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Rethinking Energy–Transport Poverty: An Indicator for Vulnerable Rural EU Regions

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Abstract: This paper introduces the Composite Energy and Transport Poverty Indicator (CETPI), a tool designed to address rural vulnerabilities in the EU, with a focus on Croatia, Italy, and the Netherlands. By assuming a social practice theory perspective, this article explores the intersection of energy and transport poverty, emphasizing the need for a far more holistic approach to capture the complexity of these phenomena. Using data on household energy consumption, transport expenditure, and socioeconomic variables, the study developed a replicable indicator, pointing at areas where disparities in energy and transport access might be elusive and therefore unaddressed. As such, the findings reveal that rural areas experience unique challenges, including generally higher costs and limited access to affordable services, contributing to deeper levels of social exclusion. The CETPI provides policymakers with a framework to better understand these intertwined issues to inform targeted interventions that can alleviate both energy and transport poverty. The paper concludes by advocating for policy solutions that can improve equitable access to essential services for vulnerable rural populations.

Keywords: energy poverty; transport poverty; rural development; social exclusion; policy intervention; social practice theory; vulnerabilities; European Union



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1. Introduction

Over the past decades, energy policy practitioners and social experts have observed energy and transport poverty growing within the European Union (EU) with concern. This phenomenon is characterized by households' inability to access or afford the necessary energy to maintain adequate living conditions while also having implications for our health and overall quality of life [1]. Compared to previous years, the share of people unable to keep their home adequately warm was relatively stable at 8% in 2020; it then dropped to 6.9% in 2021, only to rise sharply to 9.3% in 2022 [2]. Parallel to energy poverty, transport poverty is emerging as another critical issue, albeit less precisely defined in both the academic literature and policy, although an official definition ('transport poverty' means individuals' and households' inability or difficulty to meet the costs of private or public transport, or their lack of or limited access to transport needed for their access to essential socioeconomic services and activities, taking into account the national and spatial context) is implemented through the Social Climate Fund Regulation [3,4]. Recently, scholars have conceptualized transport poverty as a predominant term, defining issues of affordability, referring to the inability to meet essential travel costs; mobility, which highlights challenges

in movement due to a systemic lack of adequate transport; and accessibility, which involves difficulties in reaching vital activities, such as employment or education, at reasonable time, ease, and cost, compelling people to depend on costly private vehicles [5]. Such circumstances not only strain financial resources but also limit individuals' ability to fully participate in society, restricting access to workplaces, schools, healthcare, and leisure activities [3,6].

Although previous research has shown that households can experience both energy poverty and transport poverty simultaneously, with the two issues intersecting and mutually reinforcing each other, existing literature shows significant limitations in current approaches and policies aimed at addressing the energy and transport poverty nexus [6,7]. Martiskainen et al. (2021) underline the need to break down traditional disciplinary silos and conduct research, as well as develop policies, that helps better understand and address the linkage between energy and transport poverty [3]. This need is also validated by an extensive bibliometric and content analysis of over 1000 papers by Lowans et al. (2021), which reveals the existing insufficiency of current indicators and metrics in capturing the full extent of the energy and transport poverty nexus [8]. Similarly, Sovacool et al. (2023) emphasize that existing frameworks tend to focus primarily on energy poverty, overlooking the critical intersection between energy and mobility access [9]. This gap is particularly pronounced in rural regions, where both energy and transport poverty are more acute due to infrastructural challenges [10,11], and to the best of the authors' knowledge, no significant studies have addressed this issue in these contexts. In this context, this research aims to bridge this knowledge gap by assessing existing energy and transport poverty indicators and proposing a novel approach for the creation of relevant indicators, focused on rural regions, through a broader perspective informed by social practice theory (SPT).

SPT challenges traditional perspectives like individualism, structuralism, and objectivism by analyzing routines and daily activities within broader socio-cultural and material contexts. Some scholars challenge existing policies for their implicit, albeit unaddressed, influence on practices [12]. In alignment with this, SPT can support policymaking by analyzing how technological innovations, such as the Just Transition, meaning that no one is left behind or pushed behind in the transition to low-carbon and environmentally sustainable economies and societies [13], depend on corresponding shifts in practices, practices that will disproportionately affect rural areas. Through this lens, it becomes evident that policies must address the habits of daily life for all citizens, especially in hard-to-reach communities, to achieve collectively planned sustainability goals [12]. Furthermore, building from the rich tradition offered by SPT, an ethical dimension can be introduced to the study of policies from an SPT perspective [14], further advocating for a rights-based approach that can guarantee both an equitable access to sustainable infrastructures as well as the capabilities required for sustainable living.

Addressing the SPT complexities related to transport and energy, as well as policy- and decision-making, is not easy, and it requires contextualization within the broader discourse on it. Firstly, energy consumption is embedded in various household activity practices [12], such as cooking and washing [15], which are governed by collective rules and structures, rather than being an isolated activity [16]. As such the practices that turn a house into a "home" are essential in understanding the socio-spatial dynamics of energy consumption [17]. Additionally, energy demand, as well as energy consumption [14], is heavily shaped by infrastructure and devices, as both influence and are influenced by societal practices [16]. For instance, current laundry practices have become more energy-intensive because of technological advancements and changing cleanliness conventions, despite initial reductions in resource use as people went from boiling water to machine washing [18].

New conventions then become normalized, making certain more energy-demanding practices, like driving or air conditioning, increasingly complementary/necessary within social norms and infrastructures, whether people carry out these practices consciously or not. For example, important groundwork related to practices in transport addresses car-dependent practices, and its infrastructures [19]. Despite still limited work at the intersection of energy and transport poverty, recent contributions compared fuel and transport poverty, showing where differences lie, and also where interactions arise between them [20]. Building on this understanding, SPT can inform how transport poverty influences daily life beyond economic considerations. There are many specific factors conditioning the mobility and transport poverty discussion, such as transport affordability, which centers the financial challenges faced by individuals, especially in developed countries, where car ownership becomes a significant burden [5]. Therefore, such perspective urges scholars and policy experts to move beyond simplistic views of behavior changes and include the study and grasp of broader socio-cultural, economic, and political factors.

In light of these, this study proposes a new indicator the Composite Energy and Transport Poverty Indicator (CETPI) that not only integrates traditional metrics but also encompasses considerations of accessibility, vulnerability, and the impact of the climate on energy consumption across several rural case studies in the EU, namely Croatia, Italy, and the Netherlands. Current metrics often lack the granularity and holistic perspective necessary for developing effective interventions and policies, leaving significant gaps in our understanding. By critically examining existing indicators and proposing improvements informed by SPT, this research aims to improve our capacity to address energy and transport poverty effectively. Overall, the novel contribution of our work is threefold.

We introduce a comprehensive indicator for energy and transport poverty that combines the use of traditional metrics with factors related to transport accessibility and vulnerability and climate patterns.

We employ SPT to gain insights into the socio-cultural and contextual influences that shape energy and transport behaviors.

We analyze the lack of interconnectedness of energy and transport poverty indicators, specifically in rural regions, offering insights for policy interventions in areas often overlooked in existing research.

