DEPARTMENT OF
ENVIRONMENTAL SCIENCES AND
ENGINEERING

JOÃO PEDRO MACHADO BODIÃO
BSc in Biology

DWELLINGS ACCESS TO MOBILITY IN A GROWING ENERGY VULNERABLE REALITY

MASTER IN ENVIRONMENTAL ENGINEERING
SPECIALIZATION IN ENVIRONMENTAL SYSTEMS ENGINEERING

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To my mum and dad. Forever indebted to you.
("Today's" dinner's on me.)

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”

“

‘With the courage to begin and the discipline to endure, victory becomes a matter of time.’

(Unknown author, n.d.)

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Abstract

Modern-day societies, wherever they live, are struggling to cope with both energy demand and energy costs. Not helping, a global pandemic, followed by unexpected geopolitical events, sparked a global energy crisis. In this context, households were led to painful, sharp pressures on their energy bills and pushed into poverty realities. In this regard, international studies are emerging, intending to explore and expand the horizons of 'Energy Poverty (EP)' as a vulnerability while looking deeper into transport and mobility, acknowledging it as 'Transport Poverty (TP)'.

This research has as its primary objective to explore this dimension of vulnerability in access to transport/mobility in Europe, resorting to identifying and analysing relevant indicators for posterior comparison between European nations. These indicators follow one of four different contours: i) metrics that estimate travel time; ii) metrics for affordability of transportation for dwellings according to their household expenditures ceiling; iii) metrics of accessibility; and iv) metrics of availability to transportation as well as the conditions how these are provided. Furthermore, an assessment of the Portuguese perspective for increased insights at a more detailed spatial scale on this subject matter was also undertaken.

The current study has revealed that EP is a multifaceted phenomenon that is influenced by a range of social, economic, and environmental factors. Southern European and Balkan countries, more prone to EP manifestation, owing to their correlation with lower incomes and poorly insulated housing exhibit a higher prevalence of EP, which is comparatively lower among Scandinavian countries. Additionally, TP is a critical factor in understanding households' access to essential services, which has received less attention in the discourse on EP vulnerability studies. Households experiencing EP and TP (described as Double Energy Vulnerability (DEV)) face compounded difficulties in accessing essential services, increasing their vulnerability to poverty and social exclusion, particularly in peri-urban and rural areas. Despite having a significant share of energy-poor households, Portugal has made commendable progress in reducing the number of people unable to adequately warm their homes - one of the main constituents of EP in the country. However, Portuguese TP is a matter of concern, revealing a lack of investment in public transportation services

and public transport infrastructures that could potentially benefit those most in need.

In conclusion, this study illuminates the complexity of EP in Europe and Portugal and the critical role of TP in exacerbating these challenges. Significant strides can be made towards a more equitable and sustainable future by addressing EP and TP in tandem and considering the unique needs of different regions and demographic groups. Thus, while considering regional nuances and socioeconomic disparities, policymakers must adopt a holistic approach to addressing EP and TP, recognising the synergies between these two forms of poverty and developing integrated policies that alleviate the combined burdens they impose on vulnerable households, ensuring equitable access to essential services.

Keywords: Energy poverty, Transport poverty, Double energy vulnerability, Indicators, Portugal, Dwellings

Resumo

As sociedades modernas, independentemente do local onde se encontram, enfrentam dificuldades para lidar tanto com a procura como com os custos da energia. A desajudar, uma pandemia de proporções globais, seguida de eventos geopolíticos inesperados, desencadeou uma crise energética mundial. Neste contexto, os agregados familiares estão a enfrentar fortes pressões nas suas faturas de energia, o que os empurra para uma realidade de 'Pobreza Energética' (EP). Nesse sentido, estudos internacionais com o objetivo de explorar e alargar os horizontes da EP como uma vulnerabilidade, investigando a dinâmica dos transportes e da mobilidade neste contexto, começam a surgir. Para este efeito, tal dinâmica é reconhecida como 'Pobreza nos Transportes(TP)'.

Esta investigação tem como objetivo principal explorar esta dimensão da vulnerabilidade no acesso aos transportes/mobilidade na Europa, recorrendo à identificação e análise de indicadores relevantes para posterior comparação entre nações europeias. Esses indicadores regem-se segundo quatro abordagens distintas: i) métricas que estimam o tempo de deslocação; ii) métricas de acessibilidade aos transportes com base no limite de despesas do agregado familiar; iii) métricas de acessibilidade; e iv) métricas de disponibilidade de transportes, bem como as condições em que são fornecidos. Além disso, foi também realizada uma avaliação da perspectiva portuguesa para uma maior compreensão a uma escala espacial mais detalhada sobre este assunto.

O presente estudo revelou que a EP é um fenómeno multifacetado, e que é influenciado por uma série de factores sociais, económicos e ambientais. Os países do sul da Europa e dos Balcãs, mais propensos à manifestação de EP, devido à sua correlação com rendimentos mais baixos e habitações mal isoladas, apresentam uma prevalência mais elevada de EP, que é comparativamente mais baixa nos países escandinavos. Além disso, a TP é um factor crítico na compreensão do acesso dos agregados familiares a serviços essenciais, que tem recebido menos atenção em estudos de vulnerabilidade de EP. Os agregados familiares que vivem em EP e TP (situação descrita como 'Vulnerabilidade Energética Dupla (DEV)') enfrentam dificuldades acrescidas no acesso a serviços essenciais, aumentando a sua vulnerabilidade a situações de pobreza e exclusão social, particularmente nas zonas periurbanas e rurais. Apesar de ter uma percentagem significativa de agregados familiares em carência energética, Portugal registou progressos louváveis na redução do número de pessoas incapazes de aquecer adequadamente as suas casas. No entanto, a TP portuguesa é motivo de preocupação, por revelar uma possível falta de investimento em serviços de transporte público e infra-estruturas de transporte público que poderiam potencialmente beneficiar os mais necessitados.

Em conclusão, este estudo ilumina a complexidade da EP na Europa e em Portugal e o papel crítico da TP na exacerbação destes desafios. Ao abordar a EP e a TP em conjunto, e considerando as necessidades únicas de diferentes regiões e grupos demográficos, podem ser feitos avanços significativos em direcção a um futuro mais equitativo e sustentável. Assim, os decisores políticos, devem adoptar uma abordagem holística para abordar a EP e a TP, reconhecendo as sinergias entre estas duas formas de pobreza e desenvolvendo políticas integradas que aliviem os encargos combinados que impõem às famílias vulneráveis.

Palavras-chave: Pobreza energética, Pobreza de transporte, Vulnerabilidade energética dupla, Indicadores, Portugal, Habitações

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Acronyms

DEV	Double Energy Vulnerability
EC	European Commission
EP	Energy Poverty
EPAH	European Poverty Advisory Hub
EU	European Union
Eurostat	European Statistical Office
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HICP	Harmonised Index of Consumer Prices
IEA	International Energy Agency
INE	Portuguese National Institute of Statistics (*Instituto Nacional de Estatística*)
ktoe	Kilotonne of oil equivalent
LAU	Local Administrative Unit
LUFC	Land Use Change and Forestry
NUTS	Nomenclature of Territorial Units for Statistics
OECD	Organisation for Economic Co-operation and Development
PORDATA	Contemporary Portugal Database (*Base de dados de Portugal Contemporâneo*)
SDGs	Sustainable Development Goals

toe Tonne of oil equivalent
TP Transport Poverty

UN United Nations

WB The World Bank

1

Introduction

1.1 The Modern Global Status of the Energy and Transportation Industries

1.1.1 Energy

We have to face it. Modern-day societies, whether living in the Western or Eastern hemisphere, whether living in the North or South half of the globe, live in a growing energy-demanding world; in other words, the significance of rising energy prices increases as energy access becomes more valuable (Jiglau *et al.*, 2023), and the reality is that *we* are failing to keep up with it. For the past thirty years, efforts to reduce extreme poverty rates have succeeded and are in line with global goals to eradicate poverty by 2030 (World Bank, 2022a; Hasell *et al.*, 2022). Around 8/9% of the world's population lives in extreme poverty. According to the World Bank, individuals under extreme poverty live under $2.17 a day (World Bank, 2022b).

As we (try to) evolve as an unified humanity, whether in our societal relationships or as a functional world economy, we are much more interlinked than ever. Said statement was clearly put to the test with the outbreak of the COVID-19 pandemic which subjugated the world economy to improvise, adapt, and overcome said curveball. When things started to get 'back on track', due to unexpected geopolitical events occurring in East Europe, a global energy crisis sparked, having far-reaching implications for entire economies, in which households and businesses rely on.

In relation to the aforementioned events, living costs arose with energy prices being at the forefront of it. The aftermaths of this reality showed an inversion of the trends with the world's poorest mainly shouldering the steepest costs of it all, twice as high as the world's richest (World Bank, 2022b). In this context, households were led to painful sharp pressures on its energy bills, and forcefully pushed into poverty realities (IEA, 2022 World Bank, 2022b).

In addition and having both the *Paris Agreement* and the *European Green Deal* in mind, with their net-zero goals set to 2050, "*to combat climate change and to accelerate and intensify* *the actions and investments needed for a sustainable low carbon future*" (UNFCCC, n.d.), it is relevant that emissions from energy are brought up into the conversation of the present work.

To put matters into perspective, according to ClimateWatch, n.d.-a (see Figure 1.1) and further backed by the International Energy Agency (IEA, 2021), 75% of total global GHG emissions came from the energy sector alone.

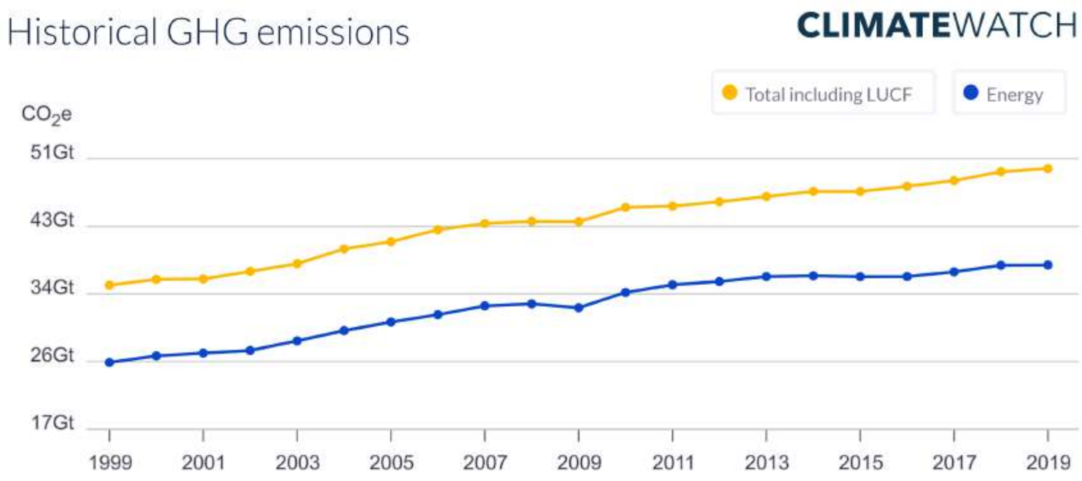


Figure 1.1: Historical global GHG emissions, since 1999. Yellow line represents total emissions including LUFC: 47.76 $GtCO_{2e}$ (2019); Blue line represents energy sector total emissions: 37.64 $GtCO_{2e}$ (2019). Retrieved from ClimateWatch, n.d.-b. Adapted.

From an European viewpoint regarding the total energy used in 2020, households assumed 27% of final energy consumption, mainly for heating (62.8%), water heating (15.1%), lighting and appliances (14.5%), with the remaining being applied to other household activities (Eurostat, 2022).

Therefore, in order to tackle climate change and mitigate negative effects from it, it is critical to take energy as one of the primary targets. As the United Nations (UN) states, '*Net-zero commitments must be backed by credible action*' (UN, n.d.). Thus, acquiring cleaner energy production systems, and reducing energy use and demand combined with better energy efficiency strategies at all levels, are crucial to attaining such objectives.

1.1.2 Transportation

2021 saw global total emissions reaching values close to 56.6 gigatonnes of carbon dioxide equivalent ($GtCO_{2e}$), with Europe's footprint, being culprit for around 6.8 $GtCO_{2e}$ of it. Portugal, in particular, was responsible for emitting 51.5 megatonnes of CO_2 equivalent ($MtCO_{2e}$) (Our World in Data, n.d.).

As told above, 75% of said total emissions regard the energy sector alone. Transportation, however, embodies around 22% of it. Having released more than 7 gigatonnes of CO_2 into the earth's atmosphere (Teter and Voswinkel, 2023), it becomes clear that the transport sector must be acknowledged as a key sector to tackle both energy crisis that may emerge and climate change, as it is expected for transport demand to grow in the coming decades (Ritchie, 2020; Tiseo, 2023).

Correspondingly, in Europe, the transport sector is accountable for almost a quarter of total GHG emissions. It presents itself as one of the main barriers to achieve climate neutrality by the European Commission (EC) (European Commission, n.d.). Furthermore, with car ownership increasing for the past 10 years across the *'old continent'* (Eurostat, 2023o), both climate action and poverty reduction objectives may be hindered.

In a Portuguese context, as of 2021, the number of registered passenger cars reached 5 632 644 units; an increase of 16% compared to 2016, the 7^{th} highest in the European Union (EU) during that period. The majority of which being older than 10 years (close to 65%) (Eurostat, 2023).

However, this increase in car ownership by the Portuguese raises concerns regarding the social and economic constrains that may emerge from said ownership. Hypothetically speaking, this could well be due to poor public transport networks and synergies between different modes of transport. Also, it could be due to the existence of trade-offs in commodities whilst commuting, where private transportation rivals with public transport in comfort, travel duration and (sometimes) costs. Thus the relevance of the present work to this topic.

1.2 Dissertation framing and key concepts

Energy Poverty (EP) (also commonly referred to as *'fuel poverty'* in some literature), both nationally and at a European level, is an increasingly linked reality, affecting the health and well-being of individuals, populations (Martiskainen *et al.*, 2021), as well as the proper functioning of the services from which these depend on.

In this regard, international studies are emerging, intending to explore and expand the horizons of EP as a vulnerability while looking deeper into transport and mobility, acknowledging it as 'Transport Poverty (TP)', adding to the more established and well-known enforced incapacity to obtain and use defined necessary amounts of domestic energy services, such as heat, hot water, and lighting, also known as EP (e.g., Bouzarovski and Petrova, 2015; Mattioli *et al.*, 2017; Robinson and Mattioli, 2020; Simcock *et al.*, 2021). However this definition is not yet 100% consensual within literature (Lowans *et al.*, 2021).

Similarly, there is still uncertainty regarding the concept of TP, whether if it relates to a deficiency in availability of transport, and/or if it relates to the accessibility of said asset to allow an individual to participate in society, and/or if it even relates to "some minimum level of mobility" (Lucas *et al.*, 2016). Nonetheless, for the present work, TP, will be considered as *"the enforced lack of mobility services necessary for participation in society, resulting from inaccessibility, and or unaffordability, and or unavailability of transport"* as per (Lowans *et al.*, 2021), since the deprivation of access to activities and services can result in a deficiency of qualifications and skills, which may subsequently give rise to structural manifestations such as poverty and low income (Székely and Novotný, 2022).

At European level, indicators like "*Inability to keep home adequately warm*" or "*Arrears on utility bills*" and several others, available in the European Poverty Advisory Hub (EPAH) (see EPAH, 2023) online interactive dashboard, are already used to quantify *"aspects of energy poverty levels across Europe using the most recent EU wide statistics"*.

Within this matter, policies like the '*Warmer Homes Scheme*', taking place in Ireland – which provides energy upgrades to homeowners below a certain income threshold (or granted by some sort of social welfare allowance), without any extra costs to homeowners –, or the '*Disconnection protection Catalonia*' programme in Catalunya – which protects the most vulnerable dwellings from getting cut off essential needs like electricity, gas and water supply –, are trying to tackle domestic EP.

In this context, past studies have extensively looked into household EP as well, like Karpinska *et al.*, 2021; Mahoney *et al.*, 2020; and Horta *et al.*, 2019, in example. Karpinska *et al.*, 2021, focused on accessing regional vulnerability to EP in Poland, using national databases for data extraction, assessing in the end that certain districts are more likely to attain EP policy actions, than others. Mahoney *et al.*, 2020, targeted the potential of the United Kingdom for the application of a common methodology for EP assessment. Their results showed that, even though large amounts of data were available, it was not possible to find common grounds to compare data between countries. Gouveia *et al.*, 2019, based on a quantitative analysis, were able to entirely characterise every Portuguese parish contributing to a better understanding of EP in Portugal, using an EP vulnerability index, where the results obtained showed the vulnerability to which Portuguese regions are exposed to.

As flourished in Chapter 2, both TP and EP can be negatively loop-reinforcing concepts that can further increase unfavourable impacts on individuals' (and dwellings') well-being. Said reinforcement evidence a "new" concept such as ' Double Energy Vulnerability (DEV)'. In this work, DEV, comprises an individual's or dwelling's increased struggle to fulfil both energy and transportation requirements (Figure 1.2) in such a way that *he, she* or *them* cannot have a good quality of life. In other words, DEV, unifies in a single definition, the overlap between EP and TP.

1.3 Objectives

Regarding the Portuguese reality, TP theme is not yet sufficiently developed, making it challenging to implement mitigating actions and measures for this problem. Whether it is due to the lack of existing data and/or effort to obtain it, whether the topic is not sufficiently attractive to national political agenda in such a way that evokes new ambitions, Portuguese scarce access and/or affordability to transport services (*simply referred to as 'Portuguese TP' for the course of this work*) is, as of 2023, a blank page awaiting to be filled.

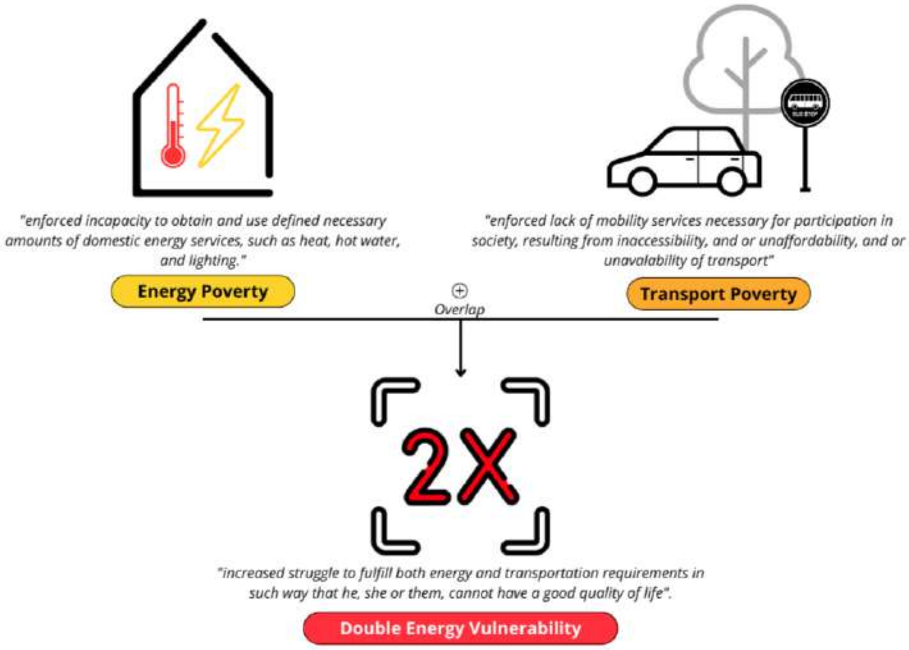


Figure 1.2: Main factors comprising Double Energy Vulnerability. Adapted from Lowans *et al.*, 2021.

In that sense, this research has as its primary objective to explore this dimension of vulnerability in access to transport/mobility in Europe, resorting to identifying and analysing relevant indicators for posterior comparison between European nations, enabling, above all, the beginning of a discussion and characterisation of the problem of mobility intertwined with other related household level energy vulnerabilities, with a view to the development of new, or ongoing political energy, housing, environmental and/or mobility synergies.

Additionally to the aforementioned main objective, this work also entails an assessment of the Portuguese viewpoint to gain enhanced insights at a more intricate spatial level regarding this particular subject matter.

1.4 Document Structure

This work is structured as follows. Following this introduction, Chapter 2, comprises a literature review aiming to a better in depth understanding and strengthening of essential concepts around TP, EP and/or DEV. In Chapter 3, the methodology used along the development of this dissertation is explained and justified. Chapter 4 presents the core analysis intended for this thesis. Chapter 5 presents the main outcomes obtained through this research based on the analysis conducted. It also outlines limitations found during its development and key implications for future works.

2

Literature Review

2.1 Energy Poverty

EP is defined in three layers of injustices, as per Stojilovska *et al.*, 2023. Those layers are related to spatial distribution of dwellings (also verified by Simcock *et al.*, 2021); households' low adaptive capacity to cope with EP; and with policies affected to the most energy vulnerable. Therefore, EP and its scale is mainly seen and described as a socio-economic concern (Moore, 2012; Bouzarovski, 2014; Kyprianou *et al.*, 2019; Palma *et al.*, 2019; Palma *et al.*, 2022b; Middlemiss, 2022). For instance, Moore, 2012, states that the scale of EP is dependent on *apriori* assumptions regarding definitions and thresholds, which are essential to obtain target populations distribution. These definitions are also important for policy formulation, monitorisation, and strategy development, according to the latter.

Notwithstanding, according to Stojilovska *et al.*, 2022, and Sareen *et al.*, 2020, EP is not only a malleable concept that takes on the characteristics of the metrics used to define it, serving as a target for policy intervention; but also, it is a political driven phenomenon, due to existing *systemic inequalities and national path dependencies*, such as existing infrastructure, dwellings features; social welfare systems; energy markets, and experience dealing with EP, in example, as well as different geographic conditions. Plus, EP also bumps 'issues such as personal safety, household time budgets labour productivity and income' (Bouzarovski and Petrova, 2015).

In this regard, Stojilovska *et al.*, 2022 showed that, the majority of EP links are made in energy efficiency policies when compared to energy costs and income vulnerability policies – the "triad of EP drivers". Thus exposing, firstly, the complexity of the problem, and, secondly, the need for better policy symbiosis across the board, having in mind that the path to diminish the existence of EP is not only a technological solution.

