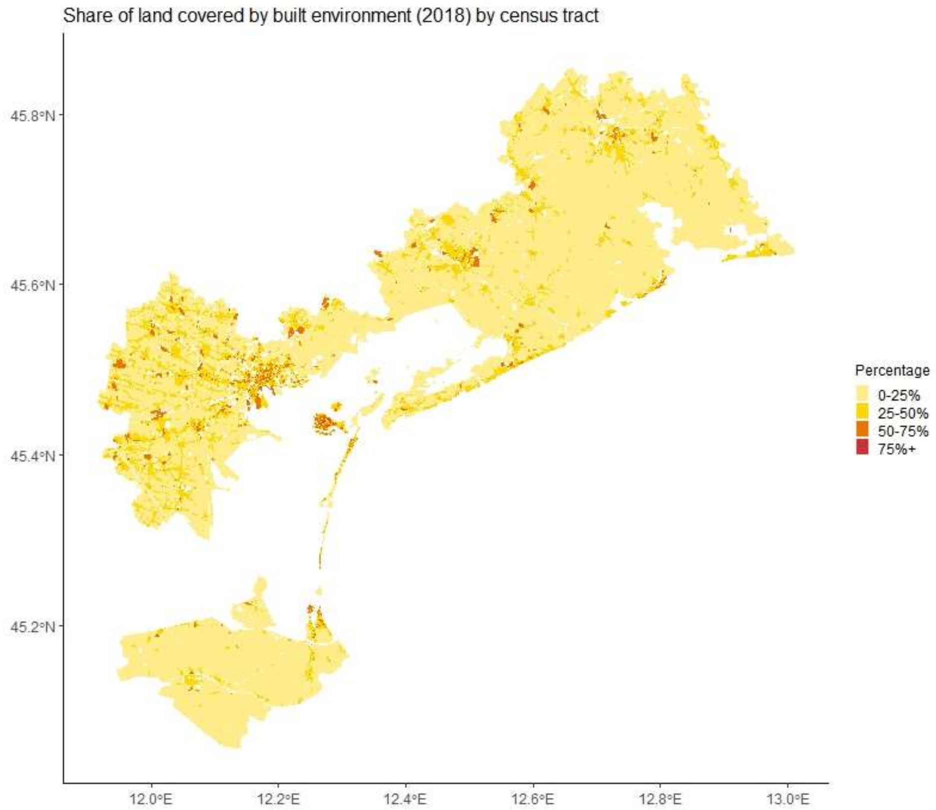
2.1.2 Infrastructure and assets

For the computation of the second dimension of the index, 4 different indicators have been extracted for capturing the multifaceted nature of the infrastructural component; the general information for each database can be observed in Table 3.

The first variable that has been calculated for the physical environment dimension is the share of land in each census tract covered by the built environment. For this scope, the data produced by the Joint Research Center (JRC) about the Global Settlement Characteristics has been considered. The database was made available in 2018 and relies on satellite imagery (Sentinel 2 composite and Landstat) and has a spatial resolution of 10 m. The information contained in the dataset has been divided into 3 categories ulteriorly classified in 5 typology each. The first category is devoted to open spaces, particularly to green and blue surfaces, while the second and third categories are dedicated respectively to residential built spaces and non-residential built spaces. The further subdivision in typologies regards additional information about the data: for the first category the type of open spaces is defined (low vegetation surfaces, medium vegetation surfaces, high vegetation surfaces, water surfaces, road surfaces), whilst for the last categories the height of the built up area is described (building height <= 3m , 3m < building height <= 6m, 6m < building height <= 15m, 15m < building height <= 30m, building height > 30m).

DIMENSION	VARIABLE	DATASET	SCOPE	SPATIAL RESOLUTION	YEAR OF PUBLISHING	REFERENCE TIME FRAME	FORMAT
Infrastructures and assets	Built environment (%)	JRC: Global settlement characteristcs	Global	10m	2018	multi-temporal (1975-2030)	Raster
Infrastructures and assets	Green and blue infrastructures (%)	Methodology by Giacomo Falchetta and Ahmed Hammad (see reference)	Potentially global	Information at Venice census tracts level	Submitted for peer review in 2024	2024	Shapefile
Infrastructures and assets	Residential buildings' year of construction (%)	ISTAT: Population and buildings census	Italy	Census tract level	2011	2011	Shapefile
Infrastructures and assets	Bus stops (number of units)	DATI OPEN: Bus stops map	Italy	/	2017	2017	CSV

Table 3 - General databases information for Infrastructures and assets dimension of SCP index

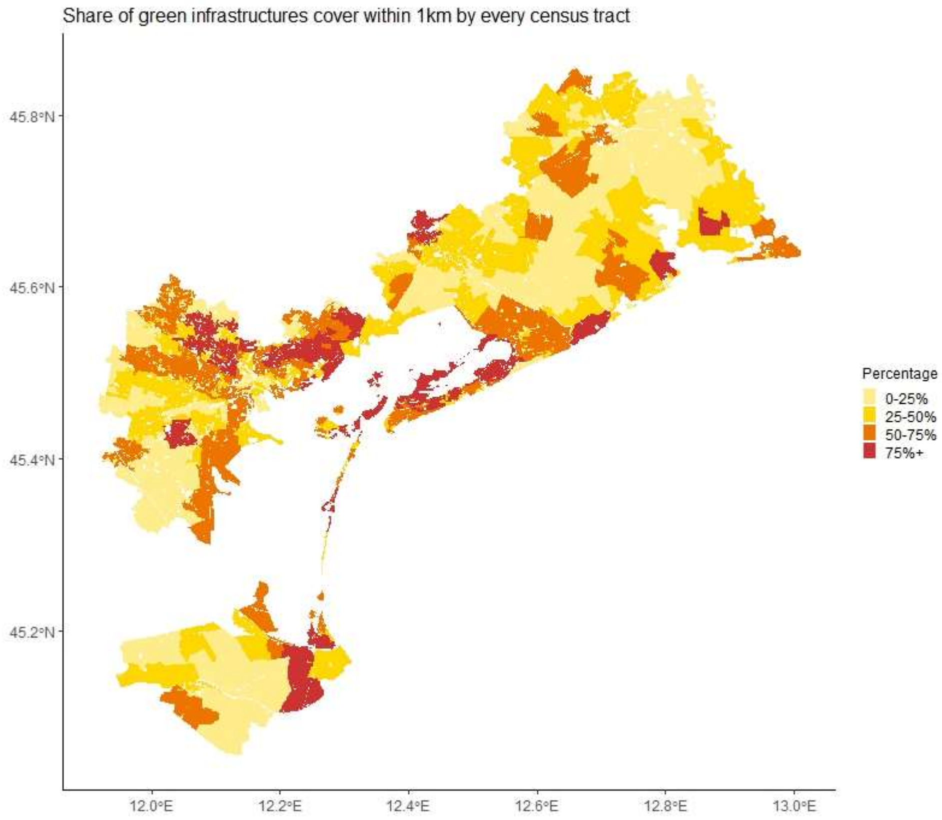


Map 2 - Share of built environment by census tract (2018)

For the objective of the analysis, we consider the percentage of area for each census tract covered by built environment, considering both the second and third categories.

In Map 2, it is possible to observe the geographical distribution of the share of built environment over the area of interest for each census tract. As expected, the distribution of built environment results denser in urbanized areas like Venice historical city center, Mestre and Marghera but also, following a northern to southern direction on the map, Portogruaro, San Donà di Piave, Jesolo, Mirano, Maerne, Martellago and Chioggia can be identified as highly urbanized.

The second variable considered for the analysis of the infrastructural dimension regards the available green spaces freely accessible to the population. For this objective the methodology by Falchetta et al. (2024) was adopted: the variable extracted represents the percentage of canopy cover available within 1km radius from each census tract's boundaries, based on Google Street View imagery.



Map 3 - Share of area covered by freely accessible green spaces by census tract (2024)

Particularly in Map 3 we observe the geographical distribution of green infrastructures accessible by the population across census areas. As it can be noted, the distribution of vegetation remains quite uneven over the territory of the Province, having a higher density in the area in proximity to the lagoon as in the cases of sant'Erasmo Island, Castello district, Lido island, Jesolo and Chioggia.

The third variable that composes the dimension regarding infrastructures and assets characteristics represents the average residential energy requirement for achieving thermal comfort through the year at the census tract level. The indicator is based on the percentage of residential buildings, at the census tract level, by classes of construction year, and on their respective annual average energy requirement load for achieving an adequate level of thermal comfort; see Table 4 for classes of construction year and respective energy requirement load.

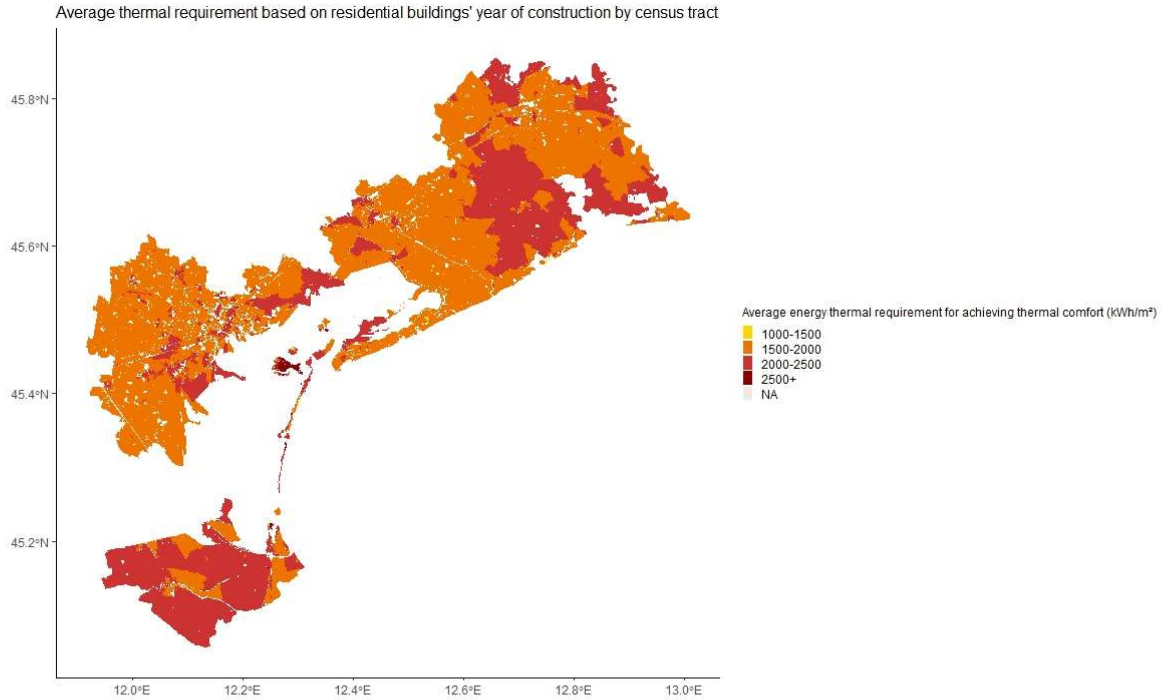
Equation 2: $E_c = \sum_{K=1}^{K} p_{c,k} \times w_k$

The variable has been calculated using a weighted average (see Equation 2). First, it has been calculated the percentage ($p_{c,k}$) of every class of residential building (k) per year of construction by census tracts (c). Secondly, every class of residential building was multiplied by the respective annual energy requirement constant (w) for every class of residential building (k). Finally, a weighted average between all the classes of residential buildings multiplied by their energy requirement load was calculated for each census tract. As a result, it has been obtained the average residential energy intensity (E) for each census tract (c) based on the year of construction of the residential buildings located in the census area.

In particular, the information about the percentage of every class of residential building by year of construction for census tracts has been extracted by the Italian National Institute of Statistics (ISTAT) census data of 2011. Instead, the respective average annual energy requirements for every class of residential building has been adopted following the Annual Report for Buildings Energy Certification released in 2024 by the Italian Agency for New Technologies, Energy and Sustainable Development (ENEA), see Table 4.

RESIDENTIAL BUILDINGS CLASSIFIED BY YEAR OF CONSTRUCTION	AVERAGE ENERGY REQUIREMENT FOR ACHIEVING THRMAL COMFORT [kWh/m^{2}year]
Built before 1945	129.7
Built between 1945 and 1980	97.2
Built between 1980 and 1990	90.7
Built between 1990 and 2005	79.3
Built after 2005	54

Table 4 - Classification of residential buildings by year of construction and respective annual energy requirements

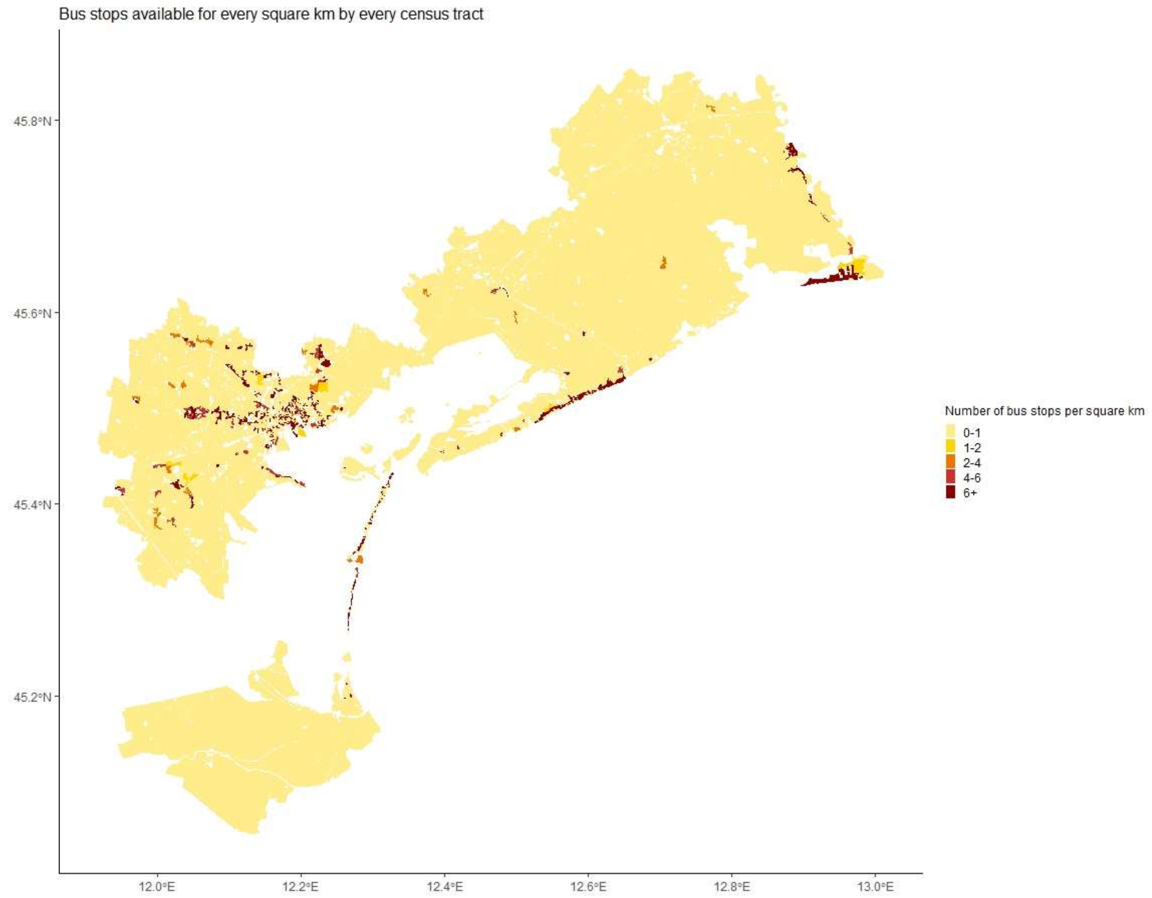


Map 4 - Average residential energy intensity by census tract (2011)

In Map 4, the geographical distribution of the variable representative of the residential energy intensity indicator of each census tract can be observed. Specifically, it can be noted that the census tracts located in Venice's historical center, together with some internal areas located between San Stino di Livenza and Eraclea, are the most energy intensive. Also, other regions of the Province have a high residential energy requirement, as for the areas belonging to Portogruaro municipality, Bibione, Mestre, Vigonovo and Chioggia.

The last variable relevant for mapping the state of the infrastructures and the accessibility of fundamental assets is that of public transportation. For this reason, the data retrieved by OpenData, for the year 2017, containing the available bus stops position for the territory have been considered. In particular, the sum of bus stops within each census tract has been computed and then divided by the area (km²) of the same census tract in order to have a measure of the density of bus stops across the concerned territory.

In Map 5 it is possible to observe the geographical density of bus stops accessible to the population. Exception made for the northern-eastern area of the territory, represented by San Michele al Tagliamento municipality, generally it can be observed that the marginal areas are the ones suffering a diffuse lack of services, with regard to access to public transportation. By contrast, urban areas and the touristic ones are the ones that are provided by higher means of public transportation, as in the case of Lido, Mestre, Caorle and Jesolo.



Map 5 - Available bus stops for km² within each census tract (2017)

2.1.3 Thermal justice

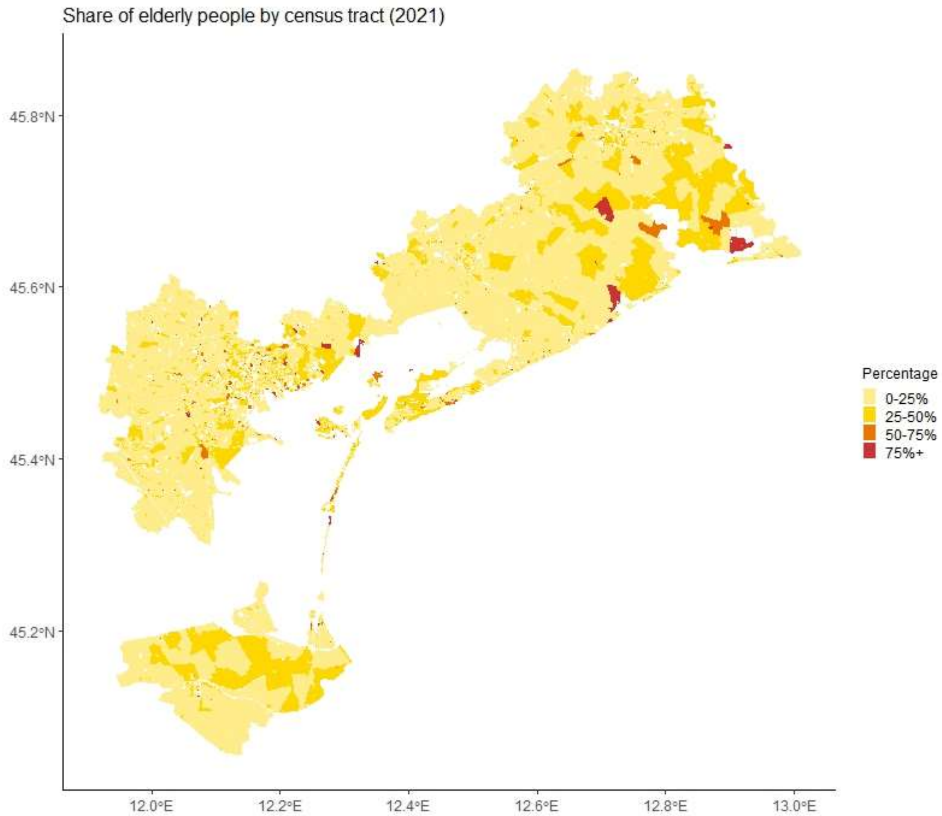
For mapping the third component of the SCP indicator, three variables have been extracted from the last census pursued in the year 2021 by ISTAT. With a frequency of ten years ISTAT records socio-demographic relevant information at the household level and finally releases the data at the census tract spatial resolution. For the scope of the analysis the percentage of elderly (over 69) people, children (under 14) and foreigners for every census tract has been calculated in order to quantify the density of the fragile population over the provincial territory; general information about the database can be observed in Table 5.

DIMENSION	VARIABLE	DATASET	SCOPE	SPATIAL RESOLUTION	YEAR OF PUBLISHING	REFERENCE TIME FRAME	FORMAT
Thermal justice	Elderly (age>69 years) population (%)	ISTAT: Population census	Italy	Census tract level	2021	2021	Shapefile
Thermal justice	Children (age<14 years) population (%)	ISTAT: Population census	Italy	Census tract level	2021	2021	Shapefile
Thermal justice	Foreigners population (%)	ISTAT: Population census	Italy	Census tract level	2021	2021	Shapefile

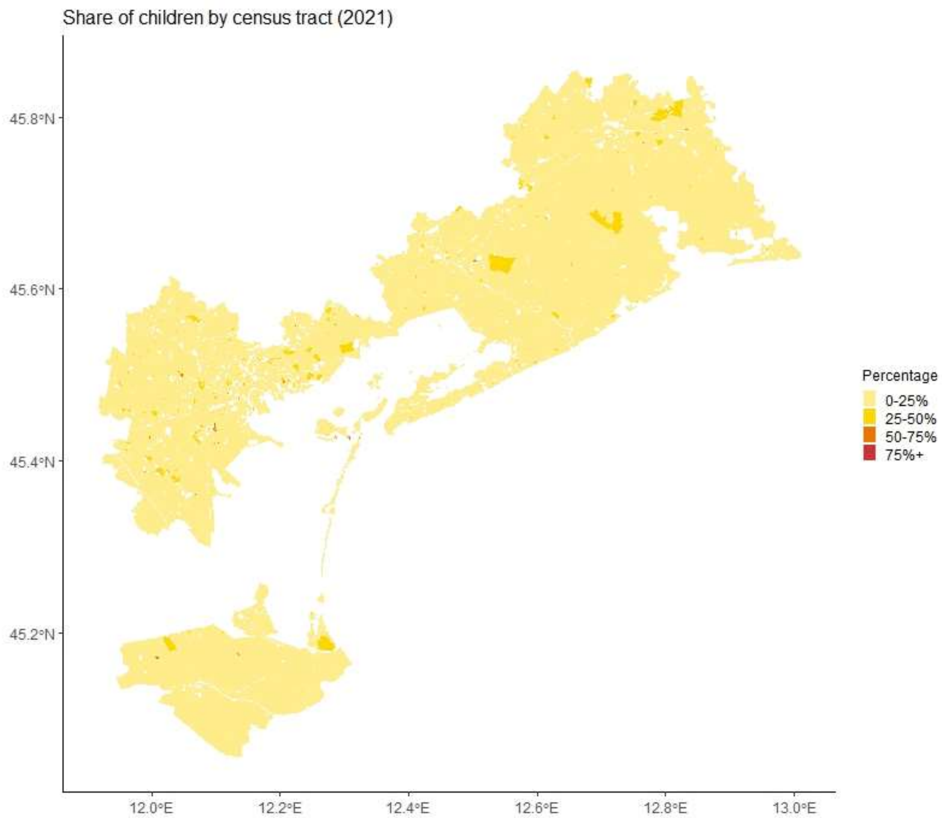
Table 5 - General databases information for Thermal justice dimension of SCP index

In Map 6, the geographical distribution of elderly people can be observed. The density of the elder population over the area concerned results highly uneven across the census tracts in the area of Venice. Some of the locations where it is possible to note a relevant percentage (75+%) of this population group are Bibione, San Stino di Livenza, Caorle and Mestre.

In Map 7, instead, the distribution of children over the territory can be noted. As expected due to the demographic decline Italy is going through in the last decades, children are evenly distributed across census tracts representing a small percentage of the total population. There emerge some census tracts with a slightly higher density (25-50% of the population), with respect to the majority of the territory, in the proximities of Portogruaro, San Donà di Piave, Mestre and Chioggia.

