A multi-dimensional spatial analysis of energy poverty in the Netherlands

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1. Introduction

Energy poverty has gained substantial relevance in recent years in the European Union (EU) by recognizing it as a multidimensional problem that adversely affects human wellbeing (EU-EPAH, 2024).Since 2020, the number of people who are unable to keep their homes adequately warm has increased to approximately 47.5 million in 2023[3] (EUROSTAT, n.d.). This situation has been exacerbated due to several factors, such as rising energy prices entangled with geopolitical destabilization between Russia-Ukraine impacting the energy supply, the aftermath of the COVID pandemic and the current energy transition to low-carbon sources (Beckman & van den Beukel, 2019; EU-EPAH, 2024; Widuto, 2022). The surge in energy prices unevenly impacts households because most vulnerable groups are often low-income with a reduced capacity to respond effectively (TNO, 2023). In this context, the European Commission (EC) has underlined energy poverty as a convergent challenge where the right to energy for all while transitioning to a zero-emission target in the economy. Therefore, achieving a more just energy transition (Bouzarovski et al., 2021).

In line with this, EU governments have been acknowledging energy poverty as a structural issue that needs to be tackled under the zero-emissions policy goals and climate change and adaptation agendas. Governments have utilized different strategies to address energy poverty, such as cash transfers and allowances, subsidizing energy bills and taxes, energy price caps (Simcock et al., 2018 ; TNO, 2023), and in-kind provision of goods and services or training and education (Croon et al., 2023). These measures aim to diminish the impact of high energy bills on vulnerable populations and tackle cascading effects on household living conditions, including disposable income, mental health conditions and social mobility (e.g. education opportunities). These top-down policies often rely on data-driven proxies to target vulnerable populations and evaluate their cost-effectiveness. However, social, economic and cultural heterogeneities are unevenly distributed across space, as well as vulnerability factors to energy poverty. This element is key in understanding the efficacy of targeting mechanisms (TNO, 2023) that ultimately can contribute to diminishing exclusion and inclusion errors in tailored policy design and implementation (Croon et al., 2024).

There is limited attention in the literature on how vulnerability factors have a spatial dimension. In other words, people tend to be more or less vulnerable to energy poverty based on where they live, both within cities and urban-rural geographies (Bouzarovski & Simcock, 2017). This is particularly relevant when multidimensional vulnerability factors are entangled and reinforced according to existing urban and regional inequalities – the distribution of economic resources and income (Simcock et al., 2018), social, physical infrastructure and technological

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[3] According to Eurostat (EU-SILC), the total number of people unable to keep home adequately warm increased by 3.7 percentage units.

(Middlemiss, 2020), and other forms of spatial injustices such as segregation or gentrification (Moroni & Franco, 2024). For instance, (Bouzarovski & Thomson, 2018) highlights how urban energy vulnerabilities in Eastern and Central European countries intersect with social inequality, energy transformation, and socio-economic trajectories at the neighbourhood scale.

To address this gap, this paper investigates the spatial dimension of energy poverty and its connection to socio-economic and environmental inequalities. Using the Netherlands as a case study, we analyze socio-economic and environmental inequalities alongside vulnerability factors to map energy poverty at the district level. Based on the tridimensional approach to measuring energy poverty in the Netherlands (Mulder et al., 2023). We analyze a set of vulnerability factors to energy poverty identified in the academic literature and their interaction with socio-economic and environmental inequalities. The novelty of using these indicators relates to their capacity to capture three complementary dimensions of energy poverty: *affordability, energy efficiency, and participation in the energy transition* in a spatial context.

2. State of the art

2.1. Socio spatial vulnerability to energy poverty

(Bouzarovski & Petrova, 2015) discusses vulnerability to energy poverty as a set of conditions that make a household more likely to become poor. This set of conditions is associated with factors or circumstances that can be tackled to prevent a household from entering energy-poor conditions in the future. Likewise, vulnerability factors can become part of the reinforcing patterns of already identified energy-poor households. (Bouzarovski & Petrova, 2015) departs the discussion of energy vulnerability factors by considering that the energy chain is a complex set of interconnected socio-technical systems which not only provide households with energy but also involve the discussion of whether or not a household's needs are satisfied. In essence, it embodies approaching energy as a service in which elements such as technological efficiency, affordability and fuel-cleanliness intervene to pursue the continuous advancement of household prosperity and enhancement of individual wellbeing (Day et al., 2016; Middlemiss et al., 2019).