Middlemiss, 2022, when alluding to the EP situation in the Global North found that people from disadvantaged social groups are more likely to experience EP. These groups, are commonly affected by one of the three main drivers for EP. Furthermore, depending on where they live, they can be affected by different 'structural determinant' factors that conduct to EP: in post-socialist states, these factors can take shape in the form of cold climates, decaying infrastructures and/or high income inequality; in Southern Europe, these factors comprise mainly in inadequate heating systems and poor quality dwellings. Kyprianou *et al.*, 2019, further expanded these suggestions, stating that each nation within the EU is responsible for dealing with this ever-growing problematic. In that way, policies that encourage both synergies between different stakeholders, as well as the integration of scientific knowledge into said policies are crucial to create effective ways to tackle EP. However, according to Jiglau *et al.*, 2023, populations have low trust in their governments which hamper the application of measures aiming at diminishing energy inequalities.

However, up until 2019, despite a rapidly increasing interest in EP with widespread and comprehensive agendas being developed to address it, due to systemic flaws 'that lead to the emergence of domestic energy deprivation (Bouzarovski and Petrova, 2015), the EU had not yet provided specific guidance to mitigate it (Kyprianou *et al.*, 2019), even though recognising EP as a matter of urgent concern within Europe, a problem that, back in 2014, was already seen as a widespread problematic across East, Central and South Europe (Bouzarovski, 2014). Notwithstanding, this changed in 2020, with the EC introducing a nine-item recommendation to member-states on how to best address EP (European Commission, 2020), followed by the EPAH inauguration, in November 2021.

Fuelwood use, therefore, for instance, is an important coping mechanism for households to EP. It enables reliable access and security to energy due to its vast availability, and thus diminishing household vulnerability to fuel price increases. Howbeit, mainly driven by social and cultural practices, said fuelwood remains an important energy source for European households, despite its detrimental effects on the health of 2.8 billion individuals who are left relying solely on traditional biomass for their cooking and heating needs disregarding high levels of indoor air pollution in their homes and the environment (Bouzarovski and Petrova, 2015; Palma *et al.*, 2022a; Stojilovska *et al.*, 2023).

In this way, in order to ensure the advancement of the Sustainable Development Goals (SDGs), but also a fair low-carbon transition of the "*European Green Deal*" plans and aspirations whilst achieving net-zero by 2050 at the same time leaving no-one behind, it is imperative that forthcoming policies of the EU acknowledge the correlation between fuelwood and energy poverty. In addition, such policies should be designed to facilitate a gradual and supportive transition away from fuelwood, without jeopardising the subsistence of those who are energy vulnerable (Stojilovska *et al.*, 2023).

Under these circumstances it is crucial to understand whom are the most in need and how can energy poverty policies support those most in need. To combat this, Bouzarovski and Petrova, 2015; and Kyprianou *et al.*, 2019, suggest that a decentralised approach, with emphasis in the local action power, can be of benefit to EP mitigation.

When EU discussions, debates and policies were still elementary, it was already clear the existence of a triad of main drivers for EP: high energy costs; low efficiency buildings, and low household incomes. Nevertheless, evidence suggested that EP was a more complex issue than the common assumption of it, proving the main driving forces of EP were involved and intrinsically linked to 'social, political and environmental' circumstances. As per Kyprianou *et al.*, 2019, European EP occurs mainly due to low incomes, high energy costs, and poor energy efficient buildings, which may lead to social constraints and unhealthy living conditions. And, according to Vandyck *et al.*, 2023, a rise on energy poor residents is considered to be on the verge if the EU does not follow up their climate policy proposals with supplementary measures, (e.g., 'alternative climate policies', and/or, 'income-targeted revenue recycling schemes'). Thus, if properly placed into action, more than 1 million households could leave energy poor status.

In this context, Bouzarovski, 2014, revealed comparative examples between Scandinavian countries and Southern European countries. Although in colder climates, the Scandinavian had less EP prevalence, whereas the Southern countries, because of more poorly insulated dwellings linked with lower incomes, demonstrated that they were more likely to manifest EP. Deep interventions aiming to better building insulation and energy efficiency are proven win-win solutions to manifestations of EP. Furthermore, one of the key challenges in the European context are the non-comprehensive EP indicators across the different available databases that, although useful for 'generic country comparison', lacks a contextualised representation of energy use and needs by European populations (Sareen *et al.*, 2020).

In a Portuguese context, Palma *et al.*, 2019, identified the existence of an "aging building stock" in Portugal. This "stock" is mainly comprised of buildings built before 1990, 'a period when there were no EP regulations in place.'. In addition, the northern and central regions of the country were proven to suffer the most with EP, with both being more vulnerable to winter and summer seasons, due to poor energy efficiency and low energy consumptions for space heating and cooling. Furthermore, the results hypothesised that this systemic inability to maintain dwellings comfortably heated and cooled may be mostly driven by socio-economic conditions with the possibility of them being linked to EP.

Following up its previous work, Palma *et al.*, 2022b, exhibited that established objectives for EP reduction, as well as climate change mitigation and decarbonisation of economies may be hindered by trade-off situations provoked by competing agendas. Hence, one way to tackle all of these problems is the promotion of energy efficiency in the residential sector. They also ruled that cultural and socio-economic constraints that lead to energy under-consumption, might still be one of the main hurdles to attain credible energy consumptions values. Still, the authors were able to verify that both "regulation levels" and "deep changing" interventions in Portuguese dwellings are effective in increasing buildings energy efficiency. As a result, EP prevalence is reduced in both heating and cooling seasons, leading to a reduction in carbon emissions, as initially intended. Moreover, the importance of private energy companies is highlighted as the authors emphasise that these companies can be part of the solution and not the problem, with "energy retrofit and inefficient equipment replacement obligation schemes.".

2.2 Transport Poverty

As previously stated, TP is yet to gain an unique definition, due to its complexity as a standalone problem. Already understood as a barrier to having an active role in society and national economy, TP (as EP) cannot be assessed by using a singular metric (Sustrans, 2012; Lucas *et al.*, 2016; Lowans *et al.*, 2021). Transport affordability, accessibility, availability and travel times to reach desired destinations, are all under the broader concept of TP. In that sense, although the individual assessment of each notion being possible, assessments and evaluations regarding the concept of TP need to look at them as a whole in order to be depictive enough of this problem (Sun and Thakuriah, 2021).

Moreover, mobility is a must for modern-day society participation, both social and economic wise as aforementioned. So, deprival of the right to mobility to individuals', can also hassle one's possibilities to access services and to grasp new opportunities that can improve their life situation (Lucas *et al.*, 2016; Sterzer, 2017; van Dülmen *et al.*, 2022; Castro *et al.*, 2022).

In this context, numerous occasions (Velaga *et al.*, 2012; Lucas, 2012; Lucas *et al.*, 2016; Lucas *et al.*, 2018; Churchill and Smyth, 2019; Allen and Farber, 2019; Lowans *et al.*, 2023) have identified that the most socially vulnerable, whether they are elderly, people with some type of disability, individuals with a low income (despite Shi *et al.*, 2022 questioning this relationship between income and TP) , and/or individuals with a lower level of education, or ethnic minorities, tend to suffer the most with TP. Not only that, the aforementioned authors, also found that there is a negative association between TP and subject wellbeing - concepts also reiterated by the New Zealand Ministry of Transport (Ministry of Transport, 2018). Interestingly, it is noteworthy to observe that, however, TP can also be beneficial to some health issues such as obesity.

For instance, Churchill *et al.*, 2023, findings depicted that transport poor inhabitants are forced into active modes of commute, like walking or cycling to their desired destination. This physical activity is thus responsible for decreasing obesity levels in the transport poor. Nonetheless, it should be noted that the existence of TP does not connote a favourable circumstance to individuals. Although, when looking into the specific context of obesity, TP situations can be of crucial importance to one's life choices, inciting those to opt for more active transportation means, for instance. Adding to it, Churchill, 2020, found that the more ethnic diversity exists, the more transport poverty is evidenced due to the linkage found between the two. Additionally, amongst the aforementioned social problems, discrimination and low trust in minorities, show a slower economic growth of minorities leading to a higher income poverty which was, and still is, identified and associated as a major cause to TP.

Lucas *et al.*, 2018 however, reasons that, in spite of certain social characteristics being conditional factors to ones' travels choices and behaviours, physical location of residency is more determinant on their travels choices and behaviours. Churchill and Smyth, 2019 add to this, although only referring to Australia, revealing that people in the suburbs do tend to spend more money, and time, on daily commutes to get to work or services, mainly because of a high car-dependence. Remarkably, Curl *et al.*, 2018 also found that acquiring a car often leads to a strong attachment to the vehicle, making it challenging to relinquish ownership, even during periods of financial hardship. Mattioli *et al.*, 2019 and Mattioli *et al.*, 2020 also observed the same problem in the global north, since the mid-twentieth century, as a result of a higher endorsement of car-dependent territorial configurations, and lack of good public transport infrastructure. The latter also referenced past studies that showcased that this problematic is also applicable to the United Kingdom and Europe.

Delbosc and Currie, 2011, already established the existence of relationships between the spatial context of transport disadvantages, social inclusiveness and individuals' well-being. Also in an Australian context, the authors were capable of demonstrating that people living in peri-urban or rural areas are more prone to be denied of activities due to transport problems. In that sense, both, Simcock *et al.*, 2021 - which looked more carefully into the northern hemisphere -, and Robinson and Mattioli, 2020 -, whilst exploring England's (United Kingdom) reality -, accomplished to build on top of Delbosc and Currie, 2011 conclusions, also showcasing that TP is more evident in rural areas. In short, as per Velaga *et al.*, 2012, rural communities are far more disadvantaged when it comes to accessibility and connectivity with the remaining society

Nonetheless, and further expanding on this idea, besides rural populations being forced to acquire cars, to decrease their accessibility problems (Székely and Novotný, 2022), rural zones were also classified as zones of special characteristics, where the often lack of "*dense*" and "*reliable public transport network*", and, long distances between communities that make walking and cycling not feasible, lead to a necessary car ownership for daily commutes (van Dülmen *et al.*, 2022; Sovacool *et al.*, 2023), increasing household running costs of energy for their mobility, even if income poor dwellings spend less energy than they actually require (Moore, 2012). Hence the car not being a merely transport variable, but also a socially conditioned variable (van Dülmen *et al.*, 2022).

Shi *et al.*, 2022, further augmented aforesaid revelations asserting that low-income populations tend to use more communal transportation to commute, whereas high-income populations tend to use their private passenger cars. However, both cases, to a certain extent, are described as TP situations. The first mentioned, is a direct translation of the incapacity to attain passenger cars for their low-income households, thus forcing them to opt for public transport (e.g., more susceptible to traffic congestions) or active transportation modes, which in turn end-up being more time consuming diminishing commute satisfaction. The latter, due to the soaring availability of private transportation, hinders commute satisfaction because of traffic congestions and longer commute duration.

Interestingly, it is noteworthy that Sterzer, 2017 also explored decision making differences between low and high-income families. Sterzer, 2017, explored how families searching for a residential location can be affected by other critical factors to make a final decision. In a nutshell, the author's findings suggest that the housing market has a significant impact on the mobility patterns and requirements of entire families, indicating a robust correlation between housing and mobility, while unveiling that both low and high-income families face mobility hardships upon relocation. Nonetheless, it became clear that low-income households only relocate if truly necessary. Additionally, the immutability of certain "points of interest", like workplace, and/or friends or family, further intensifies hardships for said families, who struggle much more to do so, due to their 'low financial flexibility', as expected.

When it comes to major transportation infrastructure investments, Velaga *et al.*, 2012 affirm that, the limitations in the development and resilience of technological infrastructures often exacerbate the constraints faced by rural transport infrastructure and services. In this context, Lucas *et al.*, 2016, identified that said financing's do not help the most in need, regarding transport affordability and accessibility. This is also true for the "*most cost- and energy-efficient transport modes*" (Mattioli *et al.*, 2017) since populations and income opportunities are leaving the urban cores and expanding into the suburban areas (Salih and Lee, 2022) . Rather, said investments end up benefitting the 'non-poor' the most (Lucas *et al.*, 2016) - the ones, whom, consequently, end up travelling further and for longer times.

In other words, distant and time-consuming journeys are not synonyms of greater social inclusion (Lucas *et al.*, 2018). In fact, the more time individuals spend commuting, the less time they spend actively taking part in society, such as, for instance, connecting with friends and family (Sterzer, 2017). Higher distances to "points of interest" are deemed to increase both financial burdens, and travel comfortability (in the likes of higher travel times, or even interconnectivity of the different means of transport), which for that matter, exacerbate 'transport-related social exclusion' (Székely and Novotný, 2022). In addition, Castro *et al.*, 2022 displayed that inhabitants loosing up to 2 hours in commuting time, can end up losing in about a quarter of their max income potential. Thus, in accordance with Salih and Lee, 2022 stating that decentralised transportation systems are shown to increase overall accessibility to populations, modern cities need changes to their traditional monocentric metropolitan areas, into polycentric cities. Moreover, Shi *et al.*, 2022, showcased that low-income households suffering from TP could see it reduced with more accessible and available transports to the outskirts of the urban cores where they're dominantly settled, which further promotes Salih and Lee, 2022's beliefs. Therefore, if traffic and urban planners fail to properly address so, populations may see their income opportunities get hindered, as stated above, due to a loss of attractiveness in said fortuities, which diminish as the directness of the route and frequency of service decrease, and travel time increases (Salih and Lee, 2022).

Like so, the implementation of well-conceived and effectively executed mobility policies, with the involvement of both local authorities and inhabitants, can help to decrease TP (Székely and Novotný, 2022), and is a crucial factor in fostering economic, social, and environmental progress (Castro *et al.*, 2022). Thus, progress to a new 'low emission transport sector' reality, aiming at the increase of public transport commute, with the disincentive of car use – by removal of parking spaces and/or increased road tolls and fuel prices –, may reduce car commuting, but can also be a negative choice when considering the lack of commute alternatives to the population (Lunke, 2022).

2.3 Double Energy Vulnerability

The susceptibility of certain social groups, including the elderly, low-income individuals, ethnic minorities, those with disabilities, and those with dependents, to either EP or TP, already constitutes a form of inherent disadvantage. Furthermore, according to Martiskainen *et al.*, 2023, low-income is not the sole reason that drives DEV. In 'high income' countries, '*the cost of services, access and availability of services, payment types, the materiality of the home, the home's location, and also household make up, age, and disabilities*' are also forms of vulnerability that drive DEV. Downing *et al.*, 2022, (although only looking into an UK context) stated that both EP and TP are 'deep-rooted' societal problems, caused by several socio-economic factors such as low-incomes, insufficient housing quality, little to none access to public transport and forced car ownership, that can have injurious consequences to citizens wellbeing. Although, in order to tackle the latter problem, for instance, Downing *et al.*, 2022 further suggested that policymakers should aim at addressing car-use reduction measures in order to diminish travel emissions, which would one way or another help 'Net Zero polices'. Nonetheless, as has been demonstrated throughout this work, this is also applicable across Europe.

Expanding on section 1.2, DEV, is a phenomenon that may compel individuals, or even entire households, to make difficult choices regarding the allocation of resources. In short, DEV imposes trade-offs on households, forcing them to prioritise one need and making others inaccessible, which most of the time lead to social exclusion Martiskainen *et al.*, 2023. Such choices may involve prioritising between essential services, such as heating the household or financing school transportation (Lowans *et al.*, 2023). Interestingly, it is noteworthy that households are very resourceful and creative when discovering new solutions to mitigate DEV realities (Martiskainen *et al.*, 2023). Hence, EP and TP - described by Lowans *et al.*, 2023 as 'conditions linked by overlapping causal factors' - can be reinforcing concepts that lead to the necessity of trade-offs within dwellings (Robinson and Mattioli, 2020; Martiskainen *et al.*, 2021), and can further increase the impacts felt by individuals on their wellbeing.

Hence, according to some (e.g., Simcock *et al.*, 2021; Martiskainen *et al.*, 2021), when seeking an active participation in society, individuals/dwellings experiencing DEV can feel exacerbated difficulties trying to do so, which can be present in the form of further social and geographic exclusion. Aforesaid statements were further extended by Székely and Novotný, 2022, who elongated that the occurrence of TP based on social exclusion factors, is intrinsically linked to specific geographic locations that suffer from lack of transportation accessibility and transport policies. These social and geographic exclusions, for that matter, end up forcing car ownership within dwellings. For example, Curl *et al.*, 2018, in a Scottish context, specifically for the city of Glasgow, cars are seen as necessity to low-income urban households, 'especially those with children', as a result of transport planning agendas not reaching those most in need of transport. Hence, despite being in financial unstable situations, many dwellings' are being subjected to forced car ownerships, to improve their mobility status.

Likewise, both Robinson and Mattioli, 2020 and Simcock *et al.*, 2021 showed that DEV is more evident in rural areas. In succession, Downing *et al.*, 2022 displayed rural areas as the most vulnerable to DEV, where its inhabitants find themselves in disadvantageous socio-economic and demographic situations. Also, peri-urban lifestyles are associated with misestimated transportation costs by homeowners, consequently increasing housing, and transportation burdens (Lowans *et al.*, 2023). Therefore, for DEV contexts, the assessment of housing affordability, where the distribution of travel energy demand among income groups is greater than that of housing energy demand (Downing *et al.*, 2022), needs to encompass not only the expenses associated with housing, but also those related to transport. As a matter of fact, housing costs implying more than 30% of the household income is considered unaffordable. Additionally, transportation costs were also found to exhibit significant fluctuations across metropolitan regions, typically escalating in proportion to the distance from the urban core (Coulombel, 2018). Besides, low-income households - the ones with less adaptative capacities to EP and or TP (Lowans *et al.*, 2023), for that matter, are the most vulnerable to higher household and transportation costs burdens (Coulombel, 2018), and also increasing dwellings' vulnerability to fuel price variations (Lowans *et al.*, 2023). Contrastingly, in line with prior projections, 'above-median' income households are less vulnerable to housing costs (Coulombel, 2018) but also are less vulnerable to fuel prices oscillations. Slightly changing the paradigm into the worldwide desired transition to low-carbon technologies, Martiskainen *et al.*, 2021 and Martiskainen *et al.*, 2023, made it evident that said transition can also increase EP, TP, or DEV, stating that 'Net Zero policies' can however be also a factor that increases DEV prevalence within communities with reduced capacities to electrification and modernisation of their homes. In addition, according to Vandyck *et al.*, 2023, achieving an equitable low-carbon energy society in the future necessitates acknowledging groups that are vulnerable to both EP and TP, since 'transport and housing choices are closely linked'. Thus, lived experiences are seen as very useful to the design of new 'Net Zero policies', as those who suffer/suffered from DEV in some part of their lives can help policy makers to better recognise, understand, and develop new targeted and/or holistic strategies and policies to help the most vulnerable, besides also 'humanising' their decision-making (Martiskainen *et al.*, 2023). Moreover, Vandyck *et al.*, 2023 findings presented that, in order to reach the *Paris Agreement* goals, the said transition crucially needs to be speed up.

3

Methodology

This Chapter, comprised of five main sections, aims to explain the methodology used along the development of this work. It also aims to make evident its pros and cons. The first section thoroughly details the development of the Literature Review (Chapter 2) with which search parameters were used to conduct it. The second section presents an overview of the main reasons backing the choice process of the present case studies, Europe (in a macro approach) and Portugal (as a specific case study). The third one explores the selection procedure of relevant indicators, whether EP, TP, or DEV-related, that contribute to the evaluation of the case study. In the fourth section, the process behind the conducted data extraction is briefly depicted. Lastly, the fifth section describes the application of selected indicators to the data extracted in order to disclose how the Portuguese dwellings' vulnerability was assessed.

3.1 Literature Review

A careful assessment of the available literature was done to gain a thorough grasp of the state of the art in the field and to spot any gaps that the ongoing inquiry work may fill, as well as to obtain an overview of existing indicators used for assessing EP, TP and DEV, which is explained further down.

A selective search method was devised across multiple scientific databases, including *'Science Direct'*, *'Web of Science'*, *'Scopus'*, and *'Google Scholar'*, to find pertinent peer-reviewed publications such as articles, papers, and other sources. Moreover, studies and other references from respectable international organisations, like the International Energy Agency (IEA) and the The World Bank (WB), were all included in the inclusion criteria. The inclusion criteria are comprised in 1) restrain search results to the time frame 2010 to 2023, 2) usage of known keywords and respective dualities that may emerge from said keywords, and, 3) consultation of literature from established authors in EP and TP. Moreover, peer-cited works were also used to encounter more pertinent literature.

From the kick-off, basic keyword searches were conducted (e.g., 'energy poverty'; 'transport poverty'; 'double energy vulnerability'). To ensure that all relevant materials were found, Boolean operators were deemed necessary to assure so, with refinements being done during the search process. Thus, the outcome of these refinements to the search process, originated aforementioned Boolean inquiries for keywords like: (*"transport poverty"OR"mobility poverty"*) and (*"energy poverty"OR"fuel poverty"*), for example.

In order to pinpoint main ideas, themes, and conclusions, a screening procedure was used to determine which literature was the most pertinent. Each source's titles, abstracts, and keywords were carefully examined as part of the screening process to see if they matched the inclusion requirements.

3.2 Case Study Selection: Europe and Portugal

The choice of Europe as a case study is driven by several key factors. Firstly, Europe represents a diverse and complex region with varying levels of energy and transportation challenges across its different climates, geomorphologies, and socio-economic architectures.

Secondly, the lack of comprehensive studies that specifically focus on the intersection of energy and transport poverty issues at a European level highlights the existence of a relevant research and policy gap. While there have been studies on EP and TP separately, there is a need to understand their interconnectedness and the potential synergies between energy and transportation policies within the European context.

Lastly, looking into Europe, and not only the EU, allows for a more holistic view of the mobility difficulties, trends and challenges ahead for the European continent.

On the other hand, the selection of Portugal as a case study arises from two main reasons, albeit somewhat similar and interconnected. The little to no mention of transportation or mobility difficulties when echoing Portugal's residential lack of energy efficiency and thermal comfort (e.g., Gouveia *et al.*, 2019; Palma *et al.*, 2019) in its dwellings and population prompts the existence of a research gap. This discrepancy fails to exhibit said energy setback regarding social inclusiveness and households' capabilities to withstand possible trade-offs pertaining to energy-related vulnerabilities. Moreover, the lack of mention to mobility in the early drafts of the Portuguese "*Long-Term National Strategy to Combat Energy Poverty 2022-2050*", also incites the development of the present work to culminate the existent research gap.

Overall, by examining Europe and Portugal, we can identify common challenges and differences that may lead us to successful interventions and policy approaches to address EP, TP, and DEV both within Europe and in other regions facing similar issues.