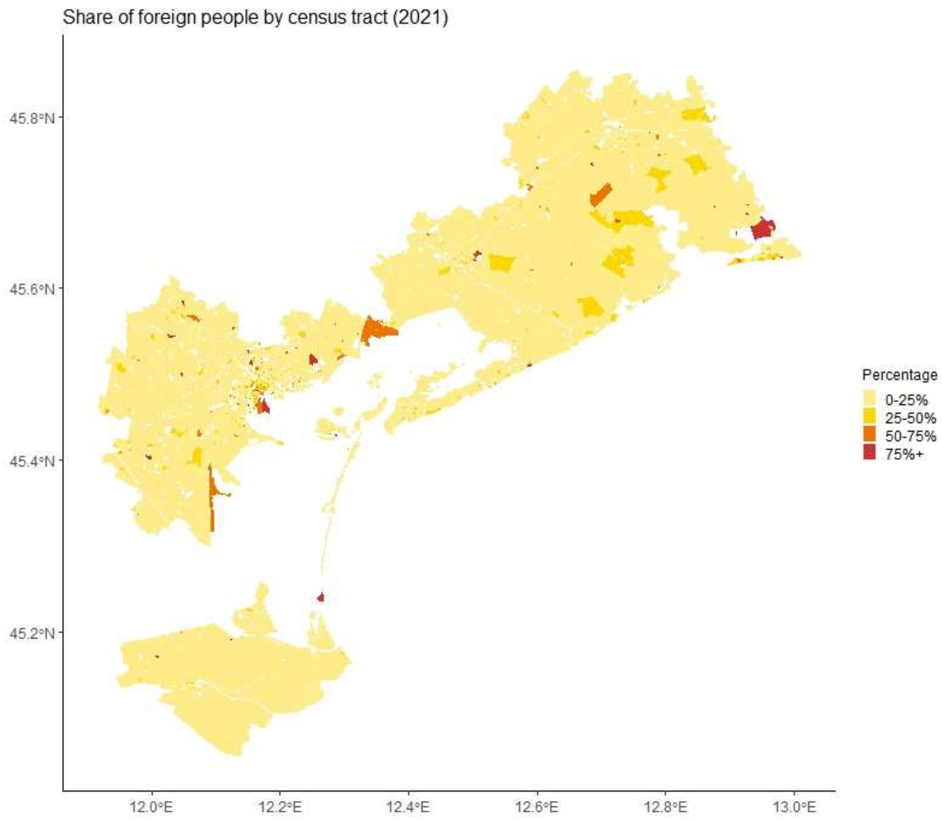


Map 6 - Share of elder population by census tract (2021)



Map 7 - Share of children by census tract (2021)

In Map 8, finally, the percentage of foreigners can be observed. As for elders, the population of foreigners results unevenly distributed across the Provincial area, with the majority of the territory being covered by a low percentage of foreign population. At the same time, areas where the density of this population group increases sensibly (50-75, 75+% of foreigners) can be noted, and are clustered preponderantly, around the municipalities of Bibione and Portogruaro and in Tessera, Mestre, Marghera, Mira, Mirano and Scorzè.



Map 8 - Share of foreigners by census tract (2021)

2.1.4 Health

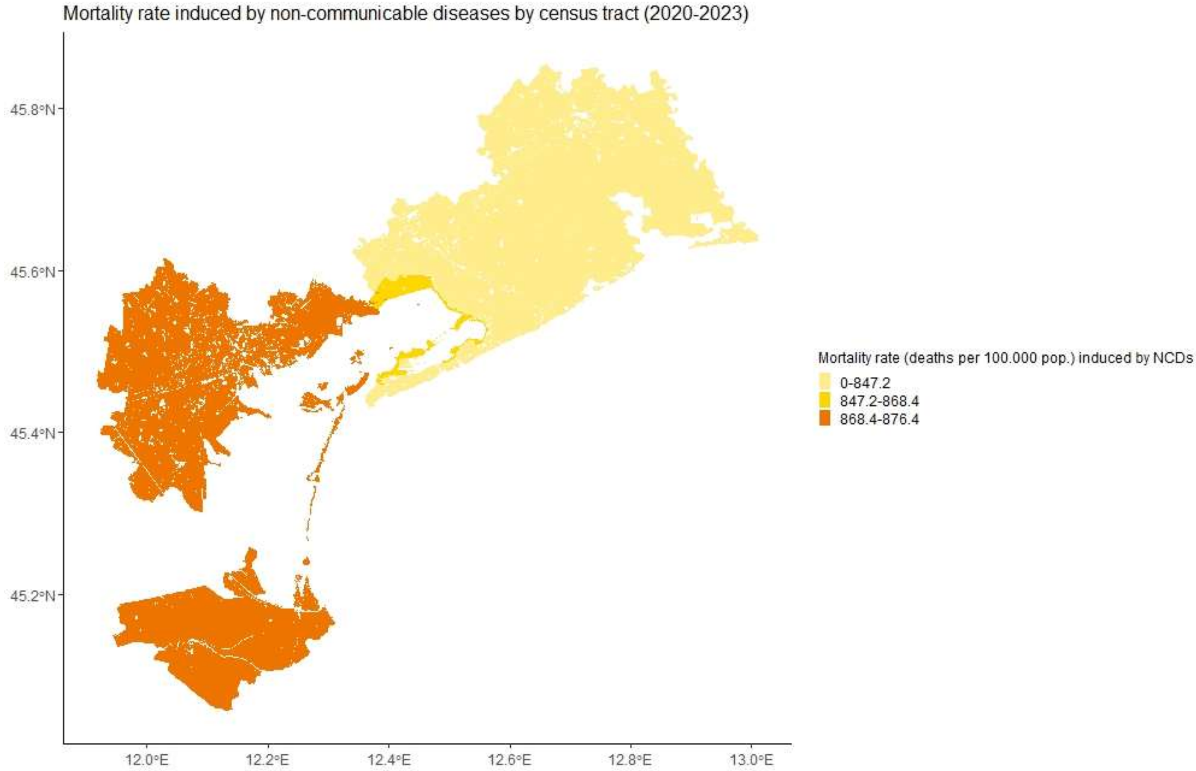
For the measurement of the deprivation level of the population living in each census tract regarding the dimension relative to health, three variables have been extracted from different datasets; see Table 6 with the general dataset information. The first variable that has been extracted for the evaluation of the health dimension was that representative of the mortality rate by cause of death released by the Veneto region Epidemiological Registry Service (SER) for the time window spanning from 2000 to 2023 at the Local Social-Health Units (AULSS) level. For the scope of the analysis the mortality rate induced by non-communicable diseases was extracted for the time window spanning from 2020 to 2023 with respect to AULSS 3

Serenissima, covering the southern half of the territory considered, and to AULSS 4 Veneto Orientale, covering the northern area of the Provincial territory. Due to the spatial resolution of the database, it was not possible to map the variable at a more granular level.

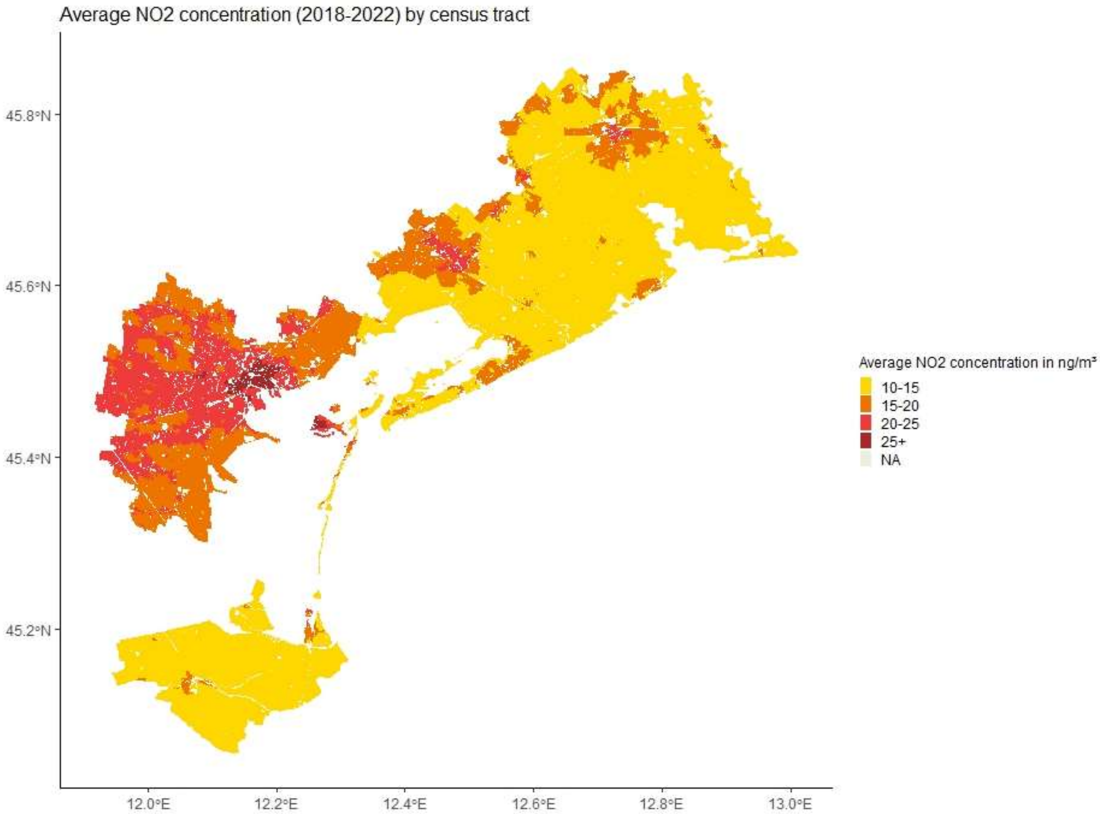
DIMENSION	VARIABLE	DATASET	SCOPE	SPATIAL RESOLUTION	YEAR OF PUBLISHING	REFERENCE TIME FRAME	FORMAT
Health	Standardized mortality rate of deaths caused by non communicable diseases	SER Veneto: Standardized mortality rate by cause	Veneto region	ULSS	2023	2020-2023	Shapefile
Health	NO_2 concentration (ng/m^3)	European Envirnment Agency: NO_2, European air quality data	Europe	1km	2024	2018-2022	Raster
Health	Travel time to nearest healthcare facility (minutes)	Methodology by Weiss et al. (see reference):Travel Time to Nearest Healthcare Facility with Access to Motorized Transport	Global	1km	2019	2019	Raster

Table 6 - General databases information for Health dimension of SCP index

The variable regarding the mortality rate induced by non-communicable diseases across AULSS can be observed in Map 9. It has to be noted that the area in yellow, with a medium mortality rate compared to the respective southern and northern areas, is the one covered by the census tracts that are geographically located between the two AULSS. In particular, the AULSS 3 Serenissima, represented in orange, presents a higher mortality rate compared to the northern region and that is probably due to the high concentration of air pollutants released by the petrochemical factories located in Marghera.



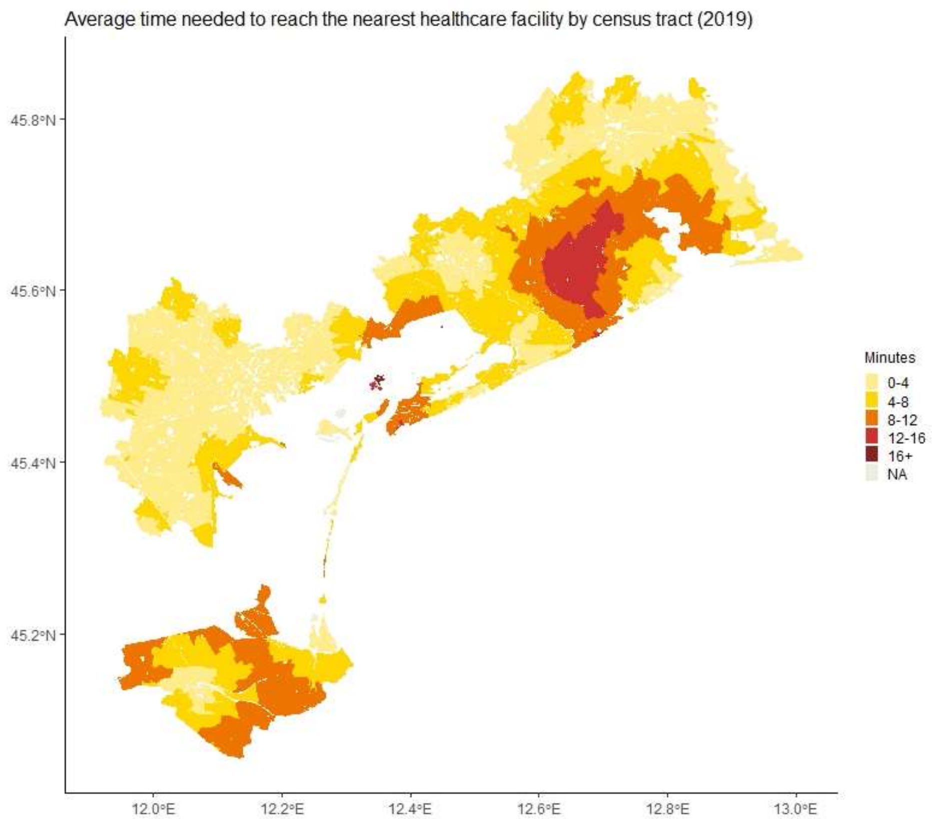
Map 9 - Mortality rate induced by non-communicable diseases across AULSS (2020-2023)



Map 10 - Average NO_2 concentration (ng/m³) by census tract (2018-2022)

The second variable that was extracted for the Health dimension of SCP index was that related to the average NO_2 atmospheric concentration over the provincial area. The database from which the information was extracted was that of the European Environment Agency that provides NO_2 concentration yearly data from 2010 to 2022 at 1 km spatial resolution over the European region. For the aim of the study the average NO_2 concentration was extracted from the year 2018 to the year 2022 across the concerned census tracts. The resulting spatial distribution of the pollutant can be observed in Map 10. As expected, the area having the lowest air quality, with respect to NO_2 concentration is that around Mestre and Marghera, where the industrial hub is located, and in more extended urbanized areas as in the cases of Venice, San Donà di Piave and Portogruaro.

The last indicator that was considered for the representation of the Health dimension was the one related to the average time (in minutes) needed to reach, with motorized transport, the nearest health care facility by each census tract. The variable was extracted by the Malaria Atlas, created following the approach by Weiss et al. in 2020. In particular the database in Malaria Atlas contains the indicator of interest, which was released in the year 2019, with a spatial resolution of 1 km and global coverage.



Map 11 - Average travel time with motorized transport by nearest health-care facility by census tract (2019)

In Map 11 the spatial distribution of travel time needed to reach the nearest health care facility by each census tract can be observed. The more disadvantaged areas, with respect to this variable, are the rural ones and least urbanized. In particular, the inland area of Eraclea municipality and Burano island represent the most critical areas, needing more than 12 minutes of travel by motorized transport for reaching the nearest health care center.

2.1.5 Education and work standards

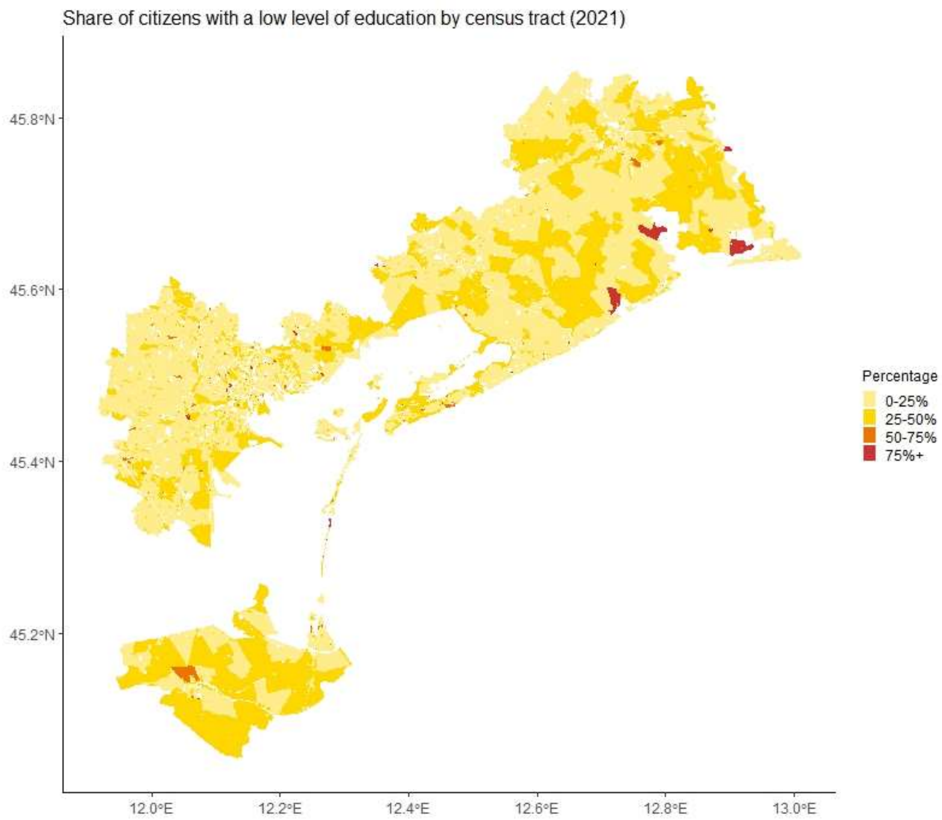
For mapping the fifth dimension of the SCP index, 2 variables have been extracted from the last census conducted in the year 2021 by ISTAT; see Table 7 for database information. The database has a spatial resolution at the Italian census tract level. For the purpose of the study the percentage of people having a low educational level, that are represented by people older than 9 years that have attended elementary school or not owning any school qualification, has been measured. In addition to that, the percentage of unemployed population for every census tract has been calculated.

DIMENSION	VARIABLE	DATASET	SCOPE	SPATIAL RESOLUTION	YEAR OF PUBLISHING	REFERENCE TIME FRAME	FORMAT
Education and work standards	Population having low educational level (%) – people older then 9 years that attended elementary school or not owning any school qualification	ISTAT: Population census	Italy	Census tract level	2021	2021	Shapefile
Education and work standards	Unemployed population (%)	ISTAT: Population census	Italy	Census tract level	2021	2021	Shapefile

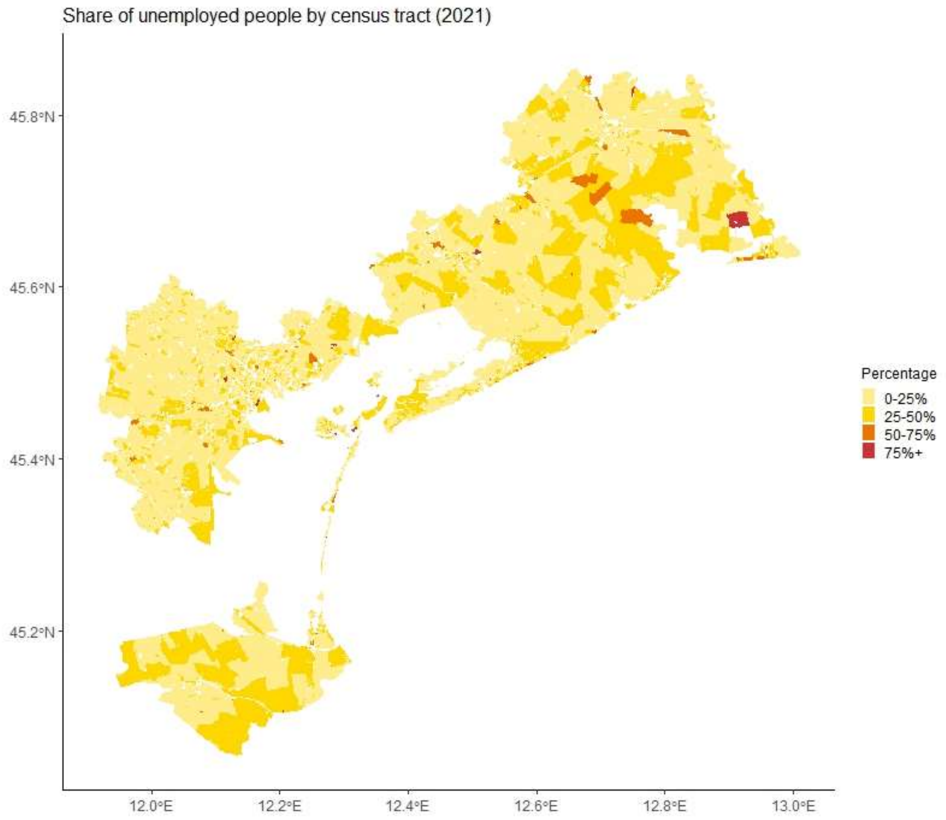
Table 7 - General databases information for Education and work standards dimension of SCP index

As it can be observed in Map 12, the geographical distribution of people presenting a low level of education is quite even across the territory concerned. Many census tracts present a medium concentration (25-50%) of this group of population, in particular in rural areas like across the municipalities of Portogruaro, San Michele al Tagliamento, Eraclea, Tessera and Chioggia. A higher percentage (50-75%,75%+) of people with low educational attainment are clustered in the proximities of Bibione, Portogruaro and Mestre.

A similar spatial distribution can be noted in Map 13, regarding the share of unemployed people across census tracts. The areas with a higher density (50-75%,75%+) of unemployed population are again clustered around the municipalities of Portogruaro, Bibione and Mestre.



Map 12 - Share of population with low educational level by census tract (2021)



Map 13 - Share of unemployed people by census tract (2021)

2.2 Indicators' binary discretization

After the identification and extraction of the variables necessary for the characterization of each dimension of SCP, a binary categorization has been computed for every variable. For the assignment of the criteria defining if the census tract could be considered deprived with respect to Systemic Cooling for each variable, two different methodologies have been explored. The first approach is based on the distribution of each variable, while the second one follows a normative threshold approach.

2.2.1 First variables deprivation definition: data distribution approach

For the assignment of the binary value defining if the census tracts could be considered deprived, with a value equal to 1, or not deprived, equal to 0, with respect to systemic cooling, the first approach was based on the distribution of each indicator (See Equation 3 and 4, where $d_{c,v}$ stands for discretized variable at the census tract level, $x_{c,v}$ for the variable's value at the specific census tract level and μ_v represents the mean value of the selected variable). More specifically, the threshold value for identifying if the census tract was deprived or not was the mean of each indicator (see Table 8 for each variable's distribution and Table 9 for the Equation adopted for each variable). For what concerns the discomfort index, the share of built environment, the average residential energy intensity, sociodemographic characteristics contained in dimensions 3 and 5 and the variables belonging to the health dimension, each census tract exceeding the mean value for each indicator was considered deprived, with an associated value equal to 1 (following Equation 3).

Instead, for the variables related to the presence of green infrastructures and bus stops, every census tract showing a value lower than the mean, according to the distribution of that variable, was considered deprived, consequently associated with a categorical value equal to 1 (following Equation 4). Instead, in the first case (Equation 3), census tracts with a value lower than the mean for each indicator were considered not deprived, hence a value equal to 0 was assigned to each census area presenting these characteristics. While, for the second set of indicators (Equation 4), census tracts presenting values higher than the mean, according to the distribution of the variable, were associated with a value equal to 0, identifying not deprived census tracts.

	Unique	Missing Pct.	Mean	SD	Min	Median	Max	Unit of measure
DI_24	2108	0	54.3	27.5	3.4	64.1	96.3	°C
green_blue_infra1km	640	0	38.8	24.4	0.0	35.3	100.0	%
Residential_energy	6190	0	2032.5	254.7	1080.0	1944.0	2594.0	kWh/m²year
share_built_env	7874	0	40.2	19.5	0.0	40.9	100.0	%
bus_stop_km	556	0	3.8	20.4	0.0	0.0	359.4	Bus stops/km²
share_children	1924	0	10.3	8.1	0.0	10.0	100.0	%
share_elders	2252	0	22.3	16.7	0.0	20.0	100.0	%
share_foreigners	2161	0	9.8	14.3	0.0	5.2	100.0	%
share_loweduc	2174	0	19.6	13.8	0.0	18.2	100.0	%
share_unemployed	2037	0	21.2	12.3	0.0	20.8	100.0	%
mortality_rate	3	0	868.4	13.0	847.2	876.4	876.4	deaths per 100.000 population
travel_health	4535	6	2.8	2.7	0.0	1.9	17.0	minutes
NO_2	4834	0	20.3	4.7	10.1	21.1	30.3	ng/m³

Table 8 - Summary statistics of the indicators composing each dimension of SCP index

DIMENSION	VARIABLE	SYSTEMIC COOLING DEPRIVATION	DEPRIVATION APPROACH
Climate	Discomfort Index	Deprived if the average sum of days per year exceeding 24°C are more than the mean value	Equation 3
Infrastructures and assets	Share of area covered by built environment	Deprived if the percentage of urbanized area is higher than than the mean value	Equation 3
Infrastructures and assets	Share of accessible green areas	Deprived if the percentage of area covered by accessible green spaces is lower than the mean value	Equation 4
Infrastructures and assets	Annual energy intensity	Deprived if the annual energy intensity exceeds the mean value [kWh/m²year]	Equation 3
Infrastructures and assets	Available bus stops	Deprived if the ratio between sum of bus stops and area of the census tract [km²] is lower than the mean value	Equation 4
Thermal justice	Share of elder population	Deprived if the percentage of elederly exceeds the mean value	Equation 3
Thermal justice	Share of children	Deprived if the percentage of children exceeds the mean value	Equation 3
Thermal justice	Share of foreigners	Deprived if the percentage of foreigners exceeds the mean value	Equation 3
Health	Mortality rate by cause	The AULSS with higher mortality rate (deaths per 100.000 population) induced by non communicable diseases is considered deprived	Equation 3
Health	NO_2 concentration	Deprived if the average NO_2 concentration exceeds the mean value [ng/m^3]	Equation 3
Health	Travel to nearest health care center	Deprived if the minutes needed to reach the nearest health are facility are higher than the mean value	Equation 3
Education and work standards	Share of people with low educational level	Deprived if the percentage of people with low educational attainment level exceeds the mean value	Equation 3
Education and work standards	Share of unemployed population	Deprived if the percentage of unemployed population exceeds the mean value	Equation 3

Table 9 - Data distribution definition for the characterization of the census tracts' systemic cooling deprivation by variable

Equation 3: $d_{c,v} = \begin{cases} 1 \; if \; x_{c,v} > \mu_v \\ 0 \; if \; x_{c,v} < \mu_v \end{cases}$

Equation 4: $d_{c,v} = \begin{cases} 1 \; if \; x_{c,v} < \mu_v \\ 0 \; if \; x_{c,v} > \mu_v \end{cases}$

2.2.2 Second variables deprivation definition: normative threshold approach

As it can be noted in Table 10, for the second deprivation assignment methodology, following a normative approach, for characterization of each variable at the census tract level, a different deprivation threshold has been selected for each indicator (See Equation 5 and 6, where $d_{c,v}$ stands for discretized variable at the census tract level, $x_{c,v}$ for the variable's value at the specific census tract level and T_v represents the normatively assigned threshold value for the selected variable).