2. Materials and Methods

The main objective of this study is to introduce CETPI, an indicator designed to identify rural areas potentially subject to higher levels of energy and transport poverty in the EU, with a focus on Croatia, Italy, and the Netherlands. To do so, we follow a methodology of four key steps, as illustrated in this section. These steps are shown in the Case Study Selection, Components Identification, Indicator Replicability, and SPT Assessment Sections to ensure a comprehensive and context-sensitive approach to developing the CETPI.

2.1. Case Study Selection

The three EU countries—Croatia, Italy, and the Netherlands—were selected for their geographic and socio-economic variability, as well as the availability of relevant data on energy and transport poverty. These nations represent diverse regions within the EU, each facing distinct energy and transport challenges.

First, Croatia has been struggling with the issue of energy poverty for several years [11]. Its situation reflects a general pattern observed throughout Eastern Europe, where the number of energy-poor homes in the country has been steadily rising, and not so surprisingly, Croatia has the greatest growth in energy prices at 5%, despite having a greater net income than both Bulgaria and Romania [21]. The energy landscape in Croatia also took a severe hit

in 2022 due to an intensive energy price shock because of global oil price rising, following the Russian invasion of Ukraine [22]. Additionally, a significant proportion of Croatia's population resides in rural areas, with only Zagreb classified as a predominantly urban area, and they face notable energy poverty challenges due to older building stock, low incomes, and limited access to energy infrastructure [10]. To further exacerbate this divide, approximately 32.4% of individuals in rural areas report significant difficulty accessing public transportation, especially in the countryside, where transport already accounts for a significant portion of household expenditures, increasing from 12% in 2008 to 15.8% in 2019 [23].

In Italy, where less than 25% of Italy's population lives in rural areas, although these regions are significantly affected by energy poverty [10], fuel prices have also been worrying as, even before the Russian invasion of Ukraine, Italy had some of the highest petrol and diesel prices in the EU because of its strong reliance on oil import [24]. This high cost of fuel, combined with Italy's reliance on private vehicles, has led to increased household expenditure on transport fuels. In 2015, densely populated areas saw households spending 4% of their expenditure on transport fuels, while in sparsely populated areas, this figure rose to over 6% [25]. Conversely, the energy poverty rate in Italy reached 8.5% in 2021, affecting approximately 2.2 million households, a 0.5 percentage point increase from the previous year, although it is important to stress that regional disparities exist, with Calabria recording the highest rate at 16.7% and the Marche the lowest at 4.6% [26].

For the Netherlands, which is a mainly urbanized country [27] and therefore it stands in contrast with the Croatian and Italian cases, a spatial analysis of energy poverty in the country reveals that 7% of households are energy poor, either due to affordability issues or poor energetic home quality [28]. Alarming, almost half of Dutch households (48%) are not equipped to participate in the energy transition independently, primarily because they reside in poorly insulated homes, and they lack the means to upgrade due to financial constraints or tenancy status. A significant 75% of these energy-poor households are under the purview of social housing associations [28]. Transport has also been studied in Dutch research circles, and preliminary studies have identified several groups that face transportation issues, including low-income individuals, job seekers, the elderly, people with migration backgrounds, those without a driver's license or car, individuals with reduced physical mobility, and residents of rural areas [29].

2.2. Components Identification

The new indicator brings together four components following an in-depth analysis of the multifaceted dimensions of energy and transport poverty, assessing traditional metrics in energy and transport poverty studies with a particular focus on EU regions. These components are the Per Capita Expenditure (PCE), the Accessibility Score (AS), the energy consumption (EC), and the Vulnerability Index (VI).

The PCE builds on household's expenses for energy; as such, quantitative information is generally used to evaluate households' fiscal health and overall quality of life [30], and for transport, its related poverty manifestation happens when families are compelled to allocate an unreasonable portion of their income to travel costs [5], especially when owning and operating a car [31]. As such, research proved how the expenditure burden correlates with local and regional economic performances, influencing energy and transport costs for such services in households [31].

The AS is grounded in the concept of multi-accessibility, where the multimodality of transport intersects with the unequal access and distribution of transport modes [32], motivating the choice of selecting multimodal transport data, as well as a clear component

for car ownership, given the structural role it plays in slowing down evolving mobility practices [33].

The EC component assesses the energy consumption of a region to compare this with the expenditure level of households across different geographical areas and to support the identification where anomalies between usage and prices might be happening. By observing annual meteorological trends through heating and cooling degree days, it is possible to make sense of different time/space-specific challenges [34].

The VI intends to inform where the risk of poverty or social exclusion is high, as vulnerable households often find themselves in a precarious balancing act, trading off expenditures on energy and transport, leading to sacrifices in one side of the budget to meet the demands of the other [3].

With the components identified, data were collected from Eurostat (<https://ec.europa.eu/eurostat/>, accessed on 26 January 2025), European Union Statistics Database, and ESPON (<https://database.espon.eu/search/>, accessed on 26 January 2025), a spatial EU-based collection of data, to identify recent and comprehensive datasets that aligned with the conceptual model. Upon retrieving the datasets, available at <https://doi.org/10.5281/zenodo.14746809> (accessed on 26 January 2025), an assessment was conducted to determine the availability of data at different NUTS levels. As a regional issue, rurality cannot be adequately explained through standard national-level analyses. Given the variability in data availability across regions and years, the decision was made to base the indicator primarily on 2022 data and at the NUTS 2 level (The NUTS classification (<https://www.europarl.europa.eu/factsheets/en/sheet/99/common-classification-of-territorial-units-for-statistics-nuts->, accessed on 26 January 2025) is hierarchical in that it subdivides each Member State into three levels: NUTS 1, NUTS 2, and NUTS 3. The second and third levels are subdivisions of the first and second levels), with the exception of data at the NUTS 3 level for PCE. As such, the NUTS 2 classification offers a finer-grained regional perspective to capture rural contexts that would otherwise be lost in broader national frameworks. It is important to clarify that this analysis focuses explicitly on rural areas and not peri-urban areas, as these zones often exhibit characteristics that overlap both urban and rural domains, calling for a more nuanced and separate assessment.

2.3. Indicator Methodology

This section explains how each part of the CETPI is executed. The process involves four components: the Per Capita Expenditure (PCE—Figure 1), the energy consumption (EC—Figure 2), the Accessibility Score (AS—Figure 3), the Vulnerability Index (VI—Figure 4), and the rurality assessment. Each step uses publicly available data and involves clear formulas and normalizations to ensure consistency. By following the process, the indicator can be carried out across other regions within the EU for comparative analysis. By comparing the obtained final normalized values side-by-side of each component and its rural–urban division, we can identify regions with overlapping or extreme values across multiple indices. This approach helps pinpointing areas where vulnerabilities might converge, such as high energy consumption combined with low accessibility or regions with high vulnerability indices but insufficient energy affordability. Such insights enable policymakers and stakeholders to focus on specific areas of concern, facilitating targeted and effective interventions.

