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European energy poverty metrics: Scales, prospects and limits

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ABSTRACT

Energy poverty, a condition whereby people cannot secure adequate home energy services, is gaining prominence in public discourse and on political and policy agendas. As its measurement is operationalised, metrical developments are being socially shaped. A European Union mandate for biennial reporting on energy poverty presents an opportunity to institutionalise new metrics and thus privilege certain measurements as standards. While combining indicators at multiple scales is desirable to measure multi-dimensional aspects, it entails challenges such as database availability, coverage and limited disaggregated resolution. This article converges scholarship on metrics – which problematises the act of measurement – and on energy poverty – which apprehends socio-political and techno-economic particulars. Scholarship on metrics suggests that any basket of indicators risks silencing significant but hard to measure aspects, or unwarrantedly privileging others. State-of-the-art energy poverty scholarship calls for indicators that represent contextualised energy use issues, including energy access and quality, expenditure in relation to income, built environment related aspects and thermal comfort levels, while retaining simplicity and comparability for policy traction. We frame energy poverty metrology as the socially shaped measurement of a varied, multi-dimensional phenomenon within historically bureaucratic and publicly distant energy sectors, and assess the risks and opportunities that must be negotiated. To generate actionable knowledge, we propose an analytical framework with five dimensions of energy poverty metrology, and illustrate it using multi-scalar cases from three European countries. Dimensions include historical trajectories, data flattening, contextualised identification, new representation and policy uptake. We argue that the measurement of energy poverty must be informed by the politics of data and scale in order to institutionalise emerging metrics, while safeguarding against their co-optation for purposes other than the deep and rapid alleviation of energy poverty. This 'dimensioned' understanding of metrology can provide leverage to push for decisive action to address the structural underpinnings of domestic energy deprivation.

1. Introduction: a scalar lens on energy poverty metrics

Over the past decade in Europe, we have come a good way on addressing energy poverty, a condition whereby people are unable to secure adequate levels of energy services in the home [1]. The issue has moved from the margins of academia during the late 20th century and the 2000s (cf. [2], to one that has garnered attention from policymakers at the national and European Union (EU) scale. Pan-European initiatives have taken off and organised efforts to systematically address energy poverty alleviation as a key priority.

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The challenge of measurement has emerged as one of the key tasks in pushing forward with this agenda, and must resolve practical barriers linked with limited databases, coverage and disaggregated resolution. There are other challenges – such as lack of political will by policymakers and implementers, and conditions that limit and inhibit public engagement – but the focus here is on metrics, as improvements on this front are claimed to serve as a basis for practical action (cf [3–5].

While existing databases of relevant indicators are treated as comparable across most European countries, these are far from comprehensive in terms of capturing what energy poverty *is*. These databases primarily allow for generic country comparison and are thus of limited use for national policymakers. Composite indices are hard to institutionalise both due to questions around how to assign weightage and ensure transparency and commensurability across components [6] and because the EU policymaking environment prefers simplification of metrics [7]. Most European contexts lack energy poverty indicators that represent contextualised energy use issues, including energy access and quality, expenditure in relation to income, built environment related aspects and thermal comfort levels. Without tracking a greater variety of multi-dimensional attributes, and being able to unpack them at more disaggregated scales than mainly the national, current efforts risk failing to actually alleviate energy poverty due to selection biases, perverse policy effects, regressive cost burden distribution and exclusion of energy poor people from support schemes through misrecognition and imprecise targeting. Insufficient data and metrics may direct excessive attention to the more easily recognisable symptoms of energy poverty at the expense of obscuring injustices and inequalities deeply embedded in domestic energy provision systems. Having seen global efforts at addressing poverty more broadly extend over decades with limited effectiveness, it is desirable to avoid a similar fate for the narrower but nonetheless complex issue of energy poverty in Europe.

Specific methodologies to measure energy poverty are emerging rapidly in many EU countries as well as regions and cities [8,9]. In this paper, we take stock and posit an overview of what reflections and measures must inform and accompany such methodological innovation to progress energy poverty alleviation. After problematising the act of innovating and instituting indicators at multiple scales as inevitably fraught with data politics and problematic tendencies, we frame this process as five dimensions within an analytical framework.

These interrelated dimensions capture the full range of multiscalar concerns the EU must address as it develops methodologies and adopts metrics for measuring energy poverty and constitute the core around which the paper is organised. The first dimension focuses on the existing pathways of energy poverty metrics: *historical trajectories*. This concerns the path dependencies of the technologies involved in measurement and of the sector where the problem manifests. The next two dimensions capture aspects of how metrology (i.e., the study of measurement) is enacted, namely through *data flattening* and *contextualised identification*. The dynamics between these countervailing forces capture the politics of which actors are able to generate and access data to develop and implement particular measurements. The last two dimensions address how metrics are reconfigured, namely through *new representation* and *policy uptake*. They set focus on what happens as actors institutionalise metrics (privilege emerging measurements as standards) through national or higher scale policies in order to track and systematise energy poverty alleviation.

In our conceptual and analytical discussion, we set out the theoretical problematic of the act of measurement and relate this to the general issue of measuring energy poverty (Section 2). Based on a strong emerging literature, we abstract out five dimensions for energy poverty metrology research (Section 3). We then move into an empirical section (Section 4) that illustrates our analytical framework using multiple cases at varied spatial scales across three European country contexts. Our application identifies numerous challenges and opportunities in three European country contexts – Portugal, Spain and the United Kingdom (UK) – which offer rich contrasts but also similarities. The concluding section (Section 5) reflects on the implications for energy poverty metrology research: the measurement of energy poverty must be informed by the politics of data and scale in order to institutionalise emerging metrics while safeguarding against their co-optation for purposes other than the deep and rapid alleviation of energy poverty.