3.3 Selection of Pertinent Indicators for Transport Poverty Vulnerability Analysis

Regarding the selection of relevant indicators for vulnerability analysis, a similar search procedure to section 3.1, was put in place with Boolean searches (e.g. *("transport poverty" OR "mobility poverty") AND ("metric" OR "measure" OR "indicator" OR "indicators" OR "indices" OR "index" OR "evaluation" OR "assessment")*).

Besides the aforementioned databases, other sources like the European Statistical Office (Eurostat); the Contemporary Portugal Database (*Base de dados de Portugal Contemporâneo*) (PORDATA); the Portuguese National Institute of Statistics (*Instituto Nacional de Estatística*) (INE); the Organisation for Economic Co-operation and Development (OECD); and the EPAH were also used for data extraction and to obtain an overview of the existing indicators around and within the field of transportation related to EP.

Altogether a total of 87 indicators were retrieved (see Annex 5.2). An Excel file was used to store said indicators and correspondent relevant information such as the database which they were extracted from; time span of measurement of the indicator; indicator units; and respective access links. This Excel allowed for a rough comparison between indicators. This comparison then led to the creation of classes of indicators where similar indicators were compiled into the classes that best fitted its descriptions or measurements (see Annex 5.2 for more information).

Four main categories were conceived:

1. "*Travel Time*", regarding the time spent in commutes (12 indicators);
2. "*Affordability*", regarding expenditures of travel (30 indicators);
3. "*Accessibility*", regarding commodities that aid travel needs (24 indicators);
4. "*Availability*", regarding the existence of alternatives to choose from to fulfil aforesaid travel needs (14 indicators).

The remaining seven indicators are enacted as composite indicators, and others that do not fit into these four categories. As a result of limited data availability and the appropriateness of data for an adequate number of European nations, including Portugal, only a fraction (*11/87*) of the total indicators identified were applied in vulnerability assessments and evaluations, thereby enabling more comprehensive analyses and comparisons. Moreover, a few socio-economic (e.g., *'Population on 1 January by age group, sex and citizenship' indicator; 'Population on 1 January' indicator*) indicators were collected to improve data contextualisation of the Portuguese reality regarding the vulnerability assessment metrics within a European framework.

In this context, the chosen relevant indicators for TP are therefore described in the following subsections. Subsection 3.3.1, presents the indicators used to conduct an European overview and contextualisation in regards to TP, which in turn, includes the Portuguese reality. Howbeit, subsections 3.3.2.1 through 3.3.2.4 further depict the indicators used for the more in depth analysis of the Portuguese case study.

3.3.1 European contextualisation

As earlier introduced, the gathering of contextualisation indicators was imperative to support data crossovers. Table 3.1, presents the indicators retrieved across different databases. It also presents the identification code used by the source; the name which identifies the indicator on the database; the period in which data is available, and the provenience(s) of the indicator(s).

Table 3.1: Technical details concerning the retrieved socio-economic indicators for further data contextualisation.

Name (Unit)	Eurostat Code	Reference Period	Source
Stock of vehicles by category and NUTS 2 regions (per 1000 inhabitants)	TRAN_R_VEHST;	annual (1990-2021)	Eurostat, 2023m;
Passenger cars, by age (Nº)	ROAD_EQS_CARAGE;	annual (2013-2021)	Eurostat, 2023i;
Distribution of population by level of difficulty in accessing public transport, income quintile and degree of urbanisation (%)	ILC_HCMP06;	annual (2012; 2014)	Eurostat, 2023d;
Final consumption expenditure of households by consumption purpose (% of total)	NAMA_10_CO3_P3;	annual (1975-2022)	Eurostat, 2023e;
Income of households by NUTS 2 regions (€ per inhabitant)	NAMA_10R_2HHINC;	annual (1995-2022)	Eurostat, 2023h;
Final energy consumption by sector (ktoe)	TEN00124;	annual (2010-2021)	Eurostat, 2023f;

Furthermore, the following sub-subsections (from 3.3.1.1 to 3.3.1.4) present further available disaggregation options of the indicators above illustrated in Table 3.1.

3.3.1.1 Stock of vehicles by category and NUTS 2 regions

The stock of vehicles by category and NUTS II regions, per 1000 inhabitants indicator, represents the ownership rate of a motorised mode of transportation per inhabitant in the EU. It also takes into account non-private vehicles.

Regarding data availability, this indicator only has data from 1990, as expressed in Table 3.1. When it comes to data disaggregation, this indicator can be disaggregated into geopolitical entities down to a NUTS II level, but also into nine classes by type of vehicle:

- Type of vehicle:
  - All vehicles (except trailers and motorcycles);
  - Total utility vehicles;
  - Lorries;
  - Road tractors;
  - Trailers and semi-trailers;
  - Motorcycles;
  - Passenger cars;
  - Motor coaches, buses and trolley buses;
  - Special vehicles;

Due to the scope of the present work, only **passenger cars** will be taken into avail and further evaluations.

3.3.1.2 Passenger cars, by age

The number of passenger cars, by age indicator, represents the proprietorship rate of a personal motorised mode of transportation in the EU as well as the ageing of the European vehicle fleet.

Regarding data availability, the mentioned indicator only has data which amounts back to 2013, as expressed in Table 3.1. When it comes to data disaggregation, besides geopolitical entities at NUTS I level, this indicator can be further broken down into six different age classes, such as:

- Age class:
  - Total;
  - Less than 2 years;
  - From 2 to 5 years;
  - From 5 to 10 years;
  - From 10 to 20 years;
  - Over 20 years;

3.3.1.3 Distribution of population by level of difficulty in accessing public transport, income quintile and degree of urbanisation

The "*Distribution of population by level of difficulty in accessing public transport, income quintile and degree of urbanisation*" indicator, represents, as the name implies, how hard is to populations to satisfy their public transportation needs, whether in urban, peri-urban and rural locations in order to successfully participate in society.

Regarding data availability, this indicator only has data for 2012 as expressed in Table 3.1. When it comes to data disaggregation, this indicator can be disaggregated into geopolitical entities down to a NUTS I level, but also as show by Table 3.2.

Table 3.2: Available further data disaggregation options for the "Distribution of population by level of difficulty in accessing public transport, income quintile and degree of urbanisation" indicator

Degree of urbanisation	**Level of difficulty**	**Quintile**
Total;	Very high;	Total;
Cities;	High;	First quintile;
Towns and suburbs;	Low;	Second quintile;
Rural areas;	Very Low;	Third quintile;
		Fourth quintile;
		Fifth quintile;

3.3.1.4 Final consumption expenditure of households by consumption purpose

The final consumption expenditure of households by consumption purpose indicator, represents the national consumption intentions of the population by breaking down "*GDP aggregates and employment data by main industries and asset classes*".

Regarding data availability, this indicator has data which amounts back to year 1975, as expressed in Table 3.1. When it comes to data disaggregation, this indicator can be disaggregated into geopolitical entities at NUTS I level, but also into nine classes by type of vehicle as shown by Table 3.3.

Table 3.3: Available further data disaggregation options for the "Final consumption expenditure of households by consumption purpose" indicator

Classification of individual consumption by purpose	**Unit of measure**
Total;	Percentage of total;
Transport;	Others;
Purchase of vehicles;	
Operation of personal transport equipment;	
Transport services;	
Others *(related to households and day-to-day living expenses)*;	

3.3.1.5 Income of households by NUTS 2 regions

The income of households by region indicator, represents the average income of households within NUTS II regions.

Regarding data availability, this indicator has data which amounts back to year 1975, as expressed in Table 3.1. When it comes to data disaggregation, this indicator can be disaggregated into geopolitical entities at NUTS II level, and as visible in Table 3.4.

Table 3.4: Available further data disaggregation options for the "Income of households by NUTS 2 regions" indicator

Direction of flow	**National accounts indicator**	**Unit of measure**
Paid; Received; Balance;	Final consumption expenditure; Compensation of employees; Property income; Social benefits other than social transfers in kind; Balance of primary incomes/National income, net; Consumption of fixed capital; Operating surplus and mixed income, net; Other current transfers; Disposable income, net; Current taxes on income, wealth; Net social contributions; Adjusted disposable income, net; Social transfers in kind;	Million euro; Euro per inhabitant; Million units of national currency; Million purchasing power standards; Purchasing power standard, per inhabitant;

3.3.1.6 Final energy consumption by sector

The final energy consumption by type of consumer sector indicator, intends to illustrate how energy is used by European end-users across multiple sectors such as transport and households, *etc. (e.g., industry; agriculture; and services, are amongst the sectors also covered by this indicator)*. Moreover, and as per Eurostat, it does not include energy used by the energy sector itself or losses during energy transformation and distribution.

Regarding data availability, this indicator has data which amounts back to year 2010, as expressed in Table 3.1. When it comes to data disaggregation, this indicator can be disaggregated into geopolitical entities at NUTS I level, and as depicted by Table 3.5.

Furthermore, in order for this indicator to be representative of every country's reality, it was necessary to calculate their energy consumptions *per capita*. This meant that, the crossover of the final energy consumption indicator, with demographic indicators to calculate the total resident population energy consumption, was deemed. Table 3.6 presents the identification codes used by the source; the names which identify the indicators on the database; the periods in which data is available; and the source of these indicators.

When it comes to data disaggregation, these indicators could be disaggregated into geopolitical entities at NUTS I level and some aggregates of countries (e.g. EU). Only

Table 3.5: Available further data disaggregation options for the "Final energy consumption by sector" indicator

Energy balance	Standard international energy product classification:	Unit of measure
Final consumption - energy use; Final consumption - industry sector - energy use; Final consumption - transport sector - energy use; Final consumption - other sectors - households - energy use; Final consumption - other sectors - commercial and public services - energy use;	Total;	Thousand tonnes of oil equivalent;

Table 3.6: Technical details concerning the retrieved demographic indicators for population accounting.

Name (Unit)	Eurostat Code	Reference Period	Source
Population on 1 January by age group, sex and citizenship (Nº)	MIGR_POP1CTZ;	annual (1998-2022)	Eurostat, 2023l;
Population on 1 January (Nº)	TPS00001;	annual (2012-2023)	Eurostat, 2023k;

the indicator identified by the code *'MIGR_POP1CTZ'* in Table 3.6 could be further disaggregated as follows (Table 3.7):

Table 3.7: Available further data disaggregation options for the "Population on 1 January by age group, sex and citizenship" indicator

Age Class	Country of Citizenship	Sex
Total; Other 26 age classes;	Total; Other 284 options, including *'Unknown', 'Stateless', and 'Recognised non-citizens'*;	Total; Male; Female;

3.3.2 Portuguese contextualisation

Similarly to subsection 3.3.1, the gathering of contextualisation indicators was imperative to support data crossovers. The following sub-subsections (from 3.3.2.1 to 3.3.2.4) present further available disaggregation options to each indicator with the four indicator categories. In this way, the identification code used by the sources; the name which identifies the indicator on their respective database; the period in which data is available, and the provenience(s) of the indicators, are also presented in their respective tables (Table 3.8 to Table 3.15).

3.3.2.1 Travel duration indicators

Average time spent on commuting of employed or student resident population using collective mode of transport by place of residence

The average commute duration using communal transportation, represents the amount of time spent in transit by both, employed citizens and students, either by bus/tram; train; metro; boat, and, if any, company's/school's communal transportation. The last available data is affected to the Census that took place in 2021 in Portugal. Nonetheless, data from 2011 is also available as expressed in Table 3.8.

For that matter, Table 3.8, presents the identification code used by the source; the name which identifies the indicator on the database; the period in which data is available, and, the source of the indicator. The dataset in question was directly retrieved from the INE and PORDATA databases.

Although only available at the INE database, this indicator can only be further disaggregated in relation to the place of residence of the population, such as:

- Place of residence:
  - NUTS I;
  - NUTS II;
  - NUTS III;
  - Local Administrative Unit (LAU)s;

Table 3.8: Technical details concerning the average commute duration by communal transportation indicator.

Name (Unit)	**Code**	**Reference Period**	**Source**
Average time spent on commuting of employed or student resident population using collective mode of transport by place of residence (min.)	0011794 *(INE)*;	decennial (2011;2021)	INE, 2023a; FFMS, 2021;

Average time spend on commuting of employed or student resident population using individual mode of transport by place of residence

The average commute duration using individual transportation, represents the amount of time spent in transit by both, employed citizens and students, either by bicycle; motorcycle, and, passenger car (whether being a passenger or the driver). The last available data is affected to the Census that took place in 2021 in Portugal. Nonetheless, data from 2011 is also available as expressed in Table 3.9.

For that matter, Table 3.9, presents the identification code used by the source; the name which identifies the indicator on the database; the period in which data is available, and, the source of the indicator. The dataset in question was directly retrieved from the INE and PORDATA databases.

Table 3.9: Technical details concerning the average commute duration by individual transportation indicator.

Name (Unit)	Code	Reference Period	Source
Average time spend on commuting of employed or student resident population using individual mode of transport by place of residence (min.)	0011795 *(INE)*;	decennial (2011;2021)	INE, 2023b; FFMS, 2021;

Although only available at the INE database, this indicator can only be further disaggregated in relation to the place of residence of the population, such as:

- Place of residence:
  - NUTS I;
  - NUTS II;
  - NUTS III;
  - LAUs;

3.3.2.2 Affordability indicators

Disposable income of households (with expenditure greater than zero) spent on essential goods and services by income quantiles

The disposal income spent on essential goods and services by households, illustrates said households capabilities to afford, or not, essential needs to their welfare such as transportation, which includes both private transportation, public transport services, among others (Kenton, 2023; Eurostat, 2023c (see subsection 3.4 of the indicator's metadata for more information)).

Regarding data availability, the Eurostat database (the source of the indicator presented in Table 3.10), already includes some data referring to 2020 for some countries. However, for Portugal, there is only data back from 2015.

For that matter, Table 3.10, presents the identification code used by the source; the name which identify the indicator on their database; the period in which data is available, and, the source of the indicator.

Table 3.10: Technical details concerning the affordability of transportation by income quantile of households at national level indicator.

Name (Unit)	Eurostat Code	Reference Period	Source
Disposable income of households (with expenditure greater than zero) spent on essential goods and services by income quantiles (%)	ICW_AFF_01;	Five-year (2015;2020)	Eurostat, 2023c;

The disposable income of households spent on essential goods and services indicator can be further disaggregated by income quantile; European geopolitical entities; and consumption purpose:

- Income quantile:
  - Total;
  - Quintiles;
  - Deciles;
- Classification of individual consumption purpose:
  - All-items Harmonised Index of Consumer Prices (HICP);
  - Transport;
  - Operation of personal transport equipment;
  - Fuels and lubricants for personal transport equipment;
  - Maintenance and repair of personal transport equipment;
  - Transport services except passenger transport by air, sea and inland waterway;
  - Others *(related to households and day-to-day living expenses)*;

3.3.2.3 Accessibility indicators

Distribution of population by level of difficulty in accessing public transport, income quintile and degree of urbanisation

The "*Distribution of population by level of difficulty in accessing public transport, income quintile and degree of urbanisation*" indicator, represents, as the name implies, how hard is to population to satisfy their public transportation needs, whether in urban, peri-urban and rural locations in order to successfully participate in society.

Table 3.11, presents the identification code used by the source; the name which identifies the indicator on the database; the period in which data is available, and, the source of the indicator.

Regarding data availability, the last available data for countries, as expressed in Table 3.11, is 2012, although an option to select the year 2014 to evaluation is possible but only

Table 3.11: Technical details concerning the proportion of population with access to public transport.

Name (Unit)	Eurostat Code	Reference Period	Source
Distribution of population by level of difficulty in accessing public transport, income quintile and degree of urbanisation (%)	ILC_HCMP06;	annual (2012)	Eurostat, 2023d;

with data for the aggregate "Euro area - 20 countries (from 2023)". When it comes to data disaggregation, this indicator can be disaggregated into geopolitical entities down to a NUTS I level, but also as shown by Table 3.12.

Table 3.12: Available further data disaggregation options for the "Distribution of population by level of difficulty in accessing public transport, income quintile and degree of urbanisation" indicator

Degree of urbanisation	Level of difficulty	Quintile of income
Total;	Very High;	Total;
Cities;	High;	First quintile;
Towns and suburbs;	Low;	Second quintile;
Rural areas;	Very Low;	Third quintile;
		Fourth quintile;
		Fifth quintile;

Resident population using at least two means of transport according to the Census: total and by place of work or study

The amount of population using more than one mode of transport, represents, as the name of the indicator implies, the number of modes of transportation used to commute by resident population, which, therefore, can possibly be also a representation of the hardships felt by both, employed citizens and students, to reach a specific destination.

The last available data is affected by the Census that took place in 2021 in Portugal. Nonetheless, data from 2011 is also available, as expressed in Table 3.13.

Within this context, Table 3.13, presents the identification code used by the source; the name which identifies the indicator on the database; the period in which data is available, and, the source of the indicator.

The dataset in question was directly retrieved from the INE and PORDATA databases.

Regarding data disaggregation, this indicator can be disaggregated into four groups in the INE's database, such as: Place of residence; Sex; Activity status; and, work or study location (Table 3.14).

Table 3.13: Technical details concerning the population percentage in need of multiple means of transport to reach destination indicator.

Name (Unit)	Code	Reference Period	Source
Resident population using at least two means of transport according to the Census: total and by place of work or study (%)	0011705 *(INE)*;	deccennial (2011-2021)	INE, 2022b; FFMS, 2022;

Table 3.14: Available further data disaggregation options for the "Resident population using at least two means of transport: total and by place of work or study" indicator

Place of residence	Sex	Activity status	Work or study location
NUTS I; NUTS II; NUTS III; LAUs I;	Total; Male; Female;	Employed; Student;	In the parish where is residing now; In the same municipality, but other parish; In another municipality; Abroad;

3.3.2.4 Availability indicators

Car ownership per 1000 inhabitants

Individual transportation ownership was characterised using three indicators. The first two indicators, as presented in Table 3.15, have already been described in subsections 3.3.1.1 and 3.3.1.2, with the only variation being the unit of analysis for the former. Therefore, in this sub-subsection, the indicator "Car ownership per 1000 inhabitants" will be further elaborated upon.

Table 3.15: Technical details concerning the availability of total number of passenger cars, their class age, and respective density per 1000 inhabitants.

Name (Unit)	Eurostat Code	Reference Period	Source
Stock of vehicles by category and NUTS 2 regions (Nº)	TRAN_R_VEHST[a];	annual (1990-2021)	Eurostat, 2023m;
Passenger cars, by age (Nº)	ROAD_EQS_CARAGE[b];	annual (2013-2021)	Eurostat, 2023i;
Car ownership per 1000 inhabitants (‰)	0007248 *(INE)*; ROAD_EQS_CARHAB;	annual (1990-2021)	INE, 2022a; Eurostat, 2023b;

[a] - Indicator already described in subsection 3.3.1.1; Unit used for analysis differs;
[b] - Indicator already described in subsection 3.3.1.2;

With that said, the density of passenger cars per 1000 inhabitants is indicative of the Portuguese population's inclination towards private modes of transportation to fulfil their travel requirements (INE, 2023c). This preference is primarily manifested through the ownership of passenger cars, irrespective of their affordability for the household. Regarding data availability, this indicator has data which amounts back to year 1990, as expressed in Table 3.15. When it comes to data disaggregation, this indicator can only be disaggregated into geopolitical entities at NUTS I level.

For that matter, Table 3.15, presents the identification codes used by the sources; the names which identifies the indicators on the database; the period in which data is available, and, the source of the indicator.

3.4 Data Extraction

Data extraction procedures targeted the retrieval of the most up-to-date data available in the aforementioned databases. In other words, data from 2023 was projected as the ideal scenario. Notwithstanding, this was not possible due to data availability. Hence, some indicators may refer to periods between 2010 and 2023, in accordance with the data frame used for the literature review as previously stated.

Furthermore, in the event that the most recent data available are for 2020, the year 2019 was considered as the most recent year, in order to avoid any possible deviation of the data due to the COVID-19 pandemic. Every dataset collected was gathered in Excel files to ease data manipulation for vulnerability analysis.

3.5 Double Energy Vulnerability

Two vulnerability analyses were conducted. Due to data availability, vulnerability analysis may vary both in-depth and detail. The first one, consummated in a more broader manner, aimed a synopsis of the European situation regarding TP, thus being an exploratory analysis. The second analysis targeted the Portuguese TP reality.

The conducted vulnerability assessment of the Portuguese dwellings' circumstances regarding TP and DEV, as aforementioned, aims to obtain a thorough grasp of said problematics, in order to characterise them as best as possible.

Thus, an analysis of the Portuguese reality was first conducted using the indicators described in the previous section 3.3. When possible, a direct comparison between the most up-to-date data available and previous years where data was collected was conducted. This allowed not only for a more complete analysis of the observed behaviour of the indicators across a certain time span but also to evaluate the Portuguese population quality of life in relation to the broader concept of energy vulnerability.

Secondly, a crossover between the Portuguese position in relation to TP, and the work already developed by Palma *et al.*, 2019, regarding the Portuguese scenario of EP, was performed, resorting to the four indicators depicted in the following subsections (3.5.1.1 to 3.5.1.4), which consequently are further detailed in Chapter 4. In this way, this crossover (subsection 4.3.3) is intended to map out the Portuguese dwellings' who suffer from DEV, and see where are the most affected regions by this phenomenon. Furthermore, this crossing also considers the European reality between its countries, in an attempt to verify the existence of some form of overlap between the top 5 and the bottom-3 classified countries in the analysed indicators of EP and TP, therefore enabling the highlighting of regions where dwellings are particularly vulnerable and more susceptible to experiencing the aforementioned phenomena or from DEV.

3.5.1 Pertinent Indicators for Household Vulnerability Analysis

3.5.1.1 Arrears on utility bills

The "arrears on utility bills" indicator, represents both the economic strains and accountability of dwellings towards utility bills, reported as the share of population within said condition. Regarding data availability, this indicator only has data which amounts back to year 2003, as expressed in Table 3.16.

Table 3.16: Technical details concerning the arrears on utility bills indicator.

Name (Unit)	Eurostat Code	Reference Period	Source
Arrears on utility bills (%)	ILC_MDES07;	annual (2003-2022)	Eurostat, 2023a;

When it comes to data disaggregation, this indicator can be disaggregated into NUTS I level geopolitical entities, and as follows:

- Income situation in relation to the risk of poverty threshold:
  - Total;
  - Above 60% of median equivalised income;
  - Below 60% of median equivalised income;
- Type of household:
  - Total;
  - Single person;
  - Single person with dependant children;
  - Two adults with two dependant children;
  - Other 13 togglable options;

Due to its relevancy and commonality regarding TP for the present work, as per the reviewed literature and available data (FFMS, 2023), only "*Total*", "*Single person*", "*Single person with dependant children*", and "*Two adults with two dependant children*" typologies of households were considered.