In particular, with regard to the indicator representative of the Discomfort Index, it has been established that every census area showing an average sum of days exceeding 24°C greater than 28 days, could be considered deprived along the climate dimension. The reason for which the threshold of 28 days has been established is that during the northern-Italian summer period, normally, there happens to be one month, usually between July and August, characterized by extremely hot temperatures. According to Thom et al. (1959), with DI>24°C more than half of the population is in a condition of thermal stress (see Table 2). Moreover, it has been recognized by Khatana et al. (2022) that in their study across a large number of counties in the USA in the period between 2008 and 2017, each additional day of extreme heat was associated with a 0.12% increase in the monthly rate of cardiovascular mortality. For this reason, census tracts showing an average of days exceeding 24°C greater than 28 are considered to be systematically deprived with respect to the climatic dimensions, hence being assigned a value equal to 1 (Equation 5).

DIMENSION	VARIABLE	SYSTEMIC COOLING DEPRIVATION	DEPRIVATION APPROACH
Climate	Discomfort Index	Deprived if the average sum of days per year exceeding 24°C are more then 28	Equation 5
Infrastructures and assets	Share of area covered by built environment	Deprived if the percentage of urbanized area is higher then 43.4	Equation 5
Infrastructures and assets	Share of accessible green areas	Deprived if the percentage of area covered by accessible green spaces is lower then 75	Equation 6
Infrastructures and assets	Annual energy intensity	Deprived if the annual energy intensity exceeds 1500 [kWh/m²year]	Equation 5
Infrastructures and assets	Available bus stops	Deprived if the ratio between sum of bus stops and area of the census tract [km²] is lower than 1	Equation 6
Thermal justice	Share of elder population	Deprived if the percentage of elederly exceeds the value of 17.6	Equation 5
Thermal justice	Share of children	Deprived if the percentage of children exceeds the value of 12.7	Equation 5
Thermal justice	Share of foreigners	Deprived if the percentage of foreigners exceeds the value of 10.2	Equation 5
Health	Mortality rate by cause	The AULSS with higher mortality rate (deaths per 100.000 population) induced by non communicable diseases is considered deprived	Equation 5
Health	NO_2 concentration	Deprived if the average NO_2 concentration exceeds 10 [ng/m^3]	Equation 5
Health	Travel to nearest health care center	Deprived if the minutes needed to reach the nearest health are facility are more than 8	Equation 5
Education and work standards	Share of people with low educational level	Deprived if the percentage of people with low educational attainment level exceeds the value of 19.2	Equation 5
Education and work standards	Share of unemployed population	Deprived if the percentage of unemployed population exceeds the value of 6.1	Equation 5

Table 10 - Normative thresholds definition for the characterization of the census tracts' systemic cooling deprivation by variable

For what concerns the dimension representative of the physical environment, for the variable quantifying the percentage of land cover by built environment a threshold value of 43.4% has been identified. The criterion has been defined by taking into consideration the average urbanization rate for the Veneto region that is equal to 43.3% (ISTAT, 2014). Census tracts showing a lower value will be considered not deprived along this variable, hence assuming a value equal to 0. The contrary will happen to census tracts with a value exceeding the threshold, to which a value equal to 1 will be assigned (Equation 5).

On the other hand, for the variable regarding the percentage of areas presenting accessible green infrastructures within 1 km buffer from each census tract, the threshold value was set to 75. There is a relevant amount of academic reference reporting the beneficial effects, both in terms of heat attenuation capacity and wellbeing increase associated with green areas. In this perspective, a 1 km buffer represents a walk of about 10 to 15 minutes from the boundaries of each census tract. Consequently, if the census tract presents a percentage of accessible canopy cover lower than 75, even expanding the boundaries of 1 km, the census tract will be considered deprived (Equation 6).

With respect to the indicator considered for the average annual energy intensity of each census tract, the threshold has been assigned through the distribution of the data, since it is a composite indicator and there is no direct evidence on how this measure should be considered in literature. In this perspective, census tracts presenting an average residential energy intensity higher than 2000 [kWh/m^{2}year] are considered deprived (Equation 5).

The cut-off for the variable concerning the bus stops density across census tracts has been set to 1. In particular, when the ratio between available bus stops in the census tract and the area of the census tract in square kilometers is lower than 1, it means that there is less than a bus stop for each square kilometer. Similarly to the variable regarding green availability, 1 km is usually covered in 10-15 minutes' walk. Hence, each census tract having a bus stop density lower than 1 will be considered deprived (Equation 6).

With regard to the indicators composing the third and fifth dimensions of the SCP index, the same methodology has been followed for the identification of the limitation value. In particular, for each variable, if census tracts had a value greater than the average percentage of that group of population in Veneto region (ISTAT, 2021; ISTAT 2023), see Table 9 for each specific value, the census tract was considered of particular vulnerability level, needing more attention from local authorities, hence deprived (Equation 5).

Lastly, the threshold values have been defined for the dimension concerning health. Firstly, for the variable regarding mortality rates induced by non-communicable diseases, the census tracts falling in the territory belonging to the AULSS with the most elevated mortality rates induced by non-communicable diseases were considered deprived (Equation 5).

After that, the cut-off measure was delineated also for the variable accounting for atmospheric NO_2 concentration. The Global Air Quality Guidelines released by WHO in 2021 were considered for delineating the threshold value, set to 10 [ng/m³]. In particular, the census tracts presenting a higher concentration than 10 [ng/m³] were considered deprived (Equation 5).

Finally, the threshold value for the deprivation characterization along the variable related to the time needed to reach the nearest health care center was defined. Specifically, in the literature it is found evidence that, in case of stroke, brain cells start dying, due to brain anoxia and irreversible damage, between 6 and 10 minutes after the heart attack starts. That is why the threshold has been established to 8 minutes. In this perspective, census tracts located more distant than 8 minutes travel, by motorized transport, by the nearest health care facilities are considered deprived along this variable (Equation 5).

Equation 5: $d_{c,v} = \begin{cases} 1 \; if \; x_{c,v} > T_v \\ 0 \; if \; x_{c,v} < T_v \end{cases}$

Equation 6: $d_{c,v} = \begin{cases} 1 \; if \; x_{c,v} < T_v \\ 0 \; if \; x_{c,v} > T_v \end{cases}$

2.2.4 Index aggregation: dimensions equal weighting

After the 13 variables were discretized into binary deprivation indicators, they have been aggregated into the five dimensions composing the Systemic Cooling Poverty Index following the procedure delineated in Equation 7.

Equation 7: $D_c = \frac{1}{n} \sum_{i=1}^{n} x_i \Rightarrow SCPI_c = \frac{1}{5} \sum_{j=1}^{5} D_j$

In Equation 7, D stands for the dimension of the index considered (e.g. Climate, Infrastructures and assets…) computed at the census tract level (c), n represents the number of variables composing the selected dimension, while $SCPI$ denotes the final value of the Systemic Cooling Poverty Index at the census tract level (c).

The five dimensions of the SCP index were respectively aggregated twice: the first time by considering the deprivation indicators resulting from the data distribution approach, described in paragraph 2.2.1, and the second time with the deprivation indicators deriving from the normative threshold approach, described in paragraph 2.2.2. Particularly, the average systemic deprivation was computed for the census tracts along each dimension of the index. In this way it is possible to capture the intensity of systemic cooling deprivation deriving from each dimension. Importantly, the degree of deprivation to which every census tract is exposed to, depending on the dimension taken into consideration, can be considered a source of information for the support of local decision makers. Considering the state of deprivation coming from each dimension, the policy agenda can be updated by considering the geographical areas needing support and which systemic dimensions needing urgent attention and consequent interventions. Consequently, in order to produce the final value representative of the intensity of the Systemic Cooling Poverty Index across census tracts, the five dimensions of the index have been aggregated computing the average degree of deprivation with respect to cooling for each census tract twice (Equation 7, second part). The first time with the values for the five dimensions produced by the data distribution approach (section 2.2.1), and the second time aggregating the five dimensions resulting from the normative threshold approach (section 2.2.2).

Concluding, the linear correlation between the two resulting values for the Systemic Cooling Poverty index has been tested applying a linear regression model, following Equation 8, where $SCPI_{C,1}$, the dependent variable, stands for the value of Systemic Cooling Poverty Index at the census tract level following the 1st methodology (data distribution approach, see section 2.2.1), β_0 represents the intercept (the value of $SCPI_{C,1}$ when $SCPI_{C,2}$=0), β_1 represents the regression coefficient (how $SCPI_{C,1}$ varies according to 1 unit increase of $SCPI_{C,2}$), $SCPI_{C,2}$, the independent variable, represents the value of Systemic Cooling Poverty Index at the census tract level following the 2nd methodology (normative threshold approach, see section 2.2.2) and ε_c represents the difference between the actual observed value of $SCPI_{C,1}$ and the predicted value from the model.

Equation 8: $SCPI_{C,1} = \beta_0 + \beta_1 SCPI_{C,2} + \varepsilon_c$

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Thermal justice

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3 Results

The Systemic Cooling Poverty Indicator has been implemented through the methodology outlined in Section 2. The five dimensions constituting the Index have been composed of 13 variables representative of the conditions that lead the citizens living in each census tract of the Province to experience thermal discomfort during hot and humid periods.

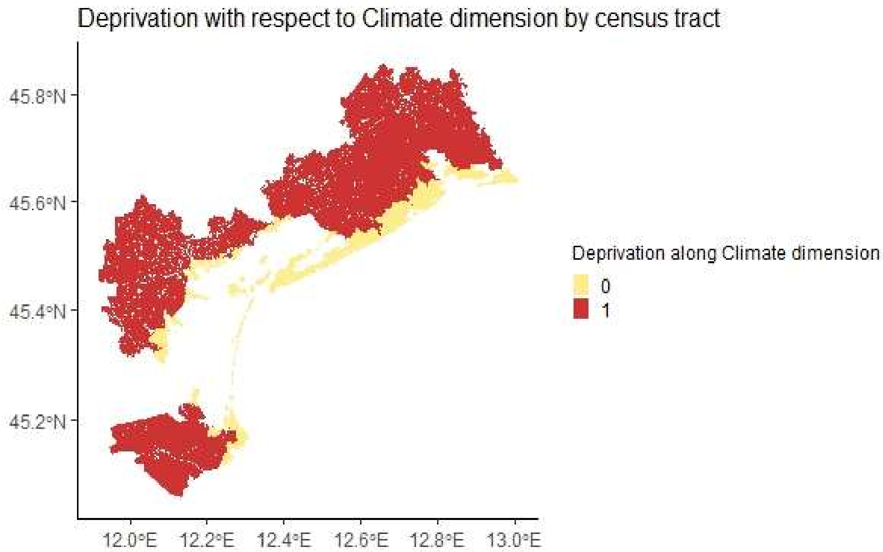
The 13 indicators have been selected according to the data availability at the local level; the information related to each variable can be found in Section 2.1. In particular, socio-demographic information, geo-spatial data and climatological data have been collected for the aim of the thesis project. After the extraction of the variables, two approaches have been computed for assessing the deprivation threshold along each variable for the census tracts falling in Venice province (see section 2.2): the first based on a data distribution approach and the second one following a normative threshold methodology. According to these two strategies a binary value was assigned to every census tract in order to define if it was deprived or not with respect to all indicators. Consequently, the five dimensions of the Index have been aggregated following the procedures delineated in section 2.3, estimating the average deprivation level for each dimension of the Index across all census tracts in the Province.

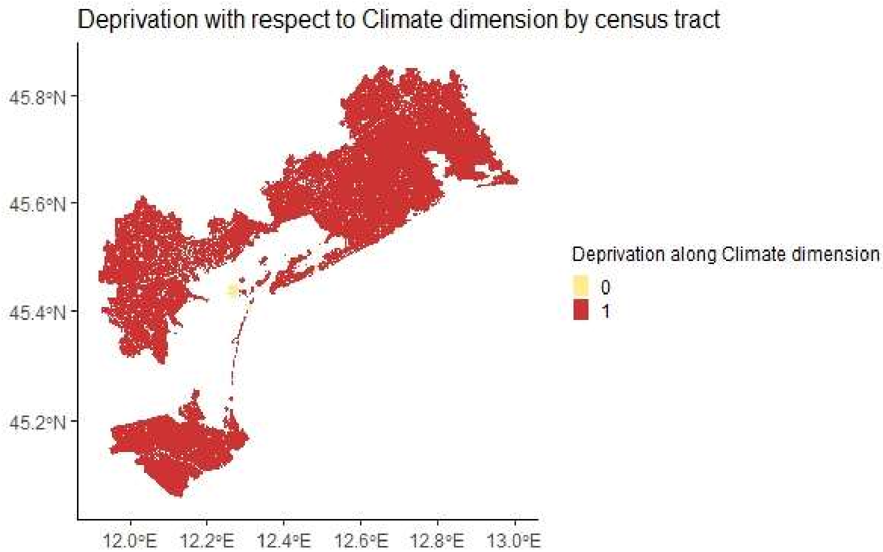
Finally, the two final SCP indicators have been calculated and the linear correlation between them has been explored through the implementation of a linear regression model in order to examine if the normative assignment of the deprivation threshold for the 13 variables was confirmed following the data distribution procedure.

3.1 Results from the two deprivation threshold methodologies

3.1.1 Climate

For the dimension relative to the climatic conditions over the territory, the Discomfort Index has been adopted as representative variable; the description of the indicator extraction can be found in section 2.1.1. In this case, the geographical distribution of the discretized variable does not change with respect to the comprehensive dimension, since the Discomfort Index variable is the only one composing the Climate dimension. The map showing the discretized values relative to the distribution of the Discomfort Index can be found in the Annex section. Instead, the geographical distribution of the deprivation level across census tracts with respect to the climate dimension can be observed in Map 14. In particular, in the upper map it is possible to observe the dimension's deprivation with respect to the data distribution approach, while on the lower part, the dimension's deprivation following the normative threshold procedure can be noted. It results evidently how the normative threshold strategy is more severe in the deprivation assignment, with the majority of the census tracts suffering acute hot and humid conditions with respect to this dimension, exclusion made for some census tracts belonging to the western area of Venice historical center. Looking at the upper map, instead, the deprivation follows the orography of the territory. More specifically, the census tracts suffering from elevated temperatures are the ones located in the inland area of the Province, while the ones located on the coastline or belonging to the islands' system do not result in being deprived.





Map 14 - On the top the data distribution deprivation along the Climate dimension of the index can be observed for the Provincial area; below the normative threshold deprivation along the Climate dimension of the index can be observed across the Province

Instead, in Figure 4, the percentage of population being exposed to the different intensity intervals of the Climate dimension with respect to the two deprivation procedures can be observed. In both cases, the majority of the population in the Province is suffering from extreme climatic conditions, with the major part of the population (94.4%) being deprived, following the normative threshold methodology, and 72.5% of the citizens being deprived following the data distribution approach.

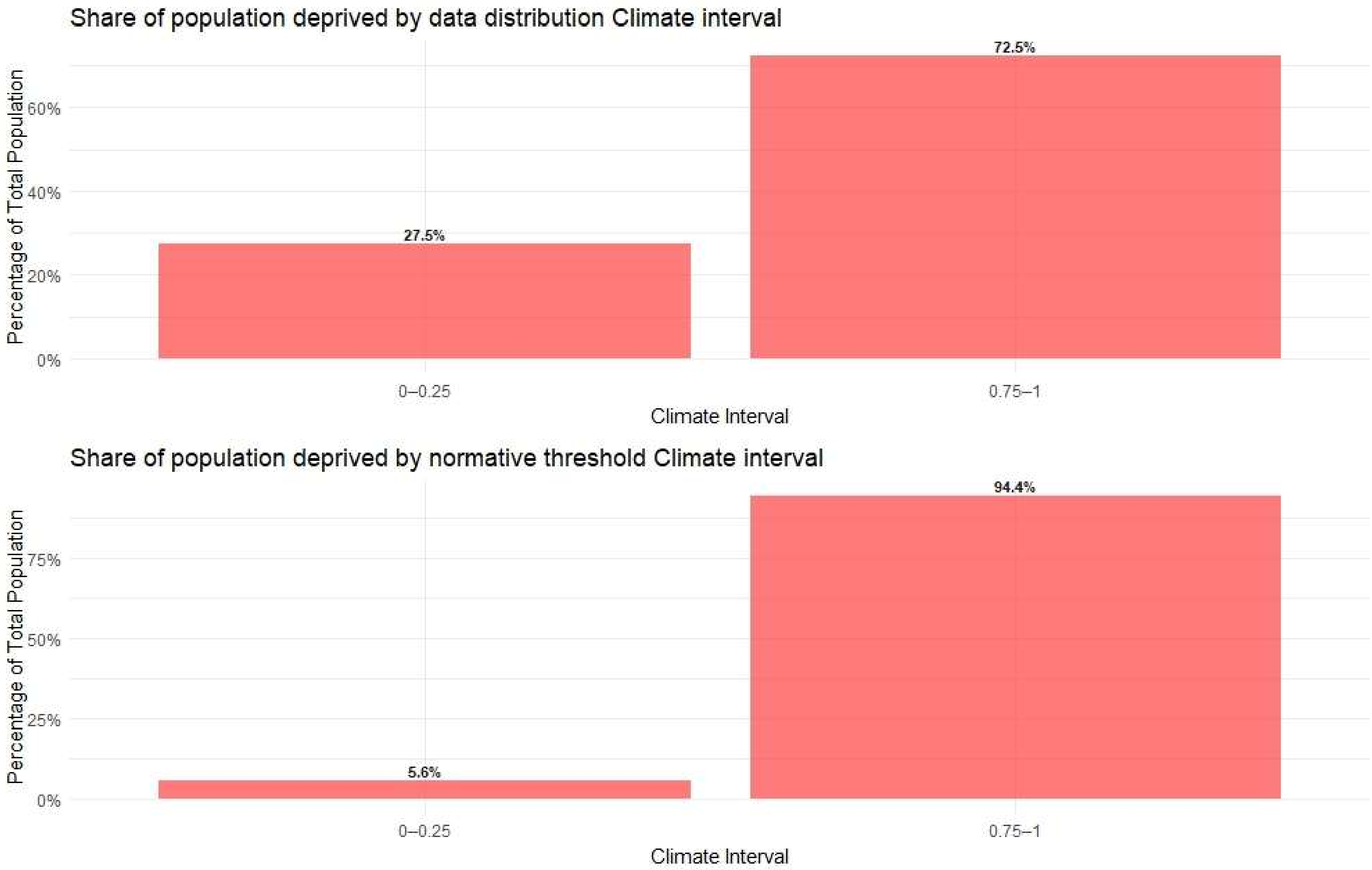
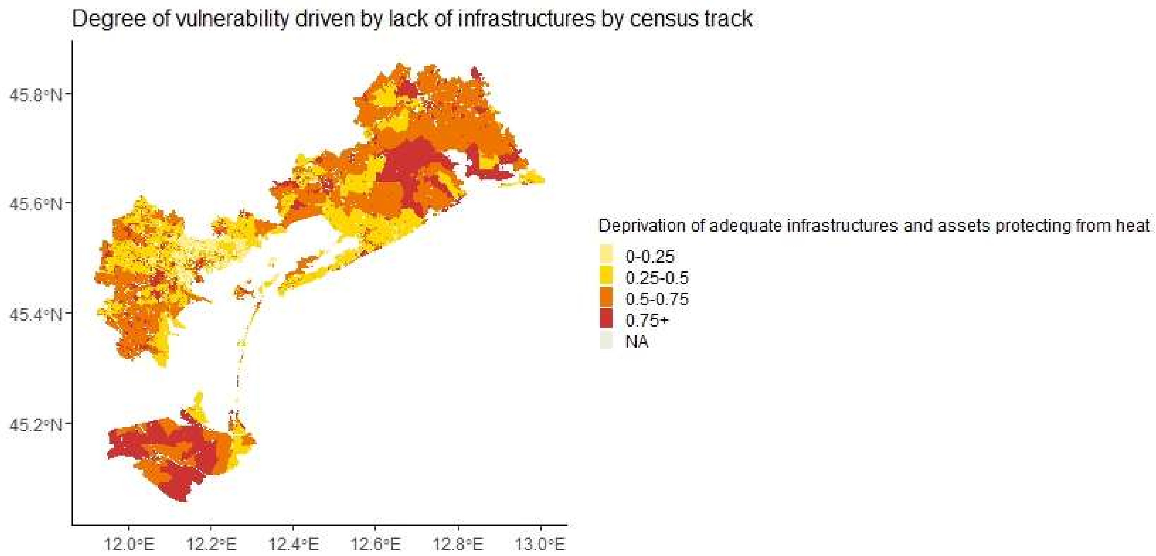
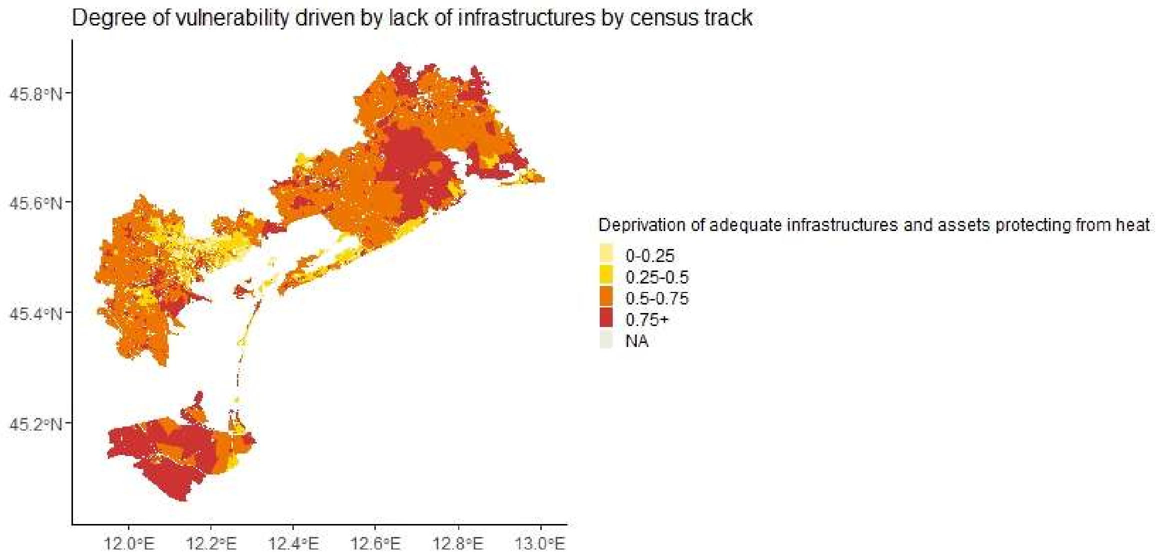


Figure 4 - Share of population deprived with respect to the Climate dimension, in the upper histogram the results from the data distribution deprivation has been applied while below the results from the normative threshold approach can be observed

3.1.2 Infrastructures and assets

For this dimension of the index four indicators have been selected and extracted as described in section 2.1.2. The maps representative of the discretization across census tracts for each variable can be observed in the Annex section. Instead, in Map 15 the distribution of lack of adequate physical environment characteristics protecting from extreme heat can be observed, the degree of deprivation according to this dimension is displayed. In particular, it is possible to note how in both maps, the hotspot showing a higher level of deprivation are the same: following a northern to southern trajectory, the areas surrounding Portogruaro, Bibione, San Stino di Livenza, some areas of Venice historical center, where Chioggia is the most critical one. In general, the map that was produced according to the normative threshold procedure, at the bottom, presents an elevated insufficiency of infrastructures helping the population to deal with extreme weather conditions. The areas in orange, showing a medium to high deprivation level, are distributed evenly and extensively across the territory in both maps. The districts presenting a decreased level of vulnerability are the ones located in Caorle, Jesolo and in Quarto d'Altino and Mogliano Veneto.