Reframing energy poverty metrology and illustrating it in terms of these dimensions requires multiple competencies. We accordingly assembled a set of co-authors with command over state-of-the-art scholarship on energy poverty, a range of measurement methodologies and participatory techniques, a reflexive understanding of metrology, and empirical research experience on how and for what purposes policies are mobilised by networked actors. In terms of disciplines, we span environmental engineering, sociology, human geography, environmental science, development studies, and Science and Technology Studies (STS). Our ambition to engage and overcome strong disciplinary silos implies a commitment to a widely accessible writing style and to presenting work with relevance for the interdisciplinary challenge of measuring energy poverty. While full data coverage and complete representation of such complex real-world phenomena are impossible, efforts to institute new, improved metrics must be premised on a critical understanding of data politics to enable energy poverty alleviation (cf [10]. These collaborative terms of engagement for actionable knowledge [11] generate theoretically informed, pragmatically oriented reflections on the tenets of energy poverty metrology.

2. Data politics and energy poverty metrics

While energy poverty governance relies significantly on data, it does not necessarily become more accountable, transparent or responsible if data choice and processing remain hidden behind the technocratic curtains. Therefore, this section opens up the black box of data, drawing on insights developed in the social scientific field of STS.[1]

Typically, data are imagined to be something that can be found, collected or gathered and neutrally processed to represent the underlying reality. This is a simple realist account; it does not hold if we turn to data-making (cf. [12], which is a practice, like many others. The social group of the 'energy poor' can be constructed differently by drawing on different data. Our assessment rests on the assumption that a universal set of metrics is unviable because

[1] STS originates in the empirically driven analysis of how knowledge and technical solutions in science and technology are historically, socially and culturally shaped, and social, cultural and political orders are shaped by knowledge and technologies. The field, thus, does not accept plans, such as textbooks', scripts' or standards' accounts of scientific and technical work as representatives of that work, but analyses these as prescriptive or performative texts, non-deterministically related to action and context [55]. Knowledge-production is situated and both socially and materially shaped. Contexts matter to the formation of the continuum between data, information, evidence, knowledge and practice [49]. This trajectory of analyses also finds technologies of representation including scientific, technical and economic data infrastructures and models to be partially shaping and transforming the realities that they are deemed to represent [109–111]. Data and metadata are analysed in STS, along these lines, as contingent socio-technical effects [29,112]. Data are political in multiple ways [113]. Adding layers of data and algorithms, under these circumstances, does not necessarily add transparency but may diminish the chance to understand what data actually represent [33].

energy poverty exhibits great context specificity. Indeed, energy poverty has activated scholarship across Europe but also beyond, in substantially contrasting countries like Japan [13], Australia [14], India [15], South Africa [16], Brazil [17] and Mexico [18]. The choice of data may be shaped by central policy actors as much as lobby groups and civil society [19]. However, it is not just interest groups that matter, but also material and human 'resources' – availability of data, algorithms, computing power, data scientists. Within energy poverty representations, furthermore, temperature conditions, the weather, make a context relevant. Thus, the stability of the climate matters for assessing energy poverty; however, climate change is causing more chaotic weather, rendering energy poverty and its measurement chaotic, too [20]. Data processing presumes negotiations as well as constructions of data, dealing with uncertainties and indeterminacies in a messy world.

Constructing the 'energy poor' through data, in short, entails the work of coordinating and relating heterogeneous elements – a work of assembling. A straightforward issue is the access to relevant data on, for instance, energy-consuming equipment, heating and cooling, buildings characteristics, and the socio-economic positions of household members. In current energy infrastructure transitions, energy data may be held by private owners, e.g., in the context of smart cities [21]. Even if some data are available and accessible, it matters whether those data, the producer or owner can be trusted – which is a concern of power relations and legitimacy [22–24]. A challenge when measuring a multi-dimensional problem like energy poverty is to operationalise diverse metrics at multiple scales (neighbourhood, urban, district, regional, national) to maximise coverage and minimise biases in representations of outcomes [13,25]. This means embracing data hybridity and methodological versatility to systematically align and employ multiple databases and multi-dimensional indicators. Thus, in scaling up energy poverty metrics, scales are socio-politically shaped [26]. This constitutes an opportunity to formally bring hybrid actors, such as civil society organisations, municipalities, regional authorities, utilities, various national agencies and citizens themselves into roles of measurement and monitoring [16]. Such co-production and polycentric governance of energy poverty metrics requires keen awareness of the ways in which data infrastructures for energy poverty reconfigure relations of accountability (which actors can hold which others to account) by informing policy-directed reporting processes in the EU [27].

STS posits that the political is not restricted to the social relations to preexisting data, but also shapes what is 'inside' of data, how that data is assembled [28]. There is no 'raw' data that is antecedent [29]. The making of a datapoint presumes categorisation and, often, quantification. Bowker and Star [30] show, for instance, that the meaning of categories in health policy has been changing historically; this involved not just different interpretations but also different infrastructures including shifts in metrology. Verran [31] shows that even quantifying and counting basic dimensions (like length) depends on cultural, bodily and material contexts. Metrics and metrologies are socially and materially shaped, implying implicit and explicit choices over inclusion and exclusion [32]. Consider the measurement of energy efficiency of buildings, which requires classification according to efficiency related to energy performance. Implicit are questions of what counts as a building and how its efficiency is measured – e.g., its bearing structure and type of materials, which end uses and equipment types are included – but also of how boundaries are drawn between various groups (e.g., energy classes A/B/C and so on). Assigning a building to a class of buildings establishes equivalence among its members and renders them 'commensurable' [6].

In practice, any calculation simultaneously stabilises and prioritises certain categories and metrics, which get complexified in contexts of big data [33–35]. Whilst mathematical rules and formal ontologies are highly relevant to data construction (which include calculations and algorithms), within data construction we encounter also bugs, errors, ignorance and have to assume a range of problems we are not yet aware of [36]. Therefore data and numbers cannot be assumed to be fully under control [24,37,38].