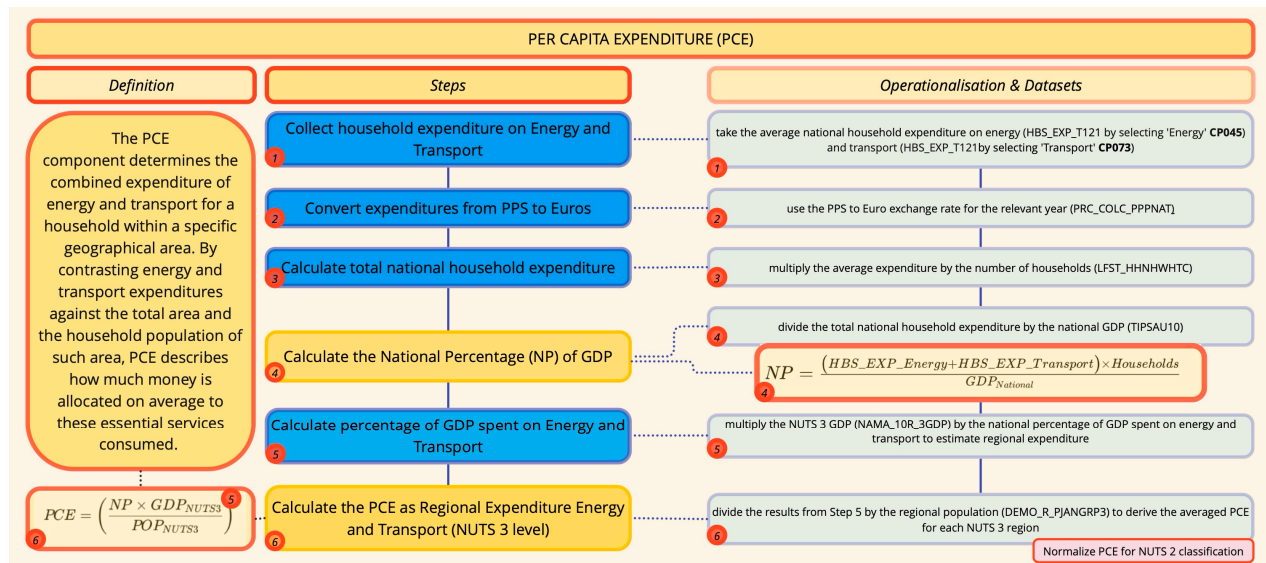


Figure 1. PCE methodology: a step-by-step guide to calculating PCE, focusing on household expenditure on energy and transport, normalized to NUTS2 and NUTS3 levels to identify regional disparities and support economic analysis.

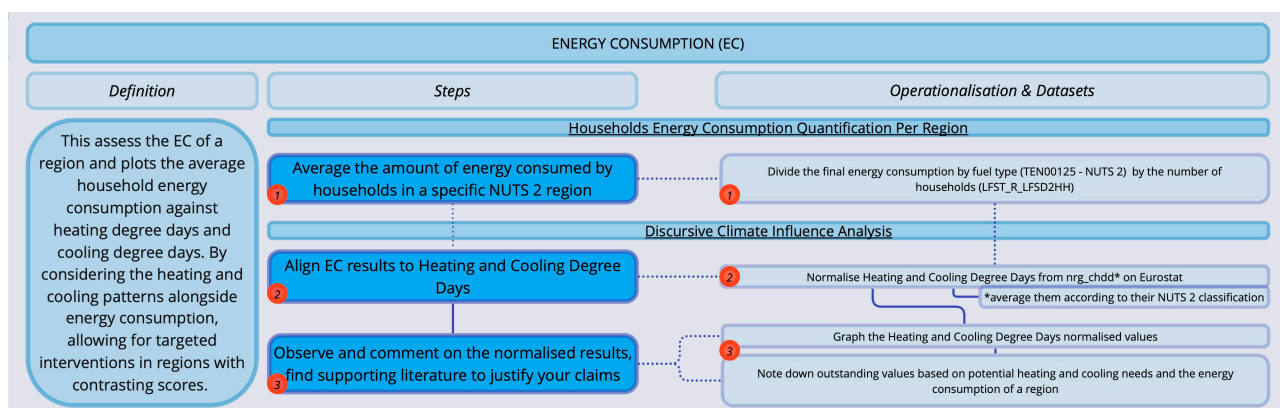


Figure 2. EC methodology: a visual representation of how household energy consumption is analyzed in relation to heating and cooling degree days, enabling an understanding of climatic impacts on energy use across regions. * This ensures that comparisons of energy consumption across regions account for variations in climate conditions at the NUTS 2 level.

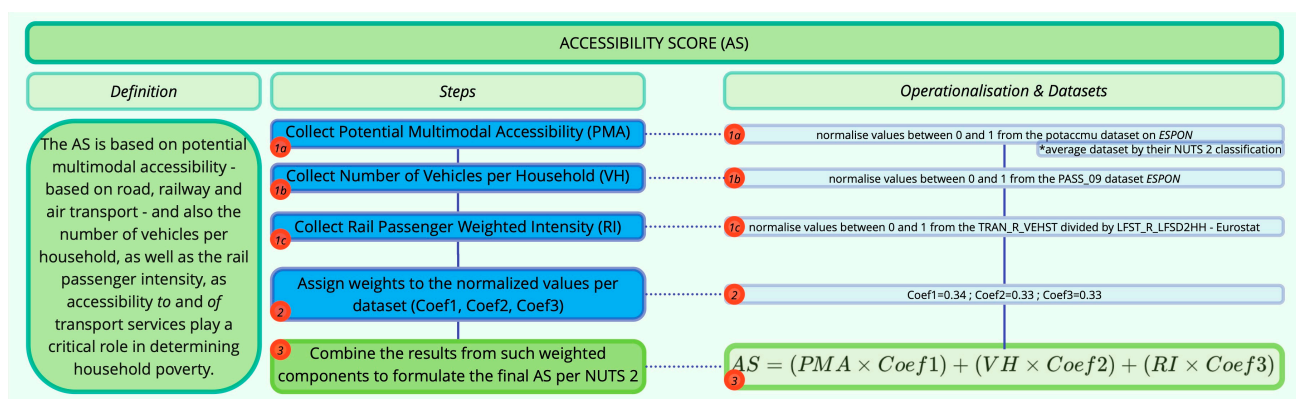


Figure 3. AS methodology: an explanation of how multimodal accessibility, household vehicle ownership, and rail passenger intensity are combined to calculate the Accessibility Score at the NUTS2 level. * This ensures that accessibility scores are comparable across regions by considering variations in accessibility data at the NUTS 2 level.