3.5.1.2 Inability to keep home adequately warm

The "Inability to keep home adequately warm" indicator, presents itself almost as a carbon-copy of the indicator expressed in sub-subsection 3.5.1.1, this time, however, it represents the share of population with hardships regarding the warm up of their households, based on the question *"Can your household afford to keep its home adequately warm?"* (Gouveia *et al.*, 2022). Concerning data availability, this indicator only has data which amounts back to year 2003, as expressed in Table 3.17.

Table 3.17: Technical details concerning the inability to keep home adequately warm indicator.

Name (Unit)	**Eurostat Code**	**Reference Period**	**Source**
Inability to keep home adequately warm (%)	ILC_MDES01;	annual (2003-2022)	Eurostat, 2023g;

When it comes to data disaggregation, this indicator can be disaggregated into NUTS I level geopolitical entities, and as follows:

- Income situation in relation to the risk of poverty threshold:
  - Total;
  - Above 60% of median equivalised income;
  - Below 60% of median equivalised income;
- Type of household:
  - Total;
  - Single person;
  - Single person with dependant children;
  - Two adults with two dependant children;
  - Other 13 togglable options;

Due to its relevancy and commonality regarding TP for the present work, as per the reviewed literature and available data (FFMS, 2023), only "*Total*", "*Single person*", "*Single person with dependant children*", and "*Two adults with two dependant children*" typologies of households were considered.

3.5.1.3 Population living in dwellings' with presence of leak, damp, and rot

Regarding populations living in dwellings' with presence of leak, damp, and/or rot, Figure 4.14, provides an overview of the share of European dwellings' whose homes are affected by at least one of the following: Leaking roof; Damp walls/floor/foundation; Rot in window frames or floor. This indicator, according to Gouveia *et al.*, 2022, is based on the answers to the question *'"Do you have any of the following problems with your dwelling/accommodation?"'* (Gouveia *et al.*, 2022). Respecting data availability, this indicator only has data which amounts back to year 2003, as expressed in Table 3.18.

Table 3.18: Technical details concerning the population living in dwellings' with presence of leak, damp, and rot indicator.

Name (Unit)	Eurostat Code	Reference Period	Source
Total population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor (%)	ILC_MDHO01;	annual (2003-2020)	Eurostat, 2023n;

When it comes to data disaggregation, this indicator can be disaggregated into NUTS I level geopolitical entities, and as follows (Table 3.19):

Table 3.19: Available further data disaggregation options for the "Total population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor" indicator

Age class	Income situation in relation to the risk of poverty threshold	Type of household	Sex
Total;	Total;	Total;	Total;
Less than 18 years;	Above 60% of median equivalised income;	Single person;	Male;
From 18 to 64 years;	Below 60% of median equivalised income;	Single person with dependant children;	Female;
65 years or over;		Two adults with two dependant children;	
		Other 13 togglable options;	

Due to its relevancy and commonality regarding TP for the present work, as per the reviewed literature and available data (FFMS, 2023), only "*Total*", "*Single person*", "*Single person with dependant children*", and "*Two adults with two dependant children*" typologies of households were considered.

3.5.1.4 At risk of poverty or social exclusion

The "Persons at risk of poverty or social exclusion by age and sex" indicator, represents the share of population facing socio-economic hardships with disposable incomes below the risk-of-poverty threshold (Gouveia *et al.*, 2022). Regarding data availability, this indicator only has data which amounts back to year 2014, as expressed in Table 3.20.

When it comes to data disaggregation, this indicator can be disaggregated into NUTS I level geopolitical entities, and as follows:

Table 3.20: Technical details concerning the at risk of poverty or social exclusion indicator.

Name (Unit)	**Eurostat Code**	**Reference Period**	**Source**
Persons at risk of poverty or social exclusion by age and sex (%)	ILC_PEPS01;	annual (2014-2022)	Eurostat, 2023j;

- Age class:
  - Total;
  - Other 33 togglable options;
- Unit of measure:
  - Thousand persons;
  - Percentage;
- Sex:
  - Total;
  - Males;
  - Females;

4

Main Findings and Results

The key findings and results gained from the analysis of data acquired throughout the course of this study are presented in this Chapter. Whilst highlighting major findings that may contribute to answering the research questions, Chapter 4, not only offers valuable insights into patterns, relationships, and trends, but also, tries to shed light on the relevance and significance of the acquired results through thorough analysis, interpretation, and discussing its implications.

4.1 European Contextualisation

4.1.1 Stock of vehicles by category and NUTS 2 regions

Regarding the European stock of passenger cars, Figure 4.1 provides an oversight of the existent car ownership per 1000 inhabitants density, across the vast majority of Europe, in the year 2021. Although there is the possibility to slim down the analysis up to NUTS II regions, due to lack of data for Portugal and other countries such as Albania, France, or Denmark, for example, this analysis was performed at a national level, instead.

In that same year, 2021, the EU-27 (*See Annex .3 for further information regarding aggregate/country labels*), had a passenger car density of 567 passenger cars per 1000 inhabitants. Still in this regard, Turkey had the least amount of passenger cars per 1000 inhabitants (166 passenger cars per 1000 inhabitants). Contrarily, Liechtenstein had the most cars per inhabitant density (777 passenger cars per 1000 inhabitants), well above the EU-27 value. As a specific case study, Portugal had a density of 544 passenger cars per 1000 inhabitants.

Furthermore, a few statements should be considered: In that regard, it should be noted that, EU-27 variation values are comprised of a time-frame between 2011 and 2021, instead of the 2010-2021 period as many of the remaining countries.

Likewise, data reports time-frames from several countries differ from this 10/11-year time-frame; Those are the cases of Albania (2013-2021), Iceland (2017-2021), and Montenegro (2011; 2014-2021). Remaining gaps in data reporting are visible in the United Kingdom in the years of 2013-2014 and 2019-2020. For Serbia, there is only reports from 2010 and 2020, which leads us to the thinking that there is a different approach to data retrieval for this indicator - decennial instead of annual. Moreover, both France in 2013 and 2014, and Lithuania in 2014 had breaks in time-series (hence the 'sudden drop' in values for Lithuania).

Upon observation of Figure 4.1, although common for the vast majority of European countries under analysis major increasing variations in car ownership per 1000 inhabitants, are more noticeable in countries like Kosovo *(from this point onwards, the use of this designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence)* (48.1%), Romania (46.5%), Albania (43.8%), North Macedonia (41.9%) and Turkey (37.4%). Portugal on the other hand, although not as noticeable as the top 5 countries previously stated, sits slightly above, the EU-27 variation, with a 18.4% variation (in comparison to a 14.3% variation), which can be partly explained in reflection of a general decrease in car ownership and maintenance costs (Curl *et al.*, 2018). Contrarily, countries such as Lithuania (3.5%), Malta (3.3%) and Luxembourg (3.2%) reported the lowest variations.

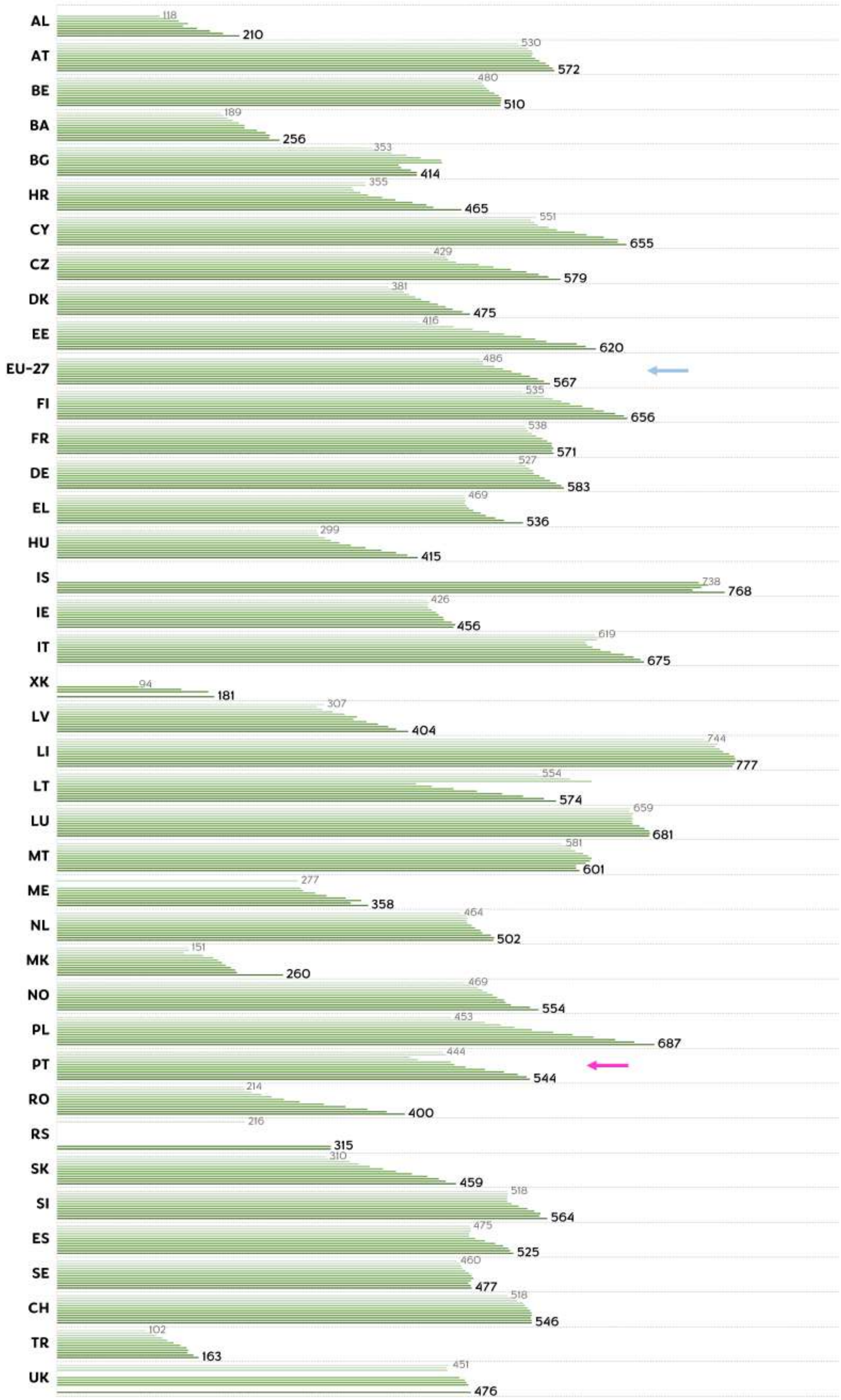


Figure 4.1: European overview of passenger car proprietorship evolution since 2010 (per 1000 inhabitants) at national level. Retrieved from Eurostat, 2023m. See Annex .3 for further information regarding aggregate/country labels.

4.1.2 Passenger cars, by age

In 2021, Europe's total number of passenger cars alone was approximately 312 million units. In 2013, this number was approximately about 270 million (Eurostat, 2023i). Table 4.1 presents the number of European passenger cars per age class in 2021. The table further categorises the vehicles based on their age, showing the distribution across different age classes.

In hindsight, it is possible to assess that, with all things compared, the number of passenger cars aged less than 2 years is only a relatively small portion of the overall European car stock. Similarly, the '2 to 5 years' age class accounted for approximately 48 million units, representing still a small portion of vehicles, but with increased significance in number of semi-new vehicles roaming about on the roads. Approximately 64 million units are comprised within the '5 to 10 years' age class, which start to show the ever-so-increasing ageing of the European car stock.

Table 4.1: Number of European passenger cars per age class in 2021. Dataset from Eurostat, 2023i.

Age Class	Number of passenger cars (Aprox.)
TOTAL	311 748 184 [a,d]
Less than 2 years	32 362 405 [b]
2 to 5 years	47 692 869 [b]
5 to 10 years	63 937 902 [b]
10 to 20 years	116 789 804 [b]
Over 20 years	37 872 772 [c]

[a] - Serbia value for 2020 included, instead of 2021, due to different data retrieval approach;
[b] - NOT INCLUDED: Bulgaria; Greece; Slovakia; Serbia;
[c] - NOT INCLUDED: Bulgaria; Czechia; Ireland; Italy; Slovakia; North Macedonia; Serbia;
[d] - 10 927 614 units not accounted for due to points [b] and [c].

Moreover, Table 4.1, still depicts the majority of passenger cars as being 10 years or older for a total of approximately 155 million units, or 52% of the total European car stock.

Note that the data for Serbia, in 2020, was included instead of 2021 due to a different data collection approach. Also, Bulgaria, Czechia, Greece, Italy, Ireland, North Macedonia, Serbia, and Slovakia were not included in the analysis for certain age classes, leading to a small portion of the total units not being accounted for, due to data not being available.

Further assessments were conducted to determine the countries that possess an older car park. Passenger cars that were 10 years old or older were considered for this purpose, since "*EU cars are now on average 12 years old*" (ACEA, 2023). The top 5 countries with the most vulnerable car parks, based on the percentage of passenger cars that are over 10 years old, are Albania (91.6%), North Macedonia (88.8%), Bosnia and Herzegovina (85.3%), Montenegro (81.1%), and Lithuania (80.9%). These percentages are relative to the total stock of passenger cars in each country. Conversely, the least three vulnerable populations are found in Luxembourg (25.3%), Belgium (33.3%), and Liechtenstein (34.27%), where passenger cars under 10 years old are the norm. As a specific case study, Portugal has a passenger car over 10 years old quota of 61.49% of its total passenger car stock.

4.1.3 Distribution of population by level of difficulty in accessing public transport, income quintile and degree of urbanisation

With respect to public transport access, and the indicator 'ILC_HCMP06' - denoted in Table 3.1, above -, it became clear what the reviewed literature manifested. According to Figure 4.2, the illustrated distribution of hardships when accessing public transport by degree of urbanisation and income quintiles shows that, European populations, have greater difficulty to satisfy their travel needs in peri-urban and rural areas.
To compose Figure 4.2 the following countries were analysed: *Belgium, Bulgaria, Czechia, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden, Iceland, Norway, Switzerland, and The United Kingdom.*

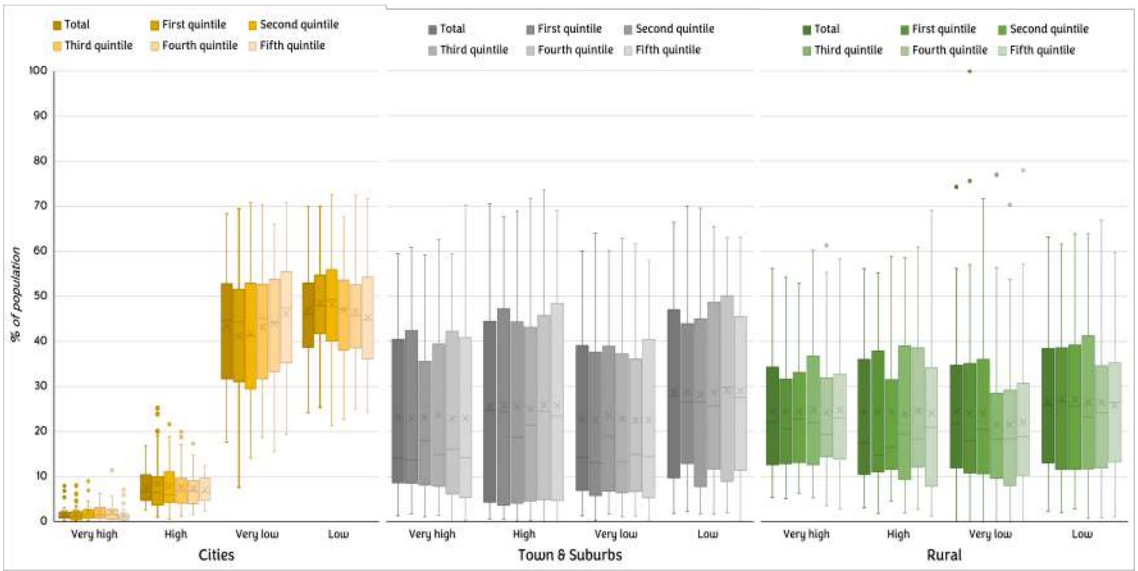


Figure 4.2: Distribution of percentage of population by level of difficulty in accessing public transport, income quintile and degree of urbanisation, in 2012. Dataset from Eurostat, 2023d.

Surprisingly, it was also evidenced that there is no real discrepancy between income quintiles, which denies, to some degree, a few examined authors (e.g., Sterzer, 2017; Coulombel, 2018). In other words, the data retrieved and subsequently analysed, showed that living on the outskirts of a city is more detrimental to easily participating in society, rather than having lower incomes, despite the latter not excluding its own adversities, as van Dülmen *et al.*, 2022 showed by demonstrating that individual social disadvantage mattered more than regional spatial disadvantage.

Figure 4.3 shows the data distribution, similarly to Figure 4.2, but only for the EU-27. Here, the same conclusions withstand. Despite having their own adversities, dwellings' income, is not such a major driver to hardships to access public transport, such as the location where the population lives.

For reference, each colour set identifies an income quintile - *'Blue' bars are related to the first quintile; 'Green' bars are related to the second quintile; 'Yellow' bars are related to the Third quintile; 'Orange' bars are related to the fourth quintile; and, 'Grey' bars are related to the fifth quintile* - which is then comprised of four bars symbolising four classes of difficulty (these being, *'Very high' - darkest shade; 'High'; 'Low'; and 'Very low' - lightest shade*)

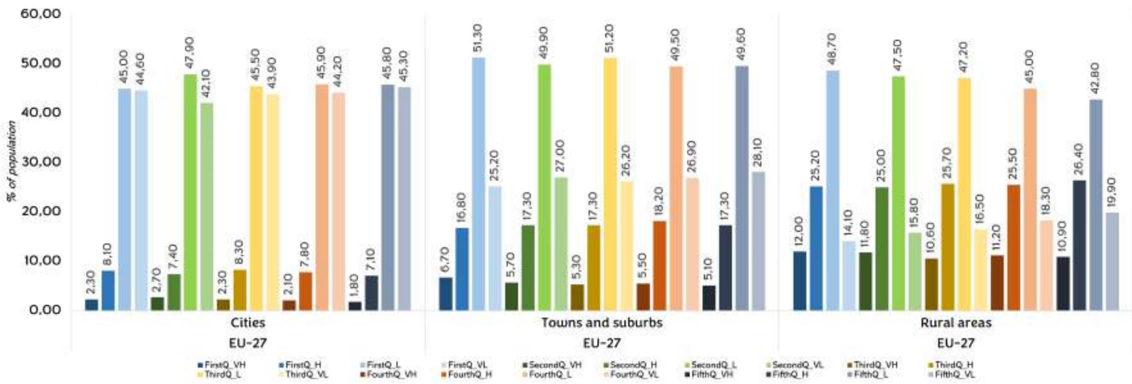


Figure 4.3: Percentage of EU-27 population, by level of difficulty in accessing public transport, income quintile and degree of urbanisation, in 2012. Dataset from Eurostat, 2023d. See Annex .3 for further information regarding aggregate/country labels. Adapted.

4.1.4 Final consumption expenditure of households by consumption purpose

Regarding dwellings consumption by purpose, and by percentage of total expenditure, there is evidence of a decreasing trend of the percentage of total expenditures, since 2010, with the exception of Greece, Croatia, the United Kingdom, and Iceland where increases up to two percentage points were observed.

Nonetheless, in 2021, 19 nations are past the EU average value (49.9%) of household consumption expenditure, as illustrated by Figure 4.4. Of those, Montenegro (87.6%), Greece (71.5%), Bosnia and Herzegovina (70.7%), Croatia (70.3%), and Serbia (65.3%), make up the top 5 as the countries whose household consumption expenditures, as a ratio to GDP, are the highest. Portugal makes up the top-6 with a household income burden of 64.7%.

Data from Albania, North Macedonia, and the United Kingdom are from 2019 which means that, if visible trends continue, the top 5 would change. Being then comprised by: Montenegro (87.6%), **Albania (79.2%)**, Greece (71.5%), Bosnia and Herzegovina (70.7%), and Croatia (70.3%).Portugal would end dropping down to the 7^{th} position, as Figure 4.4 illustrates. Contrastingly, Ireland (24.1%), Luxembourg (31.1%), and the Netherlands (36.0%), present the least amount of economic pressure amongst their households.

Generally speaking, transportation costs to households , are also seen to be between the top 3 major pressures on dwellings' budgets (Eurostat, 2023e), usually after "housing, water, electricity, gas and other fuels" costs and "food and non-alcoholic beverages". Figure 4.5, pictures transportation expenditures by households, as a percentage of the total household expenditure, in the year 2021 *(similarly to Figure 4.4, data from Albania, North Macedonia, Switzerland and the United Kingdom are from 2019).*

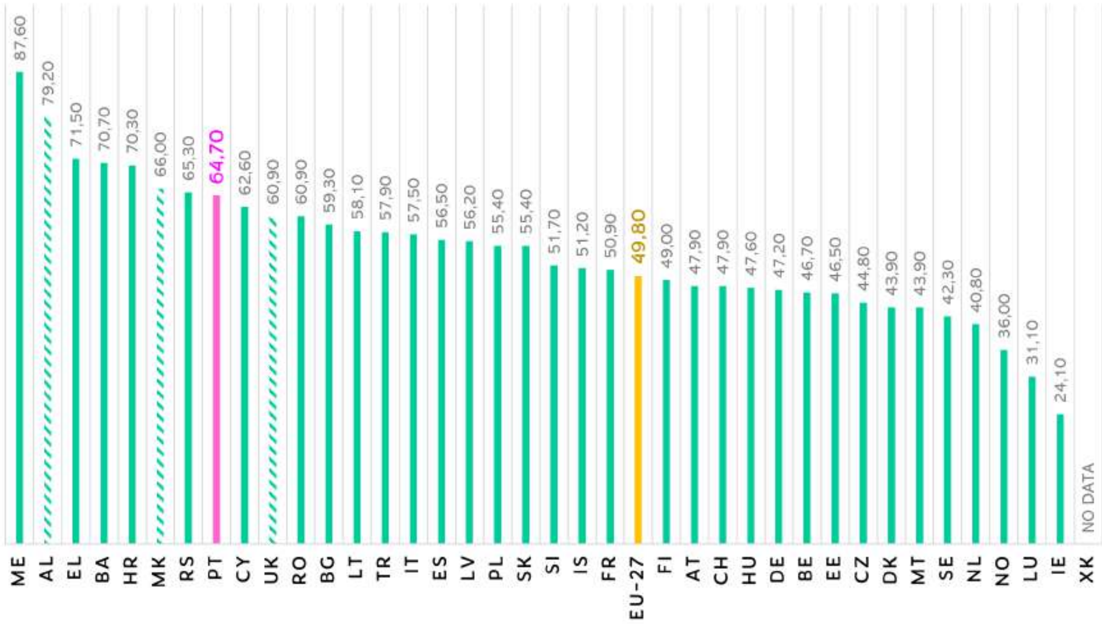


Figure 4.4: Household consumption expenditure by European country, in 2021, as a ratio to GDP. Dataset from Eurostat, 2023e. Data from Albania, North Macedonia, and the United Kingdom are from 2019. See Annex .3 for further information regarding aggregate/country labels. Adapted.