Map 15 - On the top the data distribution deprivation along the Infrastructures and Assets dimension of the index can be observed for the Provincial area; below the normative threshold deprivation along the Infrastructures and Assets dimension of the index can be observed across the Province

In Figure 5 instead, it is possible to consider the percentage of population interested by each deprivation interval with respect to physical environment characteristics. Specifically, the number of people deprived according to the two different deprivation assignment methodologies do not vary significantly. The majority of the population (47.1% data distribution and 54.3% normative threshold method) is deprived with a value ranging between a low to medium intensity (0.25-0.5), followed by the 23.3%, according to data distribution approach, and 27.6% of the population, with regard to the normative threshold strategy, presenting a medium to high (0.5-0.75) deprivation of adequate infrastructures in the census tracts where they live. The third interval, for population involved, is the one depicting the lowest deprivation level (0-0.25) and interests the 28.2% of citizens, according to the data distribution approach, and 14.3% of the population according to the normative threshold strategy. The interval portraying the highest level of infrastructural poverty (0.75-1) involves 1.4% of the citizens according to the first approach and 3.7% of the inhabitants in accordance with the second methodology.

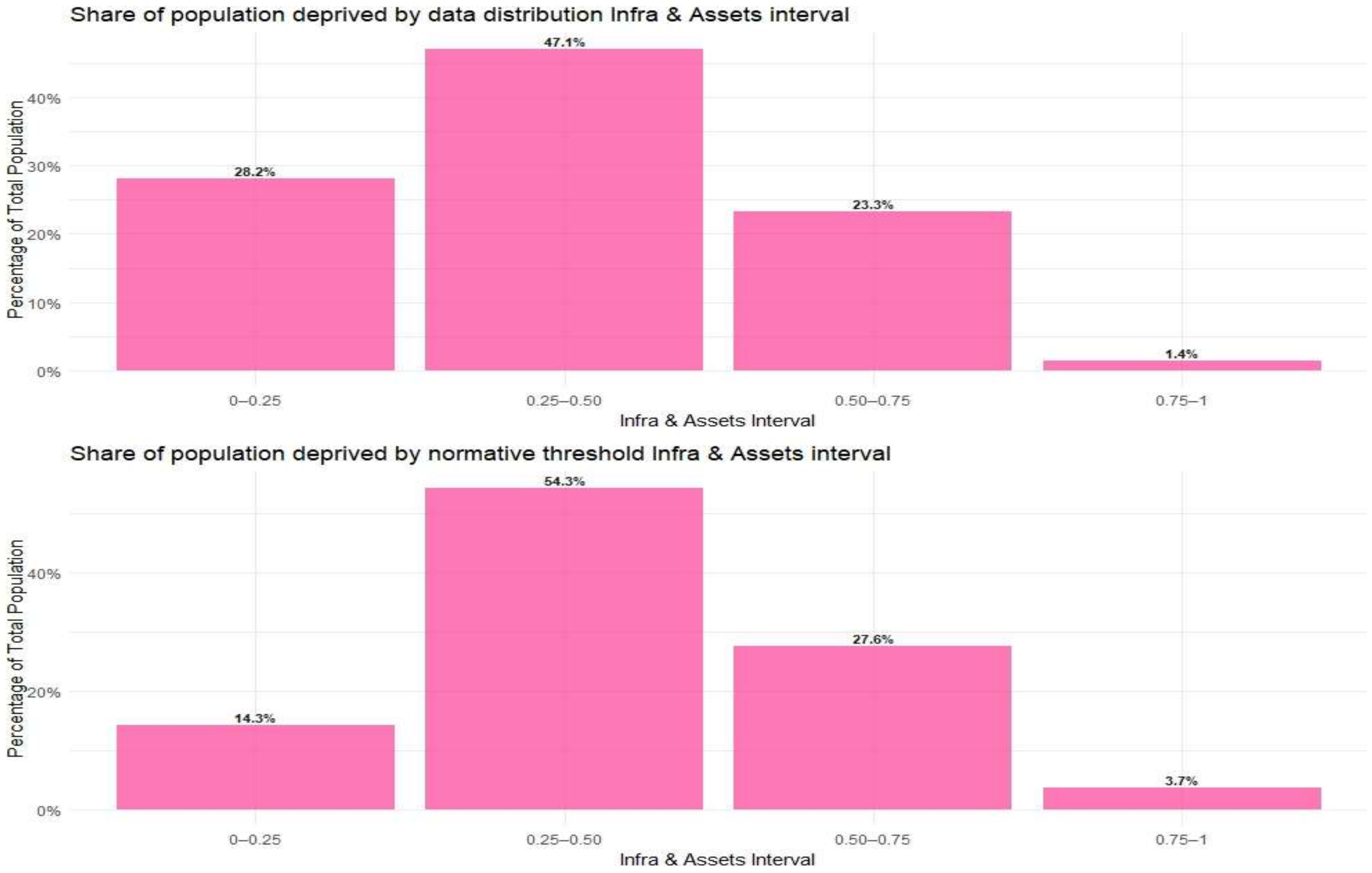
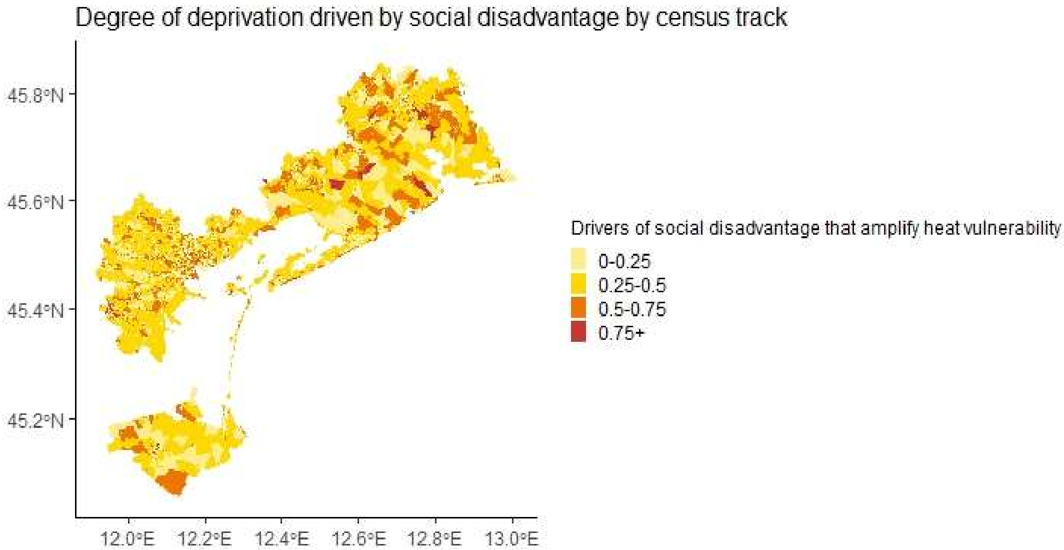
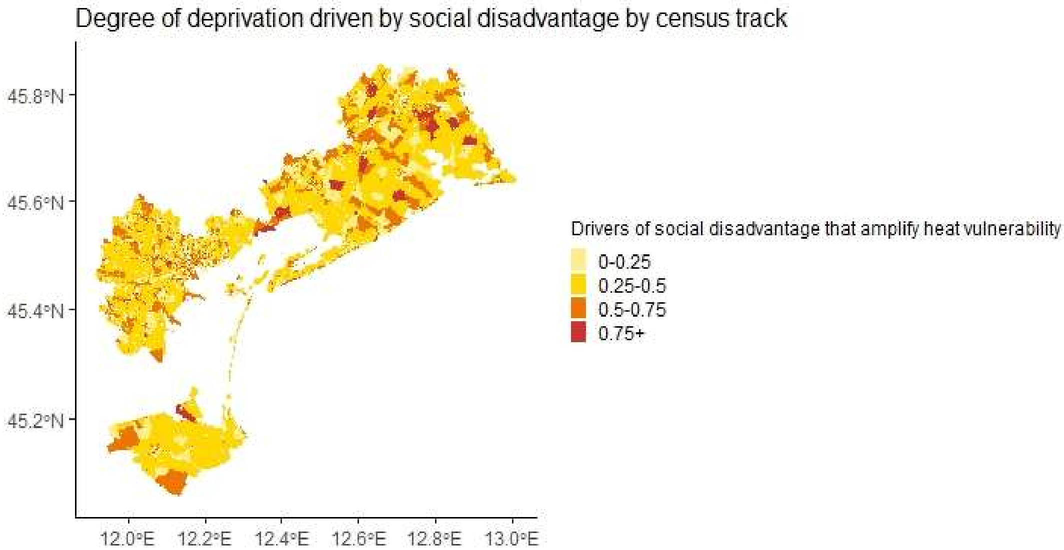


Figure 5 - Share of population deprived with respect to the Infrastructures and Assets dimension, in the upper histogram the results from the data distribution deprivation has been applied while below the results from the normative threshold approach can be observed

3.1.3 Thermal justice

The third dimension of Systemic Cooling Poverty overarches the social components that can render the population more fragile in dealing with elevated temperatures. The maps regarding the binary distribution of poverty with regard to elderly, children and foreigners' concentration over the territory can be found in the Annex section; information on the data can be found in section 2.1.3. Map 16 shows the geographical distribution and intensity of social disadvantage across census tracts. In both cases, the intensity of deprivation with regard to this dimension varies widely over the area concerned. Census tracts presenting medium to high vulnerability levels are in both cases clustered around the municipalities of Portogruaro, San Stino di Livenza, Favaro Veneto and in some areas located along the southern boundaries of the provincial area.





Map 16 - On the top the data distribution deprivation along the Thermal Justice dimension of the index can be observed for the Provincial area; below the normative threshold deprivation along the Thermal Justice dimension of the index can be observed across the Province

Figure 6 highlights the percentage of inhabitants that suffer from social vulnerability along each interval of the dimension related to Thermal Justice. The population falls in the dimension's intervals similarly along the two calculation strategies that have been implemented. Specifically, in both cases, about half of the citizens present a low to medium disadvantage (0.25-50) and around 30%, according to both procedures, have a medium to high (0.5-0.75) deprivation level. A smaller group of inhabitants (4.7% according to the data distribution approach and 6.8% with regard to normative distribution methodology) presents a high level of social vulnerability (0.75-1). In both cases, ten percent of the citizens experience a low degree of fragility (0-0.25) with respect to this dimension.

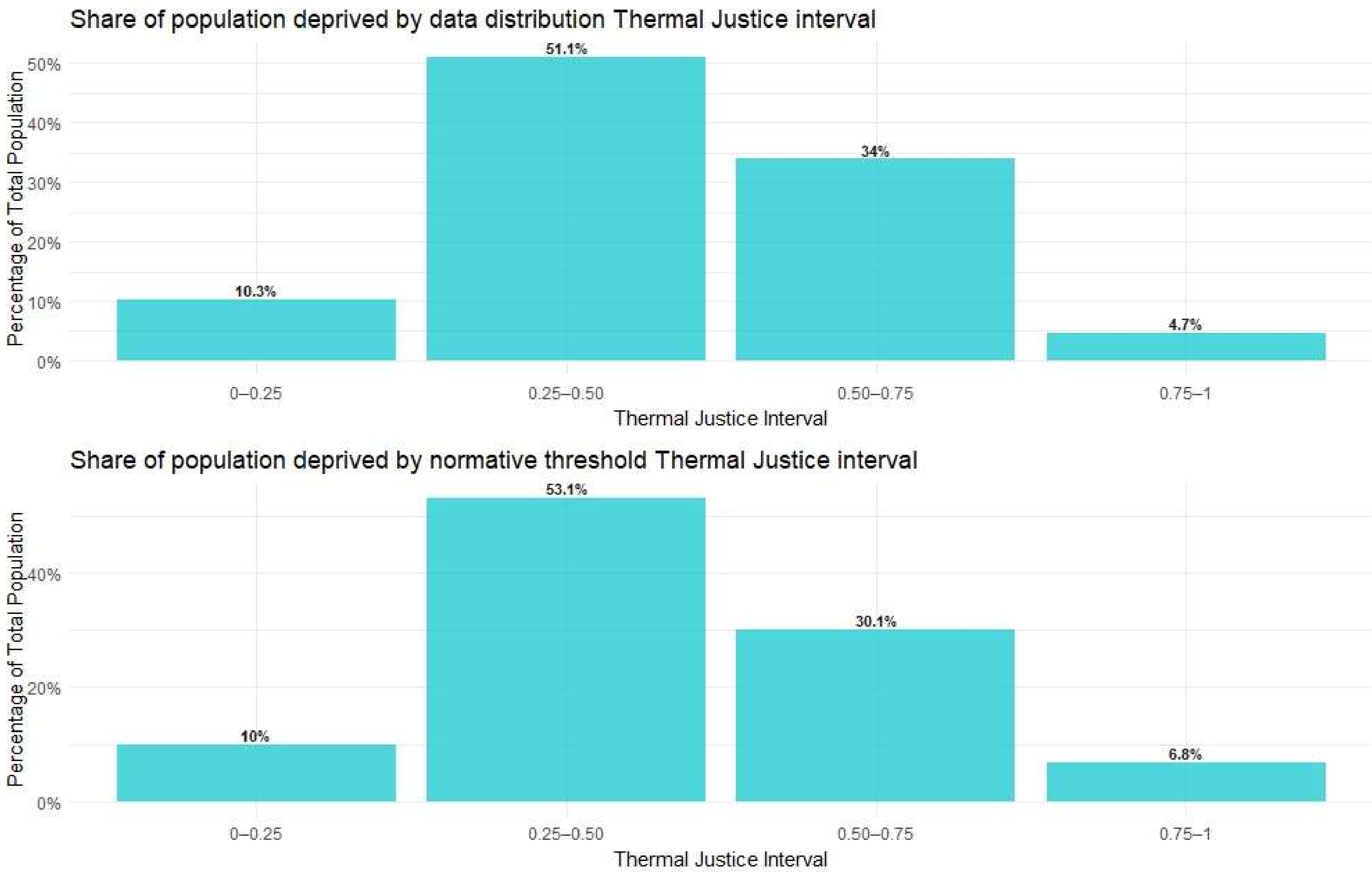
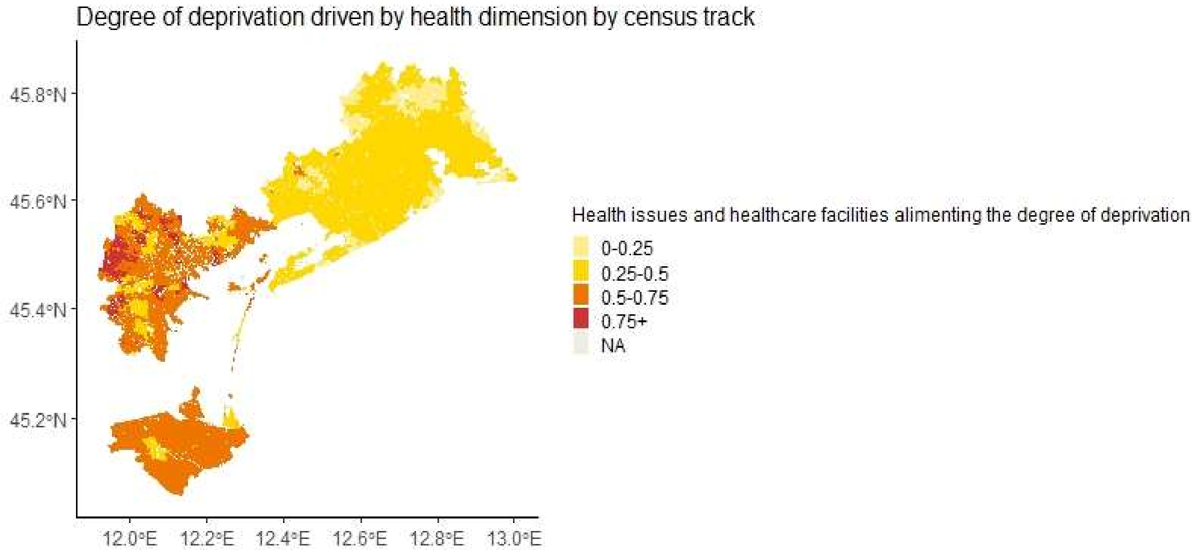
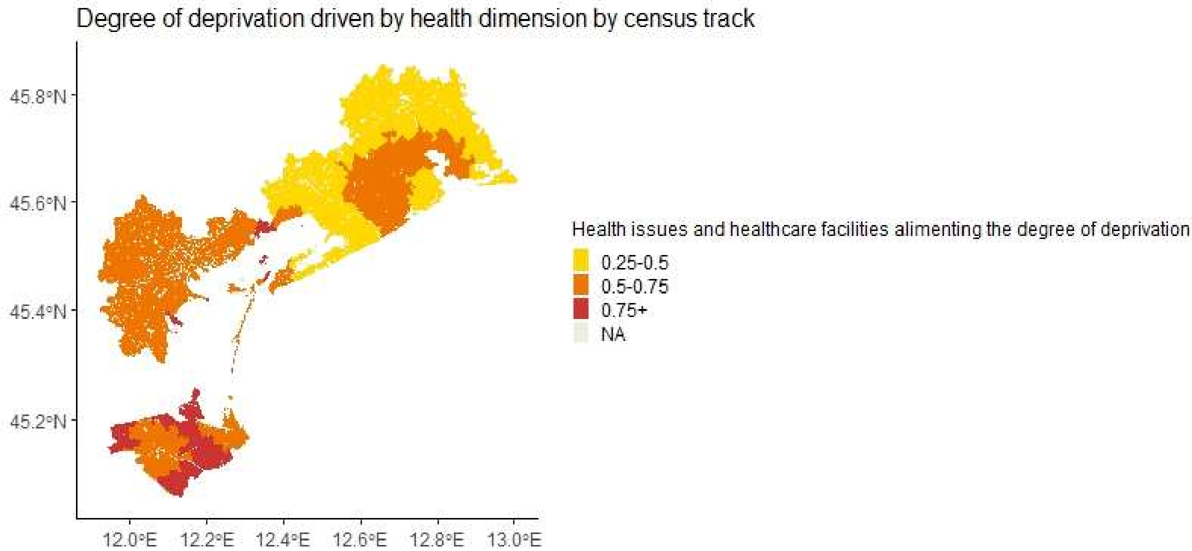


Figure 6 - Share of population deprived with respect to the Thermal Justice dimension, in the upper histogram the results from the data distribution deprivation has been applied while below the results from the normative threshold approach can be observed

3.1.4 Health

For the fourth dimension of the SCP Index, 3 variables have been extracted as presented in section 2.1.4. The binarized variables' geographical distribution over the territory can be found in the Annex section. Map 17, instead, summarizes the deprivation level with respect to health conditions of the population and health services provided over the provincial area. The census tracts located in the northern area generally present a scarce disadvantage in the inhabitants' health conditions and for the quality of services provided. It is worth noting that in the map at the bottom, following the normative threshold procedure, while the northern area looks better equipped with respect to health, the internal area falling between Bibione, San Stino di Livenza and Caorle presents a more acute (0.5-0.75) deprivation level with respect to the other census tracts located in the northern region. On the other hand, in both maps, the southern area presents a more critical situation, with the one following the data distribution approach highlighting some areas where urgent action would be needed, in particular in the municipalities of Scorzè, Noale and Mirano. Instead, the map produced according to the normative threshold procedure highlights other hotspots of deprivation, concentrated in the areas of Favaro Veneto, Sant'Anna and Cavarzare.





Map 17 - On the top the data distribution deprivation along the Health dimension of the index can be observed for the Provincial area; below the normative threshold deprivation along the Health dimension of the index can be observed across the Province

According to Figure 7, with respect to the data distribution methodology half of the population face a medium to high (0.5-0.75) lack in health conditions or health-care services. Almost 30% of the inhabitants present a low to medium health related risk, while around 10% of the citizens face a low (0-0.25) or high (0.75-1) vulnerability with regard to the health dimension.

The situation presented by the normative threshold strategy is quite different, picturing the majority of the population (73.5%) to be medium to highly vulnerable to health risk enhanced by hot temperatures and almost a quarter of the inhabitants to face low to medium (0.25-0.5) deprivation in health conditions and care services. A minor amount of population (1,5%) presents a high severity in health care facilities accessibility and on health conditions.

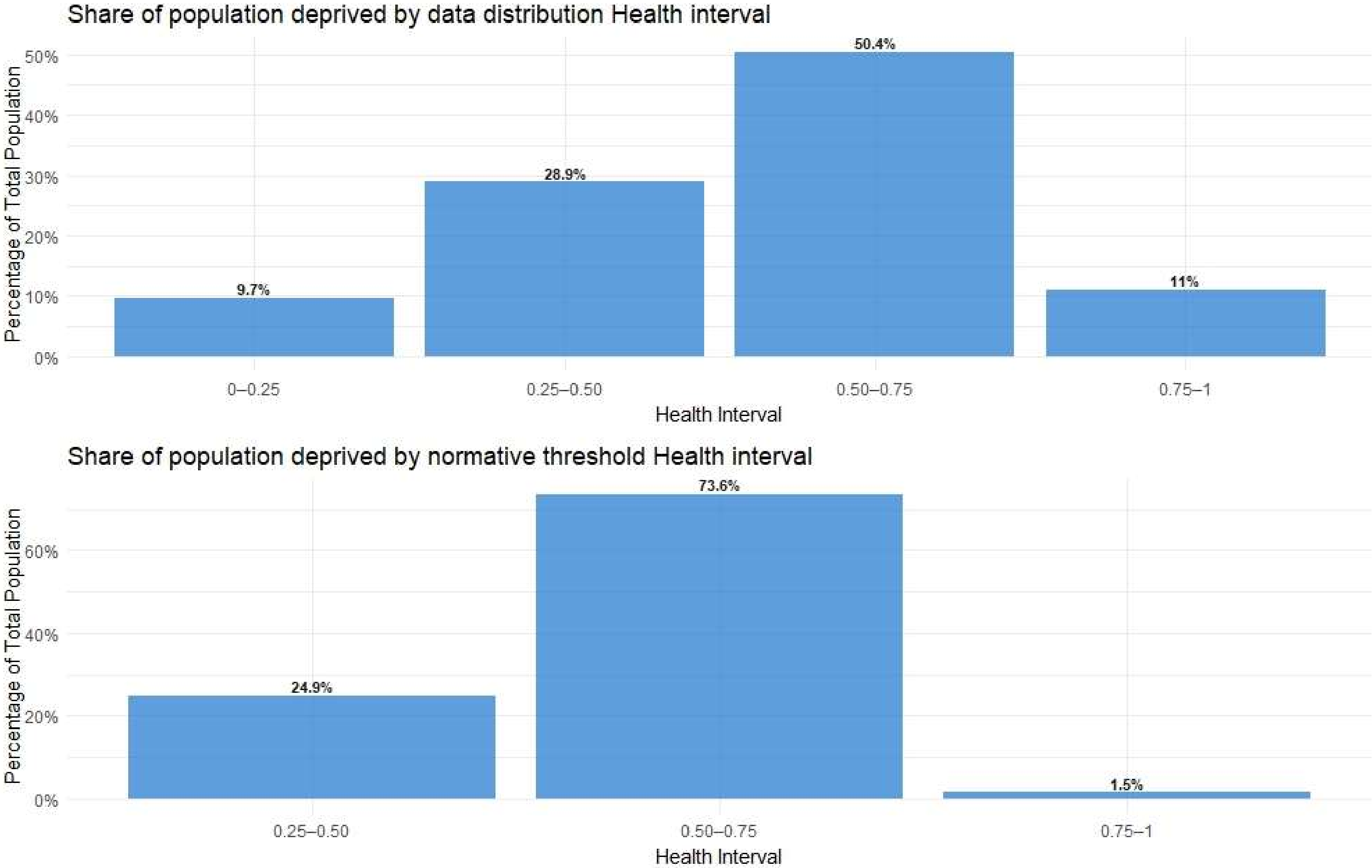


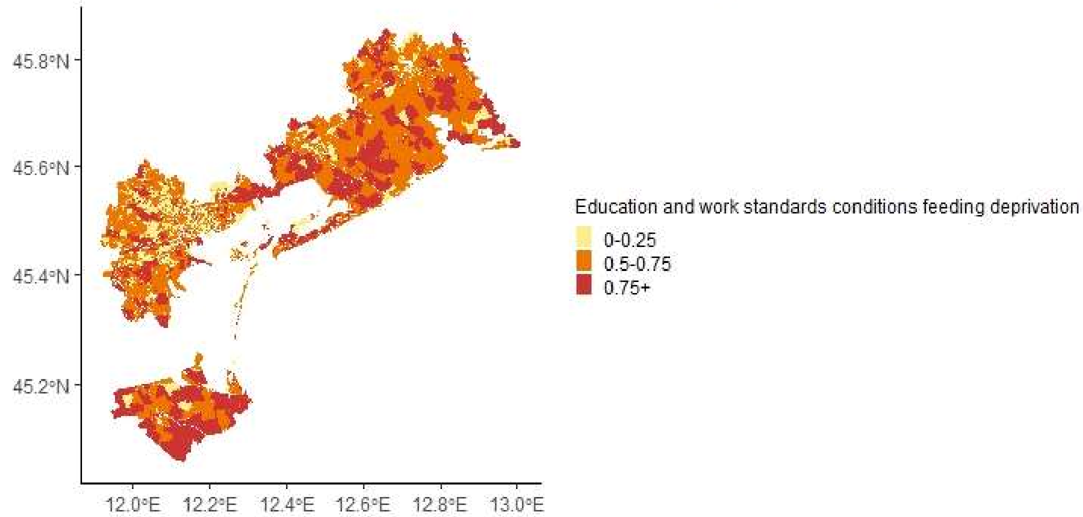
Figure 7 - Share of population deprived with respect to the Health dimension, in the upper histogram the results from the data distribution deprivation has been applied while below the results from the normative threshold approach can be observed

3.1.5 Education and work standards

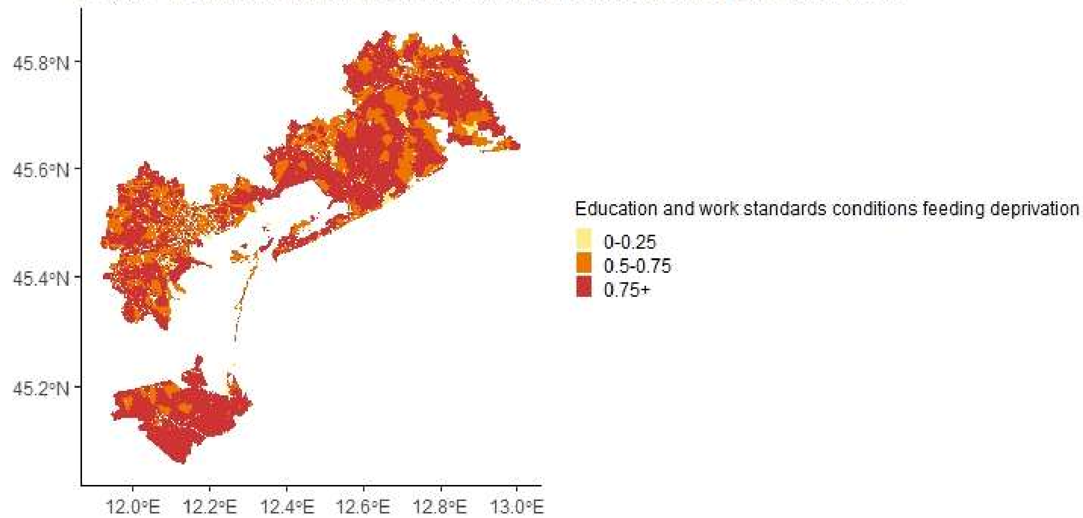
For the fifth dimension of the Index, two indicators were selected and operationalized following the procedure in section 2.1.5. In this framework, the maps delineating the binary indicators and their geographical distribution can be found in the Annex section.