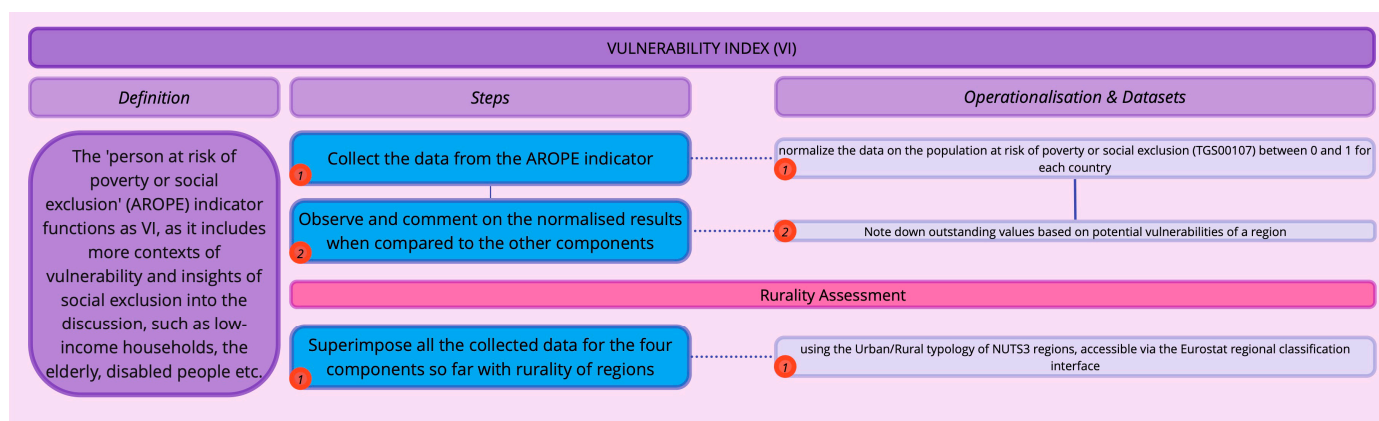


Figure 4. VI and rurality assessment: a methodological overview of how the AROPE indicator and rurality data are combined to evaluate vulnerability, with a focus on identifying regions at greater risk of social exclusion and poverty.

2.3.1. Per Capita Expenditure

Calculating the PCE begins with collecting average household expenditures on energy and transport and converting these figures from the Purchasing Power Standard to Euros. Subsequently, total national household expenditure is calculated by scaling these averages to the number of households, followed by determining the national percentage (NP) of GDP allocated to energy and transport. This national percentage is applied to regional GDP data to estimate regional expenditure, which is then normalized by the regional population to derive the PCE at the NUTS3 level. Finally, the PCE is further normalized to the NUTS2 classification for comparative analyses.

2.3.2. Energy Consumption

The average energy consumed per household in a NUTS2 region is obtained by dividing total energy consumption by household numbers. Next, heating and cooling degree days are normalized and aligned with these energy consumption figures to assess potential climatic impacts, which are then analyzed, stressing regional discrepancies and identifying outstanding patterns through the available literature.

2.3.3. Accessibility Score

The process begins by collecting and normalizing datasets on potential multimodal accessibility (PMA), the number of vehicles per household (VH), and rail passenger intensity (RI) at the NUTS2 level. Weighted coefficients are then assigned to each component. These weighted values are combined to calculate the final AS for each NUTS2 region, providing insights into the role of transport accessibility in influencing household poverty.

2.3.4. Vulnerability Index and Rural–Urban Division

This last part starts with normalizing AROPE data, which are then observed to identify notable regional vulnerabilities compared to other components. In the final step, the four components are also compared with their typology (urban, peri-urban, and urban) using the urban/rural typology of NUTS3 regions, enabling a more nuanced understanding of vulnerabilities in rural regions.

2.4. Social Practice Theory Assessment

After assessing the current landscape of such indicators, as well as conceptualizing and implementing the newly proposed one, the research is dived into addressing the indicator's missing links, perspectives, and integrations. Hence, this section critiqued the

indicator's reliance on economic metrics by emphasizing the importance of human agency, socio-cultural contexts, and material entanglements in energy and transport practices [16]. To identify key areas for study on energy and transport poverty, SPT provides a framework to critique and obtain new insights to (1) bridge energy and transport poverty theory and practices to offer context-sensitive insights and (2) assess the prominent role of tangible elements—materials in SPT—in current indicators' practices to argue for more encompassing strategies. More precisely, the idea of “practices” embrace many interpretations based on the interaction between individual actions and social structures; while Bourdieu emphasizes the role of habitus, in which social structures are unconsciously ingrained in individuals, shaping their actions based on class position [35], Giddens and Schatzki theorize essential elements in building practices, referred to as routines and explicit rules, and teleoaffective structures, defined as goal-oriented and meaningfully substantive objectives [15]. Indeed, Reckwitz (2002) expands on this by incorporating bodily actions and technologies, viewing practices as collective and constituted through core elements like the body, mind, and knowledge [36]. While the complexity and variability of social practices can make it difficult to develop standardized indicators that capture the full breadth of these phenomena, on the practical side, SPT can support in understanding what aspects are understudied in research and unapprised in policies and consulting, suggesting its potential for real-world impact [12,37].

3. Results

The Results Section presents the CETPI findings, stressing regional disparities in energy and transport access across Croatia, Italy, and the Netherlands. The interpretation focuses on identifying vulnerable rural areas, revealing how factors like accessibility, energy costs, and socioeconomic conditions contribute to energy–transport poverty in these regions.

3.1. Croatia

As illustrated in Figure 5, in Croatia, rural areas are distributed quite evenly across Panoninska, Jadranksa, and Sjeverna Hrvastka. In Panonska Hrvatska and Jadranska Hrvatska, consumption and expenditure show contrasting patterns. While the first has moderate values for both components, Jadranska Hrvatska has high EC, suggesting a warm climate with potentially significant cooling needs, exacerbated by aggressive coastal tourism and improper intervention to assure efficiency [38], but a very low expenditure. Specifically, for Panonska Hrvatska, the moderate AS contrasts with the relatively higher EC, as transportation options are available but probably energy-intensive, therefore possibly indicating that households are spending relatively more on transport. For Jadranska Hrvatska, despite having a low Accessibility Score, the region has the highest EC, but a low expense level suggests that while energy is consumed, the actual expenditure on transport is limited. On the other hand, Zagreb has low values for both PCE and EC but a high AS. Then, for Sjeverna Hrvatska, the high AS is in fact influenced by its multimodal accessibility and vehicles per household values. This stands in contrasts with the lowest EC but a relatively higher PCE that can indicate the very cold temperature and therefore higher local heating needs [39], in line with its alpine climate [40]. Also, research shows that households throughout the various counties are exhibiting increasing uniformity in their electricity consumption habits, leading to a convergence in their usage patterns [41]. The disparities in PCE on transport and energy in Croatian households can be traced back to the historical and economic context of the country. Centralization has been a persistent feature in Croatia, even during its transition into a market economy, and this is evident in disparities across various indicators such as unemployment, income per capita, and the

presence of different infrastructure components [42]. The varying pattern attributed by the Accessibility Score can be linked to the assessed impact of major transport infrastructure investments on accessibility, ruling on the positive effects on different locations [43]. An example is the case of the Istrian Y Motorway, which not only increases tourism flow but also reduces accidents, the traveling time, and costs [44]. Lastly, the observed variabilities in the vulnerability of citizens in post-socialist countries are often linked to the legacies of the centrally planned economy [45]. Experts point out that issues like poor thermal insulation of housing stock and low energy prices contribute to this vulnerability [46], confirming the observed increasing trend of poverty in Croatia, which became particularly noticeable post-2008 [47].