Whereas the EU mean expenditure in transport sits around 12.1%, Slovenia (16.9%), Turkey (16.2%), Lithuania (15.3%), Norway (14.4%), and Luxembourg (14.2%), make up the top 5 as the countries whose transport expenditures, are the highest. Contrastingly, Slovakia (5.3%), Croatia (7.6%), and Czechia (9.5%), present the least amount of economic pressure amongst their households.

Portugal, as a specific case study, when it comes to expenditure in transportation, sits near the middle of the scale with an 11.6% expense of total expenditure, in similar fashion to Greece and Hungary. As stated above it is also the third major expense to Portuguese households, following "housing, water, electricity, gas and other fuels" costs (19.8%) and "food and non-alcoholic beverages" costs (17.9%).

This total transport expenditure percentage for Portugal can be further broken down into purchase of vehicles (34.5%); operation of personal transport equipment (57.8%); and transport services (7.8%) costs, which demonstrates the hefty burden that is to own a personal transport in Portugal.

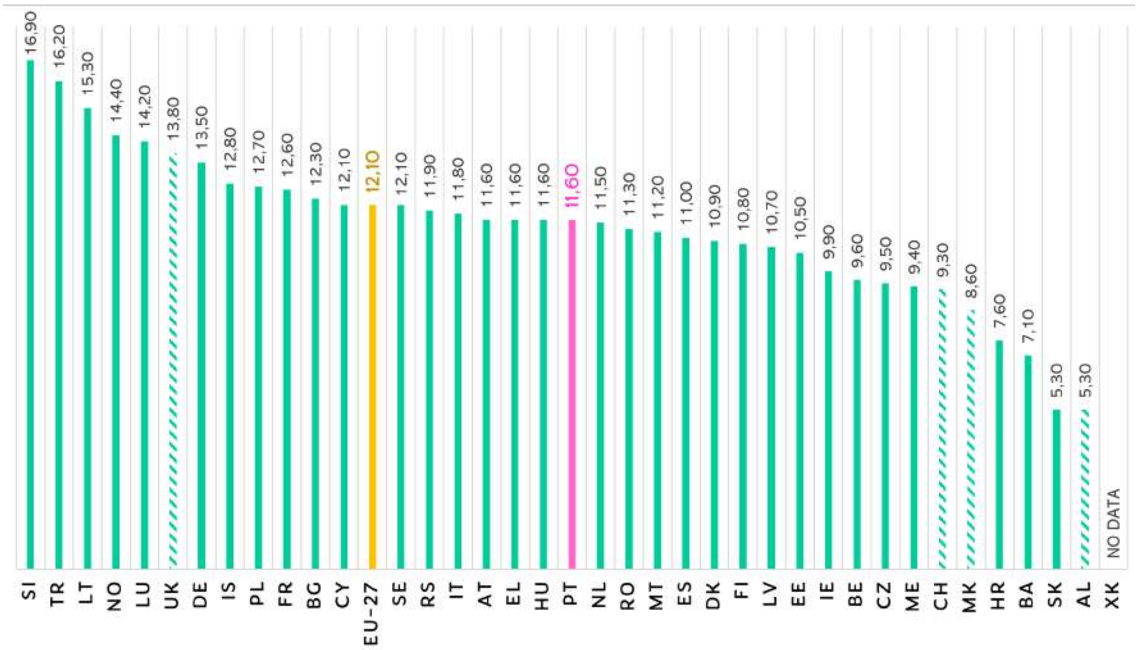


Figure 4.5: Household consumption expenditure by country, in transportation, in 2021, as percentage of total expenditure. Dataset from Eurostat, 2023e. Data from Albania, North Macedonia, Switzerland, and the United Kingdom are from 2019. See Annex .3 for further information regarding aggregate/country labels. Adapted.

4.1.5 Income of households by NUTS 2 regions

Unlike subsections 4.1.1, 4.1.2, and 4.1.4, where 2021 was the year under analysis, due to the nonexistence of sufficient data for the same year, 2019 was chosen instead, acknowledging section 3.4, in order to avoid any possible deviation of the data due to the COVID-19 pandemic.

A total of 250 NUTS II regions were analysed. Table 4.2, ranks and shows the average annual income of households per NUTS II region, emphasising both the top 5 and bottom-3 most and least earning regions, respectively. It also shows the average income of EU-27 households, and how the Portuguese reality compares itself amongst its NUTS II regions counterparts.

To put matters into perspective, at country level, common trends were found. Firstly, it was observed that households in the west-central and northern European countries were the richest with average national incomes up to 34 900 €. These countries, (e.g., Norway, Germany, and Denmark) for instance, have the most prevalent NUTS II regions in high annual income statuses, were the richest countries average national incomes go up to 34 900 €, which can be translated into less vulnerable households to increments in essential services costs , such as housing costs (utility bills) or travel needs, for example (Coulombel, 2018). Those who comprise the bottom-3 of less vulnerability regarding an average national household annual incomes, *per capita*, hence, having the most annual earnings are: Luxembourg, with an average national household income of 34 900 €, therefore standing in the number one spot, followed by Norway (29 000 €), and Austria (24 100 €).

In contrast, the poorest countries are confined to the Balkans and Eastern Europe regions, with the most NUTS II regions prevalent in low annual income *per capita* situations, further expanding on the ideas of prior disclosed literature (e.g., Castro *et al.*, 2022; Shi *et al.*, 2022) stating that low-income areas are the most vulnerable to TP. Bulgaria (5 000 €), Romania (6 600 €), Croatia (7 700€), Hungary (7 900€), and Poland (8 100 €) are the 5 most vulnerable countries, towards households regarding average national household annual incomes, *per capita*.

Table 4.2: Top 5, Portugal's, and bottom-3 annual incomes, per inhabitant of households of NUTS II regions, for the year 2019. EU-27 value included for comparison purposes - Not NUTS II region. See Annex .3 for further information regarding aggregate/country labels.

Rank	**Label**	**NUTS II Region**	**Annual income** *(€ per inhabitant)*
1^{st}	LU	*Luxembourg*	34 900
2^{nd}	NO	*Oslo og Viken*	30 500
3^{rd}	NO	*Vestlandet*	28 900
4^{th}	NO	*Nord-Norge*	28 100
5^{th}	DE	*Oberbayern*	28 000
...	...	...	...
139^{th}	EU-27	*European Union - 27 countries*	17 100
...	...	...	...
151^{st}	PT	*Algarve*	15 500
153^{rd}	PT	*Área Metropolitana de Lisboa*	14 800
172^{nd}	PT	*Região Autónoma dos Açores*	12 400
176^{th}	PT	*Alentejo*	12 300
178^{th}	PT	*Região Autónoma da Madeira*	12 200
179^{th}	PT	*Centro*	12 000
185^{th}	PT	*Norte*	11 200
...	...	...	...
246^{th}	BG	*Yugoiztochen*	4 000
247^{th}	BG	*Severoiztochen*	3 900
248^{th}	BG	*Severozapaden*	3 800

The 249^{th} and 250^{th} ranks are corresponding to NUTS II regions of "*Malta*" (MT - Malta) and "*Crna Gora*" (ME - Montenegro), respectively, which did not had data for the year 2019.

Last but not least, it is noteworthy to disclose that more details about the type of urban fabric of the analysed regions could be depicted, if solid data was available for a more robust analysis, however, given the lack of depth of the indicator regarding NUTS III regions, this was not possible. However, as demonstrated by Table 4.2, Portugal and any of its NUTS II regions sit below the average European household income. Within this Portuguese context, since there is no disparity between 'Área Metropolitana de Lisboa' (*urban*), 'Algarve' (*peri-urban*), 'Região Autónoma da Madeira' (*urban*) and, 'Região Autonóma dos Açores' (*peri-urban*) NUTS II regions, to NUTS III regions, both in nomenclature and regional territory (see Annex .2; Eurostat, 2022), it is possible to witness that urban and peri-urban areas are the amongst the most earning regions in the country, thus enriching Lucas *et al.*, 2018 findings and, once again, revealing the increased difficulties rural regions face regarding TP.

4.1.6 Final energy consumption by sector

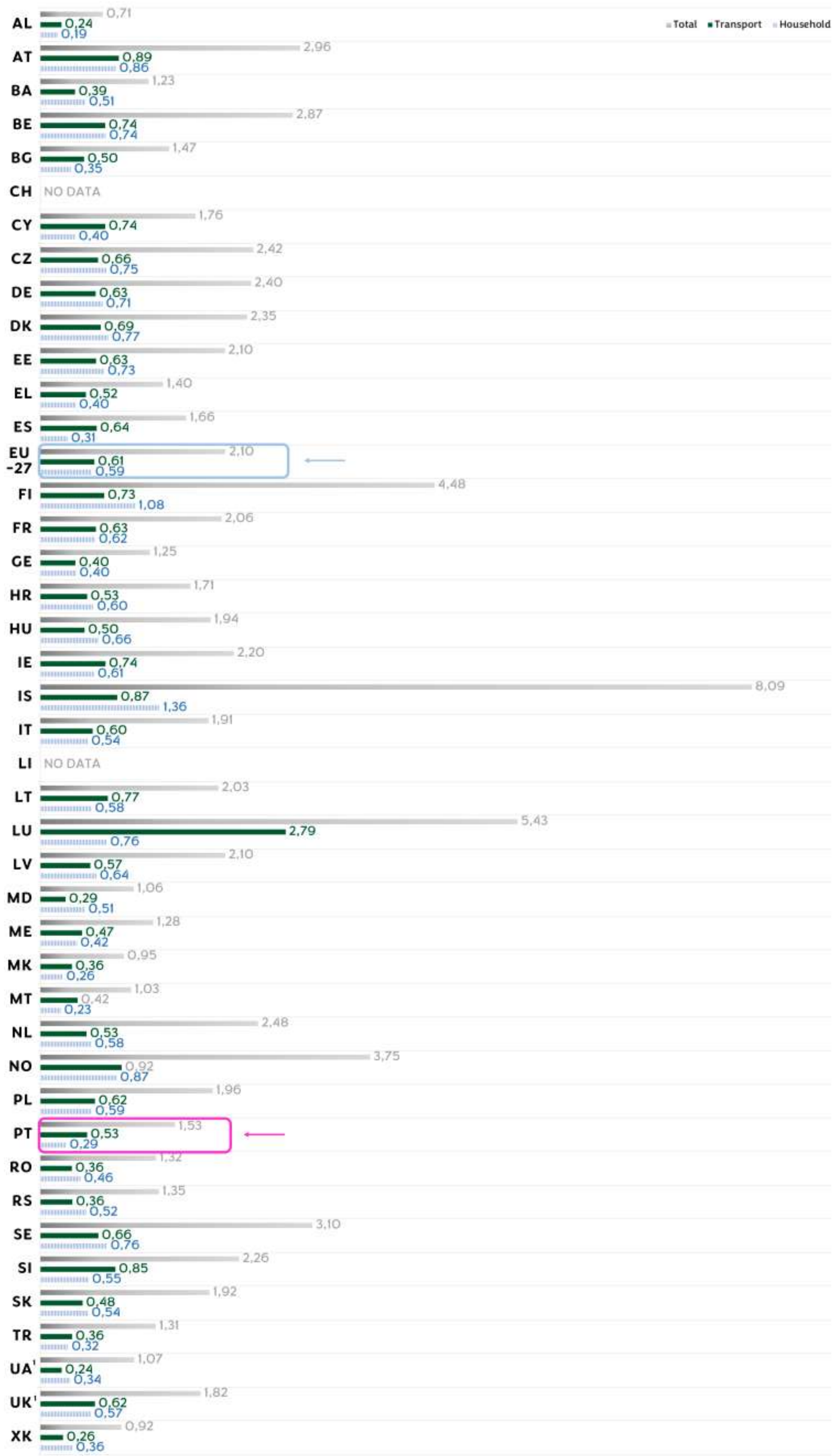
Succeeding to data visualisation and analysis regarding "final energy consumption by sector" indicator it is clear that, overall, in 2021, European countries consumed similar amounts of energy for both the transport and household sectors. Moreover, in most countries, when combined, these sectors mainly comprise more than half of the totality of energy used for consumption by end-users, something that is noticeable opposing to Northern European countries in the likes of Finland, Sweden, Iceland and Norway. In these nations, although there is a slight higher consumption of energy in the households' sector in comparison to the transport sector, when combined, these sectors do not amount to more than 50% of the total energy consumption.

As illustrated by Figure 4.6, energy consumption by end-users, averaged a total of 2.10 Tonne of oil equivalent (toe) *per capita* in the EU-27 countries, with the transport sector covering a total of 6.15 toe *per capita*, and the household sector covering a total of 5.86 toe *per capita*, of said total energy consumption. This not only leaves 8.99 toe *per capita* "remaining" to be distributed per other sectors, but also follows the aforementioned trend in major European countries. Hence, concerning European rankings in total energy consumption, the top 5 of most consumption *per capita* is composed by, Iceland with an energy consumption *per capita* of 8.09 toe, followed by Luxembourg (5.43 toe), Finland (4.48 toe), Norway (3.75 toe), and Sweden (3.10 toe). Whereas the bottom-3, which means they have the least total energy consumption *per capita* are North Macedonia (0.95 toe), Kosovo (0.92 toe), and Albania (0.71 toe). The Portuguese total energy consumption *per capita* is estimated to be at 1.53 toe *per capita*, amongst the Balkans and Eastern European countries such as Croatia, Montenegro, Greece and Romania.

Interestingly, this partially diverts from Bouzarovski, 2014 findings where the author evidenced that EP was comparatively lower among Scandinavian countries. In contrast, Southern European countries displayed a greater propensity for EP manifestation, owing to their correlation with lower incomes and poorly insulated housing (Middlemiss, 2022).

Furthermore, the findings of the present work indicate the potential presence of socio-economic factors, in conjunction with environmental components that may lead to cooler thermostats temperature settings contributing to the lower levels of energy consumption observed in Southern European nations as compared to their Scandinavian counterparts (where '*temperatures are mostly lower and might sink down to 10-20 degrees below zero Celsius. Some places can even experience a bone chilling minus 40 degrees Celsius!*' in winters (VistitNorway, n.d.)), for example and, accordingly, to lower levels of energy consumption. Higher energy use can also be triggered by winter nights mostly affecting the Scandinavia region in winter time, where days are shorter (VistitNorway, n.d.) and nights longer, and therefore, more demanding for households energy consumption (van der Wiel *et al.*, 2019).

In short, despite the fact that Scandinavian countries exhibit higher energy usage, they possess more energy-efficient residential structures, and technological solutions in comparison to those found in Southern European countries (Gouveia *et al.*, 2022). Not only that, Southern households incapability to attain technological solutions to warm or cool their homes also hinders its dwellings' energy consumption (Bardazzi *et al.*, 2023).



1 - Values correspond to 2019 consumptions.

Figure 4.6: European overview of final energy consumption by end-users in 2021, at national level, in tonne of oil equivalent (toe) *per capita*. Dataset from Eurostat, 2023k. See Annex .3 for further information regarding aggregate/country labels.

4.2 Portuguese Contextualisation

4.2.1 Travel duration indicators

The Portuguese scene regarding travel time on commutes by employed residents and/or students has worsened between the years 2011 until 2021. In short, both the average commute duration by students or employed residents in Portugal has increased (INE, 2023a; INE, 2023b). Howbeit, despite not being able to do so due to data availability, it should be noted that 'time' itself does not provide a fair assessment of vulnerability regarding commute time. Other factors such distance, for instance, or even the status of degradability of the infrastructures of mobility, need to be taken into account since it differs from individual to individual, and can affect individuals in different manners and aspects of their lives (*(e.g. Despite living just 3 kilometers away from the nearest train station, "Rita", takes around 40 minutes to travel this route, by bus, so that "she" can get to the university on time. Opposingly, "Rui", who uses "his" individual mode of transport is capable of reaching "his" workplace, 40 kilometers away from his dwelling, in the same time "Rita" needs to reach the train station.*)).

Figure 4.7 illustrates the Portuguese panorama regarding the year 2011 per the *'old'* LAU I regions (municipalities), whereas Figure 4.8 goes deeper in its analytic overview, reaching down up to the *'old'* LAU II level (civil parishes). In both figures, the 'Y' axis represents travel time spent by both employed and student population (*the majority actors who are members of an active population, and who therefore constitute the main users of public and private transport*) to commute to work or school, where a positive value means that it is beneficial the use of private transportation, such as passenger cars to commute. Contrastingly, negative 'Y' values, intend to exhibit that the use of public transportation, are the most beneficial to commute to work or school. For reference, any means of "*public/communal transportation*" is regarded to have in mind bus, train, underground and boat/ ferry trips, whereas "*individual/private transport*" has in mind commutes by car, both as driver and passenger, and motorcycles.

In that sense, therefore, it was observed that, in Portugal, in the year of 2011, citizens spent an average of 23 minutes and 26 seconds in commute by collective transport, and, an average of 19 minutes and 11 seconds in commute by individual transport. Similarly, in 2021, said average values increased up to 26 minutes and 7 seconds and 21 minutes and 14 seconds, respectively, which translates to a 10% increase in commuting times by communal transportation, and in a 12% increase in commuting times by individual/private transport. It is clear that this comparison is "unnatural" due to the different depths in data used for comparison being distinct (municipality vs parish level) - hence the great disparity observed in data points for 2011 and 2021 -, and not fully comprehensive of the reality of the regions evaluated; nonetheless, the results are helpful to understand the variation occurred in the period between 2011 and 2021.

Accordingly, in Figure 4.7, "Barrancos" municipality presents itself as the municipality

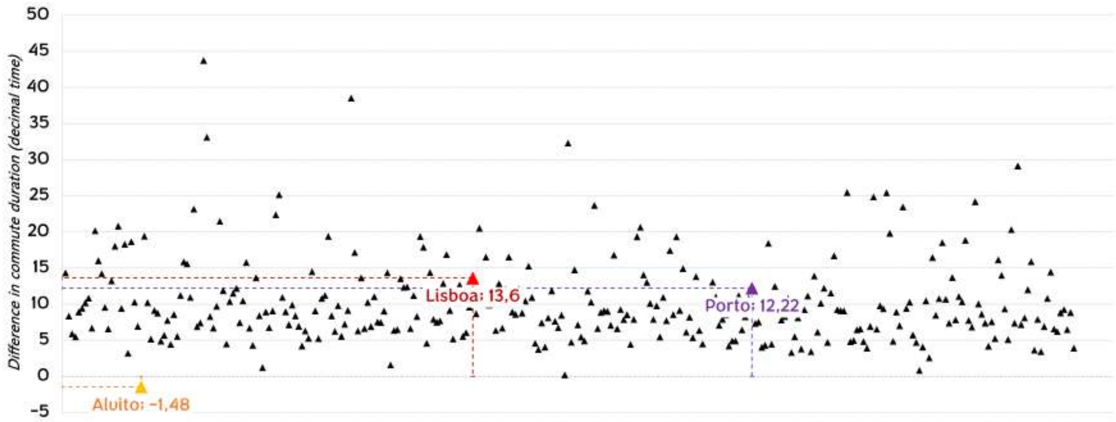


Figure 4.7: Difference of average time spent on commute of employed or student resident population using individual or collective mode of transport by place of residence (municipality level). Each-dot represent a Portuguese municipality. Data from INE, 2023a. Positive values represent a benefit of using individual transportation in commutes. Negative values represent a benefit of using collective transportation in commutes.

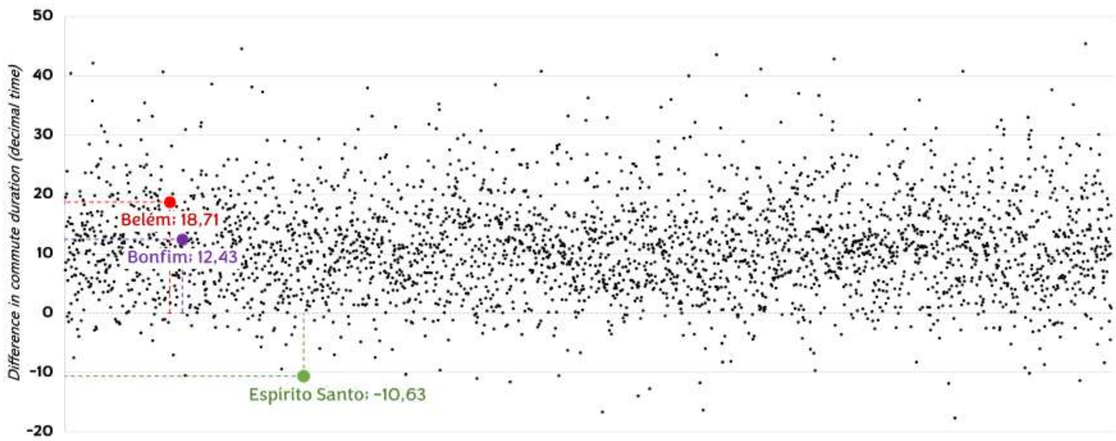


Figure 4.8: Difference of average time spent on commute of employed or student resident population using individual or collective mode of transport by place of residence (parish level). Each-dot represent a Portuguese parish. Data from INE, 2023b. Positive values represent a benefit of using individual transportation in commutes. Negative values represent a benefit of using collective transportation in commutes.

with the highest average commute time to work or school by the population, with an average commute time of 43 minutes and 44 seconds, at the other end of the spectrum sits "Alvito" municipality with an average commute time of -1 minute and 29 seconds (therefore the use of collective transportation being more beneficial to commute). Interestingly, regarding degree of urbanisation in these municipalities, both are classified as "predominantly rural" since being within the boundaries of the same NUTS III region as per the *'NUTS 2021 Classification'* - *'Baixo-Alentejo'* (See Annex .2). In Figure 4.8, "Vila Nova da Barquinha" civil parish presents itself as the municipality with the highest average commute time to work or school by the population, with an average commute time of 45 minutes and 23 seconds, at the other end of the spectrum sits "União das freguesias de Quirás e Pinheiro Novo" civil parish with an average commute time of -17 minutes and 40 seconds (therefore the use of collective transportation being more beneficial to commute). Interestingly, regarding degree of urbanisation in these civil parishes, both are classified as "predominantly rural" (See Annex .2).