The literature about energy poverty vulnerability factors has been developing comprehensively. Beyond the mainstream discussion about the affordability-access dichotomy, vulnerability factors are also associated with the integration of efficiency, flexibility, social practices and concepts of energy needs (Bouzarovski & Petrova, 2015; Robinson et al., 2018b, 2018a; Thomson et al., 2017). Table 1 presents an overview of the state-of-the-art umbrella factors involved in a comprehensive approach to energy poverty vulnerabilities. These factors are associated with potential losses on individual and household well-being from energy poverty that can be linked to internal or external conditions in the home (Robinson et al., 2019). Additionally, the factors are associated with more specific aspects of the energy as a service framework, such as the energy chain, the conversion to useful energy at home, and the household demand linked to household needs and practices.

Table 1: Conceptualizing energy poverty vulnerability factors

Factor	Driving force to vulnerability	Internal or external to the home	Dimension of energy as service
Access	Inability to access appropriate fuel types Poor availability of energy carriers appropriate to meet household needs Unable to benefit from new technology	Internal-External	Energy chain
Affordability	High ratio between the cost of fuels and household incomes, including the role of tax systems or assistance schemes. Inability to invest in the construction of new infrastructure	External-Internal	Energy chain
Flexibility	Inability to move to a form of energy service provision that is appropriate to household needs	Internal-External	Conversion to useful energy
Energy efficiency	Disproportionately high loss of useful energy during energy conversion in the home (e.g. appliances or housing infrastructure) Inability to invest in energy efficiency Limited eligibility for efficiency	Internal	Conversion to useful energy
Needs and practice s	A mismatch between household energy requirements and availability of energy services: for social, cultural, economic or health reasons Lack of knowledge and support programs or ways of using energy efficiently at home	Internal-External	Household demand

Source: Based on (Bouzarovski & Petrova, 2015; Robinson et al., 2018b, 2019; Thomson et al., 2017)

3. Data and methods

We collected district-level data for the Netherlands to examine the spatial context of energy poverty. Drawing from an extensive literature review, we identified a set of vulnerability factors related to the five different topics presented in Table 1. Using the 2023 geographical delineation of administrative boundaries in the Netherlands, we mapped and analyzed these vulnerability factors. Table 2 presents a concrete list of vulnerability factors derived from the literature.

Table 2: List of vulnerability factors to energy poverty and proxies

Factor	Proxy	Spatial resolution	Year	Source
Older old	Percentage of vulnerable group over 65 years old: Elderly, living in social isolation, and weak health.	District	2020	Klimmat Effect Atlas
Young children	Percentage of households: couple with children, or lone parent	District	2021	CBS/Buurt en Wijk Kaart
Single person household	Percentage of one-person households	District	2021	CBS/Buurt en Wijk Kaart
Retired	Percentage of people pension from AOW (Reliant on state pension.)	District	2021	CBS/Buurt en Wijk Kaart
Disability or permanent ill	Percentage of people who receive a disability benefit under several circumstances WAO, WAZ, WIA, Wajong, wet Wajong	District	2021	CBS/Buurt en Wijk Kaart
Unemployed	Unemployment people. % people unemployment Act (WW)	District	2021	CBS/Buurt en Wijk Kaart
Precarious living or caring conditions	Precarious part-time. % people under WMO (social support act)	District	2021	CBS/Buurt en Wijk Kaart
Precarious (or inefficient) central heating system	Type of central heating system: Individual CV, District heating, Electrically heated, Block heating	District	2022	CBS/Hoofdverwarmingsinstallaties
Housing tenure and market conditions	Ratio between total rented and owner-occupied housing	District	2021	CBS/Buurt en Wijk Kaart
Low energy efficient property	Energy Consumption (Gas and electricity). Expressed as percentage of gas or electricity consumed in the rental housing sector	District	2021	CBS/Buurt en Wijk Kaart
	Low or medium low efficient houses according energy label : Low = (A to G)	District	2022	Klimaat Monitor
	Percentage of homes with registered solar panels	District	2022	Klimaat Monitor
	Construction year			Basisregistraties Adressen en Gebouwen (BAG)
	Housing typology			
Climatic exposure and environmental local characteristics	Number of summer (frost) days.	District	2022	KNMI
	Total percentage of grey per neighborhood	District	2020	Klimmat Effect Atlas
	Total percentage of green per neighborhood	District	2020	Klimmat Effect Atlas