3.2. Italy

In Italy (Figure 6), the rural divide is most pronounced in the southern regions, including Calabria, Sicily, and Basilicata. Here, transport accessibility is lower than in the north, and energy poverty is shown through economic constraints. Also, the CETPI results confirm that while households in Northern Italy spend more on transport, those in the south struggle with limited public transport infrastructure and high fuel costs. Indeed, high multimodal accessibility and rail intensity contribute to a good AS in northern regions. However, along with the high EC, the PCE reflects that households are paying more, possibly due to the higher quality, maintenance, and efficiency of services. A moderate AS does not allow for significant observations in southern regions because of their varied EC levels, while the lower PCE in some regions indicates economic constraints. Regardless of many policy interventions, this divide has remained persistent over the last twenty-five years [48]. In fact, Milano confirms this trend, and accordingly, other cities, like Agrigento in Sicily, present a contrasting picture. In fact, the risk of energy poverty manifests differently across Italian regions, where Lombardia, with its high incomes, faces potential energy poverty due to older buildings, and regions like Campania and Sicilia, with the country's lowest incomes, may also experience energy poverty risks due to inefficient dwellings [49]. In central regions, a high AS is observed next to high EC, suggesting that transport options are accessible, and households are likely willing to spend on these options. Interestingly, in the case of island regions, the low AS, despite the anomalously high value for multimodal accessibility, suggests that more intense air and water transport might hinder the understanding of the situation on the ground. This disparity between service availability and usage is further confirmed by an analysis of the competitive effects of high-speed rail in Italy, where their introduction, especially in the north-central regions, has considerably improved the national rail network capacity [50]. The presence of competing high-speed operators, namely Trenitalia and NTV, particularly on the Rome–Milan route, has not only increased rail utilization but also influenced strategic pricing in both the rail and airline sectors, fostering a more competitive environment that benefits consumers through reduced airfares and improved rail services. However, the concentration of such infrastructure in the north-central region shows a regional imbalance in accessibility [50]. A substantial increase in rail passengers in Italy, likely influenced by the expansion and improvement of rail services, including high-speed rail [51], further corroborates this trend. As the North–South divide is a historically well-documented phenomenon, with the northern regions generally being more affluent and the southern regions grappling with higher levels of poverty and social exclusion, this divide is even more exacerbated by urban–rural disparities [52], where urban areas tend to have lower vulnerability to fuel price increases due to higher incomes and less reliance on cars, as opposed to rural or suburban populations [25].

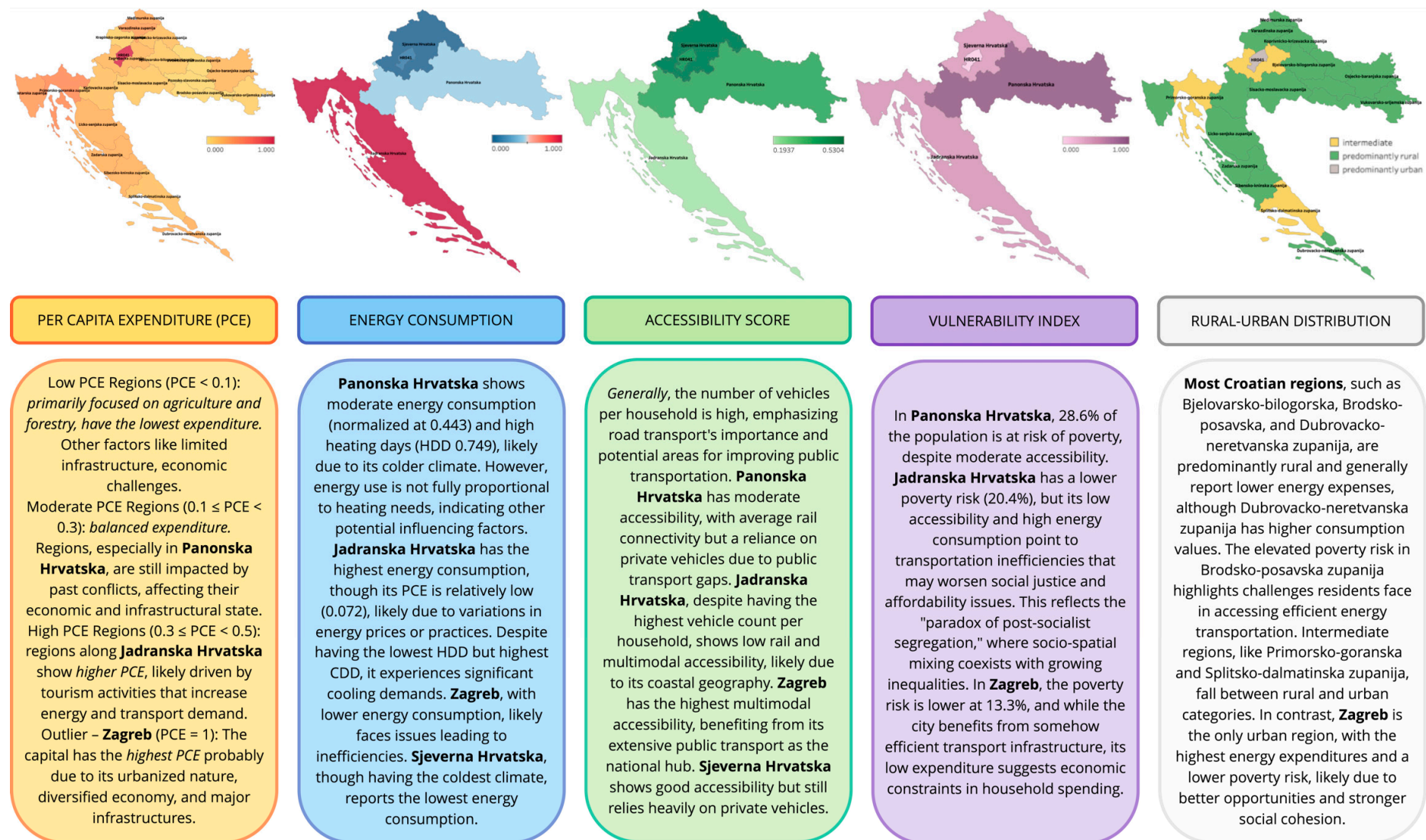


Figure 5. Regional disparities in energy and transport poverty indicators across Croatia: maps visualize the Per Capita Expenditure (PCE), energy consumption, Accessibility Score, Vulnerability Index, and Rural–Urban Distribution. Higher resolution maps are in the Data Availability Statement.



Figure 6. Regional disparities in energy and transport poverty indicators across Italy: maps visualize the Per Capita Expenditure (PCE), energy consumption, Accessibility Score, Vulnerability Index, and Rural–Urban Distribution. Higher resolution maps are in the Data Availability Statement.