Map 18 represents the average deprivation level of each census tract with respect to educational level and employment conditions. It is possible to observe how, again, the normative threshold methodology for determining the deprivation level across census tracts is more severe with respect to the data distribution approach. In particular, the upper map presents a heterogeneous distribution in the intensity of deprivation with respect to this dimension across census tracts. The places showing more critical conditions are the ones falling in the surroundings of Bibione, Portogruaro, San Stino di Livenza, Caorle and in Sant'Anna. Better conditions can instead be noted for the areas in the city centers of Portogruaro, San Stino di Livenza, Venice and Mestre and Marghera. A diffused critical situation can be noted in the map produced according to the normative threshold methodology that presents a reduced number of census tracts not suffering from deprivation with respect to education and employment conditions. The areas suffering less in this context are the ones located in city centers as in the map concerning the data distribution methodology. Instead, the majority of census tracts falling in marginal areas and in less urbanized census tracts are the ones suffering the most from an educational and employment perspective.

Degree of deprivation driven by education and work standards by census track

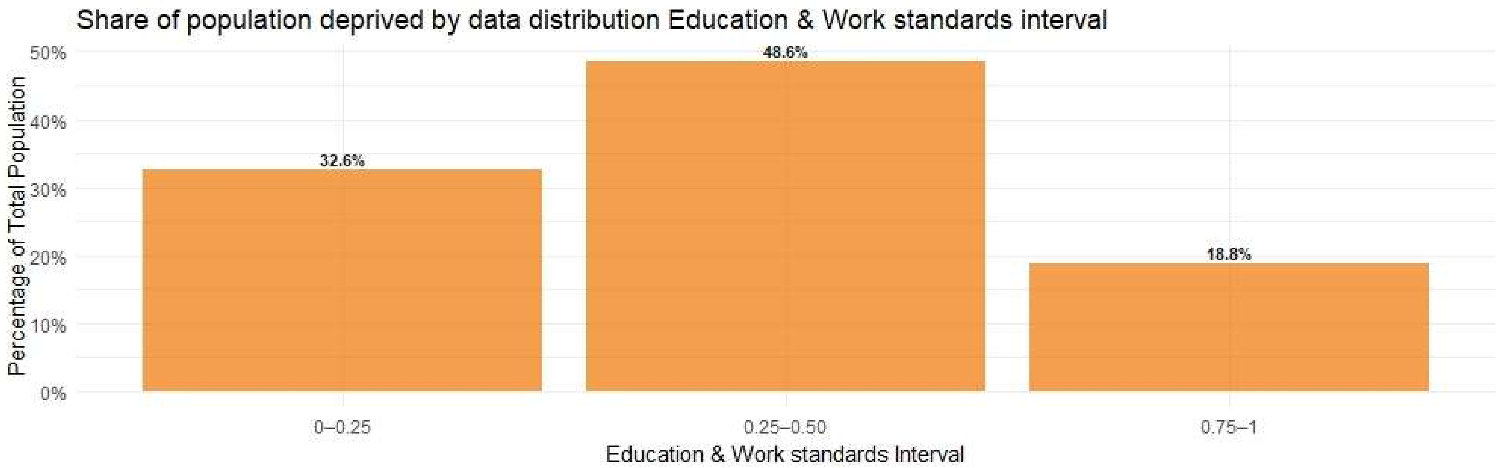


Degree of deprivation driven by education and work standards by census track



Map 18 - On the top the data distribution deprivation along the Education and Work standards dimension of the index can be observed for the Provincial area; below the normative threshold deprivation along the Education and Work standards dimension of the index can be observed across the Province

Figure 8 portrays the share of the population interested by each degree of deprivation interval along the Education and Work standards dimension with respect to the two deprivation assignment strategies. In particular, in both cases half of the population (48.6% for data distribution and 59.6% for normative threshold) show a low to medium vulnerability level. The percentage of population falling in the interval characterizing the most critical situations (0.75-1) are respectively 18.8% for data distribution and 40.1% for normative threshold method. Instead, the citizens showing a low (0-0.25) degree of disadvantage are 32.6% with regard to data distribution methodology and just 0.2% according to the normative threshold methodology.



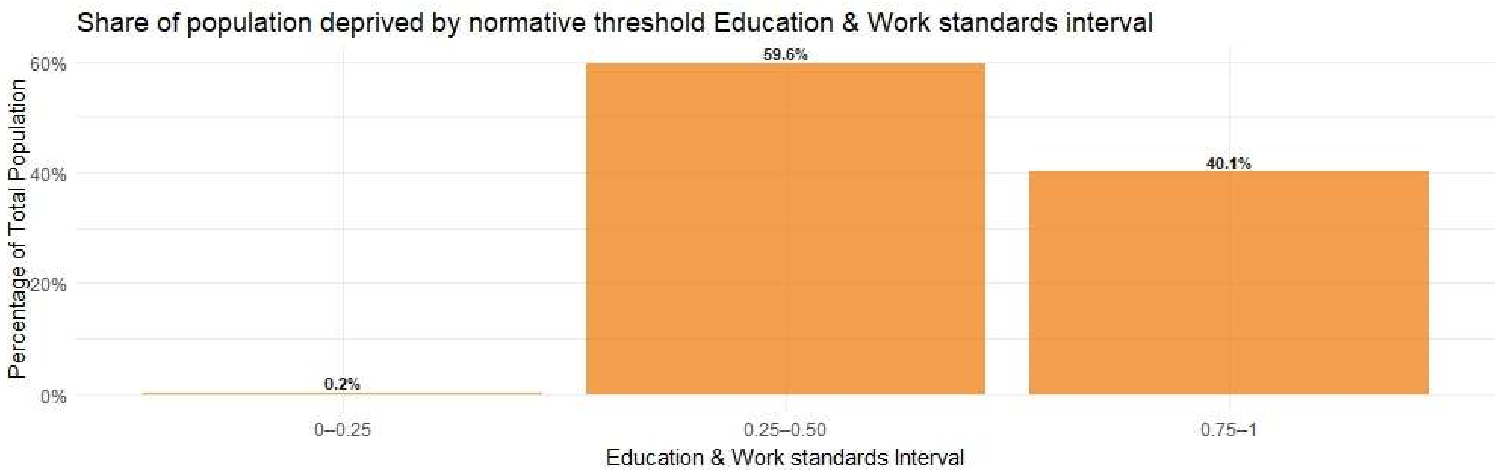
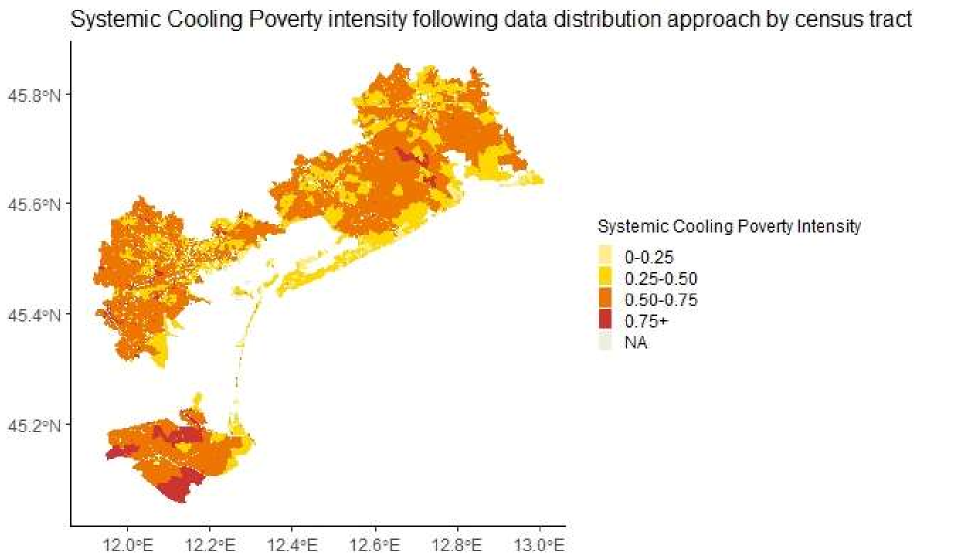
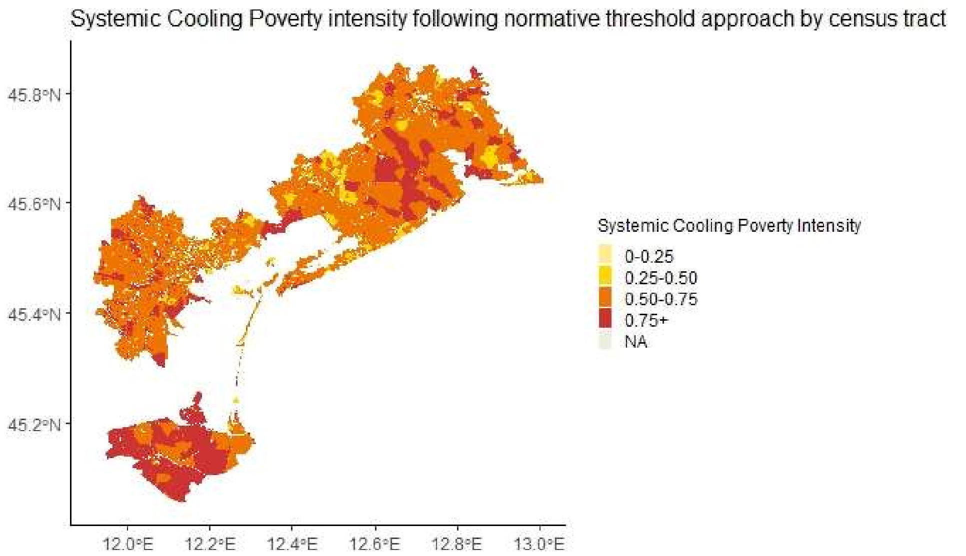


Figure 8 - Share of population deprived with respect to the Education and Work standards dimension, in the upper histogram the results from the data distribution deprivation has been applied while below the results from the normative threshold approach can be observed

3.2 Results from the Index aggregation

The final Systemic Cooling Poverty Index has been computed following the methodology delineated in section 2.3. Accordingly, two different measures have been produced following the data distribution approach for the deprivation assignment and the normative threshold deprivation assignment methodology. In particular, Map 19, shows the geographical distribution of the Systemic Cooling Poverty Index across census tracts with regard to their intensity of deprivation. The two maps are similar for the deprivation distribution but the lower map, regarding the normative threshold, highlights more areas suffering intense deprivation. In particular, the areas suffering scarce adaptive capacity to hot and humid intensified conditions are the ones located in the internal area of San Stino di Livenza and Caorle. Mira, Cavarzare and Sant'Anna also emerge from both maps as areas presenting intensified deprivation. In the lower map, a larger number of census tracts with severe cooling poverty are located in Favaro Veneto, Scorzè, Noale and Mirano. Furthermore, the areas urging immediate action with respect to cooling poverty are more extended in the lower map, in the southern area of the provincial territory, located in Sant'Anna, Cantarana and Cona. On the contrary, census tracts presenting low vulnerability are located in the territory belonging to Portogruaro, San Stino di Livenza and Caorle. Moreover, in the map concerning the data distribution methodology, Systemic Cooling Poverty shows low levels also in some districts of Venice, Mestre and Marghera, Jesolo and Chioggia.





Map 19 - On the top the data distribution deprivation along the Systemic Cooling Poverty index can be observed for the Provincial area; below the normative threshold deprivation along the SCP index can be observed across the Province

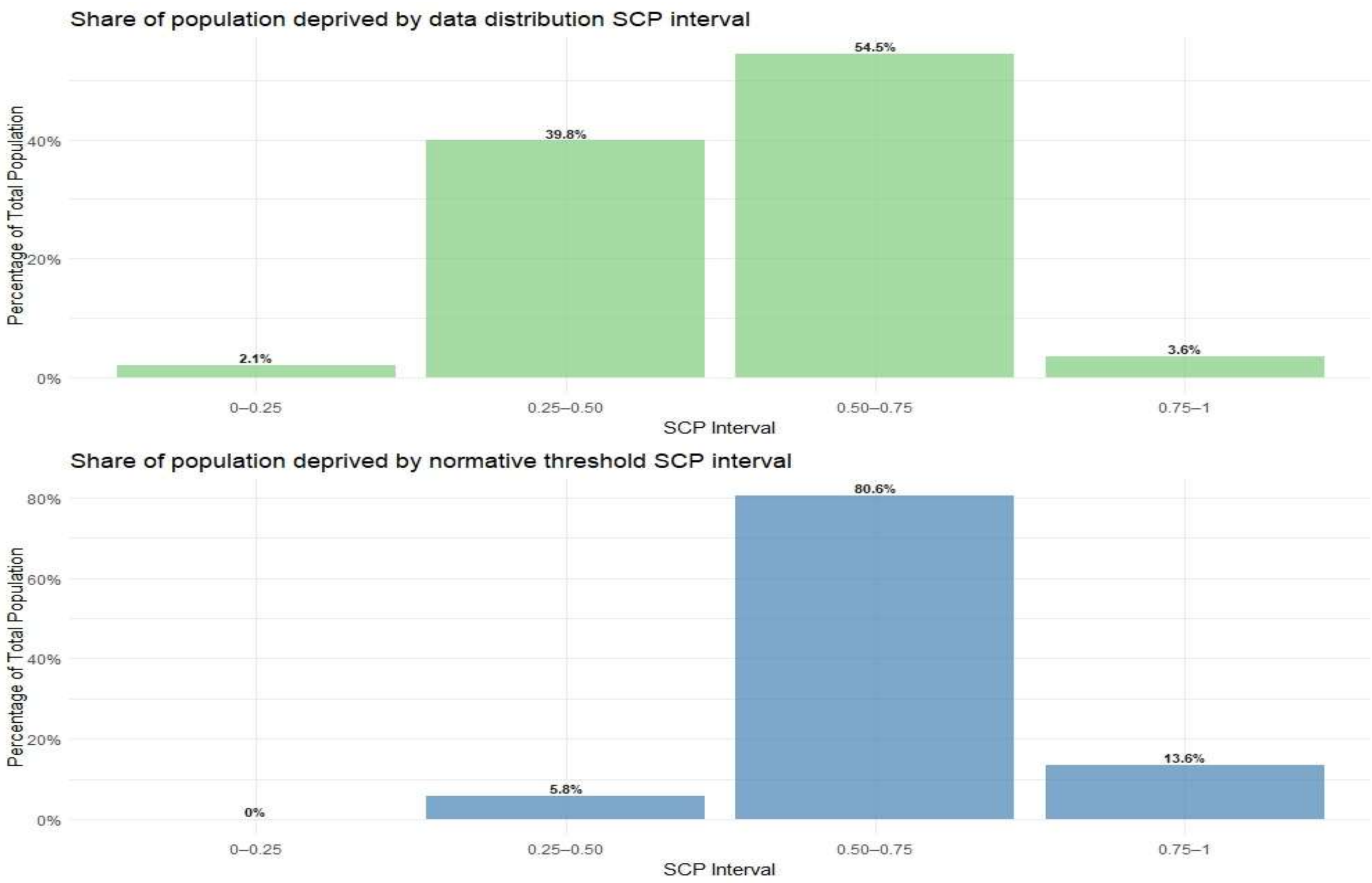


Figure 9 - Share of population deprived with respect to the Systemic Cooling Poverty Index, in the upper histogram the results from the data distribution deprivation has been applied while below the results from the normative threshold approach can be observed

Figure 9 reports the share of population falling in each interval of SCP intensity with respect to both deprivation assignment methodologies. In both SCP calculations the majority of the inhabitants suffer from medium to high deprivation in adaptive capacity to heat (0.5-0.75), in particular 54.5% of the citizens according to data distribution approach and 80.6% to the normative threshold procedure. In both cases the minor fraction of populations suffers low to medium (0-0.25) vulnerability level, having 0% of the population falling in this interval following the second procedure and 2.1% of the inhabitants showing the same deprivation level according to the data distribution procedure. For what concerns the data distribution method, the second largest fraction for the share of population (39.8%) presents a low to medium Systemic Cooling Poverty, while 3.6% of the citizens present the highest vulnerability to heat (0.75-1).

On the other hand, according to the normative threshold approach, 13.6% of the citizens fall in the most critical interval (0.75-1), while 5.8% of the population presents a low to medium (0.25-0.5) Systemic Cooling Poverty intensity.

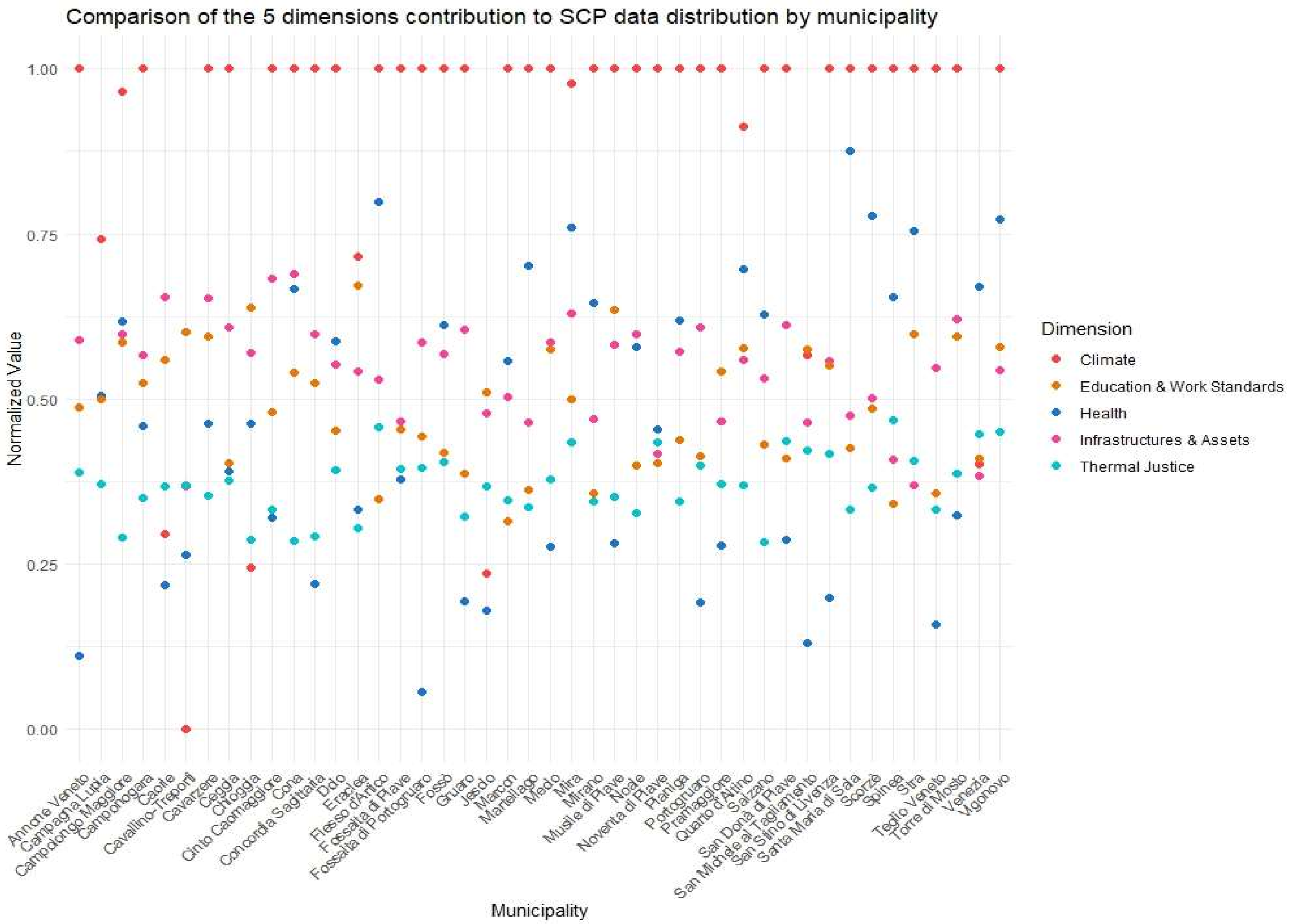


Figure 10 - Contribution of each dimension of the index to the deprivation level of SCP with respect to each municipality of the provincial area (data distribution approach).

Figure 10 highlights the average contribution of all five dimensions of the SCP Index implemented following the strategy based on data distribution. The climate dimension, for every municipality of the provincial area, is the largest contributor in terms of vulnerability. Just Cavallino-Treporti, Jesolo, Chioggia and Caorle, the municipalities located on the seaside, present a low exposure with respect to hot and humid climate. The second driver of fragility is preponderantly represented by the dimension relative to infrastructural conditions. The majority of municipalities, among which Cona, Cinto Caomaggiore, Cavarzare and Caorle show a value higher than 0.50 in the lack of access to adequate infrastructures. Health is one other great contributor in shaping the vulnerability to hot temperatures: municipalities like Santa Maria di Sala, Fiesso d'Artico, Mira, Scorzè and Vigonovo are the first five municipalities for increased vulnerability with respect to health conditions of the population and health care services provided. Education and Work standards show particularly high poverty values in the cases of Chioggia, Eraclea and Musile di Piave municipalities. Thermal Justice is the dimension, after Climate, showing the most even distribution across municipalities with values ranging from 0.25 to 0.5, showing the most critical values across the municipalities of Spinea, Fiesso d'Artico and Vigonovo.