Our methodological approach integrates an exploratory spatial analysis with a spatial econometric approach. Specifically, we employed a Geographical Weighted Regression (GWR) to investigate global and local vulnerability factor patterns. Additionally, we utilised a Spatial Durbin Model (SDM) to assess the spatial spillover effects at both local and global levels (J. P. Elhorst et al., 2014; P. Elhorst & Halleck, 2013; LeSage & Pace, 2009). To ensure a robust analysis, we explored multiple spatial econometric models to determine the most effective framework suitable for capturing spatial distribution of energy poverty (See Table A-1).

4. Conclusions (Tentative - Currently under analysis)

The initial aim of this paper was to understand the spatial condition of various types of vulnerabilities to energy poverty. The focus on the Netherlands helps further explore traditional dichotomy access-affordability views on energy poverty and dive more into other types of social, economic and environmental elements that contribute to exacerbating or diminishing it. This approach contributes to strengthening policymaking to reduce energy poverty by considering the regions as a key element to go beyond the one-size-fits-all type of policies.

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A. Appendix

Table A-1: Comparison between spatial econometric approaches: SEM, SLX and SDM

	SEM	**SLX**	**SDM**
(Intercept)	-4.76201***	-5.27664***	-4.23053***
	(0.40184)	(0.58116)	(0.57142)
p_fragile_health_65	0.04149***	0.03905***	0.03944***
	(0.00256)	(0.00311)	(0.00300)
p_single_person_household	0.00546*	0.00958***	0.00897***
	(0.00228)	(0.00247)	(0.00238)
p_with_young_children	-0.00278	0.00101	0.00074
	(0.00218)	(0.00236)	(0.00227)
p_pension_coverage_rate	-0.00008**	-0.00007*	-0.00007**
	(0.00003)	(0.00003)	(0.00003)
p_unemployment_rate	0.00064***	0.00061***	0.00056***
	(0.00010)	(0.00010)	(0.00010)
p_precarious_part_time	0.00007*	0.00004	0.00004
	(0.00003)	(0.00004)	(0.00003)
p_disability	0.03783***	0.03412***	0.03360***
	(0.00385)	(0.00417)	(0.00402)
ratio_owner_rental	0.06289***	0.07143***	0.07284***
	(0.01671)	(0.01730)	(0.01665)
p_gas_consum_rental	0.87628***	0.84072***	0.84918***
	(0.08774)	(0.09004)	(0.08669)
p_elec_consum_rental	0.46105***	0.49883***	0.47093***
	(0.13026)	(0.13378)	(0.12881)
p_individual_CV	0.00627***	0.00577***	0.00567***
	(0.00060)	(0.00066)	(0.00063)
p_elec_heat_high_gas_consum	0.01018*	0.01033*	0.00913*
	(0.00470)	(0.00480)	(0.00462)
p_elec_heat_no_gas_consum	0.01124***	0.01061***	0.01085***
	(0.00240)	(0.00246)	(0.00236)
p_homes_without_solar_panels	0.00567***	0.00641***	0.00640***
	(0.00107)	(0.00120)	(0.00116)
p_green	-0.00096	-0.00033	-0.00039
	(0.00067)	(0.00086)	(0.00083)
p_gray	-0.00408***	-0.00293***	-0.00308***
	(0.00069)	(0.00085)	(0.00082)
CDD	-0.00622***	-0.00305	-0.00754
	(0.00141)	(0.00635)	(0.00613)
HDD	0.00116***	0.00115***	0.00084***
	(0.00010)	(0.00021)	(0.00020)
t_h_type_apartment	-0.00155***	-0.00165**	-0.00165***
	(0.00040)	(0.00051)	(0.00049)
t_h_type_detached	0.00935**	0.00730*	0.00593*
	(0.00291)	(0.00302)	(0.00291)
t_h_type_semi_detached	-0.00077	-0.00272	-0.00251
	(0.00423)	(0.00440)	(0.00424)
t_h_type_terraced_semi_detached_corner	0.00619**	0.00583*	0.00567*
	(0.00226)	(0.00238)	(0.00229)