3.3. The Netherlands

In the Netherlands (Figure 7), only one region was coded as rural, Zeeuwsch-Vlaanderen, and it did not show any extreme vulnerability. In fact, in the rest of the country, despite a moderate AS, driven mainly by high multimodal accessibility, the western regions have high EC, suggesting that transportation options are accessible, especially in urban areas that have led to sustainable travel habits, as a significant portion of the Dutch population often opts for walking, cycling, or using public transportation [53]. Under this aspect, the PCE reflects that households are spending more, possibly due to a higher cost of life and the quality of transport services. For example, the high rail passenger intensity in urban areas like Amsterdam indicates efficient public transport systems. In this regard, the recent literature has stressed the persistent income inequalities between central and peripheral regions [54], making a case that the higher value identified in bigger cities like Amsterdam is attributed to their greater economic resilience and growth, which in turn fuels higher energy and transport costs and demands. The lower AS in eastern and northern regions, influenced by lower multimodal accessibility, contrasts with varied EC levels, and the expenditure level indicates that households might be spending more than average on necessary services. In contrast, a generally high AS, driven by both multimodal accessibility and rail intensity, fits with moderate EC PCE and indicates that households are willing to spend on these options. In addition, the high percentage of households with unaffordable energy costs in all income deciles [55] indicates that even in regions with higher PCE, there may be underlying challenges that are not immediately apparent from PCE figures alone. Lastly, the concept of social exclusion offers a broader viewpoint on the challenges met by vulnerable groups in the Netherlands [56]. The development of an overall index for social exclusion, incorporating aspects like material deprivation, limited social participation, and insufficient normative integration, revealed that certain groups, such as non-western immigrants, divorced individuals, and the least educated, are particularly vulnerable to social exclusion. On the same level, this vulnerability is also closely related to self-reported health statuses, adding another layer to the complexity of social challenges in the country [56], which in return will exacerbate poverty conditions [3].



Figure 7. Regional disparities in energy and transport poverty indicators across the Netherlands: Maps visualize the Per Capita Expenditure (PCE), energy consumption, Accessibility Score, Vulnerability Index, and Rural–Urban Distribution. Higher resolution maps are in the Data Availability Statement.

4. Discussion

4.1. The CETPI and Social Practice Theory

As new (energy and transport) practices become normalized in daily life and are accepted as the norm, the dynamic nature of social practices and how they evolve in response to both material and immaterial factors need to be discussed. Here, social practice experiences are leveraged to observe if the indicator's individual components fit within the relevant discussions around them as fields of practices.

For PCE, considering only energy or transport expenses is no longer enough to describe situations of poverty. For example, some of the Croatian regions with a low PCE also overlap with more rural areas; here, the reliance on the primary sector means energy and transport practices can be heavily influenced by local resources/constraints; if this can highlight some areas of concern, where PCE is too low or too high, it fails to report on lived experiences in such regions. Likewise, in moderate to high PCE regions in Italy, it would be possible to conclude how urbanization and industrial activities may drive higher energy and transport expenditures, reflecting urbanized practices. Indeed, regions with similar values of PCE in the Netherlands would also stress how urbanization and industrial activities necessitate higher energy and transport expenditures, reflecting modern energy-intensive practices. However, neither of the two results can inform on what are such practices, as well as how practitioners can intervene in these issues. Indeed, while the relative costs of modern fuels play a role in how people use energy, factors like ease of access and cost of local resources, cultural preferences such as taste and cooking style, and the availability of materials still influence choices and behaviors [57].

For EC, in discussing energy consumption as a layered relationship of habits, technological structures, and societal norms, traditional approaches focusing on behavior often overlook the unconscious habits and technological structures behind consumption [15]. As such, it is necessary to point out right away that such elements have not been integrated in the current version of the indicator. The link between technological advancements, economic shifts, and everyday practices is studied to show how social structures and relationships significantly influence how someone's values translate into action and how one's personal preferences can lead to energy-intensive choices [58]. Especially through energy efficiency, supported by the integration of modern (and more efficient) energy systems with renewable energy sources, energy poverty can be tackled to improve the social welfare of households, as has been argued for in European countries [59]. For example, Zagreb's lower consumption levels despite significant heating needs could point to infrastructural inefficiencies, asserting the fundamental role of materiality of technological structures and the influences that they can have on people, while in Italy, the consistent variation in energy consumption across regions with similar heating and cooling degree days may also inform on the influence of regional infrastructure and household behaviors, but more ethnographical work is needed to deepen the knowledge in the field.

For AS in transport practices, a lot of focus is given to car dependency, because it not only touches upon automobility or infrastructure systems, but it is also very connected to specific patterns of temporal co-dependence and spatial relationships [19]. By changing the narrative and describing transport practices as collective and routine-like performances [60], scholars acknowledge the determining significance of factors such as frequency, comfort, reliability, and network coverage in shaping perceptions of regional public transport [61], proving the importance of incorporating such perspectives. For example, in Jadranska Hrvastka, low rail connectivity can indicate physical infrastructures that are insufficient to meet local transport needs, while in Italy's central regions, the balanced transportation system and the high rail passenger intensity could reflect both good physical infrastructure

and high perceived accessibility, although perceived accessibility has not been actively included here.

For VI, energy vulnerability is not understood as static—as it is not a constant/unalterable state—but as probabilistic, so households deemed ‘energy service poor’ at a given time might overcome this status in the future, while others might fall into this category due to changing circumstances [62]. As such, the ever-changing nature of vulnerability helps us consider both the current state of energy poverty and the conditions leading to it. By including more indicators of vulnerability, it is possible to provide a more accurate representation of the situation/region in which real-world energy use and challenges take place. For example, Campania and Sicily exhibit high poverty risks (49.4% and 42.5%, respectively, in 2021) alongside moderate accessibility and significant energy consumption disparities, showing the critical link between rural constraints and vulnerability, where limited economic opportunities and underdeveloped infrastructure contribute to heightened poverty risks.

Hence, SPT can help develop culturally sensitive strategies to address vulnerabilities and foster climate resilience among diverse rural communities by recognizing the interactions between cultural identities, practices, and infrastructures, such as cultural institutions and evolving physical and virtual community spaces.

4.2. The Role and Strengths of SPT

Recognizing the dynamic and socially constructed nature of “normal” living conditions [12] is more than necessary for addressing the environmental and social implications of overconsumption and energy deprivation [58]. When considering the approach taken in CEPTI, SPT points to many challenges stemming from the considerations provided and offers the space to conceptualize more encompassing ways of addressing poverty starting from the limitations of the indicator. As this perspective calls for the inclusion of daily routines, the available literature shows how energy consumption and transport are integral parts of complex practices, amongst which there are households’ dynamics. It is logical to deduce then how practices that make a house a “home” are necessary to explain such dynamics like embodied habits, institutionalized knowledge, meanings, and technological influences.