Moreover, while still acknowledging both Figures 4.7 and 4.8, it is possible to witness that both "Belém" (Lisbon ("Lisboa") Municipality) and "Bonfim" (Porto Municipality), for example, in representation of its municipalities have higher average commute times in 2021, when compared to their respective municipalities averages in 2011. More so, even if accounting all of 24 civil parishes existent in "Lisboa", their average commute duration would still be higher (15 minutes and 6 seconds) than that of 2011 (13 minutes and 36 seconds). Plus, it was also observed that in all parishes, the use of the private car would still be more beneficial than the use of public transport. For "Porto", the same occurrence was witnessed for its seven civil parishes: average commute times in 2021 sit around 13 minutes and 24 seconds, compared with 12 minutes and 12 seconds in 2011. Like in "Lisboa" the use of the private car would still be more beneficial for the population to commute. These two are inserted in NUTS III considered as "predominantly urban" as per the *'NUTS 2021 Classification'*.

These results can thus have several meanings. First, they can help explain the population's convenience preferences, since, according to documentation from the (INE), "light cars are the preferred means of transport" for the population. However, on the other hand, they can make evident a lack of investment in public transport that is accessible, efficient, and comfortable for the daily use of the population, or even demonstrate the non-existence of public transport (Churchill and Smyth, 2019; Székely and Novotný, 2022; Silver *et al.*, 2023). Furthermore, they can provide evidence of the demographic transition towards major urban centres, such as Porto and Lisbon e.g., through the observed increase in commuting times for the active population. Thus, this phenomenon can be attributed to the higher population density and resulting infrastructure saturation in these urban areas (European Commission, 2023; INE, 2023c). Relating to the latter, the *'NUTS 2021 Classification'* is a great indication of said populational shift: Only three NUTS III regions are classified as "predominantly urban" - *(PT11A) Área Metropolitana do Porto*; *(PT170) Área Metropolitana de Lisboa*; and *(PT300) Região Autónoma da Madeira*. Five NUTS III regions are classified as "intermediate" - *(PT112) Cávado*; *(PT119) Ave*; *(PT11C) Tâmega e Sousa*; *(PT150) Algarve*; and *(PT200) Região Autónoma dos Açores*. The remaining NUTS III regions are classified as "predominantly rural" (See Annex .2 for more information).

4.2.2 Affordability indicators

Like any other country, Portugal faces the complex challenge of ensuring that households have access to essential goods and services without compromising their financial stability. The "Percentage of disposable income of households spent on essential goods and services, by income deciles" indicator reveals the extent to which dwellings across different income deciles allocate their disposable income to cover these fundamental necessities.

The indicator's insights underscores the persistence of disparities in affordability among different income groups for 2015. The variation across income deciles exposes a dichotomy: while higher income deciles may allocate a relatively smaller proportion of their disposable income to essential goods and services, lower income deciles face a disproportionately larger burden. Furthermore, the aforementioned indicator sheds light on the intricate interplay between housing costs, food, and transport affordability.

In fact, for that same year, the first decile of income had a financial burden, solely for those three groups of needs, of 141.9% of their disposable income. Interestingly, the tenth decile is the one with the least amount of financial distress when accounting for the disposable income allocated for transport, food and housing costs with a summed average of 37.6% of the total disposable income of the household. In between, Portuguese dwellings' range from 94% to nearly 50% of disposable income allocated for their major expenses groups. In short, the vast majority of the Portuguese income deciles, exhibited narrow financial margins to address other essential needs.

However, it is also noteworthy to mention that, the most hurtful condition to Portuguese dwellings', ends up being housing costs. In other words, dwellings' in domestic EP situations are most vulnerable to higher financial distresses than those only with mobility hardships.

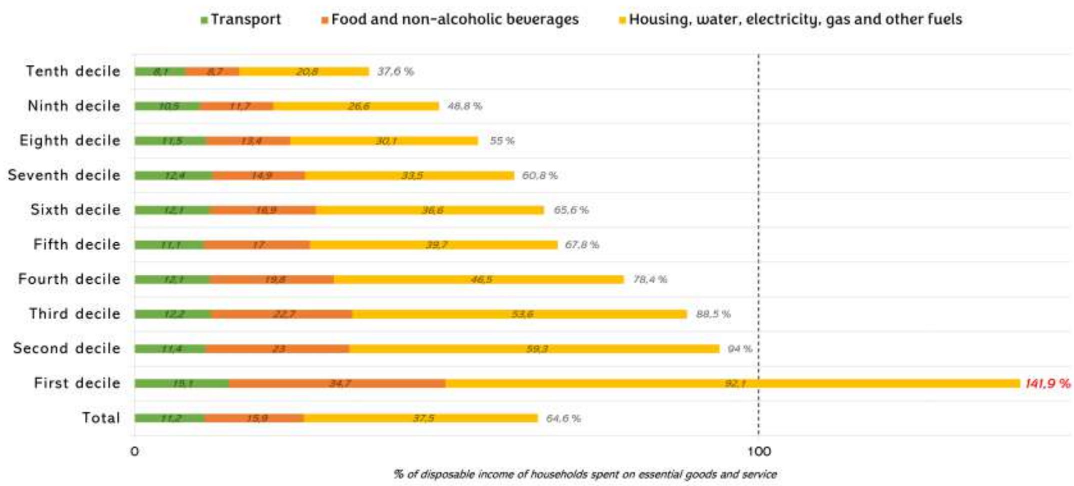


Figure 4.9: Percentage of disposable income of households spent on essential goods and services, by income deciles, 2015. Dataset from Eurostat, 2023c.

Thus, for households experiencing EP, TP, or even DEV, the need to allocate such high percentages of their disposable income to cover their expenses, perpetuates a cycle of financial vulnerability and hampers efforts to break free from poverty status. If situations like the one presented by Figure 4.9, specifically for the first income decile, are sustained in time, entire national-wide economies risk to become unsustainable and lead to major consequences nation-wide.

By dissecting the data across income deciles, policymakers can identify specific groups that are most susceptible to financial strain. Like so, this information can guide the development of targeted interventions, in the form of new or 'renovated' policies, such as income support programs or transport related subsidies, for instance, to alleviate the burden on the most vulnerable households, as shown by Silver *et al.*, 2023.

4.2.3 Accessibility indicators

4.2.3.1 Difficulty in accessing public transport by income quintile and degree of urbanisation

When diving into public transport access in a Portuguese context resorting to the indicator 'ILC_HCMP06' - denoted in Table 3.1 above -, Lucas *et al.*, 2018 findings became evident, with the physical location of residency ultimately proving to be the most significant determinant to travel choices and behaviours, despite the fact that certain social characteristics may serve as conditional factors influencing an individual's said choices and behaviours. Figure 4.10, classifies the hardship of access to public transport by degree of urbanisation and income quintiles of the population. Each colour set identifies an income quintile - *'Blue' bars are related to the first quintile; 'Green' bars are related to the second quintile; 'Yellow' bars are related to the Third quintile; 'Orange' bars are related to the fourth quintile; and, 'Grey' bars are related to the fifth quintile* - which is then comprised of four bars symbolising four classes of difficulty (these being, *'Very high' - darkest shade; 'High'; 'Low'; and 'Very low' - lightest shade*).

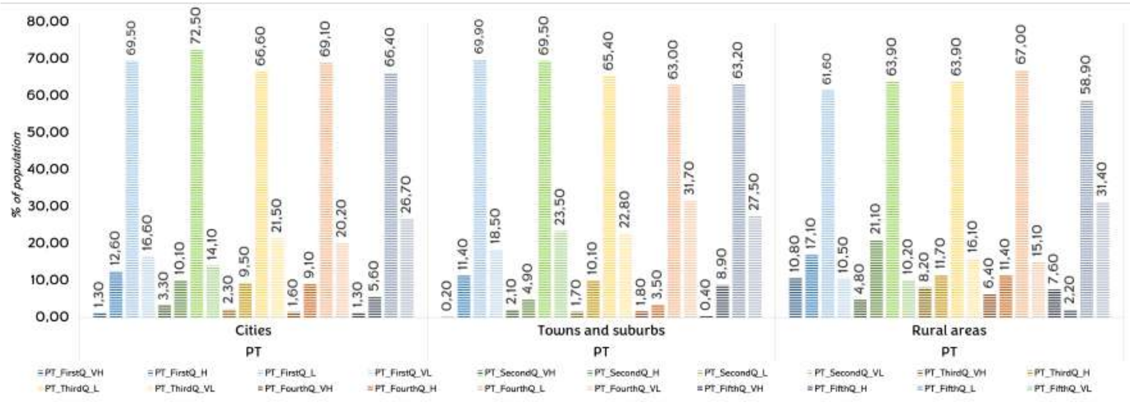


Figure 4.10: Percentage of Portuguese population, by level of difficulty in accessing public transport, income quintile and degree of urbanisation, in 2012. Dataset from Eurostat, 2023d.

In the greater scheme, the Portuguese seem to claim as having a *'Low'* difficulty with access to public transport independently of income class and dwellings' location. However, the Portuguese reality, somewhat mimics what was described in subsection 4.1.3: populations have greater difficulty to satisfy their travel needs in peri-urban and rural areas.

Furthermore, in Portugal, without regards to income quintile, around 12%-16% of Portuguese cities inhabitants claim *'Very high'* to *'High'* hardships with access to public transport; 70% claim *'Low'* difficulty when accessing public transport; The remaining 16% relate to *'Very low'* difficulties, which, when compared to the nearly 80% of EU-27 populations stating *'Very Low'* to *'Low'* distress when accessing public transportation, reveals that Portuguese cities have greater difficulties in accessing public transport.

When looking into towns and suburbs, first quintile income receivers, although not expressing their hardships in accessing public transport as *Very High'* difficulties they (12% of the population) do express and recognise, however, some *'High'* difficulties in doing so.

A greater vulnerability to populations living in rural areas and within the first income quintile, is most noticeable. Here, nearly 11% of inhabitants claim to have *'Very high'* difficulties when accessing public transportation, which correlates to the 12% observed for the EU-27 in Figure 4.3 back in subsection 4.1.3.

4.2.3.2 Usage of two or more modes of transport to commute

When accounting for public transport usage to work or school by the Portuguese, in short, it appears to be evenly distributed between men and women as evidenced by Figure 4.11. However, this statistical parity does not necessarily translate to universal accessibility.

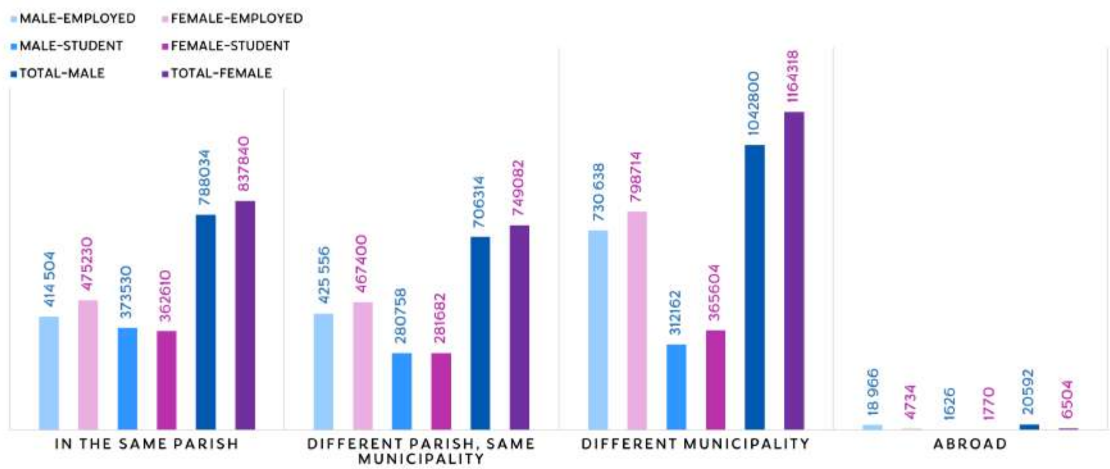


Figure 4.11: Number of employed inhabitants, and/or students, per sex, that use one or more modes of transport to commute for work, or school, whether if it locates in the same parish, municipality, or not. Data from INE, 2023b.

To some extent, this can manifest the inefficiency of public transport infrastructure in Portugal, meaning that they do not reach crucial areas for the population, single-handedly, which can then also translate into more costs for the user (Velaga *et al.*, 2012; Churchill and Smyth, 2019; Mattioli *et al.*, 2020). With the vast majority of the population going to work and/or going to school outside of its civil parish, it becomes clear that it is thus crucial to recognise that equal usage does not automatically indicate accessible transportation.

In other words, the decision of individuals to utilise or abstain from utilising public transportation may be influenced by factors such as inconvenience or high costs that outweigh the benefits, which is in line with Curl *et al.*, 2018, which states that "*Accessibility is not just about proximity, but also the (. . .) frequency and viability of the public transport (. . .) to provide an alternative (. . .) to allow full participation in economic and social activity*". Conversely, certain individuals may lack convenient access to public transportation yet are compelled to utilise it due to the necessity of reaching a destination. In addition, there exists a segment of the population who may not have easy access to public transportation but possess the financial means to incur higher transportation expenses in order to fulfil their travel requirements.

4.2.4 Availability indicators

With regards to availability indicators, an examination was conducted using three indicators, as previously outlined in sub-subsection 3.3.2.4. Based on this premise, the analysis yielded the subsequent outcomes.

In hindsight, Table 4.3 presents a comprehensive analysis of the number of passenger cars in different age categories in Portugal during 2021, along with corresponding variations in comparison to 2013. Additionally, it provides valuable insights into Portugal's car ownership landscape across various age categories, revealing noteworthy trends such as a surge in newer car ownership, a decline in the 5 to 10-year category, and a resurgence in older vehicles.

The "Total" row indicates that Portugal, in 2021, had approximately 5 632 644 **passenger cars** and that, since 2013, the total number of vehicles in Portugal increased 30.2%, indicating a substantial growth in car ownership over the eight-year period. According to INE, the Portuguese car stock, for that same year, was comprised in 7.1 million units (see INE, 2022). The "*Less than 2 years*" age category had 519 293 units, marking a remarkable 166.7% increase from 2013 (194 719 units). This dramatic surge could imply increased purchasing of newer vehicles, possibly due to various factors such as improved economic conditions, enhanced features, and changing preferences among consumers.

In opposition to this surge in newer vehicles, the "*Over 20 years*" age category also exhibited a substantial 169.4% increase, totalling 1 363 464 units in 2021, comparatively to 506 165 units in 2013. This soar may indicate an increase in the preservation and usage of older vehicles, possibly due to sentimental value, lower ownership costs, or certain vehicles becoming classics. Howbeit, it can also be a signal of an increased incapacity to afford newer equipment which will aggravate ones' financial burden with passenger car ownership. Thus, further in depth studies must be taken to better understand the reasons behind this increase.

Accounting for the remainder age classes, only slight variations were observed. The "*2 to 5 years*" age class, reflected a 35.7% increase in passenger car units, totalling 753 339 units as of 2021, suggesting a somewhat steady adoption of semi-new vehicles, when compared to 2013. The "*5 to 10 years*" age category experienced an 8.1% decrease, with 896 657 units in 2021. This decline in numbers indicates that a portion of cars within this age range may have been replaced or simply removed from the total count. Finally, the "*10 to 20 years*" age category displayed a minimal 0.2% increase, amounting to 2 099 891 units in 2021. This suggests a relative stability in the number of cars within this age bracket over the years.

Table 4.3: Number of passenger cars per age class, in Portugal, in 2021, and variation *versus* 2013. Dataset from Eurostat, 2023i.

Age Class	**Number of passenger cars (Aprox.)**	**Variation vs. 2013 (%)**
TOTAL	5 632 644	30.2% increase
Less than 2 years	519 293	166.7% increase
2 to 5 years	753 339	35.7% increase
5 to 10 years	896 657	8.1% decrease
10 to 20 years	2 099 891	0.2% increase
Over 20 years	1 363 464	169.4% increase

Upon examination of Europe's, and Portugal's car density per 1000 inhabitants, it is evident that Portugal falls below the EU-27 average (See Annex .3 for further information regarding aggregate/country labels), with a density of 544 passenger cars per 1000 inhabitants, compared to an average density of 567 passenger cars per 1000 inhabitants. It is important to note that an inquiry was made to the INE in an effort to delve deeper into the NUTS level, similar to subsection 4.1.1, but unfortunately, it was unsuccessful.

4.3 Double Energy Vulnerability

4.3.1 Transport poverty analysis recap

The analysis carried out on each of the indicators selected for this work concerning the context of mobility, both in Europe and in Portugal, is summarised below.

Regarding the European stock of passenger cars, Figure 4.1 presents the increasing number of passenger cars in Europe for the past decade. Major variations were observed in Kosovo (48.1% increase), Romania (46.5% increase), Albania (43.8% increase), North Macedonia (41.9% increase) and Turkey (37.4% increase). Portugal is slightly below EU-27's average density of passenger cars (567 per 1000 inhabitants) with a density of 544 passenger cars per 1000 inhabitants. This high number of passenger cars may be related to the existing disincentive on the part of existing infrastructures to not use public transport systems and rather the car (Mattioli *et al.*, 2019 and Mattioli *et al.*, 2020), which can be observed in subsection 4.2.1, where travel times are denoted as one of the main factors. Although while only looking into Swede urban municipalities, Henriksson *et al.*, 2021, already made this evident, thus somewhat backing this work findings.

Regardless of passenger cars increasing, it seems that the European fleet keeps ageing, with approximately 155 million units, or 52% of the total European car stock being 10 years or older. When looking into the Portuguese scene, the same trend applies (see Table 4.3) which may be considered as distressing, considering the incremented burden (Moore, 2012) that this can have in household's incomes, especially for those in the lowest quartile of income revenue. Regarding household incomes, persistent income disparities continue to exist among Portuguese dwellings, with the lower deciles of society bearing a disproportionate burden. Housing costs are particularly noteworthy as a significant source of stress, as enlightened by Kim *et al.*, 2023. Individuals experiencing energy or TP are especially vulnerable, as allocating a high percentage of their income towards these expenses perpetuates their financial insecurity.

This easily correlates with difficulties when accessing to public transportation. Figures 4.2 and 4.3, show that the main hardships when accessing public transport by degree of urbanisation and income quintiles appear to be mostly located in peri-urban and rural areas (e.g., Delbosc and Currie, 2011). Although some results in subsection 4.2.1 contradict this statement, they do not represent the observed national trends, where, European populations, have greater difficulty to satisfy their travel needs, hence the more dependence in private vehicles to commute. No real discrepancy between income quintiles, within the same degree of urbanisation was observed. Portugal alludes to the European scenes, with peri-urban and rural areas having greater difficulty in accessing public transport, even though mainly considered as *'Low'* difficulty, independently of income class and dwellings' location.

Additionally, it was also observed the need of a large proportion of the Portuguese population, without regards of gender, to take two or more modes of transport to commute to work or school. The reason for this occurrence can be speculated, however, it is assumed that it can be associated with the fact that public transport infrastructure in Portugal could be inefficient and/or disconnected amongst itself in the existing different modes of transportation (e.g., Velaga *et al.*, 2012; Lucas *et al.*, 2016), thus, the need for more concrete data on why, or even if infrastructure investments are enough to answer the needs of the population, as further explained by Virág *et al.*, 2022, that states that "*constantly expanding mobility infrastructure stocks, as well as steadily increasing mobility activity in terms of travelled distances translate into improved well-being*". In short, it is plausible that individuals possess the ability to utilise public transportation, yet opt not to do so as a result of the inconveniences or exorbitant expenses that surpass the advantages. Conversely, certain individuals may encounter difficulties in accessing public transportation, yet are compelled to utilise it due to their imperative need to arrive at a destination. In the midst of these scenarios, it is feasible to encounter individuals who may not have effortless access to public transportation, but possess the financial means to incur greater expenses in transportation to fulfil their travel requirements.

4.3.2 Household energy poverty synopsis

In similar fashion to the previous section, the analysis conducted on each of the four selected indicators for this study, namely *'Arrears on utility bills'; 'Inability to keep home adequately warm'; 'Population living in dwellings' with presence of leak, damp, and rot';* and, *'At risk of poverty or social exclusion'*, pertaining to the context of domestic EP in both Europe and Portugal, is not only based on the research carried out by the EPAH (Gouveia *et al.*, 2022), and the EC recommendation on EP (European Commission, 2020), but is also outlined below. Nonetheless, regarding the former, the EPAH's National Indicators Report (Gouveia *et al.*, 2022) further explains limitations, applicability, and further data on the indicators here presented. Notwithstanding, additional information regarding these indicators is subsequently provided within the context of the present research.

The "arrears on utility bills" indicator evaluates the economic strain and accountability associated with utility bill payments in residential properties, while examining the proportion of the population that is in arrears. The metric can be disaggregated by income situation and household typology. Balkan countries and Turkey have higher arrears rates, with regional patterns being evident. Furthermore, across Europe, single-parent households with at least one dependant, face significant increased arrears challenges, which may contribute to EP. Portugal, despite its high prevalence of EP, has an arrears rate of 5.3%, thus prevailing below the EU-27 average, indicating a unique situation.

Nonetheless, this metric may be of limited application, since it does not capture households different energy usages and needs, in other words, it does not account for over and under-consumption (Cong *et al.*, 2022) of energy by families, hence the greater risk in erratic evaluations of populations suffering from EP . Moreover, it provides insight into the financial burdens associated with essential services for households, while also supporting decision-making, and informing eligibility for targeted policies.

The examination of households' capacity to maintain adequate home heating reveals a discernible trend of decreasing proportions of the population struggling with this issue across the EU-27. As of 2022, 23 nations fall below the EU average of 9.3% for households unable to adequately heat their homes. However, 23 countries still surpass the average rate of difficulties in keeping homes warm. Notably, Portugal has made remarkable progress in reducing its share of the population unable to heat homes adequately, now at 17.5% and nearly halved compared to 2010. This improvement can be attributed to the implementation of energy efficiency policies and schemes over the years. Moreover, Southern and Balkan countries face higher challenges in heating homes, while Nordic and mountainous nations like Switzerland, for example, excel in this regard due to their colder climates.