We need to recognise that data are often perceived by data users – e.g., policymakers, implementing agencies, researchers, citizens – as more trustworthy, if the contingencies, the choices and politics of inclusions and exclusions involved in the data construction are rendered *invisible*. The context is removed; in effect, the remaining text, the figure, becomes the essence. Typically, a data point is sent to travel without accounts of these contexts of construction. This means data travel black-boxed, as immutable mobiles [39]. The less context can be traced, the more difficult it is to comprehend what the data mean and to assess them from a position of a to-be-informed actor.

Thus, within data generation and processing, experts are rarely the single decisive factor that shapes data; rather, the eventual formation and content of data depends on the specific, situated and contextual relations between the actors, technologies and the environment involved. STS has shown this to be the case for data that underlie, e.g., climate science or shale gas governance [24,28,38,40]. The following dilemma ensues: if data come with too little context, accountability relations are weakened or destroyed, but providing too much context may be overwhelming and paralyse action. Given that data users are differentially equipped with resources to read, interpret and assess data, there is no universally optimal balance between context provision and removal. Furthermore, readers themselves, as well as the social and historical environment in which data get used, are changing over time. Keeping data infrastructures stable, however, also risks data inertia, e.g., lock-ins and path dependence [33,41], undermining the recognition of energy poor actors and their ability to exercise upward accountability.

3. An analytical framework for energy poverty metrology research

Data handling (generation, structuring and interpretative treatment) is a contingent outcome of the intersection of social, political and technical matters. Its output, namely measurement, aims to inform action; energy poverty as a multi-dimensional locus of measurement further complicates these challenges [42]. This section organises these processes into five related dimensions and proposes an analytical framework to scrutinise energy poverty metrology (Fig. 1).

The evolution of energy poverty metrics displays considerable contextual variance – within Europe, it goes back over three

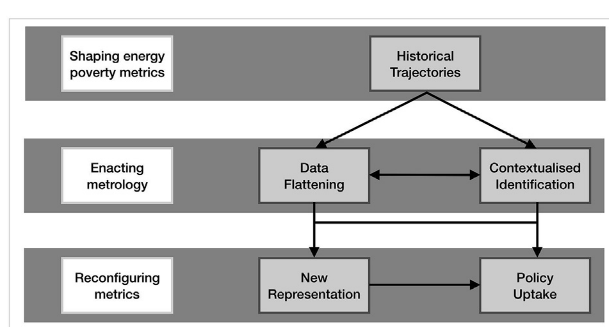

Fig. 1. An analytical framework with five dimensions for energy poverty metrology research.

decades in a few countries [43–45] while being at an emergent stage in research and policy arenas in others (cf [9,46]. Pan-European policy on the one hand, and national specificities on the other hand, imply both commonalities and differences in the metrics being promulgated and instituted, the data that thereby become available, and how suitable particular metrics and data are to alleviate energy poverty across various scales and contexts [47,48]. Thus, situated *historical trajectories* are a key characteristic of metrology: any system of measurement has a history of contestation and can be reopened for future renegotiation [30]. The attempt to assess energy poverty with universal coverage, typically at a national scale, involves some degree of *data flattening* and reduction, which is inevitable for such a multi-faceted phenomenon but neglects diversity and ignores contextuality. Data can only be generated by excluding some relations, yet the effect of exclusion is politically shaped [29]. Whilst contexts can be technically removed at any scale, contexts cannot be recovered at will [38,49]. Correspondingly, metrics risk systematic exclusions of some energy poor groups, as well as an exaggerated emphasis of energy poverty amongst other groups (cf [50,51]. This sets up the need for *contextualised identification*, which is a basic requirement in order to apply principles of affirmative action that cover vulnerable groups as well as safeguards that prevent adverse selection. Contextualised identification involves a range of scales and is enacted by various public, private and civil society actors [52].

Increasingly, energy poverty scholarship is cognisant of the need to populate energy poverty metrics with a wider range of variables at multiple scales. For instance, built environment characteristics like insulation and thermal inertia at disaggregated scales like neighbourhoods display systematic spatial variation in many cities, regions, and countries, with consequences for what aspects metrics must capture to represent energy poverty [53]. Innovative methodologies based on big data sources like smart meters and building energy certificates are coming to the fore, promoting novel metrics (e.g., Ref. [54]. Yet, new metrics and analytics are not necessarily positive, because the newest fads in data analytics can also decrease transparency and undermine accountability [33,55]. This raises questions of *new representation* – as alternative metrics are proposed with claims that they capture hitherto neglected variables, it is important to negotiate the specific politics of their inclusions and exclusions. Who develops and deploys these metrics, and based on what manner of apprehending newly emphasised variables, deserves consideration [56]. This process of how energy poverty metrics evolve shapes *policy uptake* by particular actors with their own interests and expertise [57]; see also [58]. Yet, the uptake of evidence does not guarantee the soundness of the underlying algorithms and data [37,38]. Policy uptake merits express attention to the legitimacy of metrics: who operationalises and uses emerging metrics in what precise manner [59], through what formal and informal power relations these metrics are oriented at energy poverty alleviation, and whether they risk catering to narrow interests.

These five dimensions constitute steps of an iterative process that continually reconfigures existing measurement frameworks. Fig. 1 indicates the relationship between historical trajectories of how energy poverty metrics are shaped, the characteristics inherent in the enactment of metrology (data flattening and contextualised identification), and the reconfiguration of metrics through new representation and policy uptake. We circumscribe and subsequently illustrate each dimension.

3.1. Historical trajectories

As an actionable concept, energy – or fuel – poverty has come of age over the past three decades in Europe. A particular policy discourse has accompanied this development [9,60]. Energy poverty has been unevenly recognised over time across Europe, and both manifests and is addressed to vastly different extents [61]. Specific definitions and methods for its identification that arose in one set of contexts, such as the United Kingdom, have at times been uncritically and incompletely transferred to other contexts where their suitability is questionable and potentially problematic [8,50]. For instance, an early UK indicator that defined households spending over 10% of their income on energy services as energy poor [2], was more recently uncritically adopted by countries as they began to act on energy poverty, despite their contextual needs being different from the UK. Awareness of the evolution of energy poverty metrics, the focus on specific energy services (e.g., space heating), and their historical trajectory within a given context are key towards grasping what measurements are privileged as standards and why, as well as what potentially relevant indicators and available datasets are currently under-utilised.