	SEM	SLX	SDM
building_median_ageX10Y	0.01525*	0.01679**	0.01857**
	(0.00600)	(0.00623)	(0.00600)
p_low_house_energy_eff	0.00689***	0.00693***	0.00673***
	(0.00092)	(0.00096)	(0.00092)
p_medium_house_energy_eff	0.00891***	0.00896***	0.00886***
	(0.00058)	(0.00060)	(0.00057)
urbanity_degreeurban	-0.08311***	-0.03528	-0.03079
	(0.02163)	(0.02357)	(0.02271)
urbanity_degreeno_urban	0.15010***	0.11432***	0.09907***
	(0.01959)	(0.02113)	(0.02037)
lambda	0.28578***		
	(0.02612)		
lag.p_fragile_health_65		-0.01139**	-0.01793***
		(0.00417)	(0.00411)
lag.p_single_person_household		0.00432	0.00255
		(0.00392)	(0.00378)
lag.p_with_young_children		0.00196	0.00238
		(0.00373)	(0.00359)
lag.p_pension_coverage_rate		0.00003	0.00005
		(0.00005)	(0.00005)
lag.p_unemployment_rate		0.00092***	0.00059***
		(0.00016)	(0.00016)
lag.p_precarious_part_time		0.00010*	0.00006
		(0.00005)	(0.00005)
lag.p_disability		0.01652*	0.00490
		(0.00647)	(0.00633)
lag.ratio_owner_rental		-0.00692	-0.03018
		(0.03454)	(0.03331)
lag.p_gas_consum_rental		0.06270	-0.19341
		(0.16599)	(0.16143)
lag.p_elec_consum_rental		0.00866	-0.07411
		(0.24052)	(0.23184)
lag.p_individual_CV		0.00110	-0.00040
		(0.00103)	(0.00100)
lag.p_elec_heat_high_gas_consum		0.01063	0.00899
		(0.00836)	(0.00806)
lag.p_elec_heat_no_gas_consum		-0.00327	-0.00535
		(0.00454)	(0.00438)
lag.p_homes_without_solar_panels		0.00160	-0.00006
		(0.00176)	(0.00171)
lag.p_green		-0.00155	-0.00090
		(0.00114)	(0.00110)
lag.p_gray		-0.00033	0.00067
		(0.00119)	(0.00115)
lag.CDD		-0.00040	0.00496
		(0.00644)	(0.00624)
lag.HDD		-0.00027	-0.00016
		(0.00021)	(0.00020)
lag.t_h_type_apartment		0.00070	0.00091
		(0.00067)	(0.00064)
lag.t_h_type_detached		0.01930***	0.01473***

	SEM	SLX	SDM
		(0.00437)	(0.00423)
lag.t_h_type_semi_detached		-0.00529	-0.00477
		(0.00665)	(0.00640)
lag.t_h_type_terraced_semi_detached_corner		0.00240	0.00127
		(0.00386)	(0.00372)
lag.building_median_ageX10Y		-0.03255**	-0.03321**
		(0.01135)	(0.01093)
lag.p_low_house_energy_eff		0.00206	0.00046
		(0.00167)	(0.00162)
lag.p_medium_house_energy_eff		0.00056	-0.00150
		(0.00109)	(0.00108)
lag.urbanity_degreeurban		-0.08945*	-0.06507
		(0.03833)	(0.03700)
lag.urbanity_degreeno_urban		0.18672***	0.14044***
		(0.03559)	(0.03472)
rho			0.24674***
			(0.02638)
Num. obs.	2291		2291
Parameters	30		57
Log Likelihood	-388.58191	-363.84339	-321.63178
AIC (Linear model)	937.03026		839.68678
AIC (Spatial model)	837.16383		757.26356
LR test: statistic	101.86643		84.42322
LR test: p-value	0.00000		0.00000
R^2		0.71449	
Adj. R^2		0.70759	
Sigma		0.28709	
Statistic		103.62056	
P Value		0.00000	
DF		54.00000	
AIC		839.68678	
BIC		1160.94442	
Deviance		184.28714	
DF Resid.		2236	
nobs		2291	

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$