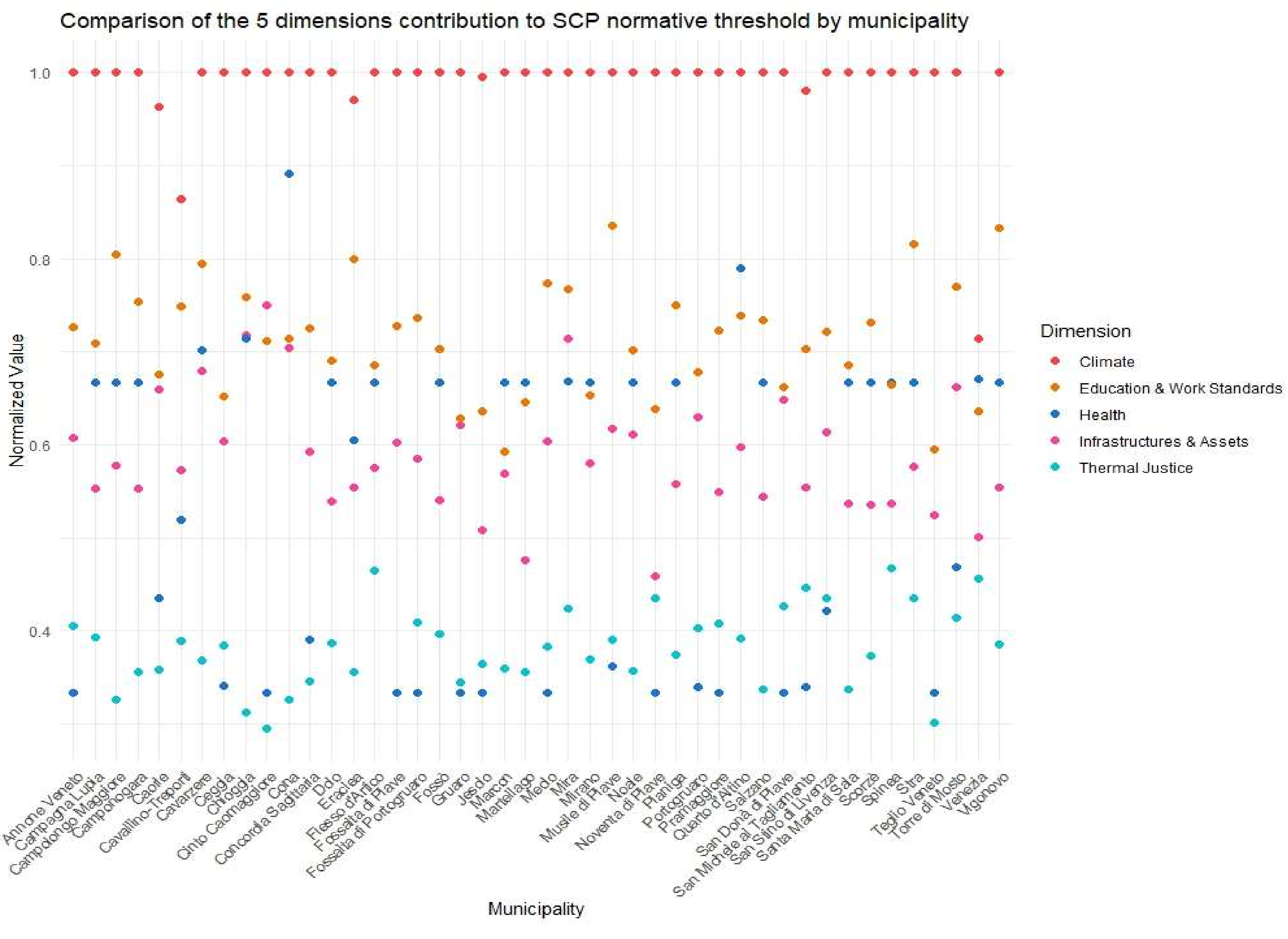


Figure 11 - Contribution of each dimension of the index to the deprivation level of SCP with respect to each municipality of the provincial area (normative threshold approach).

On the other side, Figure 11, depicts the contribution of each dimension of the Systemic Cooling Poverty Index according to the normative threshold distribution across all municipalities of Venice. As in the previous case, the climatic component is the most uniform one in enhancing the municipalities' vulnerability to prolonged heat with Venezia, Cavallino-Treporti, Caorle and San Michele al Tagliamento showing the lowest exposure.

Education and Work standards show a higher potential in shaping cooling poverty with respect to the data distribution approach: the municipalities presenting a greater disadvantage with respect to this dimension are represented by Vigonovo, Musile di Piave, Stra and Campolongo Maggiore. The Health dimension varies widely across municipalities, showing a greater lack of adequate health care services and health conditions of the populations in Cona, Quarto d'Altino and Chioggia. In the case of the normative threshold approach, the Thermal Justice dimension is the one contributing the least in shaping the Systemic Cooling Poverty across the municipalities. The ones that are found to be more disadvantaged with regard to this dimension are Fiesso d'Artico, Spinea and Venezia.

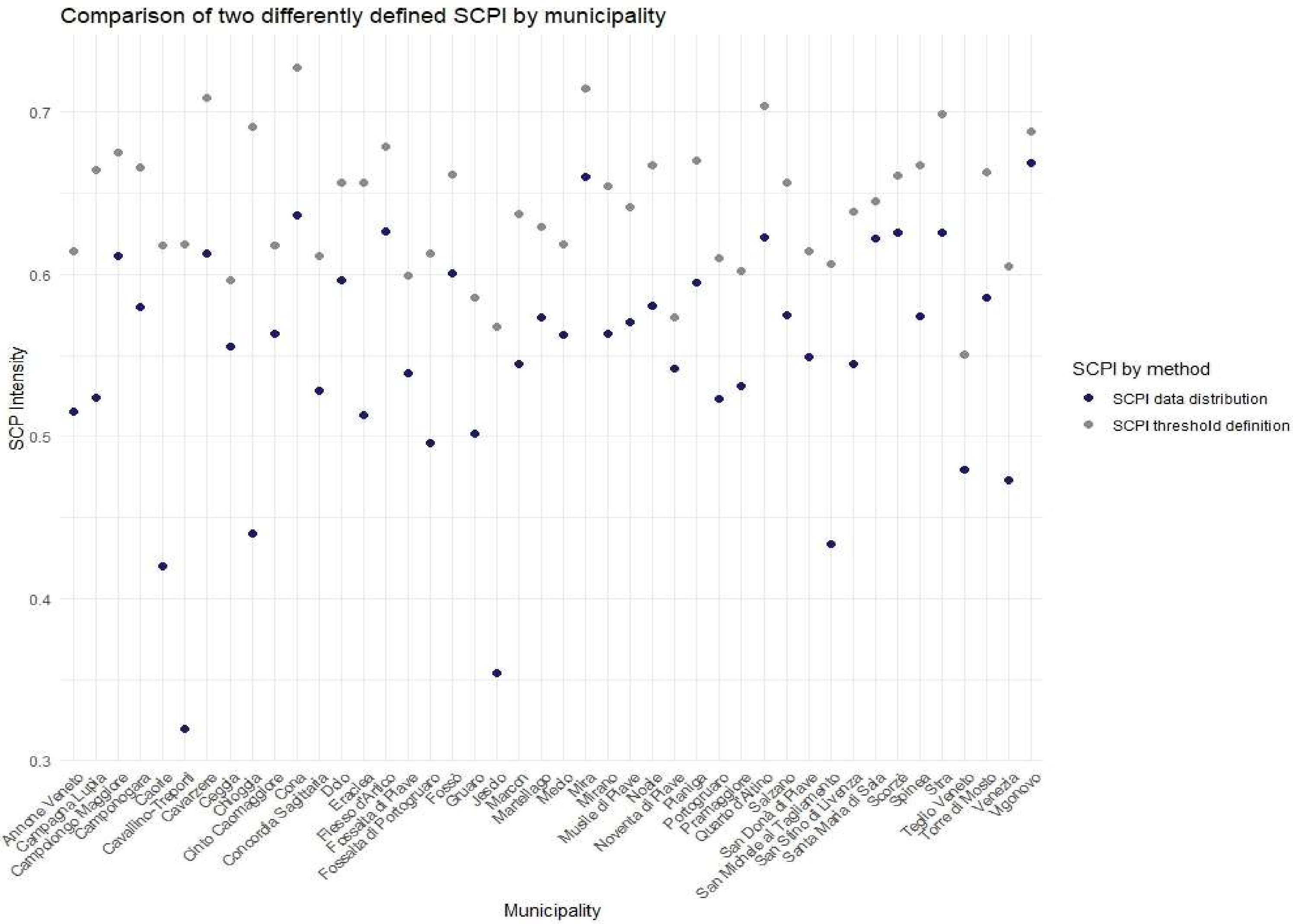


Figure 12 - Average Systemic Cooling Poverty level with respect to every municipality of the provincial area following both data distribution and normative threshold procedures.

In Figure 12 the two Systemic Cooling Poverty values that have been computed following the two deprivation assignment strategies are displayed for each municipality across the Venetian territory. In the majority of cases, the normative threshold index shows a more severe intensity of cooling poverty. The municipalities presenting a low adaptive capacity to hot weather based on the normative threshold deprivation assignment are Cona, Mira and Cavarzare, while the least deprived are Teglio Veneto, Jesolo and Noventa di Piave. According to the data distribution strategy, instead, the municipalities that show a higher cooling poverty value are Vigonovo, Mira and Cona, while the less disadvantaged are Cavallino Treporti, Jesolo and Caorle. It is possible to note that the two SCP index generally follow a similar trend across municipalities, showing very similar values in the cases of Vigonovo, Scorzè and Santa Maria di Sala and a great variation in some other cases (e.g. Cavallino-Treporti, Jesolo, Caorle).

Moreover, as outlined in Figure 13, the two indices present a strong positive correlation according to Pearsons' coefficient (R), supporting the choice of the normative thresholds' method defined in the workflow (section 2.2.2). Concluding, as reported in Annex 14, the statistics deriving from the application of a linear regression model further underline a significant positive linear correlation between the two SCP indices.

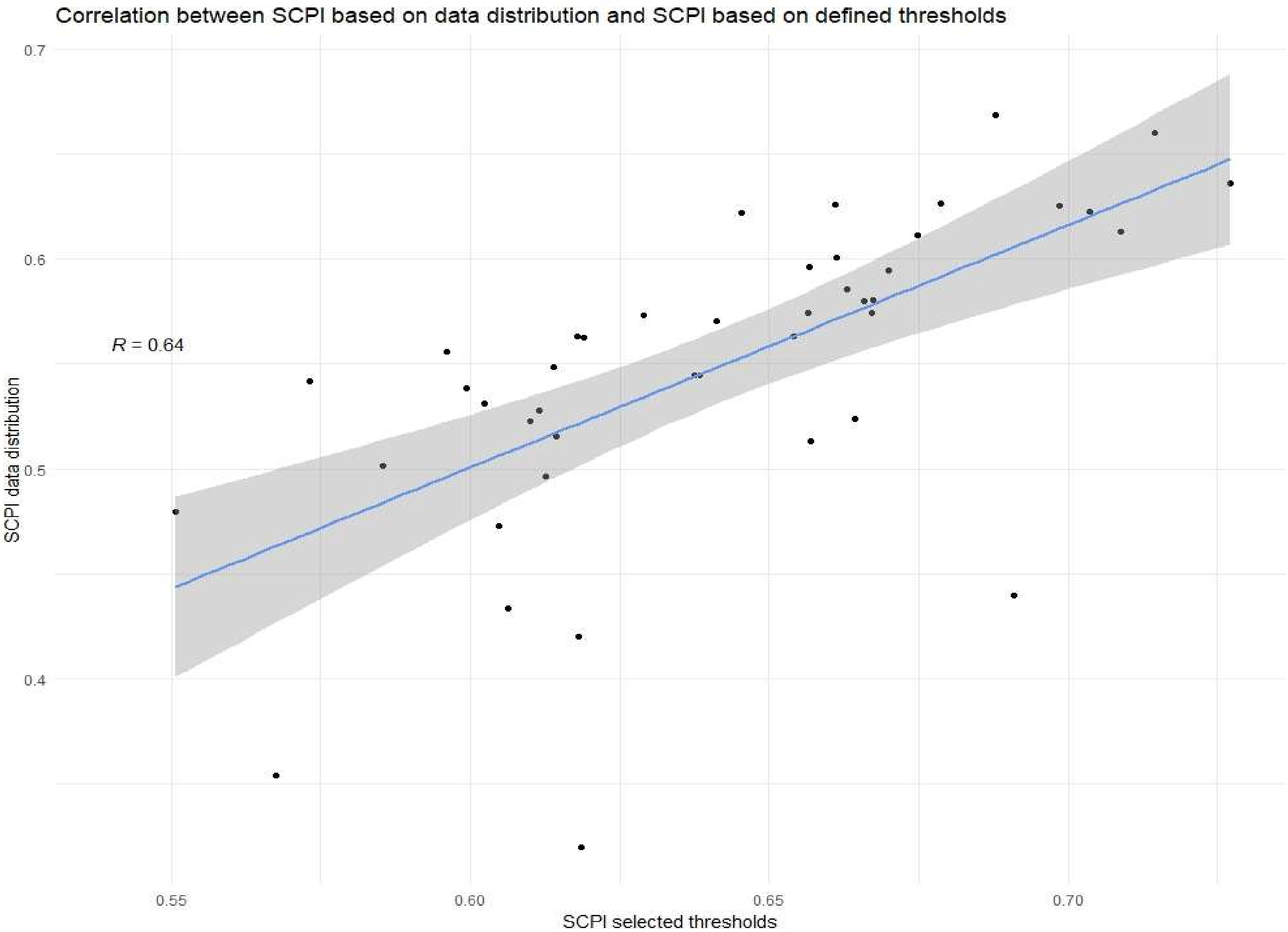


Figure 13 - Linear correlation plot of the two implementation strategies of the Systemic Cooling Poverty Index.

4 Discussion

The application of the Systemic Cooling Poverty Index on the Venetian territory reveals an heterogeneous picture with regard to the population's ability to deal with extreme temperatures. The analysis evidence how the climate injustice issue driven by each dimension of the indicator is relevant with respect to adaptive capacity to elevated heat. Comprehensively, the image emerging from the implementation of the framework highlights some critical geographical areas struggling to reach thermal comfort in conditions of persistent heat due to the combined action of multiple factors here identified. In this framework, advancements should be made in a policy implementation perspective aimed at tackling the emerging risks posed by intensified and prolonged heat.

In particular, according to the normative threshold methodology, the greatest majority of the inhabitants (80.6%) are found to be significantly exposed to hot and humid climatic conditions. Moreover, it is important to note that while the climate stressor has an important contribution to the enhancement of thermal discomfort, whose intensity is affecting almost all 7889 census tracts in the provincial territory, the adaptation measures disposable to the population living in the census tract are unequally distributed. Indeed, it is relevant to focus on the areas that lack access to invisible and tangible infrastructures, rendering it possible for the citizens to better cope with hot temperatures and chronic humidity in a future perspective.

The normative threshold methodology highlighted that around 30% of the population is suffering a medium to elevated lack of adequate infrastructures on the territory. The areas presenting an elevated level of deprivation to physical infrastructures are spread over San Stino di Livenza and Chioggia. More specifically, the indicators revealing an alarming picture are the ones representative of public transport availability and the extension of green spaces. According to the literature, widely available green spaces would act as resilience-enhancing strategies, thanks to shading and evapotranspiration, alleviating heat perception of heat and reducing outdoor temperatures, promoting psychological inhabitants' wellbeing. Also, means of public transport are one other crucial aspect when considering heat adaptation measures, since households not owning private motorized transport need to rely on public services. In this perspective, the majority of census tracts do not present sufficient access to public transportation in rural and marginal areas. The combination of both factors can lead marginalized and vulnerable communities to face further challenges and segregation issues. Moreover, it is significant to consider that increased access to public transport represents a crucial way to reach cool places during the hot summer season. Venice historical center is to be considered a particular case, in this framework, since it presents elevated residential energy requirements due to the diffuse and prevalent presence of historical buildings and just a few green areas opened to the public. Given this context, the creation of accessible green spaces acting as a passive cooling strategy could be considered as a consolidated strategy offering powerful adaptation options to households suffering from systemic exposure to high temperatures. In particular, green and blue spaces can provide multifold ecosystem services, representing a pivotal role in shaping citizens' exposure to heat. Green infrastructures act as physical barriers, downscaling the effect of hot temperatures. Indeed, green urban spaces are proved to decrease energy consumption during summer months, hence representing an interesting measure in the case of Venice, being covered preponderantly by energy-intensive historical buildings, as a turning point in tackling energy peaks induced by intense air conditioning use. More than that, both strategies, developing the public transportation network and implementing green spaces over the territory, would represent a further chance to mitigate otherwise energy intense behaviors. Favoring public transport instead of privately owned motorized transport and the use of green spaces as passive cooling strategies would both reduce the population's energy requirements and hence greenhouse gas emissions, thus reinforcing a virtuous circle in the climate justice perspective. Another infrastructural advancement that has been recently tested with positive results across European countries is that of climate shelters, also called cooling centers. These centers are being employed as freely accessible public spaces where citizens can find cool spaces and where socio-cultural activities are promoted. In this way green gentrification and urban segregation could be alleviated and heat adaptive capacity could be enhanced.

For what concerns the dimension related to Thermal justice, the presence of factors producing social disadvantages over the territory is heterogeneous. Clusters evidencing high social vulnerability are presented, for the normative threshold approach, in the rural areas surrounding Portogruaro, San Stino di Livenza and Favaro Veneto. Following the same methodology, more than half of the citizens suffer a low to medium vulnerability level, while 30% of the inhabitants show a medium to high rate of deprivation with respect to social conditions. Census tracts along which the deprivation is medium to high are to be considered of important interest in a governance perspective. The corroboration of social services directed towards the management and inclusion of vulnerable groups should be further encouraged across hotspots in the Provincial territory. Elevated concentration of elderly people across municipalities should be managed through the implementation of basic services to guarantee their inclusion and access to basic needs and care services. The diffused presence of foreigners should be also considered and treated by increasing integration activities and preventing them to face lack of basic utilities and needs. Children should also be considered as a vulnerable group with respect to the threat posed by extreme temperatures even if they do not represent the majority of the population, due to the general aging trend the population in Italy is dealing with in the last decades. Where the concentration of this group is observed, the services devoted to addressing children's needs should be strengthened, also taking into account the needs of parents. Also, in this case, climate shelters, empowered by a consolidated network of public transportations, tailored to the necessities of the inhabitants, could be considered a powerful strategy for reducing social isolation and preventing segregation. Social and cultural events proposed in cooling centers could build the bases for the incrementation of social capital and to increase the sense of community and cohesion among the local population.

With regard to the Health dimension of the Systemic Cooling Poverty Index the situation presented in the Venice provincial area is differentiated across the two official health assistance units, one located in the northern area and the other in the southern region of the territory. The northern area presents a more uniform and a lower intensity in decreased health conditions of the citizens and with regard to their access to health care services. Following the normative threshold approach, the conditions of disadvantage are rendered more intense due to distance from nearest health care facilities by the census tracts located in the areas of Bibione and San Stino di Livenza. The southern region instead shows a more critical image, in particular in certain areas surrounding Sant'Anna, Cavarzere and Favaro Veneto. More importantly, 73.8% of the citizens experience a medium to high lack of access to adequate medical services and to good health conditions. For this dimension, the anomalously elevated concentration of NO_2 over the region renders the living conditions harmful to the local population. Air pollution is a contributing factor in mining the population's health conditions: the area presenting greater nitrogen dioxide levels, where the petrochemical factories are located, show higher mortality rates induced by non-communicable diseases. The rise of this environmental justice issue, which is shaping the inhabithant's resilience to heat, is to be shed light on to and to be addressed with urgence. The other crucial factor that should be considered is the operationalization of further emergency health units for the census tracts located more than 8 minutes away from the nearest health care facility (e.g. Murano and Mazzorbo islands). This enactment would enable emergency units to reach people needing urgent health care in overcoming the otherwise possible risks arising from injuries needing to be treated with immediate action. Within this framework, setting up an emergency number for health assistance in cases of heat waves hitting the Province could provide benefits to the local population and render them less vulnerable to heat-health risks. There already exists a national emergency number for the prevention of heat risks on the population, “Proteggiamoci dal caldo: 1500”, but it is not available on the weekend and cannot provide local and direct support to the citizens. Another policy implementation strategy that can help manage the impacts of heatwaves over the population is to introduce the figure of urban heat relief workers. During extreme heat events, heatwave relief volunteers assist vulnerable populations distributing water and providing first aid to the fragile population (e.g. homeless people, elders, people with disabilities…).

With respect to the dimension devoted to map educational attainment insufficiency and unemployment rate of inhabitants across census tracts, the normative threshold strategy underlined a severe condition across the majority of the territory. Less urbanized areas are the ones presenting the more fragile places, fueling people’s vulnerability to high temperatures. An important percentage of inhabitants (40.1%) show a persistent lack with respect to education and work standards. In this perspective it would be relevant to understand which are the drivers of decreased educational attainment across the Province: it would be crucial to map which are the main factors influencing early school leaving and consequently implement actions aimed at reducing it. Moreover, another important phenomenon to be studied would be that of unemployment: the causes could be also lying in undeclared or informal ways of working or to be researched in other systemic lifestyle conditions affecting the ability to work of the citizens. With respect to the concerned dimension of Systemic Cooling Poverty multiple strategies could be implemented across the area, even though it remains crucial to understand the reasons why the condition related to knowledge and work represent a diffused critical picture. More specifically, early warning systems could be made more accessible to the inhabitants. Since 2004, Italy has implemented its Heat Health Watch Warning System, providing information about extreme heat to regional capital cities and for urban areas having a population exceeding 250.000 inhabitants. Nevertheless, smaller urban areas and the rural fraction of the population are still excluded by the notification of extreme events’ forecast and warning systems. Rendering these means of information more accessible to the inhabitants would play a pivotal role in enhancing the resilience of people. One additional measure that could render the inhabitants less exposed to periods of extreme heat and humidity is creating cultural opportunities for increasing the awareness of the population to avoid climate change's adverse impacts on human health.

More comprehensively, the picture emerging from the analysis evidences a diffused level of scarce adaptive capacity over the territory, with some of the municipalities being more fragile, as in the cases of Cona, Mira and Cavarzare. Indeed, according to the normative threshold method, 80.6% of the citizens suffer medium to high cooling poverty levels and 13.6% of the population shows severe deprivation conditions. These results evidence that almost every inhabitant of the territory (94.2%) lives in a medium to severe cooling poverty situation. As cooling poverty grows where insufficient systemic conditions are rooted over territories, it remains crucial to adopt a comprehensive responsive procedure with the aim of fostering long-term adaptation strategies. Far-sighted and dynamic strategies creating space for the inclusion of vulnerable people, adopting new policies for redesigning the geographical distribution of public spaces and to develop novel and technological strategies for facing growing temperatures are at the heart of building community resilience to extreme weather's adverse impacts.

Nevertheless, it has to be reported that several limitations have been identified during the Systemic Cooling Poverty Index implementation over the concerned territory. The first one emerged in the data collection phase. Social, cultural and economic indicators were not available at a more granular level than the census tracts' one. An analysis based on the study of Systemic Cooling Poverty at the household scale would have represented a more precise mapping of the issue through the Provincial area. Moreover, relevant information about the most vulnerable social groups were not available. Specifically, data regarding the concentration of people with disability or reduced mobility were not found. The same situation regarded homeless people and incarcerated citizens for whom it was not possible to retrieve data. These population groupings are already suffering amplified heat threats due to the conditions of fragility to which they are systematically exposed to.
Another limitation of the thesis work that could be addressed in future research is that this analysis is static and does not make future forecasts in predicting how the population's cooling poverty could evolve over time. Future calculation of Systemic Cooling Poverty and climate change variation could represent a further advancement in tracking how people's adaptation to heat could change over future years. In this context, it would be interesting to understand if each systemic dimension's contribution would change in the future and in which way.

A third limitation has been identified in conducting the study: the history of the policy strategies adopted at the national, regional and local level would have required an ulterior effort to identify current gaps across governance strategies. The policy analysis could produce a concrete complementary instrument to the empirical analysis provided here. Once the heat adaptive capacity of the population is mapped and the regional and local political strategies have been identified, the greater deficiencies contributing to decreasing the inhabitants' resilience could be revealed, thus creating a fertile path to propose concrete solutions to address systemic conditions exacerbating extreme and humid heat stress. A diffused exploration of the literature could provide further advancements in the recognition of effective and novel cooling strategies for the eventual local application of the same measures.