3.2. Data flattening

Much historical and current energy poverty monitoring takes place at the national scale, which is also drawn on for pan-European monitoring purposes. While important for comparability and a nation-wide picture, large-scale monitoring typically features methodological simplification, small and statistically non-representative samples at the regional scale, and a reduction of complexity in the chosen heuristics. It thus leads to a flattening of energy poverty data, missing the opportunity for local action and regional comparative assessments within a country. While widely-used databases[2] provide good coverage of affordability and needs, the main gaps at the national and pan-European scale concern detail on (i) the actual nature of energy access, (ii) the degree of choice and availability of energy carriers, (iii) the type and flexibility of the built environment (e.g., limitations to making modifications to the home due to tenancy status), and (iv) everyday practices and cultural habits [8]. Typically, databases do not contain metadata that could render the politics of data generation and transformation built into the provision of data transparent and accountable. When designing and implementing indicators, maximising coverage faces a trade-off with capturing sufficient depth and detail, especially as these requirements vary by context. For instance, heating needs are routinely tracked, whereas cooling needs – highly relevant in Southern European countries – only appear (as a summertime indoor comfort question) in ad hoc SILC modules in 2007 and 2012.

3.3. Contextualised identification

This dimension of energy poverty metrology exists in dynamic tension with data flattening, as a partial ameliorating strategy. It encompasses 'on the doorstep' measures [52], and is an essential component of a move from targeting the energy poor in policies to implementing measures to alleviate energy poverty [62]. As a complement to the data flattening of large databases, identification can be direct through cross-database identification [63], indirect through energy poverty proxies such as geographical location [64], and decentralised at lower scales such as the urban using new and increasingly available data sources like energy performance certificates or smart meter registries [62,65,66]. Contextualised identification encompasses efforts to capture hidden energy poverty

[2] These databases include the EU member states' Household Budget Surveys (HBS), the EU Survey on Income and Living Conditions (SILC), the European Quality of Life Survey (EQLS), and the Eurobarometer.

that remains invisible in prevalent comparative indicators, such as under-heating and cooling [67,68], and gaps pinpointed in the ENGAGER [20] policy brief (e.g., cross-linkages with electrical safety, health, indoor air quality, and extreme weather impacts). For instance, heat sources like biomass and butane gas are absent from Eurostat energy price statistics, but matter in many EU regions [69].

3.4. New representation

Methodological innovation is evident at multiple scales to unpack the complexity of energy poverty. This identifies additional relevant variables, measurement techniques, and advances new quantitative and qualitative bases to track performance on energy poverty. A key emerging concern is how marginalised actors contributing to such measurements, especially at lower scales such as the urban and regional, can find room for play [19,70]. Can energy poverty measurement unlock the promise of grassroots innovation and deliver decentralised modes of monitoring? Tirado Herrero [50] argues against 'exact definitions' of energy poverty and official, single-indicator energy poverty metrics like the UK's low income-high cost. In contrast, he makes the case for progressing multiple additional metrics that reflect awareness of the shortcomings of data collection and data parsing methods applied. These cautions pertain, for instance, to the diversity of household energy services and needs considered, the numerical transformations involved in the production of indicators and indices (e.g., income equivalisation, setting of thresholds, weighting factors, etc.), the subjectivity in survey responses, and contextual concerns around the "socio-demographic, spatial and temporal representativeness of data" [50]: 1018).

3.5. Policy uptake

Finally, energy poverty metrology features the institutionalisation of measurements. Through relational mobilisation by situated actors who engage with evolving institutional structures [71], data may inform and reshape policy, potentially driving the adaptive implementation of energy poverty alleviation efforts [56,57]. Such acts of institutional embedment mark the (re-)making of energy poor (and rich) subjects, as they enshrine in policy and legal documents the specific forms of metrical recognition that come to represent energy poverty. Measurements privileged as standards are deployed as new metrics through policy uptake if they successfully legitimate their claim to represent hitherto hidden, relevant energy poverty variables. Policy uptake can translate and consolidate emerging metrics into databases and systematic repositories, aiming at consistent reporting and avoiding fragmentation through polycentric governance [72,73]. This can be challenging at lower scales with weakly-resourced actors, inadequate social capital to shape decision-making, and patchy expertise [9]. Sustaining such efforts requires central support for initiatives that seek to overcome path dependency and institutional inertia, as well as concerted outreach efforts to improve the quantity and quality of democratic demand.

The next section illustrates how these dimensions can be productively deployed in the rapid current move through a design moment in energy poverty metrology, as new metrics are innovated, operationalised and compete for multi-scalar routinisation and systematic implementation.

4. Illustrating the five dimensions of energy poverty metrology

This section presents examples at multiple scales from Portugal, Spain and the UK to illustrate the analytical framework. While energy poverty first surfaced in academic and policy discourse in the UK within Europe [2], it took nearly a quarter century to gain similar traction in Spain, and in Portugal explicit policy engagement and research only began in the late 2010s. This has bearings on the existence of national definitions on energy poverty, their percolation with limited adaptation across contexts, and the state of knowledge and data about each context. Until recently, data was largely held at the national scale with statistical comparability across the EU [20]. This limited range includes, for instance, national performance expressed in percentages for indicators such as households' inability to maintain adequately warm housing during the winter or pay their utility bills on time, and the presence of moisture and rot within the house, as indicators from the EU Survey on Income and Living Conditions (SILC) illustrate. However, a wider range of indicators is emerging at regional and urban scales, opening up new options and questions for energy poverty metrology. Our examples feature currently silenced concerns and groups, where data requisite for relatively critical policy interventions are unavailable or underutilised by institutions.