Given that many factors contribute to poverty, metrics to observe such phenomena should be societally, culturally, and economically holistic to illustrate how inequality is ingrained in these intersecting elements. For energy poverty, this should focus on differences in access to resources and infrastructure affecting people’s capacity to fulfill social obligations such as access, affordability, flexibility, energy efficiency, mismatched needs, and a lack of political recognition. In the case of transport poverty, this is influenced by affordability, mobility options, accessibility, and environmental impacts. As practices related to energy and transport evolve over time due to cultural, technological, and societal changes, the indicators used should also reflect such evolution. Thus, the importance of using social practices as a unit of analysis to understand consumption, demand, and resource use in relation to sustainability [63] helps in defining limitations in this research and, by extension, in other widely available indicators. In fact, much of the focus has traditionally been on explaining broad societal trends in expenditure and their changes through time, often overlooking fixed or entrenched practices, how such practices shape historical trends of energy and transport poverty, and different paths followed by individuals. Nevertheless, by proposing a shift in the paradigm by examining material conditions, social meanings, and competences and their interactions to shape energy and transport poverty and the related practices, this study not only call attention to the socio-cultural and

systemic dimensions, but it also contributes to the broader discourse on sustainability and social justice.

By highlighting the dynamic and socially constructed nature of “normal” living conditions and energy sufficiency [46], it challenges the normative assumptions underlying current policy frameworks [64]. For instance, the insights provided by Butler (2022) on the expanded capabilities approach suggest that policies should not only address affordability but also the quality of energy services and infrastructure by possibly investing in renewable energy solutions or energy-efficient technologies that are accessible and affordable for rural households [65]. In terms of transport poverty, making transport options not only available [5] but also practical and accessible can significantly alleviate such struggles [66]. Similarly, enhancing home heating systems and public utilities can reduce energy poverty by improving energy efficiency and reducing the costs for rural households. More examples arise as we tackle the social dimensions of energy and transport poverty, such as gender, age, and disability, which are essential factors to be considered when creating inclusive policies. Some examples for such measures could include subsidies for energy-efficient appliances that reduce the time spent on household chores to relieve specific constraints faced by women, especially in single-parent households; targeted interventions for older adults, such as home retrofitting programs that improve energy efficiency and reduce heating costs; and the establishment of community energy cooperatives that allow residents to collectively invest in and benefit from renewable energy projects, like solar farms, wind farms, and biogas facilities.

4.3. SPT Perspectives to Support Sustainable Transitions in Rural Households

SPT studies are needed to open new perspectives on sustainable transitions, as well as drafting and implementing effective policy strategies [67]. If changes in practice can happen in three different ways, namely (i) elements constituting them can change, (ii) the population of carriers of practices can change, and (iii) the relation among practices can change, it is essential to consider changes happening at specific crossroads in life, particularly with regard to the necessity of systemic change, as countries (and individuals) move toward climate neutrality [67]. Similarly, others stress that researching how human lives are influenced by geography and how environments are interrelated will assist in developing a Just Transition policy that is made fairer by bringing them into line with the space-related and intangible effects of change [68]. Especially in rural contexts, different mobility behaviors are found compared to urban environments, countries, and regions; rural people concentrate on functional mobility, linking other behaviors and creating the meaning of locations, whereas urban residents observe their city flow and support it via mobility [67].

Once people are able to recognize the deeply engrained functionality of practices in rural areas, it can be easily understood why scholars challenge the status quo of the rural–urban gap and the injustices and inequities that occur in the rural space by applying the notion of spatial justice [68], where in achieving restorative justice, we must address the rural–urban gap and geographical marginalization. As such, rehabilitating the workforce and the area as a whole after the fossil fuel industry transition is the main goal of restorative justice, and by taking into account the geographical difficulties of a place, a spatial justice approach can become more comprehensive [68]. This perspective has far-reaching implications, as indicated by the trajectory of agricultural policy in the European Union which employs a different strategy that views traditional cultures as resources in rural development networks [69], as well as the Just Transition previously mentioned [70]. These networks combine economic rationality with local developmental control, facilitating local and regional growth and connecting communities with national and worldwide markets, mixing tradition with postmodern world imperatives [71].

This is especially relevant when asserting that policy implementation is constructed through chains of performances, connecting multiple actors across different scales. For instance, policy implementation is made up of multiple smaller acts, such as auditing or negotiating, that indeed require a deeper level of understanding [72]. At the same time, examining a large-scale practice bundle provides only a partial account, as the wealth of data requires focusing on specific performances. This is precisely where the greatest challenge remains to be faced by researchers, social workers, and experts regarding poverty, as tackling a systemic problem such as that of poverty by addressing specific issues related to it, like energy and transport; determining its components at both a general and individual level; and being able to provide support to all the people in need is crucial. As suggested in this study as well, by tracing external and elemental dynamics and inter-actor relationships, we can gather insights into the evolution of the practices and inform better choices. For these various reasons, the use of SPT has been particularly beneficial in clarifying the research questions, demonstrating how there is only something to gain from integrating more economic and numerical knowledge with a contextualization that is able to observe and allow for the interpretation of complex dynamics within vulnerable groups. By doing so, it is possible to provide both a critical look at the current situation and to develop policy and research recommendations that in the future could not only contribute to the theorization of the concepts of energy and transport poverty but also to their effective and efficient alleviation in rural areas.

4.4. Recommendations

There are different ways in which CETPI, like the results of the SPT critique, can be exploited both by policymakers, researchers, and other experts/stakeholders. Intuitively, one of the most immediate applications of CETPI is its ability to determine geographical areas at risk of energy and transport poverty, based on the analysis of four key components, namely PCE, AS, EC, and VI. For instance, being able to identify the PCE can help determine what type of subsidies, both direct and indirect, could be planned and offered to vulnerable citizens' groups. Furthermore, long-term strategies and plans could be pushing for economic diversification beyond traditional agriculture, especially in rural regions, introducing new opportunities and mitigating poverty. Similarly, the use of the AS can be employed to determine which types of infrastructure improvements are needed in less connected areas, as well as facilitate targeted interventions, such as establishing supportive and coordination structures that boost access to essential services, like one-stop shops (<https://energy-cities.eu/coming-soon-a-european-community-of-local-one-stop-shops-for-home-energy-renovation/>, accessed on 26 January 2025).

Furthermore, insights from the CETPI can support the design and implementation of policies focused on improving rural transportation infrastructure through both physical improvements and social interventions, like community-based transit plans, based on on-ground assessment of needs, associating new services with existing travel practices, which can change the perception and the intensity of utilization of public transport. Regarding household energy consumption, the CETPI could indicate areas of greatest need of modernization in terms of energy efficiency, for which further studies could clarify and for which information and targeted support could be offered. Such energy efficiency initiatives should be tailored to the rural context, perhaps through community-led renewable energy and renovation projects, as many are being currently promoted in the EU, such as Renoverti (<https://ieecp.org/projects/renoverti/>, accessed on 26 January 2025), Assert (<https://ieecp.org/projects/assert/>, accessed on 26 January 2025), and Locatee (<https://ieecp.org/projects/locatee/>, accessed on 26 January 2025), fostering a shift

in practices, promoting shared ownership of projects, and even financially (and locally) benefitting participants.