Regarding dwellings' with presence of leak, damp, and rot, in 2019, it was found that approximately 12.7% of the European population resided in dwellings that exhibited these issues. An analysis of the data did not reveal any clear trends, although some Scandinavian countries tended to have fewer of these problems. As such, it is noteworthy that climate alone does not account for these variations. Portugal, as a specific case study, comprises the top 5 European countries with the highest rates of dwellings with leaks, dampness, or rot. Thus, it is important to acknowledge that this indicator may be subjective as it can depend on households' individual experiences, potentially affecting its accuracy. Furthermore, it may be more relevant for measuring energy efficiency than domestic EP, as it considers building deterioration factors. Moreover, it is worth noting that monoparental families not only faced a higher prevalence of these issues but also had greater difficulties addressing them in every analysed country.

Furthermore, the Balkan countries exhibit the highest percentages of individuals at risk of poverty or social exclusion. Albania, for instance, has half of its population vulnerable to poverty and social exclusion. For most other European countries, the situation is relatively uniform, with the majority reporting between 15% to 25% of their populations at risk of poverty or social exclusion. Interestingly, Portugal's context stands out, falling below the EU-27 average. Hence, it is important to note that while this indicator is not a direct measure of EP, it does capture critical factors that contribute to EP, TP, and ultimately, domestic energy vulnerability, such as household income.

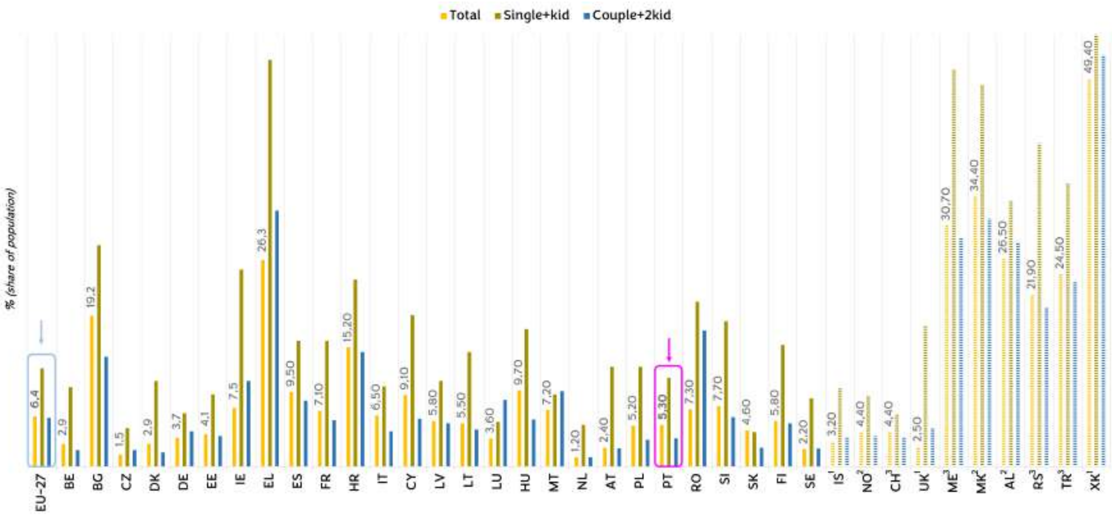
4.3.2.1 Arrears on utility bills

Figure 4.12, provides an overview of the share of European dwellings' with arrears appertaining to utility services. This indicator, according to Gouveia *et al.*, 2022, is grounded on the answers to the question '*"In the last 12 months, has the household been in arrears, i.e., has been unable to pay on time due to financial difficulties for utility bills (heating, electricity, gas, water, etc.) for the main dwelling?"*'.

At a glance, most of the Balkans, alongside Turkey, are noticeable for their high share of population with arrears on utility bills, which go from nearly 20% (Bulgaria) to almost 35% (North Macedonia) of the population with some kind of arrear in utility bills, well above the EU-27 average of 6,4%. Although most of the southern Balkans respective data is not yet updated past 2018 in some cases, it is possible to witness a regional trend.

Furthermore, unrelated to a regional domain, is the verification of an absolute tendency pertaining monoparental households with at least one dependant. With the exception of Luxembourg and Malta, every single country under analysis displays hardships to these types of households. Greece tops the scale with nearly 45% of its monoparental with at least one dependant to be with some kind of arrear on utility bills. Thus, this sort of vulnerability may be comparable with some TP related identified drivers to EP (here referred in a broader concept) by some literature (review Chapter 2).

Amusingly, Portugal, as a specific case study, regardless of being one of the most notorious countries with a large share of dwellings' in energy poor situations, prevails below the EU-27 average (6.4%) share of population with arrears on utility bills, with only 5.3% of the population with arrears. In fact, Portugal, according to EPAH's report (Gouveia *et al.*, 2022), was the country with the greater percentage increase with 1.8 percentage points



1 - Values correspond to 2018. 2 - Values correspond to 2019. 3 - Values correspond to 2021.

Figure 4.12: Share of population, per country, in situations of arrear on utility bills, for the year of 2022. Dataset from Eurostat, 2023a. See Annex .3 for further information regarding aggregate/country labels.

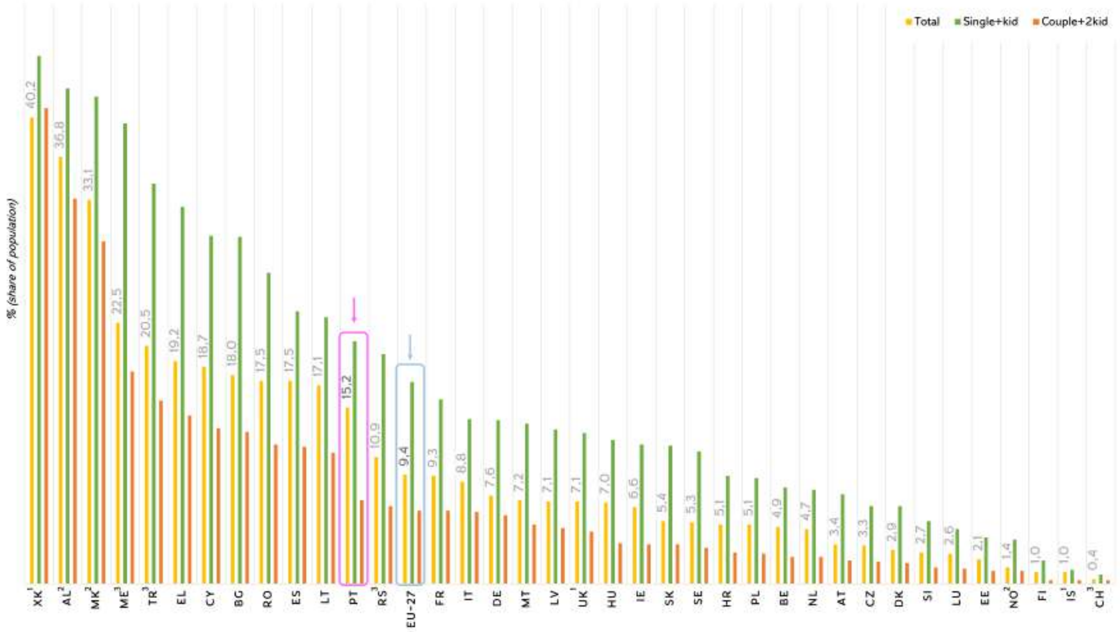
regarding arrear on utility bills, in the period 2019-2021. Plus, Portuguese monoparental households, in similar fashion to the rest of Europe, are also the most vulnerable to payment due situations, which can be a major factor to their incapacity to properly participate in society, and also a threat to their wellbeing.

Despite all of the above, this indicator may be of limited application, since it does not capture households different energy usages and needs (e.g., when in financial distress, households underconsume energy (Cong *et al.*, 2022)). Nonetheless, the "arrear on utility bills" indicator can be useful to better understand how are dwellings' coping with financial burdens imposed by necessary services to their wellbeing, for instance, 'EPAH's National Indicators Report' (Gouveia *et al.*, 2022) clearly exposed that families that incur in situations of debt thus further aggravating their vulnerability to utility expenses, is seen as one of the main factors that is not looked upon when evaluation their "inability to pay". Additionally, it provides favourable data to which decision-makers can support their actions on; and even allow for them to verify their eligibility to targeted socio-economic policies or programs that may help them avoid poverty situations.

4.3.2.2 Inability to keep home adequately warm

Regarding dwellings (in)ability to keep home adequately warm, there is evidence of somewhat decreasing trend of the total share of population incapable of heating their homes adequately across the EU-27. Nonetheless, in 2022, 23 nations are below EU's average value (9.3%) of households inability to keep their home adequately warm. For that matter, Figure 4.13 is a visual representation of said remark. Pertaining to total incapacity, 23 countries perch above average difficulties in adequately warm their households, Kosovo (40.2%), Albania (36.8%), North Macedonia (33.1%), Bulgaria (22.5%), and Turkey (20.5%)

make up the top 5 countries with greatest hardships.



1 - Values correspond to 2018. 2 - Values correspond to 2019. 3 - Values correspond to 2021.

Figure 4.13: Percentage of population incapable to keep home adequately warm, 2022. Dataset from Eurostat, 2023g. See Annex .3 for further information regarding aggregate/country labels.

Outstandingly, despite still well above EU's average, with a share of population unable to adequately warm their homes of 17.5%, Portugal has nearly reduced in half this value, when compared to 2010. The observed may possibly be attributed to the implementation of energy efficiency policies and schemes in Portugal, which have been placed into action since then, and have contributed to the improvement in energy efficiency, resulting in the observed outcomes. Contrastingly, Iceland (1.0%), Norway (1.0%), and the Switzerland (0.4%), present the greatest capacity to heat their homes.

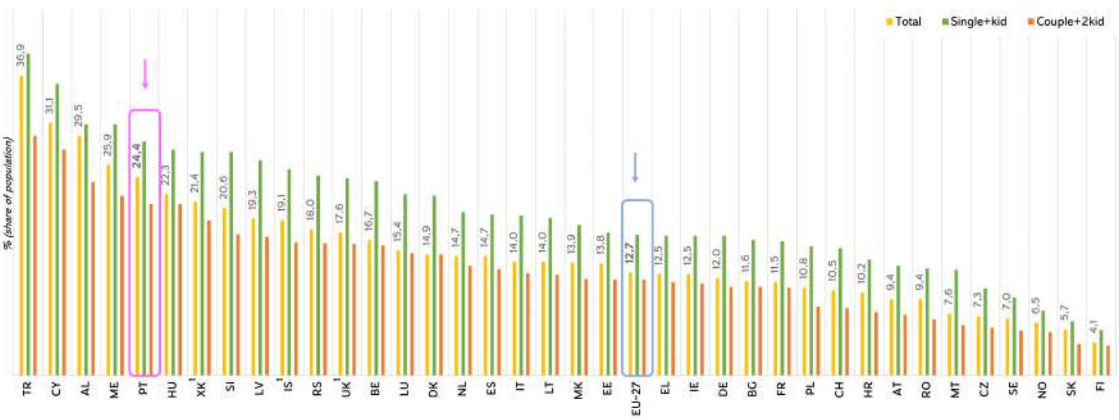
Generally speaking, the observed evidence can be partially translated by cultural factors. That is, the analyses carried out were able to demonstrate the existence of trends in European "sub-regions". These trends are characterised by the presence of a greater inability to keep their home adequately warm in Southern European and Balkan countries. On the contrary, the greater ability to do so, is most notorious in the Nordic or mountainous countries (like Switzerland, Luxembourg and Austria, for example), usually hit by low temperatures most of the year. Between these two poles, most of the countries of central and western Europe can be found.

Furthermore, according to the above mentioned report, this indicator also follows the same dichotomic dilemma - *the surveys used to gather data are comprised in a 'Yes' or 'No' answer to acknowledge the incapacity of households to adequately warm their home* - as the *'Arrears on utility bills'*, therefore, revealing itself as inadequate to properly assess the causes that hamper with the proper climatisation of the dwelling. Hence, the authors suggest the coupling of other objective variables to better grasp forerunner drivers allowing for a better contextualisation of the dwellings' reality, and that in addition to that it can also mitigate the bias of the data in the face of the unease of poorer households to disclose their inability to heat their homes (Gouveia *et al.*, 2022).

4.3.2.3 Population living in dwellings' with presence of leak, damp, and rot

Concerning to the presence of damp walls, floors or foundations, or rot in window frames or floors, and/or leaking roofs in dwellings', as of 2019, it was observed that the European 'house stock' averaged a 12.7% rate of populations living in situations with at least one of the above mentioned problems. Moreover, upon data analysis and examination of Figure 4.14, no real trends were evident, besides the least amount of dwellings' with presence of leak, damp, and/or rot being mostly comprised by the Scandinavian countries, although not fully, hence Denmark sits above EU's average value. Thus, what could possibly be partially explained by climatic conditions, is not suitable.

Furthermore, as compiled in Gouveia *et al.*, 2022, the existence of one of the aforementioned problems, could well be subjective to households lived experiences, which can mislay the accuracy and precision of this indicator. Additionally, with said subjectivity in mind, it was also depicted that the dwellings' with presence of leak, damp, and/or rot indicator can be more suitable to measure energy efficiency, than domestic EP, since it takes more into consideration building deterioration factors, a consequence of EP. In other words, like the last couple of indicators shown in the previous sub-sections, it is imperative to complement this indicator with additional indicators, as it solely relies on the attributes of the dwelling and does not take into account the financial and familial circumstances of the occupants (Castaño-Rosa *et al.*, 2019).



1 - Values correspond to 2018.

Figure 4.14: Percentage of households living with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor, per country, 2019. Dataset from Eurostat, 2023n. See Annex .3 for further information regarding aggregate/country labels.

With that said, as visible in Figure 4.14, it was possible to conclude that Turkey (36.9%), Cyprus (31.1%), Albania (29.5%), Montenegro (25.9%), and Portugal (24.4%), make up the top 5 as the countries whose dwelling's have the most presence of leaks, damp, and/or rot. Contrastingly, Norway (6.5%), Slovakia (5.7%), and the Finland (4.1%), present the least share of dwellings' living with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor.

Howbeit, as its been displayed throughout the present work, monoparental families have, not only the most presence of leaks, damp, and/or rot in their homes, but also greater difficulties to overcome it. Thus, this sort of vulnerability may be comparable with some TP related identified drivers to EP (here referred in a broader concept) by some literature (review Chapter 2).

4.3.2.4 At risk of poverty or social exclusion

The indicator referred to as "at poverty risk or social exclusion" represents the percentage of individuals within a given population who are at risk of experiencing poverty or social exclusion.

Regarding its analysis concerning populations at risk of poverty or social exclusion, it is clear that Balkan countries are the most prominent with greater shares of population in said complications. Albania, for instance, if observable trends sustain themselves, will have nearly half of its population vulnerable to poverty and social exclusion; as of 2019 this share was located at 50.7% of the population. Montenegro (31.1%), Romania (29.5%), North Macedonia (25.9%), and Turkey (24.4%), comprise the rest of the top 5 countries whose share of population are most threatened to poverty or social exclusion. On the other hand, Slovenia (13.3%), Czechia (11.8%), and Iceland (11.3%), present the least risk to their populations.

As portrayed by Figure 4.15, the scenario for the remainder European countries is somewhat homogeneous, with the vast majority of said countries with shares of population at risk of poverty or social exclusion between 15% to 25% of their respective populations. EU-27's average share of population susceptible to experiencing poverty or social exclusion sits at 21.6%. Notably, the Portuguese context exhibits a value (20.1%) that falls below that of the EU-27. This observation may be attributed to the fact that despite having low incomes, the Portuguese population demonstrates a remarkable level of financial awareness, which translates into low arrears on utility bills. Consequently, individuals do not exceed their financial capacities in their efforts to participate in society.

Even so, as stated by Gouveia *et al.*, 2022, this particular indicator is deemed unsuitable for accurately assessing EP. Nonetheless, it does capture significant factors that are widely recognised as key determinants of EP and TP, subsequently resulting in DEV scenarios, such as household income. Certain circumstances pertaining to EP situations unrelated with income poverty are also not acknowledged. Therefore, the present indicator is also seen as widespread since it also captures incapabilities of households to fulfil basic needs such as *'food, utilities, housing and health costs'* (Gouveia *et al.*, 2022). Thus, the authors suggest the intersect of other indicators thoroughly deliberated, in the likes of energy

1 - Values correspond to 2018. 2 - Values correspond to 2019. 3 - Values correspond to 2021.

Figure 4.15: Percentage of population at risk of poverty or social exclusion, per country, 2022. Dataset from Eurostat, 2023j. See Annex .3 for further information regarding aggregate/country labels.

efficiency and/or energy expenditure indicators to improve calculations of population at risk of poverty or social exclusion.

4.3.3 Data Crossing Transport Poverty and Household Energy Poverty

To better comprehend/envision how, if even, EP and TP are intertwined, this research utilises a data crossing analysis approach to explore the convergence of TP and EP, as previously mentioned in the Methodology chapter (section 3.5). More specifically, an examination of the top five and bottom three European countries for each indicator to obtain valuable insights into the intersection of these two phenomena was conducted, thus resulting in the present section of this work.

For that matter, Table 4.4 presents the overall top five and bottom three places after analysis of 10 of the total 11 indicators employed during this work (See Annex .3 for further information). The indicator "Difficulty in accessing public transport by income quintile and degree of urbanisation" (sub-subsection 4.2.3.1) was not contemplated due to its qualitative backbone, considering it depicts non-numerical information (NIH, n.d.) as variables. It depends on the population's perception (Eurostat, 2023d) to evaluate its struggles to fulfil their accessibility to public transportation.

Therefore, in a European context, the top 5 represent the five most vulnerable European countries to DEV. Contrarily, the bottom 3 highlight the three less vulnerable European countries to suffer from DEV. In this manner, an overview of the most vulnerable countries was possible.

Hence, upon analysis, the Balkans emerge as the consistently most vulnerable region impacted by DEV. This was also true for at least 8 of the ten indicators analysed. The

Table 4.4: DEV susceptibility country rankings. Top 5 countries are seen as the most vulnerable to DEV phenomenon. Bottom-3 countries are the less vulnerable to DEV.

Rank	Most commonly found in the top 5	Most commonly found in the bottom-3	Rank
1^{st}	Albania	Luxembourg	1^{st}
2^{nd}	Turkey	Norway	"
"	*North Macedonia*	Czechia	"
4^{th}	Montenegro	*Slovakia*	4^{th}
5^{th}	Kosovo	*Iceland*	"
"	*Romania*	...	5^{th}

NOTE: The countries and ranks in gray are merely illustrative. These represent the post-top 5 and bottom-3 rankings both in their respective contexts.

remaining two indicators, the "Final consumption expenditure of households by consumption purpose" indicator and the "Final energy consumption by sector" indicator, do not follow this norm - *thus aligning with indicators discussions on the EPAH reports (Gouveia* et al.*, 2022; Gouveia* et al.*, 2023) and research on hidden EP in the region*. Conversely, the Nordic countries and countries in other mountainous regions (*contrarily to Katsoulakos and Kaliampakos, 2016, whose findings (although shedding light on a Greek context) displayed these geographic regions as more vulnerable*), of the European continent, such as Czechia and Slovakia, according to data (See Annex .3 for further context), appear to be the least susceptible to encountering issues associated with DEV situations. These findings support the assertions made by Bouzarovski, 2014, as discussed in section 2.2, that presented Southern European countries as more vulnerable due to their poorly insulated dwellings and types of equipment used for climatisation.

Additionally, regarding the former, it must be noted that the Balkan countries are not in the top positions in total final consumption expenditure of households for the transport sector (a sector highlighted due to the scope of the present work). Instead, the "podium" is completed by countries located further north or with higher household financial capabilities, such as Norway and/or Luxembourg. However, if we look at the total final consumption expenditure of dwellings, the top 5 is already composed of the Balkan countries, such as Montenegro, Greece, Bosnia and Herzegovina, Croatia, and Serbia, respectively, which gives rise to the reasoning that these populations may not be characterised as "transport vulnerable" due to actual financial incapacity to attain needed levels of certain services. Lastly, it is noteworthy to display that Scandinavian countries are depicted as the ones with higher energy expenditure countries in Europe.

Concerning the latter indicator, the "Final energy consumption by sector" indicator, as seen in Figure 4.6, countries in Scandinavia as responsible for the major total energy consumption values. Conversely, the Balkans were observed to rank at the lower end of the spectrum, possibly inferring that their populations tend to under-consume energy through the adoption of 'energy-limiting behaviours' (Gouveia *et al.*, 2022) that lower their energy needs, even if these behaviours may compromise their well-being as shown by Martiskainen *et al.* (2021). However, similarly to the "Final consumption expenditure of households by consumption purpose" indicator, the transport sector was highlighted due to the scope of the present work. Even so, there were no noteworthy alterations detected in the "upper" positions of the national rankings, thereby corroborating the existing literature (e.g., Bouzarovski and Petrova, 2015; Mattioli *et al.*, 2017; Robinson and Mattioli, 2020).

Still, it is important to note that this analysis is solely based on the TP and EP-related indicators chosen for this study. Therefore, while this analysis proves valuable within the context of the present research, as it allows for some characterisation of the socio-economic landscape of Europe, it remains somewhat limited in its comprehensive examination of the intersection between TP and EP across the continent.

5

Conclusions

This study comprehensively examines the complex issues surrounding EP, TP, and their intersection, known as DEV. Through extensive data analysis and critical examination of various indicators, this research has provided insight into the multifaceted dimensions of these pervasive challenges while focusing on a European perspective, with particular attention given to the Portuguese context. The present work has then revealed that EP is a complex phenomenon that is influenced by a multitude of social, economic, and environmental factors (e.g., Bouzarovski, 2014; Bouzarovski and Petrova, 2015; Stojilovska *et al.*, 2022). Regional trends across Europe have been observed, with Southern and Balkan countries experiencing a higher prevalence of EP, primarily attributed to socioeconomic disparities, buildings quality and an history of systemic inequalities. In contrast, Nordic and mountainous regions exhibit a greater capacity to maintain adequately warm homes, driven by low temperatures necessitating robust heating solutions (Bouzarovski, 2014).

Therefore, the main aim of this research was to investigate the vulnerability aspect of mobility access in Portugal, resorting to the identification and analysis of pertinent indicators, comparing it with vulnerabilities already identified in the residential sector (e.g., Gouveia *et al.*, 2019). This work also includes an overview of the current situation in Europe regarding six mobility-related indicators enabling the comparison of performances among European countries.