4.1. Historical trajectories

The historical foundations for present day measurement of energy poverty can be found in the UK, which is recognised as the leading country in Europe for its measurement expertise and use of specialist models for estimating theoretical expenditure on energy [52]. Isherwood and Hancock [43] are credited with being the first to define the issue, but the topic did not gain widespread prominence until the publication of Brenda Boardman's seminal monograph in 1991. Boardman found that income poor households spent twice as much on fuel, as a proportion of income, than the rest of the population [2], and determined that households unable to achieve an adequate level of energy services for 10% of income are fuel poor.

The 'stickiness' of indicators is evidenced in the way these travel across countries and locations. The official UK-wide definition between 2001 and 2013 was based on Boardman's original 10% definition [2] and has been widely transferred to other contexts – both European and non-European – but mostly in an incomplete or uncritical manner [8]. England's current 'official' Low Income-High Cost (LIHC) indicator based on the 2012 UK government-commissioned Hills [74] review is still regarded as a benchmark for 'objective' expenditure- and income-based indicators. In the absence of government-sanctioned indicators in most EU member states, there have been attempts to put forward the LIHC as leading indicator for official energy poverty statistics – as an example in Spain see Romero et al. [75]. The pre-eminence of such indicators is justified on the alleged superiority of household expenditure and income data versus 'consensual' indicators [76] that rely on households' self-reported assessments of their material and living conditions. However, as the next dimension unpicks, the use of expenditure-based models often necessitates a flattening of data.

Strong historical contingency and path dependency is also evident for the World Health Organisation's (WHO) [77] recommendation for a safe internal temperature range of 18–24 °C (depending on room function) for non-vulnerable households and 20–24 °C for vulnerable groups [78]. Despite forming the basis for buildings energy performance certification and energy-related models, including the UK's official fuel poverty models, the origins and applicability of these thresholds is not widely critiqued by researchers or policymakers. A recent systematic review for Public Health England stated that

> whilst there is strong evidence that cold homes have a harmful effect on health, and there are good arguments for making

recommendations for minimum home temperature thresholds in winter … there is very limited robust evidence on which to base these recommendations [79]: 6).

This is also evident in the variance of national regulations. In Portugal, for instance, the buildings energy performance regulation of 2006 [80] defined as reference indoor temperatures 20 and 25 °C in heating and cooling seasons respectively. Its downward revision to 18 °C in the heating season in a subsequent update in 2013 [81] was justified by characterising its predecessor as very ambitious for a typical average temperature that represented citizen demand for comfort.

Standardised temperature thresholds and nominal conditions used for energy needs calculations inherently fail to recognise cross-country differences in culture, habits and expectations, occupancy schedules, consumption patterns [68,82]. They are also insensitive to ownership and the type of use of heating/cooling systems, and thus neglect the potential of adaptive comfort while setting ambitious thermal comfort levels and building energy needs [83]. By the same token, adaptive standards may consolidate unhealthy or unequal indoor thermal comfort levels. Thus, the historically contingent nature of energy poverty metrology renders existing standards and legacies significant and influential.

4.2. Data flattening

Cases of data flattening and simplification are widespread in energy poverty metrology, and generally relate to data availability. Energy poverty rates are typically reported at national scales in the EU, due to the statistical representativeness of corresponding datasets like HBS and SILC. First-time calculations and reporting of energy poverty rates have been systematically conducted at the national scale (with results sometimes disaggregated at the regional or NUTS-II scale),[3] as in Poland [84], Hungary [85] and Spain [86]. This practice reinforces the idea that domestic energy deprivation factors are primarily governed at national scales. Such representation overlooks instances where supra-national and sub-national scales play key roles in either defining the structural framework for the emergence of energy poverty or for articulating governmental action in response to the issue [48]. A prominent supra-national instance is the EU Directives, which through subsequent Energy Packages formed the current institutional architecture of the EU's 'internal market' for electricity and natural gas. At the sub-national scale, state regions and local governments are often in charge of identifying the energy poor and deploying remedial measures through social services or local support schemes. For instance, Barcelona's *Punts d'Assessorament Energètic* (city-district level energy advisory helpdesks for vulnerable consumers) largely serve energy vulnerable citizens, and Hungary's *szocialis tűzifa* (social fuelwood) programme run by local governments provides need-based subsidised firewood to households.

Averages based on national and regional datasets obscure the immense spatial complexity of energy poverty. Where data allow, sub-regional analyses should be undertaken to potentially uncover significant diversity in the drivers and impacts of energy poverty and identify national hotspots for local action (e.g., Ref. [87]. City-specific, statistically representative sub-samples populations are scarce, and the urban scale is oft-neglected in energy poverty statistics. Yet, urban-scale studies indicate substantially different rates of incidence across districts and neighbourhoods [88–90] with vulnerable populations highly concentrated in pockets [91]. These underrepresented lower spatial scales need to be re-emphasised to enrich and recalibrate energy poverty metrology.

The 'tyranny of averages' also surfaces when considering timescales of energy poverty-relevant data collection. Yearly (or even less granular) point data dominate and remove the 'temporal texture' of phenomena and experiences. The longstanding headline energy service to conceptualise energy poverty – seasonal differences in indoor thermal comfort – is weakly captured by SILC questions on households' inability to keep homes adequately warm in winter. Exemplifying the paucity of seasonally representative data, the complementary summertime indoor comfort question has only appeared in two ad hoc SILC modules (2007 and 2012). With the increased occurrence of extreme weather events like heat waves and cold spells, and higher average temperatures due to climate change, higher temporal resolution becomes more important, especially in significantly impacted regions such as Portugal and Spain [92,93]. Another notable trait is the data flattening tendency to use cross-sectional rather than longitudinal analysis [8], whereby survey questions are asked to a new sample of households each year, rather than repeating questions to the same sample over a number of years. This prevents analysis of the entry and exit points for households experiencing energy poverty.