Finally, considering the percentages of individuals at risk of poverty or social exclusion can help describe the severity and urgency of certain interventions. This includes educational initiatives aimed at shifting practices around employment and inclusion, thereby equipping rural populations with skills relevant to the modern economy. Educating communities can also take the form of resilience-building programs, mainly on sustainable practices through local workshops and training sessions, such as multiapartment building meetings to discuss energy efficiency and potential accessible subsidies. Additionally, empowering relevant stakeholder groups to assess an area's local energy consumption practices can support and identify the behaviors that could be modified to alleviate energy and transport poverty, as well as increase overall wellbeing.

In practice, this would mean carrying out a large amount of field research to determine which practices (and which interconnections) influence these aspects and whether they can be differently quantified. This research seeks to lead to the collection of more systematic and granular data, including relevant aspects, such as consensus-based information on households' behaviors on the use and habits of transport and energy. Regular assessments of these practices are essential, with updated methodologies to reflect societal changes. To ensure comparability between projects and objectives, datasets should be accessible and open source. These recommendations aim to inform ways to transform existing practices in a manner that is sensitive to the socio-cultural context of vulnerability in each country, addressing the challenges identified in the study while fostering a more sustainable and inclusive approach to the development of relevant indicators.

4.5. Limitations of the Study and Indications for Future Research

Firstly, the reliance on secondary data sources limits the depth of insight into the local nuances of social practices in transportation and energy use; this means that while some general information is available on the status of energy and transport poverty components, indicators do not reflect the lived experiences of low-income households and do not provide information on what practices, meanings, or competences are more likely to contribute in tackling the poverty issue. Additionally, as this study focused on specific indicators like PCE, EC, and AS, while informative, it did not capture the entire spectrum of factors influencing social practices in these rural regions. According to the considerations made on the use of SPT, it is important to note that both this study and others categorically lack the inclusion of the concepts of interconnection of practices, the importance of the spaces in which practices connect, and, consequently, do not offer the kind of observations that could inform us about the systemic change needed in the fight against climate change. Furthermore, while the initial results have made it possible to identify geographical areas to which particular attention should be paid, i.e., on which there should be more focus in order to observe situations of energy and transport poverty, there is no information to share on the actual behaviors of individuals, or their areas of actual need.

Lastly, the research also reveals gaps in the current understanding of how social practices around transportation and energy use evolve in different urban and rural contexts, as well as their different meanings to the relevant people, where instead more localized studies into the specific cultural, economic, and social factors that shape these practices would greatly benefit communities and policymakers. The indicators is now also being carried out for all the remaining Eurozone countries by IEECP, with the perspective of testing the CETPI further and examining what can be qualitatively and/or quantitatively improved. Some case studies will be analyzed in depth and will be complemented by

expert and local practitioners' interviews to explore a more ethnographic approach in connection with a data-based assessment.

That is why further research should also explore the impact of policy interventions on these social practices, with longitudinal studies to track the effectiveness of different policy measures in transforming policies or with comparative studies between regions within a country or across different countries to study what facilitates or hinders the adoption of sustainable practices. It would be important to be able to carry out field research like ethnographic studies, in-depth interviews, and participatory observations, for example, in the situations addressed in this same study, such as cooking, driving, working from home or in the office, and taking care of yourself and others, and begin to determine which contextualized practices can be observed based on where one is located. Precisely because of the very nature of SPT, it would also be appropriate to examine how these practices are addressed in other disciplines, such as economics or engineering, to educate practitioners who are able to grasp greater nuances of human life, thereby facilitating a holistic understanding of how social practices intersect with technical and economic factors.

Nevertheless, this research should continue to focus on energy and transport practices as well as spatial justice, particularly addressing the rural–urban gap in access to all resources by investigating how geographical and infrastructural differences impact social practices and then proposing tailored interventions that will proactively engage communities in the research process through participatory methods so that the findings and proposed solutions are relevant and beneficial to those affected. Only by involving local populations at the fore-front of the issue in identifying problems, co-creating solutions, and evaluating interventions can this lead to more sustainable and equitable outcomes for all.

5. Conclusions

The current energy and transport landscapes of the near and not so near future should aim at imagining governing scenarios to promote the fight against climate change as well as the inclusion of the most vulnerable in such plans. Indeed, while the scientific community has never been more certain and aware of the climate crisis urgency and of the extent that this will have on people's livelihood, current policies lag worryingly behind in supporting vulnerable segments of society in facing the coming hardships. Hence, this paper explored different elements for an indicator that helped in drawing a clearer picture of energy and transport poverty through observing expenses, dynamics of transportation for accessibility, energy consumption, and vulnerability in the context of urban-rural divisions within Croatia, Italy, and The Netherlands.

In Croatia, the predominance of rural regions in the Panonska, Jadranska, and Sjeverna macroareas, characterized by generally lower expense values and higher risks of poverty, marks challenges in transportation and energy accessibility, which has been further corroborated by the urban exception of Zagreb, with more money going towards transport and energy, as well as a seemingly more efficient transportation infrastructure, in contrast with the reality experienced by rural areas. While the Italian case presents a similar scenario, where urban centers like Milano and Rome show higher PCE values and available transportation options, rural areas, namely in Basilicata, Calabria, and Sicily, (so specifically in the South) grapple with financial difficulties and limited transportation options. However, the resilience of rural communities shows how the interaction of social, economic, and geographical factors can also still positively influence livelihoods in rural dynamics. Lastly, the Netherlands, with its uniquely highly urban society and only one low-risk rural areas, exhibits overall high expenditure values in many of its regions, with

also increased accessibility and a lower risk of poverty and social exclusion, compared to its European counterparts, pointing to the need of studying its peri-urban areas as well.

The application of SPT in examining each component of the indicator has demonstrated how the role of societal norms, routines, and behaviors is thoroughly underrepresented in understanding how households experience energy and transport poverty at the indicator level. While it has been shown, over and over again, that these aspects do shape poverty to such a deep extent, it is not yet possible to incorporate many of them into indicators' data that policymakers can rely on for many critical decisions, leaving scholars wondering what influence such aspects would have in shaping the transportation and energy policymaking process. In addition, incorporating today's limited indicators with a deeper awareness of why families use energy the way they do and experience transportation as they do can be a way of understanding what needs are prioritized.

To conclude, it is extremely important to set this transition in motion starting from local and engaged communities, the ones that are already present and active in the areas in need, the ones who already offer communal spaces for people, and the ones who regularly meet, and who already share aspects of their existence in order to create a constructive dialog both with representatives of the institutions and with those who will deal more with the technical side of this transition. This not only implies a big step forward compared to the mainstream of top-down approaches, but, above all, it also means reinvesting (or, more practically, redistributing) large amounts of funds to ensure that experts in the field and citizens can be brought together to discuss and identify appropriate solutions to their commonly observed vulnerabilities. While numerical values can appear similar across regions with similar data, many aspects of rural challenges are hardly quantified in proportion to the effort that rural populations must put into accessing services of any kind. Hence, the social practice theory lens reveals how traditional practices—heating, cooking, washing, economic constraints—fuel/electricity prices, income levels, and limited transportation options, such as car dependency or unavailable/unaffordable transports, have to be considered, alongside a myriad of other factors, namely education, gender, employments status, and so on, to study, understand, and act on energy and transport vulnerability patterns and poverty risks in these regions.

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