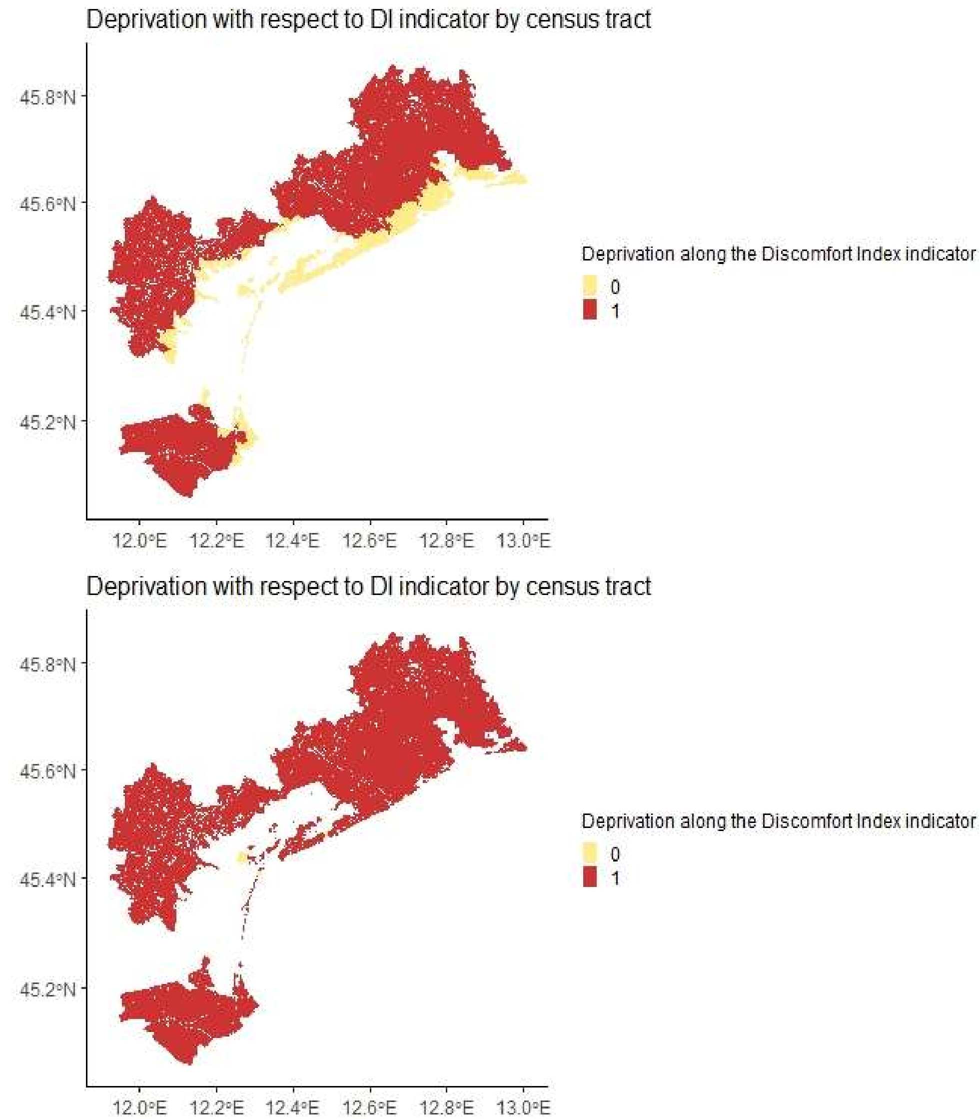
5 Conclusions

This thesis aims to map the areas of Venice provincial territory where systemic characteristics of census tracts are undermining the population's adaptive capacity to intensified heat. In this context, different datasets have been explored, including socio-demographics information, climatological and infrastructural data. For this objective, a novel framework for measuring the multidimensional nature of cooling poverty across Venice has been implemented. The Systemic Cooling Poverty framework has been designed in order to identify the underlying conditions shaping heat vulnerability levels over regions. The SCP Index has the capacity to identify different contributors of cooling poverty and to map which are the areas, both geographical and political, where urgent action is needed to enhance the citizen's resilience against heat extremes.

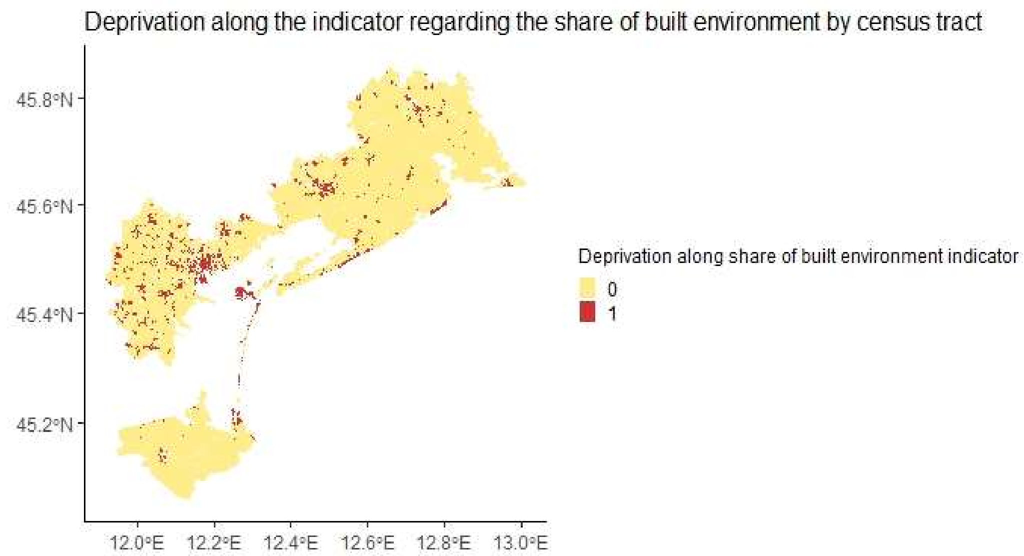
The computation of the Indicator has revealed a condition of intense cooling poverty across the population; the majority of the inhabitants suffers from medium to high deprivation in adaptive capacity to heat (80.6%), while 13.6% of the population is suffering severe deprivation. The sum of the two groups of population falling in the two intervals of SCPI with an elevated deprivation level with respect to tangible and intangible means of protection from hot temperatures represent 94.2% of the population. Specific municipalities of the Province like Cona, Mira and Cavarzare show persistent inability to tackle heat stress. Exception made for the dimension concerning climatic conditions that plays a crucial role in the Index computation due to the severity of heat and humidity over the concerned area; the more critical dimensions of the Indicator contributing to the decrease the adaptive capacity to extreme heat across the Province are represented by Education and work standards and by Health. More specifically, the concentration of people with low educational attainments and unemployed inhabitants over census tracts shows a critical image over the region that needs to be addressed urgently from local decision makers. The Health dimension, instead, is preponderantly influenced by the great scarcity of salutary air quality over the Provincial area, this can have an important role in facilitating the proliferation of non-communicable diseases. Furthermore, some internal areas or remote islands present difficulties in reaching health care facilities or emergency units in an adequate amount of time. After these dimensions, in order of criticality, the fourth one is represented from that related to physical infrastructures. In this case, the lack of a capillary and extended network of public transportation and reduced green infrastructures contribute to diminishing the resilience of the population with respect to elevated temperatures. Finally, the last dimension of the Index in terms of contribution to enhance people's fragility to hot and humid climatic conditions is that of Thermal justice. This dimension accounts for the concentration of particularly vulnerable groups of society and does not present a severely worrying picture over the Provincial region.

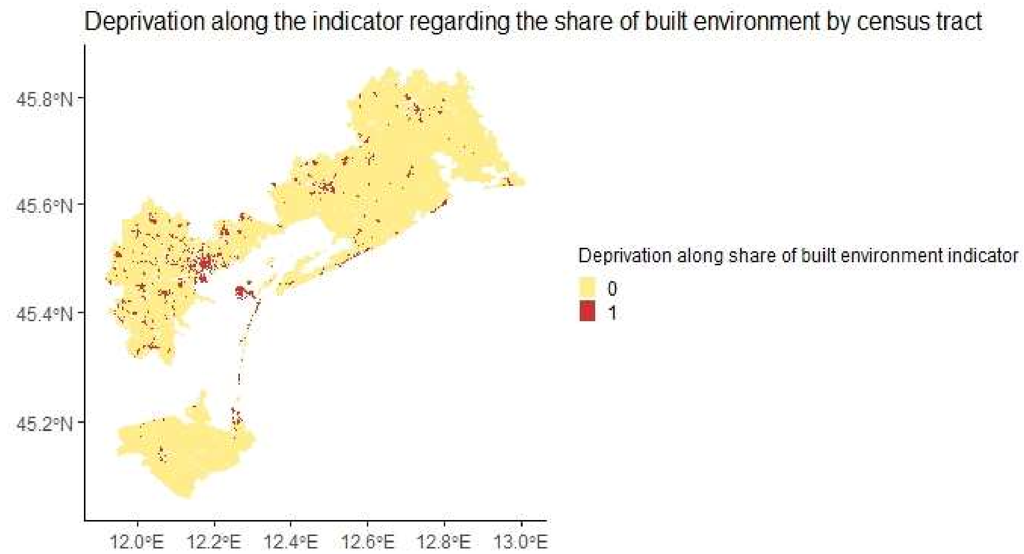
Concluding, even though some limitations have been encountered during the development of the thesis project, the final computation of the Indicator gives a diversified image over Venice's territory about its resilience against persistent heat. In this perspective, additional effort should be directed towards the implementation of multiple and systemic measures contributing to the enhancement of the citizens' adaptive capacity to tackle summer thermal discomfort. Cooling shelters, increased extension of green spaces, public services accessibility, as those devoted to health care and the ones dedicated to mobility, and increased social cohesion should be the objectives of the next policy implementation strategies over the Provincial area of Venice, in order to provide to the population solid basis on which to rely in cases of intensified heat and humidity.

ANNEX

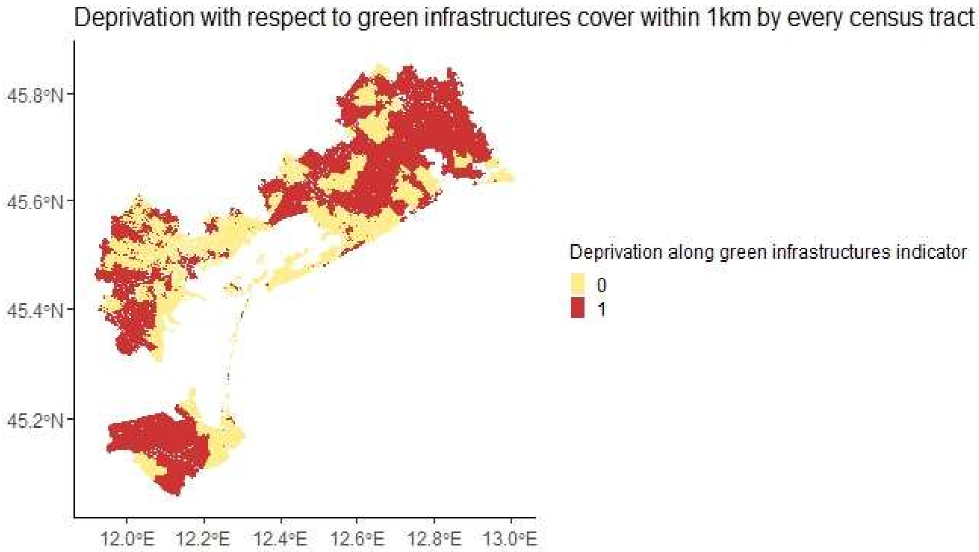


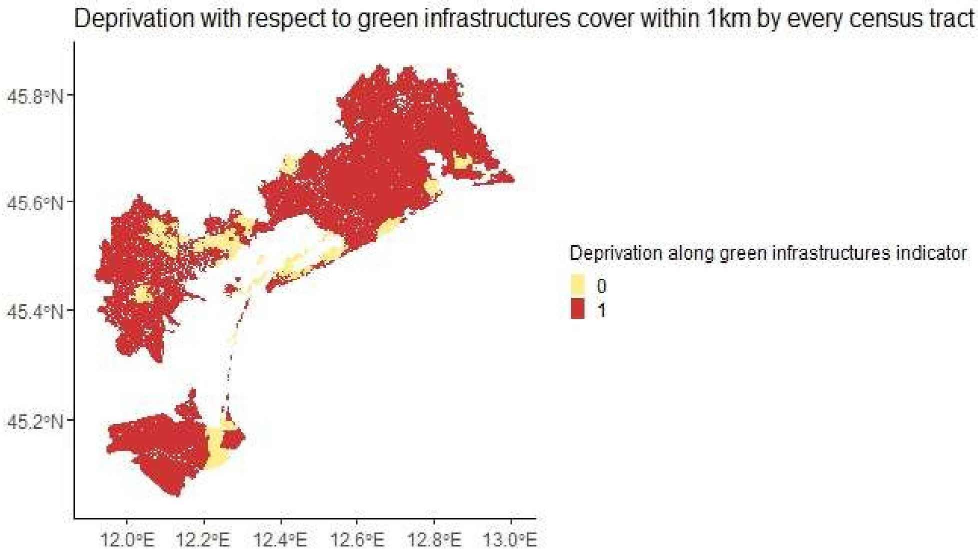
Annex 1 - On the top the data distribution deprivation along the Discomfort Index variable can be observed across the Provincial area; below the normative threshold deprivation along the Discomfort Index variable is displayed across the Province.



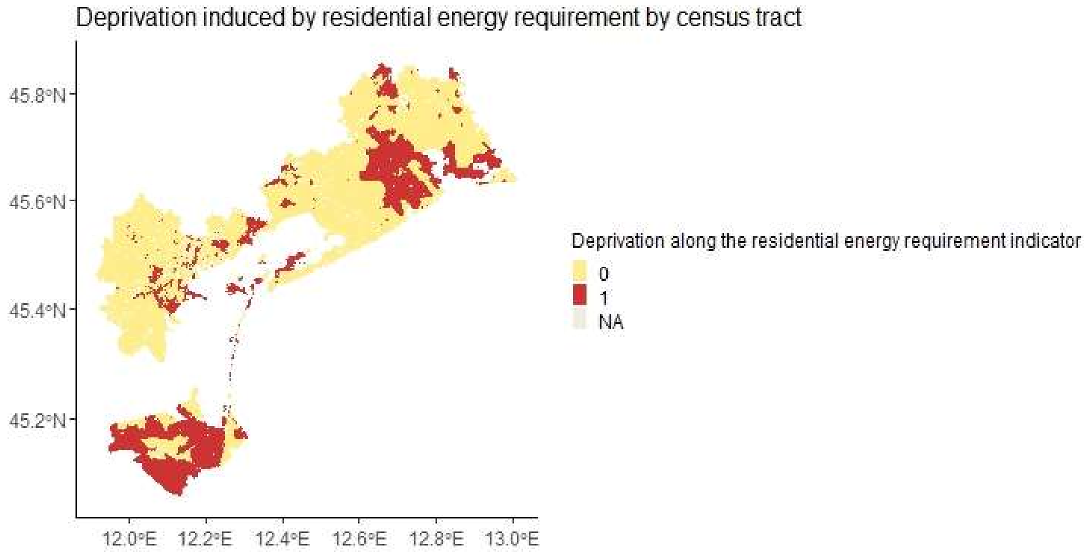


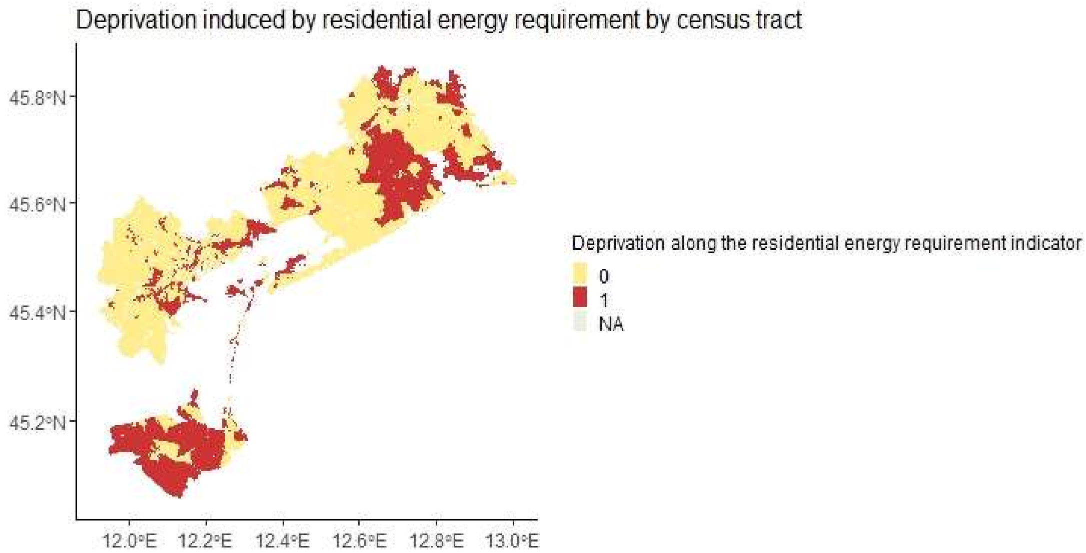
Annex 2 - On the top the data distribution deprivation along the share of built environment variable can be observed across the Provincial area; below the normative threshold deprivation along the share of built environment variable is displayed across the Province.



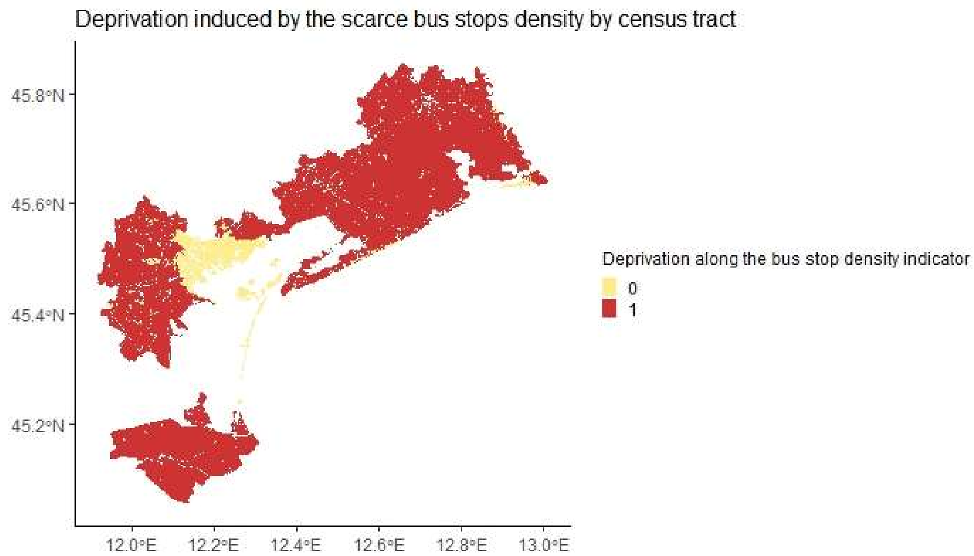


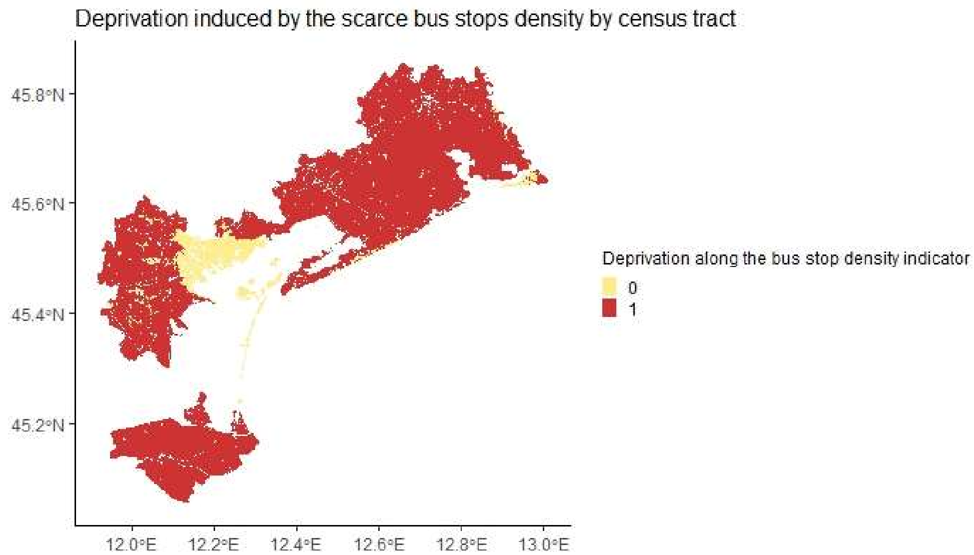
Annex 3 - On the top the data distribution deprivation along the share of green infrastructures variable can be observed across the Provincial area; below the normative threshold deprivation along the share of green infrastructures variable is displayed across the Province.



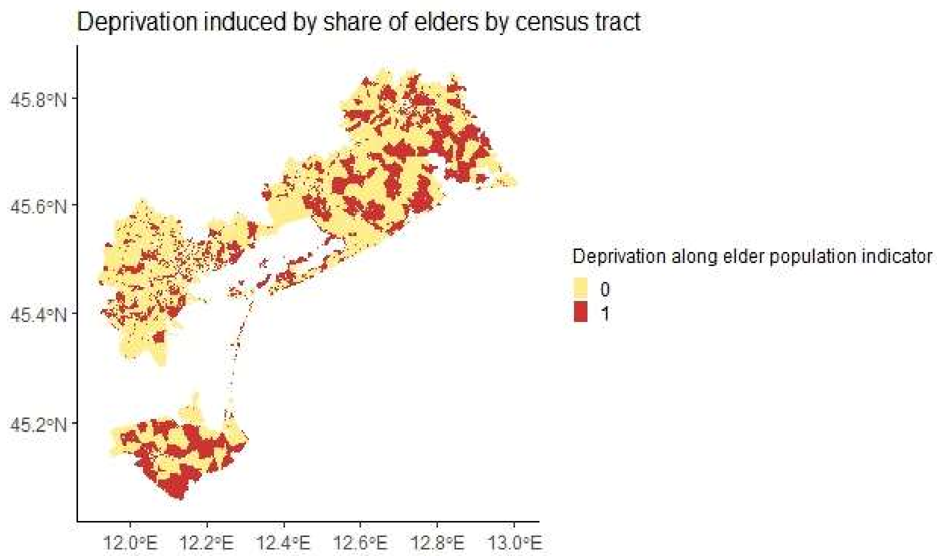


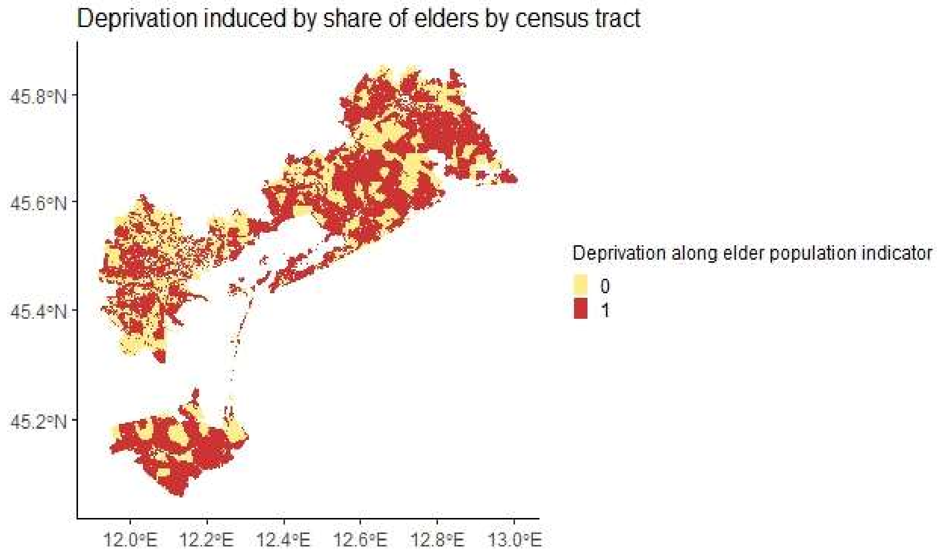
Annex 4 - On the top the data distribution deprivation along the residential energy intensity variable can be observed across the Provincial area; below the normative threshold deprivation along the residential energy intensity variable is displayed across the Province.