Temporal simplification is particularly acute in the case of domestic energy prices of natural gas and electricity reported by Eurostat. Despite being the most authoritative source for comparing energy prices across EU countries, its energy price statistics are not keeping pace with rapid developments in the commercialisation of these energy carriers, especially electricity where time-of-use tariffs are increasingly the norm in parallel with smart meter deployment. Eurostat offers some level of disaggregation by consumption level and by composition (taxes versus provision costs) but conceals the complexities in energy markets that are simultaneously heavily liberalised and regulated. In Spain and Portugal, the effective price per electric unit paid by each household exhibits wide variety. It depends on the individual conditions of their supply contracts: regulated tariffs versus 'free-market' contracts; monthly flat rates versus constant or daytime/night-time tariffs; and add-on maintenance and insurance services which are systematically embedded in 'free-market' contracts.

Examples of systematic exclusion in the UK include the Standard Assessment Procedure approach to energy modelling which ignores cultural diversity [94], the inclusion of disability related benefits as income that results in some disabled people being artificially excluded [95], and more generally, the institutionalised nature of official surveys that construct the meaning of a household in a manner that excludes transient populations such as out-of-town student tenants. On a related note, the reduction of available pan-EU data (on relevant variables such as damp, rot and cooling) compared to pre-existing standards is a concerning trend [8].

4.3. Contextualised identification

Contextualised identification refers to methodologies that bridge gaps left by national and sub-national level indicators, and enable doorstep identification of individual energy poverty cases to deliver support or alleviation measures. The prevalent lack of high-resolution spatial and temporal data makes comprehensive multi-dimensional indices potentially hard to develop. Contextualised identification inevitably accompanies data flattening, and manifests a tension with it that goes beyond simply lack of sufficient data. At the root of this tension is the process of decontextualisation inherent in the technical generation and processing of data. Versatile efforts can distinguish between 'subject-oriented strategies'

[3] NUTS-II refers to the immediate sub-national scale of regions within the tripartite Nomenclature of Territorial Units for Statistics (NUTS).

(that support households) and 'object-oriented strategies' (that target the built environment, e.g., to improve housing stock).

From a legislative perspective, 'energy poor' equals 'vulnerable consumers' as established in EU Directives on common rules for the internal market in electricity and natural gas.[4] Member states set national criteria to identify households as 'vulnerable'. These criteria vary by country and have little to do with the headline indicators used to monitor the incidence of energy poverty for statistical purposes, such as the ones proposed by the EU Energy Poverty Observatory (EPOV). In the UK, the fuel poverty strategy broadly defines vulnerable consumers as older households, householders who are disabled or have a long-term illness, and families with young children (a major population segment), but households on social benefits are considered eligible for various energy schemes more generally [96]. In Portugal and Spain, vulnerable consumers are the eligible beneficiaries of social electricity and natural gas tariffs identified through social welfare systems. As indicated by Tirado et al. [97]; in Spain many of those identified as eligible electricity social tariff recipients are not in energy poverty according to headline indicators, and vice versa. The same holds true in Portugal, surfacing the need for complementary indicators for better assessment, for instance related to the energy efficiency of building stock.

Examples of 'subject-oriented' identification strategies at the urban scale include Barcelona City Council's protocol for detecting individual energy poverty cases through the local fire service, council housing services and family doctor surgeries. These pre-existing city-wide networks are mobilised for reaching out to households that are not reporting themselves to municipal energy poverty support units [89]. A further elaboration of this approach to locate and improve the living conditions of individual subjects or households is the UK 'Boiler on Prescription' scheme. This small pilot project carried out in 2014–2016 enabled family doctors to 'prescribe' energy efficiency (e.g., double glazing, boilers and insulation) to patients with Chronic Obstructive Pulmonary Disease exacerbated by living in cold, damp homes [98]. In Portugal, social support institutions connected with very poor sections of the population undertake local identification of vulnerable consumers. A nation-wide initiative (Support Program 65 – Elderly in Security) aims to support elderly subjects, especially those living remotely in isolation from active population centres.

'Object-oriented strategies' have been applied in Madrid, where the City Council's MAD-RE (*Madrid Recupera*) programme targets building improvement interventions at so-called *Áreas Preferentes de Impulso a la Regeneración Urbana* (Priority Areas for Boosting Urban Regeneration) or APIRUs. These APIRUs have been defined through multi-dimensional urban vulnerability criteria also applied in mapping energy poverty in Madrid's suburbs [90,91]. Portugal similarly uses 1,092 Urban Rehabilitation Areas to address building stock, infrastructures, public buildings and public green spaces through subsidised renovation projects in pre-identified deprived urban areas for improved energy efficiency. Gregório and Seixas [99] designed and implemented a composite geospatial index to benchmark the capacity and opportunity for energy renovation in historic centres.

These practical experiences suggest that national and local governments rely on their own identification strategies and tools primarily to 'contextually identify' particular cases for energy poverty intervention. Wilfully or inadvertently, they thus construct new categories of energy poor subjects by highlighting household characteristics such as chronic respiratory disease incidence or residence in a demarcated neighbourhood. Considerable scope remains to enlarge the basis for contextualised identification, thereby 'making' more (or less) energy poor subjects. For instance, the use of biomass – particularly widespread in Portugal among vulnerable rural populations – typically remains unaccounted for in energy consumption and expenditure statistics due to its 'informal' collection. Alongside biomass, district heating, butane gas and other social fuels are absent from Eurostat statistics on energy prices, but constitute important heat sources for large EU populations and give form to specific, locally-important forms of energy poverty such as 'energy degradation' [8,69] that merit express recognition.