Moreover, this development has identified TP as a critical factor in understanding households' access to essential services, which has received less attention in the discourse on EP vulnerability studies. Thus, the elaborated analysis has highlighted how transport costs can exacerbate domestic energy vulnerabilities, particularly for low-income households (e.g., Lucas *et al.*, 2016; Lucas *et al.*, 2018; Castro *et al.*, 2022). Additionally, it also made evident that the financial burden of transportation disproportionately affects single-parent families, underscoring the need for targeted policy interventions.

Furthermore, this study has elucidated DEV, emphasising the interplay between EP and TP and their synergistic effects. In other words, households experiencing both forms of poverty face compounded difficulties in accessing essential services, resulting in heightened financial strain and increased vulnerability to poverty and social exclusion (e.g., Simcock *et al.*, 2021; Martiskainen *et al.*, 2021). These "doubly-poor" households are often located in peri-urban areas (Downing *et al.*, 2022), where, for instance, misestimated transportation costs further amplify housing and transport burdens (Lowans *et al.*, 2023).

The case study of Portugal provides intriguing insights into the battle against residential energy vulnerability. For instance, despite having a significant share of energy-poor households, Portugal has made progress in reducing the number of people unable to adequately warm their homes. Partially, this achievement can be attributed to the creeping implementation of energy efficiency policies in recent years, demonstrating the potential for proactive governmental action. This holds great significance owing to the considerable influence that residential EP exercises on Portuguese society, particularly for those belonging to the lower income spectrum and those who experience discomfort due to inadequate thermal conditions in their dwellings, along with its associated consequences. Nevertheless, Portuguese TP is also a matter of concern since the analysed indicators not only demonstrated that the use of private cars is increasing day by day but also displayed that the usage of passenger cars is the preferred method of transportation of the Portuguese, as stated per the INE, 2023c, possibly revealing a lack of investment in public transportation services and transport infrastructures that could perhaps bolster those most in need.

It is then crucial that policymakers, while considering regional nuances and socioeconomic disparities, adopt a holistic approach to addressing EP and TP, recognising the synergies between these two forms of poverty and developing integrated policies that alleviate the combined burdens they impose on vulnerable households, to ensure equitable access to essential services. Income support programs, targeted subsidies, regional tailored interventions, and investments in energy-efficient infrastructures are necessary and powerful tools in this endeavour (Kyprianou *et al.*, 2019; Salih and Lee, 2022).

In conclusion, this study illuminates the complexity of EP in Europe and Portugal and the critical role of TP in exacerbating these challenges. Significant strides can be made toward a more equitable and sustainable future by addressing EP and TP in tandem and considering the unique needs of different regions and demographic groups

5.1 Limitations

The current research is subject to primary limitations that hinder its analytical precision. These constraints include the inadequacy of comprehensive national-level data about mobility, transportation, and TP; The lack of data depth and granularity; The limited existing literature in the domain of TP; and the lack of standardised indicators across different data sets and databases.

Altogether, these limitations have hindered the exploration of intricate relationships between variables and dimensions crucial to a better understanding of the hardships associated with mobility in an energy poverty context and have further impeded the potential for comprehensive insights in this area of expertise. Moreover, as initially told, the absence of fine-grained data has also hindered the exploration of temporal trends and cross-sectional comparisons, further limiting the robustness of the findings with certain variables and dimensions being inadequately represented. Nonetheless, the available data has provided valuable insights to the beginning of the discussion on TP.

Furthermore, a noteworthy limitation pertains to the reduced availability of relevant literature in the domain of TP. The shortage of comprehensive studies, both regionally and globally, posed challenges in contextualising the research findings within a broader theoretical framework, possibly impacting the extent to which this study could validate or refute previous findings, thus limiting the foundation upon which the research is built.

The absence of standardised indicators across different data sets complicates direct comparisons and introduces the potential for bias and inaccuracies in the analysis. As a result, caution must be exercised when interpreting the findings, as the lack of normalisation may have made the results difficult to quantify.

In short, the data from disparate sources on which this work had to rely potentially introduced inconsistencies and further limitations to the study's analytical rigour, which may reveal themselves as detrimental to future studies. Not only that, but this research also underscores the need for further academic inquiry and underscores the novel contribution of this study to the existing knowledge landscape.

5.2 Future Work

Notwithstanding the aforementioned, there remains a significant amount of work to be undertaken to thoroughly evaluate of Portuguese TP within the context of EP. As previously argued, the absence of precise, detailed, and current data poses a significant obstacle to further assessments. Consequently, the initial measure to ensure optimal conditions for future research must involve establishing standardised indicators and providing up-to-date data.

Furthermore, future research endeavours ought to undertake a more comprehensive investigation into formulating and evaluating holistic policy frameworks that tackle the combined challenges of EP and TP. This necessitates exploring integrated subsidy programs, income support mechanisms, and energy-efficient urban planning initiatives. Hence, it is also imperative for the academic community to delve deeper into the socioeconomic factors associated with EP beyond the already established and esteemed residential EP rather than merely acknowledging their interconnections. In this regard, the present study aims to contribute to the scarce literature on TP within the context of EP.

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Annex I

Table I.1: Compiled indicators in Excel from research, per database.

DATABASE INDICATORS

NOTE: Databases with country names encompass different national statistical institutes and data from the respective governments.

NOTE2: Cyan: Accessibility indicators; Yellow: Time travel indicators; Orange: Availability indicators; Lime: Affordability indicators; Lightgray: 'Others' indicators; Magenta: Composite indicators.

Database	Timeline	Indicator	Unit
EUROPEAN COMMISSION	N/A	*Accessibility of stations and stops to people with reduced physical mobility*	%
	N/A	*Total time spent riding on public transport on daily trips*	minutes
	N/A	*Total time spent walking on daily trips*	minutes
	N/A	*Population residing <500 metres from a public transport stop*	%
	N/A	*Distance travelled to reach nearest public transport stop*	minutes
	N/A	*Availability of motorised transport alternative*	Y/N
	N/A	*Affordability of public transport for the poorest group*	%
	N/A	*Accessibility of public transport for mobility-impaired groups*	%
	N/A	*Accessibility of stations and stops to people with reduced physical mobility*	%
	N/A	*Commuting travel time*	minutes
	N/A	*Number of jobs and urban services accessible within 60 minutes by public transport*	%
	N/A	*Average income spent on transport*	%
EUROSTAT	N/A	*Share of household expenditure on transport*	% of total income
	Annual (1994-2023)	*Harmonised Indices of Consumer Prices (HICP) - (2015 = 100)*	%
	Annual (1995-2021)	*Government expenditure on transport*	% of GDP
	Annual (1990-2021)	*Stock of vehicles by category and NUTS 2 regions, per 1000 inhabitants*	‰
	Annual (2013-2021)	*Passenger cars, by age*	No.

	2012; 2014	*Distribution of population by level of difficulty in accessing public transport, income quintile and degree of urbanisation*	%
	Annual (1975-2022)	*Final consumption expenditure of households by consumption purpose*	% of total
	Annual (1995-2022)	*Income of households by NUTS 2 regions*	€ per inhabitant
	Annual (2010-2021)	*Final energy consumption by sector*	ktoe
	Five-year (2015; 2020)	*Disposable income of households (with expenditure greater than zero) spent on essential goods and services by income quantiles*	%
	Annual (1994-2023)	*Car ownership per 1000 inhabitants*	‰
OCDE	Annual (2000-2021)	*Share of household expenditure for transport in total household expenditure*	%
	Annual (2000-2021)	*Share of household expenditure for operation of personal transport equipment in total household expenditure for transport*	%
	Annual (2000-2021)	*Share of household expenditure for transport services in total household expenditure for transport*	%
	2018	*Proximity by geographic scale*	No. of destinations per distance
	2018	*Transport performance by mode*	-
	Five-year (2010-2050)	*(India Mobility Model) Public transport access index*	%
OPENEXP	2014; 2018	*Share of transport energy expenditures out of total expenditures*	%
	2017	*Share of the population not able to afford public transport on regular basis*	%
	2018	*Share of the population with high difficulties in accessing public transport*	%
EU-SILC	*NO ACCESS*	*NO ACCESS*	*NO ACCESS*
OUR WORLD IN DATA	*NO DATA*	*NO DATA*	*NO DATA*
THE WORLD BANK	*NO DATA*	*NO DATA*	*NO DATA*
EPAH	2010; 2015	*2M*	Household energy expenditure

	2010; 2015	*M/2*	Household energy expenditure
INE / *"PORTUGAL"*	Annual (2017-2021)	*Coefficient of use of transport of road passenger transport undertakings by geographical location*	%
	2010;2020	*Average annual energy consumption in means of transport per accommodation*	toe/ accommodation
	Deccenial (2011-2021)	*Average time spent on commuting of employed or student resident population using individual or collective mode of transport by place of residence*	minutes
	2010;2020	*Resident population using at least two means of transport according to the Census: total and by place of work or study*	%
	Annual (1990-2021)	*Car ownership per 1000 inhabitants*	‰
	2010; 2020	*Average annual expenditure on energy on means of transport per accommodation*	€/ accommodation
PORDATA / *"PORTUGAL"*	2011	*Average duration of daily trips of the resident population using individual or collective transport according to the Census*	minutes
	Decennial (2001-2021)	*Commute duration to the place of work or studies*	Nº of individuals / class minutes
	Annual (1995-2021)	*Average final consumption expenditure of households;*	€ / %
	Annual (1995-2021)	*Final consumption of households (by goods and services)*	€ / %
"AUSTRALIA"	Monthly	*Monthly Household Spending*	%
"NEW ZEALAND"	Annual (since 2018)	*Travel time reliability within metropolitan and high growth areas (predictability of travel time)*	%
	Annual (since 2018)	*Household spending on transport*	% of total income
	Annual (since 2018)	*Population with access to frequent public transport services (frequent = 15 minutes)*	%
	Annual (since 2018)	*Access to jobs (by mode)*	%
	Annual (since 2001); Five-year	*Rural households without access to a motor vehicle*	%
	Annual (since 2018)	*Availability of viable alternative routes*	kilometre
	Annual (since 2018)	*Fuel efficiency (trains % ferries)*	litres

	N/A	*Access for people with disabilities and/or limited mobility*	%
"CANADA"	Annual (2016-2021)	*Average Commute duration*	minutes
	2021	*Main mode of commuting refers to the main mode of transportation a person uses to travel to their place of work*	%
"USA"	Annual (1982-2020)	*Travel Time Index (TTI): The ratio of peak-period travel time to travel time at free-flow conditions.*	minutes
"SPAIN"	2011	*Average time of journey to work*	minutes
	2011	*Proportion of journeys to work by car*	%
	2011	*Proportion of journeys to work by foot*	%
	2011	*Percentage of commutes to work by public transport*	%
"FRANCE"	*NO DATA*	*NO DATA*	*NO DATA*
"BELGIUM"	*NO DATA*	*NO DATA*	*NO DATA*
"NETHERLANDS"	Annual (2018-2021)	*Time travelled*	minutes
	Annual (2018-2021)	*Distance travelled*	passenger/ kilometre

Table I.2: Compiled indicators in Excel from research, per reviewed literature.

LITERATURE INDICATORS; *N/A = Not applicable; N/D = Not disclosed.*

NOTE: Cyan: Accessibility indicators; Yellow: Time travel indicators; Orange: Availability indicators; Lime: Affordability indicators; Lightgray: 'Others' indicators; Magenta: Composite indicators.

Compiled in	Original Source	Indicator	Unit
Haghshenas and Vaziri, 2012	N/D	*Average daily user cost over GDP per capita*	%GDP per capita
Haghshenas and Vaziri, 2012	N/D	*Average time spent in traffic*	minutes
Haghshenas and Vaziri, 2012	N/D	*Sum of transportation systems for every citizen passenger-km per area*	1/m

Haghshenas and Vaziri, 2012	N/D	*Sum of transportation option vehicle per caputa divided per maximum of that option vehicle per capita in all cities*	N/D
Lucas *et al.*, 2016	N/A	*Transport affordability*	N/D
Lucas *et al.*, 2016	N/A	*Trip generation*	N/D
Lucas *et al.*, 2016	N/A	*Trip distance*	N/D
Lucas *et al.*, 2016	N/A	*Trip duration*	N/D
Lucas *et al.*, 2016	N/A	*Index of public transport*	N/D
Lucas *et al.*, 2016; Churchill, 2020; Lowans *et al.*, 2021	RAC, 2012	*10% income threshold*	%; % total household
Lowans *et al.*, 2021	Lovelace and Philips, 2014	*Commuter fuel poverty (10% income*	%
Lowans *et al.*, 2021	Mattioli *et al.*, 2016	*Car-related economic stress (CRES)*	%
Lowans *et al.*, 2021	Mattioli *et al.*, 2017	*Forced Car Ownership (FCO)*	car ownership expenditure / car based transport expenditure
Lowans *et al.*, 2021	Chatterton *et al.*, 2018	*Motoring expenditure*	N/D
Lowans *et al.*, 2021	Mattioli *et al.*, 2018	*CRES 2*	N/D
Lowans *et al.*, 2021	Salon and Gulyani, 2010	*Travel Choices*	N/D
Lowans *et al.*, 2021	Tao *et al.*, 2020	*Activity Space*	N/D
Lowans *et al.*, 2021	Shen, 1998	*Accessibility Index*	N/D
Lowans *et al.*, 2021	Gomide *et al.*, 2005	*Synthetic index of adequate service*	N/D
Lowans *et al.*, 2021	Currie *et al.*, 2010	*Transport disadvantage*	N/D
Lowans *et al.*, 2021	Kamruzzaman and Hine, 2012	*Rural activity spaces*	N/D
Lowans *et al.*, 2021	DEFRA, 2018	*Overall measure of accessibility of services*	N/D
Lowans *et al.*, 2021	Allen and Farber, 2019	*Transit access to employment*	N/D
Lowans *et al.*, 2021	Benevenuto and Caulfield, 2020	*Spatial Accessibility Poverty (SAP) indices*	N/D
Lowans *et al.*, 2021	Sustrans, 2012	*Composite risk of transport poverty index*	N/D
Lowans *et al.*, 2021	Berry *et al.*, 2016	*Composite*	N/D

Annex II

Table II.1: Portuguese NUTS regions codes, provided by the the European Commission

PORTUGUESE NUTS CODES (2021); *As per the "NUTS 2021 Classification". PT 2021 NUTS map here.*

(Code) Country	**(Code) NUTS**	**(Code) NUTS II**	**(Code) NUTS III**
(PT) PORTUGAL	(PT1) Continente	(PT11) Norte	(PT111) Alto-Minho (PT112) Cávado (PT119) Ave (PT11A) Área Metropolitana do Porto (PT11B) Alto Tâmega (PT11C) Tâmega e Sousa (PT11D) Douro (PT11E) Terras de Trás-os-Montes
		(PT15) Algarve	(PT150) Algarve
		(PT16) Centro	(PT16B) Oeste (PT16D) Região de Aveiro (PT16E) Região de Coimbra (PT16F) Região de Leiria (PT16G) Viseu Dão-Lafões (PT16H) Beira-Baixa (PT16I) Médio-Tejo (PT16J) Beiras e Serra da Estrela
		(PT17) Área Metropolitana de Lisboa	(PT170) Área Metropolitana de Lisboa
		(PT18) Alentejo	(PT181) Alentejo Litoral (PT184) Baixo-Alentejo (PT185) Lezíria do Tejo (PT186) Alto-Alentejo (PT187) Alentejo Central
	(PT2) Região Autónoma dos Açores	(PT20) Região Autónoma dos Açores	(PT200) Região Autónoma dos Açores
	(PT3) Região Autónoma da Madeira	(PT30) Região Autónoma da Madeira	(PT300) Região Autónoma da Madeira

ANNEX III

Table III.1: European country codes, in accordance to the Eurostat glossary.

Country Label	**Country Name**	**Country Label**	**Country Name**
EU-27[a]	*EUROPEAN UNION*	XK[b]	KOSOVO
AL	ALBANIA	LV	LATVIA
AM	ARMENIA	LI	LIECHTENSTEIN
AT	AUSTRIA	LT	LITHUANIA
AZ	AZERBAIJAN	LU	LUXEMBOURG
BY	BELARUS	MT	MALTA
BE	BELGIUM	ME	MONTENEGRO
BA	BOSNIA HERZEGOVINA	NL	NETHERLANDS
BG	BULGARIA	MK	NORTH MACEDONIA
HR	CROATIA	NO	NORWAY
CY	CYPRUS	PL	POLAND
CZ	CZECHIA	PT	PORTUGAL
DK	DENMARK	RO	ROMANIA
EE	ESTONIA	RU	RUSSIA
FI	FINLAND	RS	SERBIA
FR	FRANCE	SK	SLOVAKIA
GE	GEORGIA	SI	SLOVENIA
DE	GERMANY	ES	SPAIN
EL	GREECE	SE	SWEDEN
HU	HUNGARY	CH	SWITZERLAND
IS	ICELAND	TK	TURKEY
IE	IRELAND	UK	UNITED KINGDOM
IT	ITALY	UA	UKRAINE

[a] - *27 countries as of February* 1^{st}*, 2020;*
[b] - *'XK' is a code used for practical reasons and not an official ISO country code.* - Eurostat glossary.

Annex IV

Table IV.1: DEV susceptibility country rankings. **Top five** countries regarding "Passenger cars per 1 000 inhabitants" indicator.
(Eurostat Code: TRAN_R_VEHST)

Country	**%**
Kosovo	48.1%
Romania	46.5%
Albania	43.8%
North Macedonia	41.9%
Turkey	37.4%

Table IV.2: DEV susceptibility country rankings. **Bottom three** countries regarding "Passenger cars per 1 000 inhabitants" indicator.
(Eurostat Code: TRAN_R_VEHST)

Country	**%**
Lithuania	3.5%
Malta	3.3%
Luxembourg	3.2%

Table IV.3: DEV susceptibility country rankings. **Top five** countries regarding "Passenger cars, by age" indicator.
(Eurostat Code: ROAD_EQS_CARAGE)

Country	**%**
Albania	91.6%
North Macedonia	88.8%
Bosnia and Herzegovina	85.3%
Montenegro	81.1%
Lithuania	80.9%

Table IV.4: DEV susceptibility country rankings. **Bottom three** countries regarding "Passenger cars, by age" indicator.
(Eurostat Code: ROAD_EQS_CARAGE)

Country	**%**
Liechtenstein	34.3%
Belgium	33.3%
Luxembourg	25.3%

Table IV.5: DEV susceptibility country rankings. **Top five** countries regarding "Final consumption expenditure of households by consumption purpose" indicator.
(Eurostat Code: NAMA_10_CO3_P3)

TRexp_Country	**%**
Slovenia	16.9%
Turkey	16.2%
Lithuania	15.3%
Norway	14.4%
Luxembourg	14.2%

Table IV.6: DEV susceptibility country rankings. **Bottom three** countries regarding "Final consumption expenditure of households by consumption purpose" indicator.
(Eurostat Code: NAMA_10_CO3_P3)

TRexp_Country	**%**
Czechia	9.5%
Croatia	7.6%
Slovakia	5.3%

Table IV.7: DEV susceptibility country rankings. **Top five** countries regarding "Income of households by NUTS 2 regions" indicator.
(Eurostat Code: NAMA_10R_2HHINC)

Country	**€ *per capita***
Bulgaria	5 000 €
Romania	6 600 €
Croatia	7 700 €
Hungary	7 900 €
Poland	8 100 €

Table IV.8: DEV susceptibility country rankings. **Bottom three** countries regarding "Income of households by NUTS 2 regions" indicator.
(Eurostat Code: NAMA_10R_2HHINC)

Country	**€ *per capita***
Austria	24 100 €
Norway	29 000 €
Luxembourg	34 900 €

Table IV.9: DEV susceptibility country rankings. **Top five** countries regarding "Final energy consumption by sector" indicator.
(Eurostat Code: TEN00124)

TRcons_Country	***toe***
Luxembourg	2.79 *toe*
Norway	0.92 *toe*
Austria	0.89 *toe*
Iceland	0.87 *toe*
Slovenia	0.87 *toe*

Table IV.10: DEV susceptibility country rankings. **Bottom three** countries regarding "Final energy consumption by sector" indicator.
(Eurostat Code: TEN00124)

TRcons_Country	***toe***
Kosovo	0.26 *toe*
Ukraine	0.24 *toe*
Albania	0.24 *toe*

Table IV.11: DEV susceptibility country rankings. **Top five** countries regarding "Arrears on utility bills" indicator.
(Eurostat Code: ILC_MDES07)

Country	**%**
Kosovo	49.4%
North Macedonia	34.4%
Montenegro	30.7%
Albania	26.5%
Greece	26.3%

Table IV.12: DEV susceptibility country rankings. **Bottom three** countries regarding "Arrears on utility bills" indicator.
(Eurostat Code: ILC_MDES07)

Country	**%**
Sweden	2.2%
Czechia	1.5%
Netherlands	1.2%

Table IV.13: DEV susceptibility country rankings. **Top five** countries regarding "Inability to keep home adequately warm" indicator.
(Eurostat Code: ILC_MDES01)

Country	**%**
Kosovo	40.2%
Albania	36.8%
North Macedonia	33.1%
Bulgaria	22.5%
Turkey	20.5%

Table IV.14: DEV susceptibility country rankings. **Bottom three** countries regarding "Inability to keep home adequately warm" indicator.
(Eurostat Code: ILC_MDES01)

Country	**%**
Iceland	1.0%
Norway	1.0%
Switzerland	0.4%

Table IV.15: DEV susceptibility country rankings. **Top five** countries regarding "Population living in dwellings' with presence of leak, damp, and rot" indicator.
(Eurostat Code: ILC_MDHO01)

Country	%
Turkey	36.9%
Cyprus	31.1%
Albania	29.5%
Montenegro	25.9%
Portugal	24.4%

Table IV.16: DEV susceptibility country rankings. **Bottom three** countries regarding "Population living in dwellings' with presence of leak, damp, and rot" indicator.
(Eurostat Code: ILC_MDHO01)

Country	%
Norway	6.5%
Slovakia	5.7%
Finland	4.1%

Table IV.17: DEV susceptibility country rankings. **Top five** countries regarding "At risk of poverty or social exclusion" indicator.
(Eurostat Code: ILC_PEPS01)

Country	%
Albania	50.7%
Montenegro	31.1%
Romania	29.5%
North Macedonia	25.9%
Turkey	24.4%

Table IV.18: DEV susceptibility country rankings. **Bottom three** countries regarding "At risk of poverty or social exclusion" indicator.
(Eurostat Code: ILC_PEPS01)

Country	%
Slovenia	13.3%
Czechia	11.8%
Iceland	11.3%