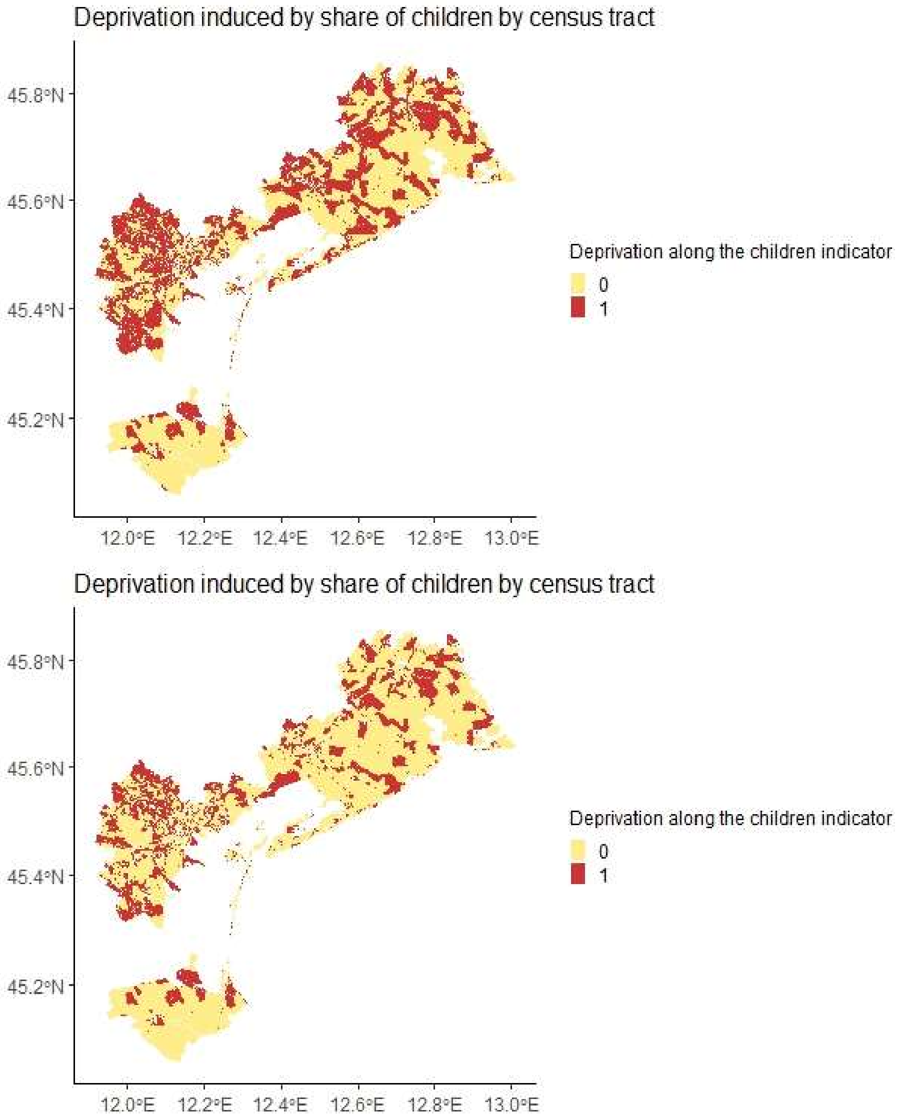


Annex 5 - On the top the data distribution deprivation along the bus stop spatial density variable can be observed across the Provincial area; below the normative threshold deprivation along the bus stop spatial density variable is displayed across the Province.

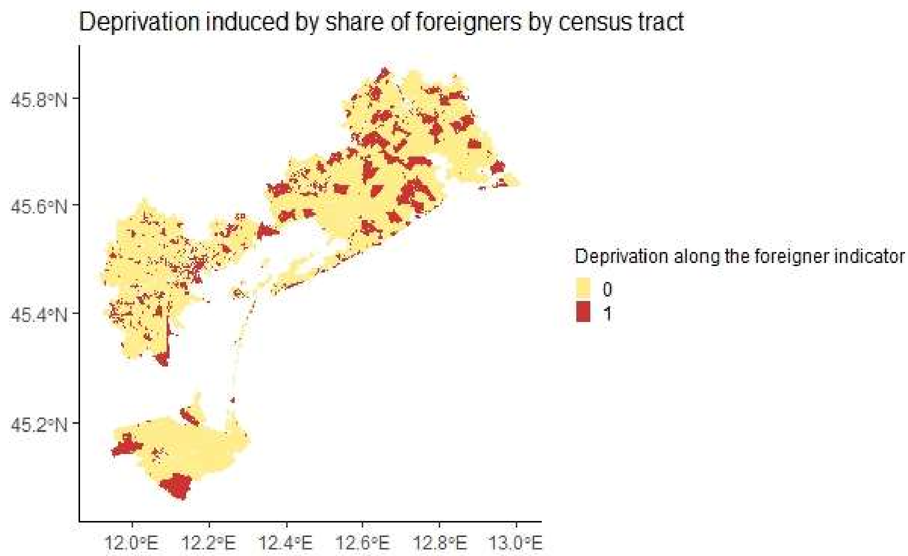


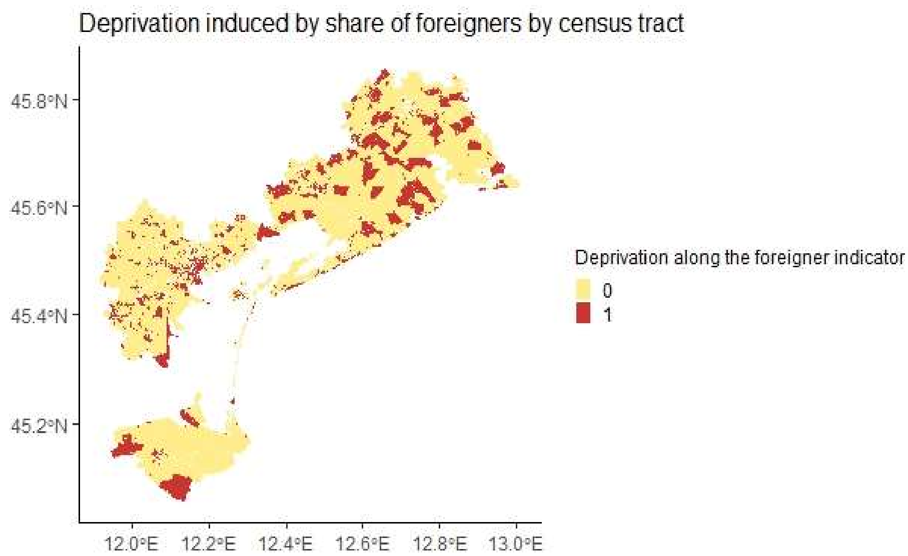


Annex 6 - On the top the data distribution deprivation along the share of elders variable can be observed across the Provincial area; below the normative threshold deprivation along the share of elders variable is displayed across the Province.

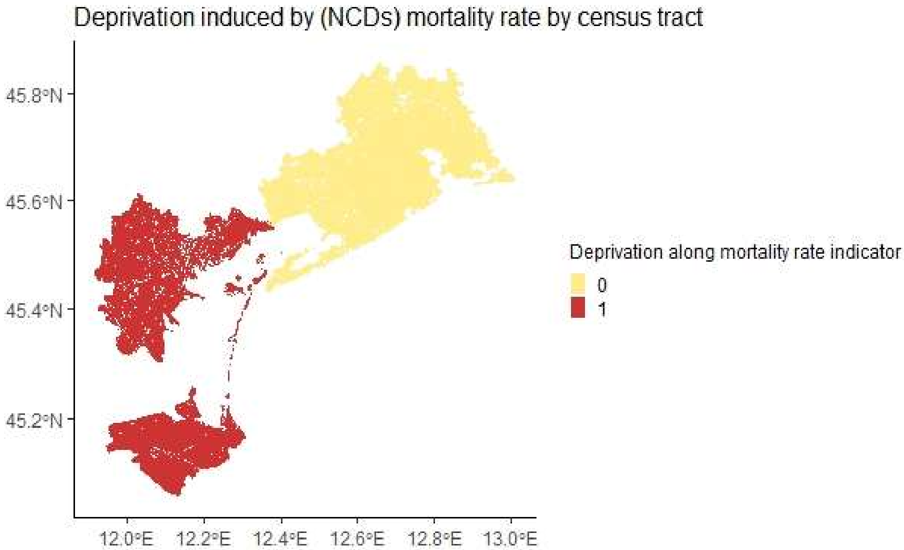


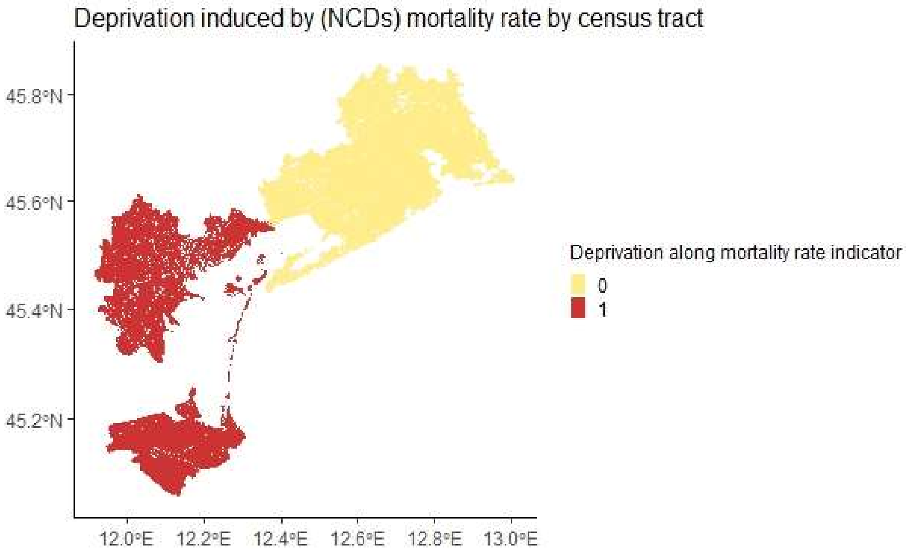
Annex 7 - On the top the data distribution deprivation along the share of children variable can be observed across the Provincial area; below the normative threshold deprivation along the share of children variable is displayed across the Province.



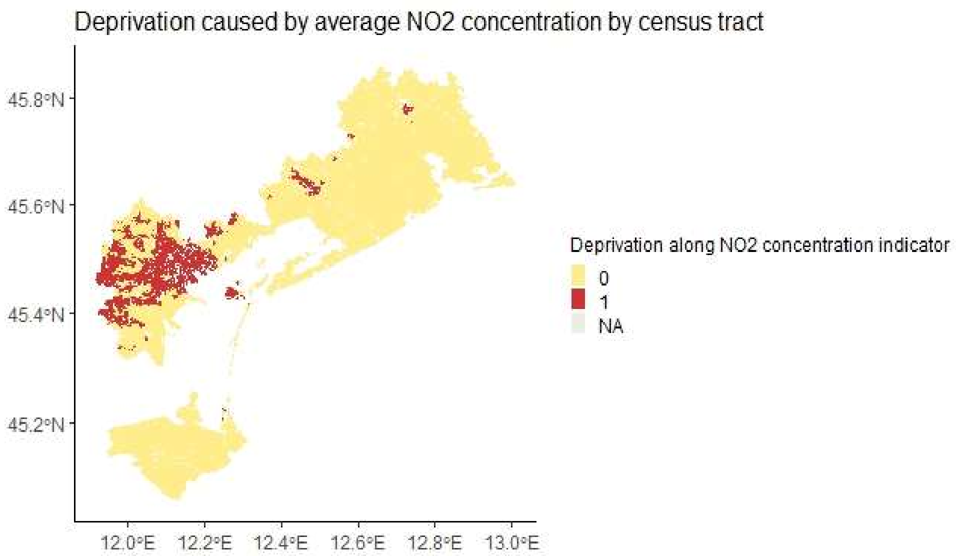


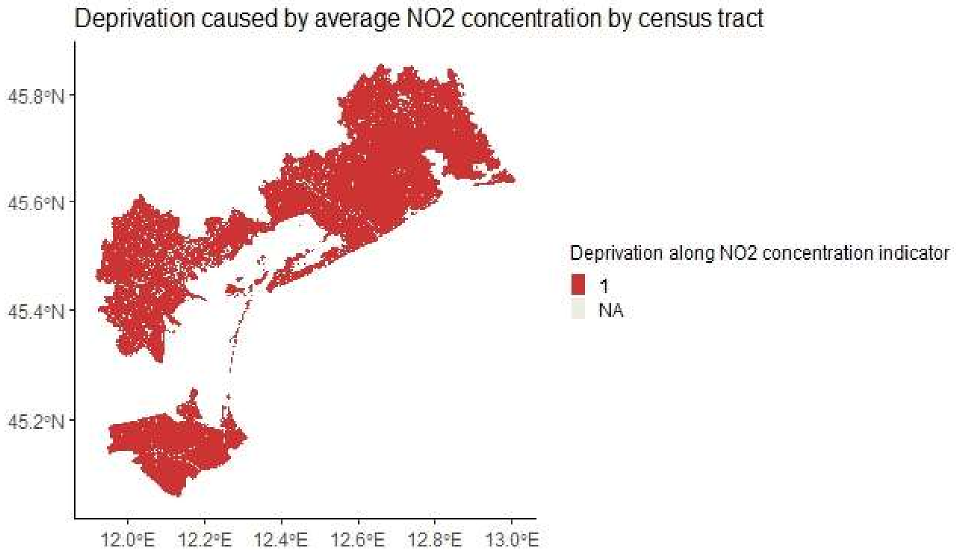
Annex 8 - On the top the data distribution deprivation along the share of foreigners variable can be observed across the Provincial area; below the normative threshold deprivation along the share of foreigners variable is displayed across the Province.



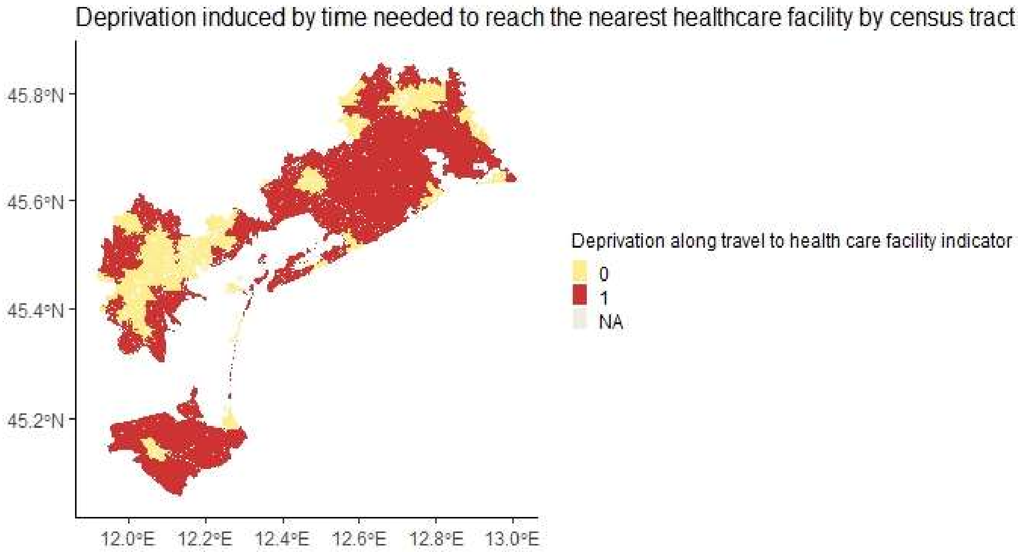


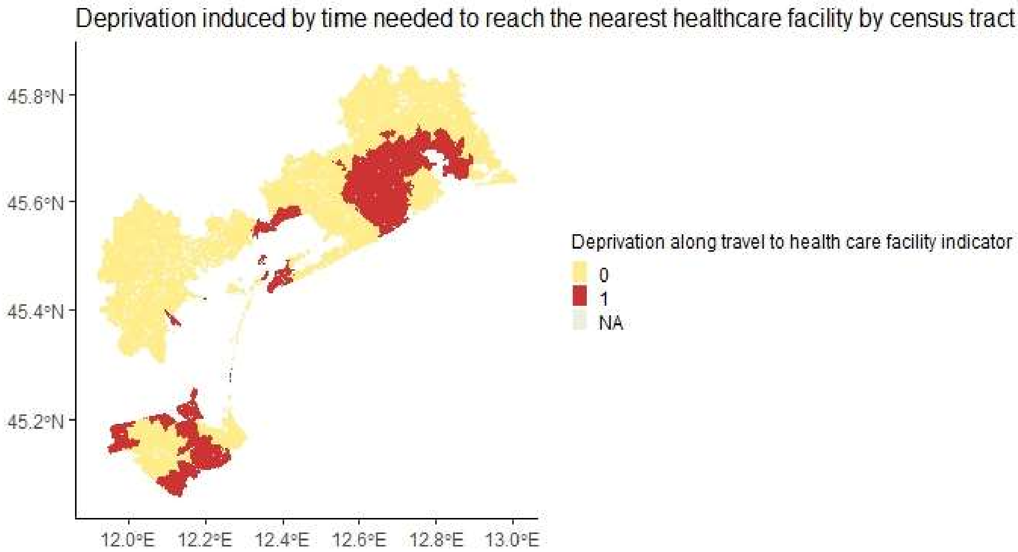
Annex 9 - On the top the data distribution deprivation along the mortality rate induced by NCDs variable can be observed across the Provincial area; below the normative threshold deprivation along the mortality rate induced by NCDs variable is displayed across the Province.



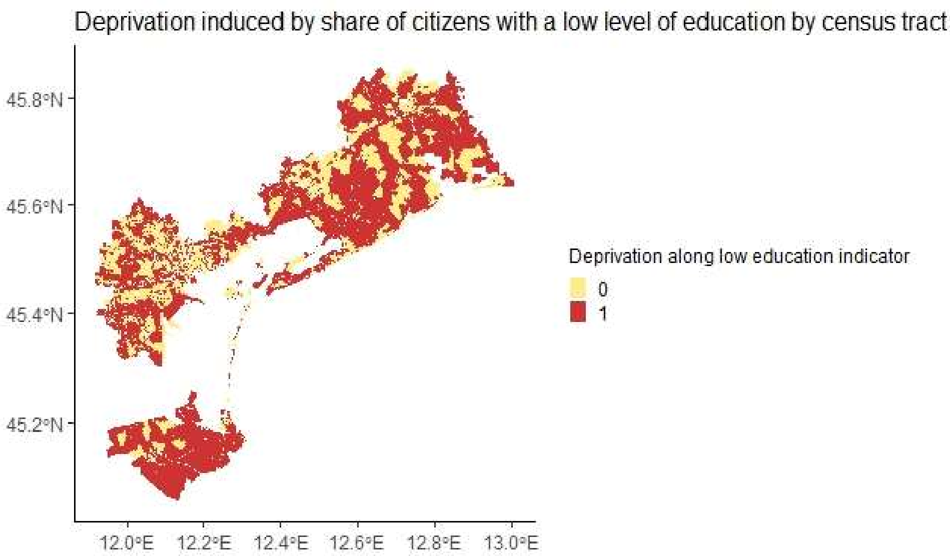


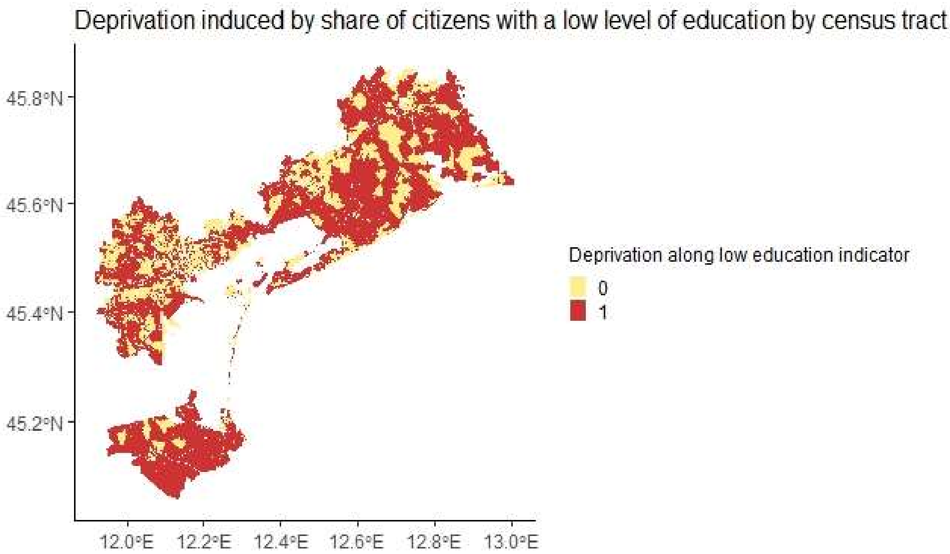
Annex 10 - On the top the data distribution deprivation along the NO_2 concentration variable can be observed across the Provincial area; below the normative threshold deprivation along the NO_2 concentration variable is displayed across the Province.



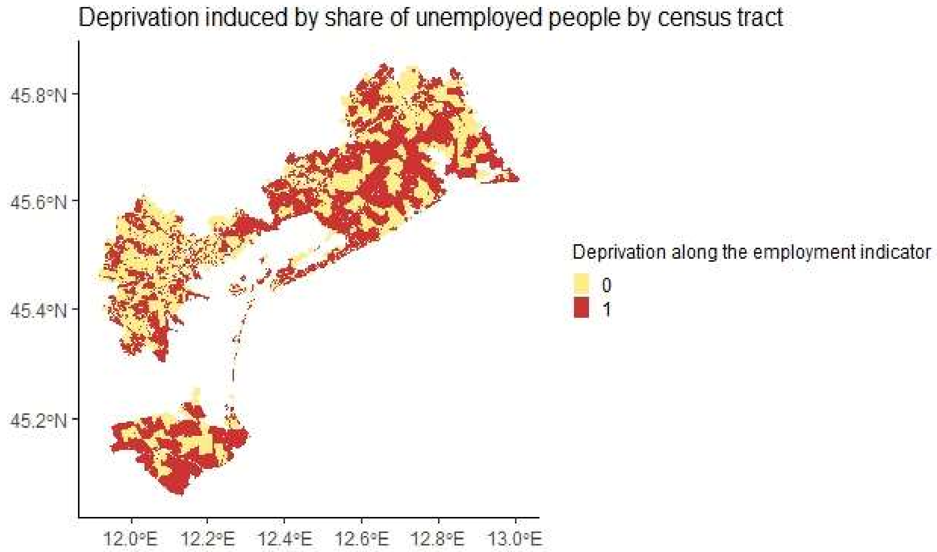


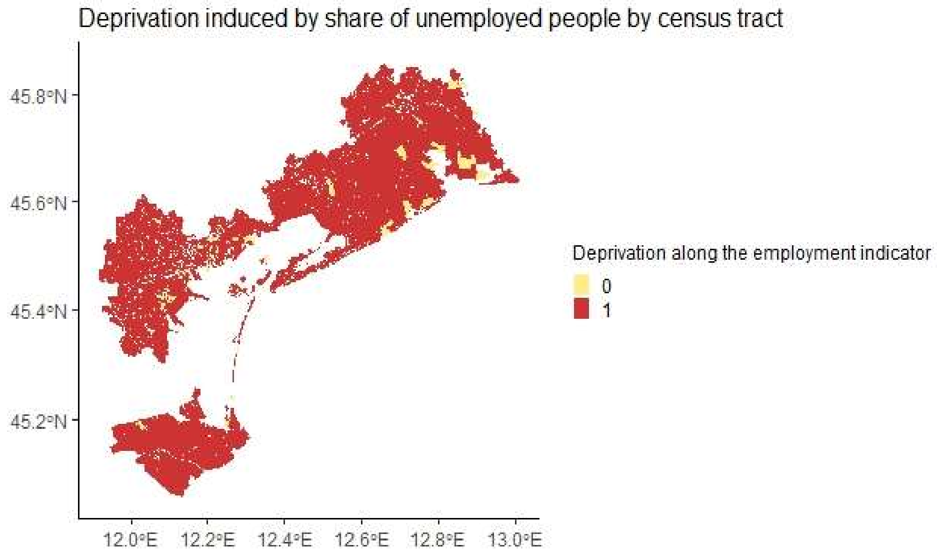
Annex 11 - On the top the data distribution deprivation along the travel to nearest health care facility variable can be observed across the Provincial area; below the normative threshold deprivation along the travel to nearest health care facility variable is displayed across the Province.





Annex 12 - On the top the data distribution deprivation along the share of people with low educational attainment variable can be observed across the Provincial area; below the normative threshold deprivation along the travel to share of people with low educational attainment variable is displayed across the Province.





Annex 13 - On the top the data distribution deprivation along the share of unemployed population variable can be observed across the Provincial area; below the normative threshold deprivation along the share of unemployed population variable is displayed across the Province.

	Dependent variable:
	SCP_mean_si
SCP_threshold	0.788***
	(0.012)
Constant	0.015**
	(0.007)
Observations	7,414
R^2	0.381
Adjusted R^2	0.381
Residual Std. Error	0.111 (df = 7412)
F Statistic	4,564.529*** (df = 1; 7412)
Note:	*p<0.1; **p<0.05; ***p<0.01

Annex 14 - Summary statistics of the linear regression model performed to test the linear correlation between the two Systemic Cooling Poverty indices (SCP threshold refers to the normative threshold approach, while SCP mean refers to the data distribution methodology).