4.4. New representation (new methodologies, data and richness)

Data availability can be increased and enriched by tapping new sources for improved metrics. National cadastres and increasingly available energy performance certificates can be tremendously rich sources of information. Cadastres systematically collect details of ownership, boundaries and real estate value mainly for taxation purposes. Both datasets contain information about the shape, size, age of construction and orientation of individual buildings and dwellings, which can yield detailed energy vulnerability metrics when combined with socio-economic census variables, as in Martín-Consuegra [100] for census tracks in Madrid, and Gouveia et al. [87] for all the 3,092 Portuguese civil parishes. But reconfigured forms of representation can also be problematic, as they may obfuscate important issues.

Innovative forms of representation include new ways of understanding and (dis)aggregating existing data and metrics. While indicators often employ the reductionist binary logic that a household is either energy poor or not based on pre-defined criteria, the reality of energy poverty is experienced in various forms and intensities and clashes with such simplified representation [50]. An easy way to capture the 'depth' of energy poverty has been through Likert-type scales in questionnaire-based surveys on indoor thermal comfort (see Refs. [45,101,102]. Expenditure- and income-based approaches have addressed the issue of depth by measuring artefacts such as the 'fuel poverty gap' of the LIHC – a calculation device that quantitatively assesses by how much the energy needs of an individual household exceed the threshold for reasonable costs [74]. Additional research has expanded this assessment by combining theoretical building energy needs and real energy consumption, as Palma et al. [68] show for Portugal by identifying regional thermal comfort gaps. Such treatment, along with recent discussion around introducing a Hidden Energy Poverty indicator by EPOV,[5] furthers understanding on problems like under-heating and under-cooling which are invisible in prevalent comparative European indicators.

An exploratory example for new ways of aggregation is a study of energy poverty indicators in Barcelona based on a 799 household city sub-sample of the Spanish SILC survey from 2016 [89]. Traditionally, SILC headline indicators have been regarded as separate metrics that individually represent different aspects of domestic energy deprivation. Interpreting SILC indicators through a relational lens surfaces a composite picture, with vulnerability levels defined based on the number and typology of energy poverty 'conditions' individual households experience. This ranges from households with inadequate thermal comfort levels at home to those that additionally show two or more arrears on utility bills and one or more energy supply interruption over the past year. This new form of representation moves towards more accurate

[4] The relevant Directives are (2009/72/EC and 2009/73/EC).

[5] After feedback from EU member states, this indicator has been adjusted to 'Low share of energy expenditure in income (M/2)'.

representation of domestic energy deprivation as multi-dimensional and granular from the perspective of affected households. The aggregation of indicators, discounting overlaps, consolidates and enlarges energy poverty numbers.

Increasing the richness of available data is crucial for bringing specific forms of energy poverty to the fore, especially for very vulnerable segments who have thus far been systematically excluded in quantitative representations. For the first time, the Spanish SILC 2016 enables an indicator that remains absent in practically all conventional data sources including Eurostat and national datasets: domestic energy supply disconnections due to inability to pay or consumer indebtedness with utility companies. It indicates that almost one million people in Spain lost access to their regular sources of domestic energy during that year [97]. Consistent numeric representation of such realities, if available, could well challenge the presumed notion of universal access to 'modern' energy in the Energy Union.

A vibrant new approach to representing energy poverty is citizen science and crowdsourced data. This pertains to purposive, non-random datasets collected by non-governmental actors through grassroots surveys or collaborative open-source mapping. In Barcelona, two civil society organisations in the struggle for housing and energy rights – Platform of People Affected by Mortgages and the Alliance against Energy Poverty – collaboratively put together a dataset of several hundred affected households that passed through their collective advisory assemblies over years. This survey fed into a report on the relationship between mental health and access to housing and energy written collaboratively with the Barcelona Public Health Agency (*Agència de Salut Pública de Barcelona*). Analysis of the first 100 households introduced in the dataset identified poor mental health conditions (as measured by the Goldberg-Shapiro scale) in 70% of men and 83% of women at risk of eviction and/or basic supply disconnections. These percentages are substantially higher than the average incidence of poor mental health in Barcelona – 16.5% for men and 20.4% for women [103]. Thus, such representation can both generate new data categories and strengthen links across existing variables.

4.5. Policy uptake

EPOV is laying the groundwork for common measurement frameworks, partially in response to EU legislation that is scheduled to introduce an obligation for member states to report periodically on the incidence of energy poverty at the national level. While its impact is still unclear, the momentum generated by this EU-wide initiative is worth noting as a window of opportunity for the uptake of more nuanced metrologies. EPOV's influence is evident in the Spanish National Energy Poverty Strategy adoption of its four headline indicators with slight methodological modifications to make them responsive to its national context [104]. The EU Cooperation on Science and Technology (COST) Action on European Energy Poverty likewise enables cross-fertilisation of policy-relevant insights on energy poverty metrics for coordinated progress on energy poverty metrology among EU member states.

Most draft National Energy and Climate Plans (NECPs) for 2030 highlight the need to address energy poverty and establish definitions and metrics, including both countries like Portugal where it is an emerging hot policy topic and those with extensive experience such as the UK. The Climate Action Network [105], however, calls for several NECPs to be more ambitious and take up measures to improve thermal comfort and reduce energy bills. Member states are deciding on monitoring tools and metrics, with EPOV advocating for multi-indicator approaches. This proposal contrasts with the former international benchmark – the UK's fuel poverty single indicator – first in the form of the 10% indicator and later substituted by the LIHC methodology. These older definitions preclude alternative understandings of the nature of and factors behind energy poverty and risk narrow identification of energy poor subjects, thus invisibilising vulnerable populations who may be dropped out of support schemes [50]. Metrics depend on policies for mobilisation, and how identification occurs can have enormous consequences. For instance, both Spain and Portugal provide social tariffs discounts to electricity and natural gas consumers. In Spain, the 25–40% social tariff discount only benefits eligible consumers that know about it and have successfully applied for it. In Portugal, a deep review was undertaken in 2016 (Law 7-A/2016) to ensure that all consumers that are entitled to the social tariff can benefit from it through a simple and automatic allocation procedure premised on information from the social welfare system, and the resultant coverage is far more extensive.[6]

Policy can also make existing but hitherto inaccessible data sources available. A case in point is the information on individual household consumption patterns collected through smart meters with very high temporal resolution being rolled out across the EU. Paradoxically, such data are difficult to access for householders and usually out of reach for researchers and governmental and non-governmental actors, who could push for affirmative policy action. Given the increasing complexity of the dynamic pricing systems that are likely to rapidly dominate electricity markets, smart meter data are being rapidly commodified – a trend referred to as 'datafication' – algorithmically translating various aspects of life into computerised data which appear as new 'value' in shifting political economies (see Refs. [33,35,106]). Mining household scale data by combining smart meter and survey techniques has demonstrated relevance for energy poverty metrics [54,65]. Smart meter data can help understand daily and seasonal energy consumption and identify energy poor consumer groups. It also prompts questions relating to what levels of data complexity and scale are desirable for designing policies and alleviation schemes. Clarity on access, ownership, requisite resources for data mining, and privacy issues under the new EU data protection regime is necessary in order to systematise metrics-relevant utilisation of these data sources.

5. Institutionalisation without cooption and the politics of scale

Europe is at a definitive moment when it comes to addressing the historically intractable and under-attended problem of energy poverty. The task of its measurement is increasingly embraced by actors like the European Commission, public and private utilities, governments at various scales, local and international civil society outfits, and influential scholars at research and training institutions. Discussion and contestation is likewise increasing among differently positioned organisations with competing interests and perspectives. This move from experimentation and innovation to adoption and routinisation represents a switch from 'ad hockery' to deeper institutional embedment. Recent scholarship on urban sustainability initiatives has emphasised the potential for catalysis across the spatial scale (e.g. Refs. [19,70], for instance through the translocal effects of performative practices [107]. A related strand of scholarship that continues to gather strength, on

[6] This law increased coverage from 200,000 to over 800,000 (14% of all residential electricity consumers); and from 15,000 to 35,000 (2.57% of all natural gas consumers). This difference relates to the lack of common eligibility criteria on the one hand, with the electricity social tariff being broader as it includes an income criterion, and to the electricity network being larger than for natural gas on the other hand [100].

polycentric governance, attunes us to pay attention to the promise and necessity of cross-scalar coordination (e.g., Refs. [72,73].

We note such developments around energy poverty metrology in multiple policy contexts – the EU and its member states constitute one set of key forums, and other global regions are evolving their own sets of protocols and state-of-the-art: contexts like India [15], Brazil [17] and Mexico [18] are addressing specific issues within energy poverty such as basic energy access and exposure to poor air quality. The concurrent trends we have analysed in different European contexts constitute valuable opportunities for cross-fertilisation. Application of our framework can thus help scholars identify how energy poverty measurement can be productively orchestrated at multiple scales and across a range of cognate sectors and actors, to collaboratively advance their common ambition of alleviating energy poverty in similar contexts.

Our dimensions show that the institutionalisation of metrics in data infrastructure as well as through organisational and policy processes involves unevenness. Current attempts must articulate and address these power dynamics to avoid 'lock-in' of power differentials and unaccountabilities. Failure to do so can enhance the policy impact of some metrics over others, based not on their greater relevance for energy poverty measurement, but rather on who is in charge of these metrics, at what scale, and how they ease portrayal of advances in energy poverty alleviation. Thus, energy poverty scholars, policymakers and practitioners must safeguard openings for progress towards the broad objective of alleviating energy poverty from co-option by dominant actors for narrower interests.

For energy poverty measurement to enable energy poverty alleviation, we argue for fostering the sort of discussion and debate of data politics and problematic tensions that the five dimensions illustrate. These identify not only 'solutions', but also the process for progress on energy poverty metrology and alleviation. The mobilisation of metrics to address energy poverty must be informed by an understanding of the quality and politics of data woven into the metrics, and thus situated within concrete contexts and key policy flows. As we have shown, such changes are relationally mobilised by actors at multiple scales, and inflected by often inequitable power relations. A world where regions as prosperous as Europe still exhibit significant levels of persistent energy poverty is by definition an unequal place. Thus, institutionalising new energy poverty measurements is a deeply political project – affected actors have different stakes and influence. Our dimensions unpack the range of mobilisation techniques that different actors can and do employ to inform action on energy poverty through networked relationships across spatial scales [71]. This insight is essential to grasp and articulate contextualised data politics, and we hope that future research will draw on the framework and five dimensions to extend this preliminary foray.

In closing, we reflect on the import that our initial problematisation of the act of measurement has for measuring energy poverty in order to alleviate it. As an object that policy acts on, energy poverty *becomes* whatever is measured. Its measurement is thus performative: versions of energy poverty metrics are enacted in such a way that the logics of their enactment are attuned to its eventual reduction. However, no measurement is perfect (the map is not the territory), hence there will always be varieties of energy poverty that policy action fails to apprehend and/or address as intended. Therefore, techniques to capture new metrics, while important, must be informed and accompanied by processes that ensure public inputs into and scrutinisation of the nature of these metrics. This can help ensure accurate and robust metrics, as well as nurture and nourish bottom-up involvement, create an 'invited space' where citizens feel empowered and welcome to engage (but see Ref. [108]) and help democratise energy poverty monitoring.

It follows that evolving metrics must be accompanied by devolving power to transform the energy sector into one that the public associates with its stakes and concerns and where people have a say. By cultivating such a process, energy poverty measurement will necessarily become participatory. Policymakers as well as local and national politicians will find it easier to be responsive to clearly articulated public needs and desires; this can to some extent overcome problems of political will. Civil society organisations, practitioners and applied researchers can build coalitions around specific claims to unlock energy poverty alleviation, leading to more organised pushes on policy levers for impact. In sum, measuring energy poverty constitutes an opportunity to mobilise actors and organisations and shape a more publicly accountable energy sector. With respect to the objective of energy poverty alleviation, the participatorily undertaken act of measurement is as vital a component as the metrics themselves.

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