Energy poverty or vulnerable consumers? An energy-economic method to compare the policy approaches to addressing vulnerabilities in the energy system in Germany

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Abstract

Energy poverty results from a combination of overlapping factors including low income, high energy prices, inefficient buildings and appliances, but in Germany the concept is not specifically recognised as separate from overall poverty and not targeted with policies and measures directly. Post-pandemic, energy prices are soaring and households are suppressing demand while stronger action towards decarbonisation demands more urgent action. As consumers of a third of the total final energy consumption in Germany, this puts households both at the heart of the energy transition and key to unlocking the potential to achieve energy and climate change targets while increasing resilience to energy price fluctuations. Yet, the majority of households are not in the financial or decision-making position to undertake the required investments in renewable and energy efficiency technologies. At the same time, households experiencing energy poverty are additionally disadvantaged in terms of meeting their energy demands (suppressed demand) and participating in the energy transition through difficulties accessing and affording resources and technologies. The current policy approach to address vulnerabilities in the energy sector revolves around providing “vulnerable consumers”, defined as social welfare beneficiaries, with subsidisation of electricity and gas consumption. A policy approach to address energy poverty would target the underlying causes through financial support for investments into energy efficiency and renewables. Using an energy system model, this research provides a socio-techno-economic empirical basis for recognising the significance of energy poverty outside of the current vulnerable consumers lens and within the energy transition process. Measures targeting the causes of energy poverty result in 25 % more renewables whereas bill support measures defined under the vulnerable consumers approach result in the persistent reliance on fossil fuel-based energy carriers for half of their consumption. Subsidies targeting investment support a shift in the energy infrastructure while subsidising consumption maintains the status quo.

Introduction

The pursuit to achieve climate objectives in the households sector within the energy transition requires significant investment largely from the private sector (Agora Energiewende 2018; Andor et al. 2017). Methods to evaluate the cost-optimal pathway to achieve these objectives often discount the financial and decision-making capacity of households due to the aggregated representation of the household sector (BMWi 2018). At the same time, energy poverty presents itself as both a challenge and an opportunity within the energy transition process. In this context, energy poverty results from a combination of low income, high energy prices, inefficient buildings and appliances as well as lack of access to clean and affordable energy sources (Dobbins et al. 2019). Access to energy is a right enshrined in the European Pillar of Social Rights and affordability is a pillar in the energy transition (EPSR 2017). The objectives of the energy transition aim to reduce the impacts of climate change by decarbonising the way we produce and consume energy. While this transformation is expected to result in more affordable energy to consumers in the long-term (20+ years), in the short to medium term (<20 years) this will require the mobilisation of capital to fund the investment costs towards increasing energy efficiency and renewable energy. Lower income households are not able to afford the high upfront costs of the necessary investments and risk being left behind. The principles behind a just transition include a fair distribution of the costs and benefits. At the same time, the next 10 years is critical for climate action, recognised by the fact that on the EU level climate milestone targets have been increased to a reduction of greenhouse gas emissions by 55 % by 2030 compared to 1990 levels (European Commission 2020b). Given this urgency to act, Germany – within the European energy policy framework – has defined targets to achieve carbon neutrality by 2045 with milestones in 2030 of 30 % renewables in the total energy consumption and a reduction of energy consumption of 30 % (BMU 2019; BMWi 2020a). The strategies relevant to the household sector developed from these aspirations require the renovation of the building envelope, replacement of inefficient, fossil-fuel driven heaters with efficient, renewable-based heating systems, increasing energy efficiency of appliances, the installation of decentralised energy generation technologies, and discouraging fossil fuel consumption through the introduction of a carbon tax (BMU 2019).

Energy poverty is increasingly prevalent in the energy transition discourse. It is no longer a question of if the energy transition will benefit lower income households, but how to enable this. To ensure the energy welfare of all households, the issue of energy poverty needs to be properly understood and methods to assess the adequacy of policy interventions to support the energy welfare of households need to be developed. With increasing energy prices, the discourse on how to provide support to lower income households includes direct bill support, and variations of carbon tax compensation schemes as direct income support. This paper describes the implications of the different policy approaches to address vulnerabilities in the energy welfare of households, then follows with a description of the method developed and a discussion of the results to better assess the energy welfare of households within the energy transition.

POLICY APPROACH: ENERGY POVERTY VS. VULNERABLE CONSUMERS

Poverty remains one of humanity's greatest challenges with more than 700 million people living on extremely low wages across the globe. Since the disruption caused by the COVID-19 pandemic and the ongoing climate crisis, it is estimated that up to 100 million additional people have moved into poverty by the end of 2021 (World Bank 2021). Inequality, and its related impacts on development, is a growing concern globally and the ability of households to afford the high upfront investment costs. Development economics shifts efforts to reduce poverty from measures focussing on broader objectives such as increasing incomes in general to measures tackling the micro-issues and causal pathways leading to poverty, such as education and health (Banerjee et al. 2019). By breaking the issue down into smaller pieces, the issue becomes not only more manageable, but also more tangible for policy intervention. Energy poverty is a situation where households are not able to adequately meet their energy needs at an affordable cost, and is caused by a combination of overlapping factors including low income, high energy prices, inefficient buildings and appliances (Dobbins et al. 2019; Pye et al. 2015). Tackling energy poverty directly as a subset of overarching poverty-reducing initiatives would be more effective in improving the quality of life through increased living standards. In the transposition of European legislation requiring member states to define energy poverty and vulnerable consumers and implement measures to reduce the numbers of households affected (Council of the European Union 2018). Some member states, like Germany, decline to recognise energy poverty as a phenomenon separate from overall poverty requiring targeted policies and measures (Bundestag 2014, 2017) and therefore address energy vulnerabilities in households through financial aid distributed through the social welfare system.

The policy approach also has implications for the final energy consumption and emissions profile for the household sector. Two prevailing policy approaches to address energy vulnerabilities in households are based largely on whether households in need of support are defined under the concept of energy poverty or that of vulnerable consumers. The concept of energy poverty is intertwined with but distinct from that of vulnerable consumers (Pye et al. 2017). The definition of each concept is critical to identifying the target group and specifying the required policies and measures required to address the issue. The key differences in the approaches means that different beneficiaries, fuel types and measures are targeted. A policy approach targeting energy poverty policy would aim to address the underlying causes of energy poverty (lack of affordability, low efficiency) in a broader target group of lower income households through measures that increase energy efficiency and the use of renewable energy. In contrast, an approach guided by a vulnerable consumers policy approach would provide bill support limited to electricity and gas consumption only to beneficiaries identified through the social welfare system (Dobbins et al. 2019). Thus, the "energy poverty approach" would shift the structure of the energy system while the "vulnerable consumers approach" would maintain the current consumption patterns in these households.

Approximately 11–21 % of the German population are estimated to be at risk of or experience energy poverty (Pye et al. 2015; Bleckmann et al. 2016; Heindl 2014). Despite these estimates, energy poverty remains a contentious issue in German politics where the resolute position remains to not recognise energy poverty as requiring attention separate from efforts to address overall poverty and is therefore neither defined nor measured (Schultz 2018; Heindl 2014; Bundestag 2017). The discourse on energy poverty in Germany has chiefly arisen as a result of the energy transition and the corresponding increasing electricity prices. Generally, Germany's strategy to address energy vulnerabilities through bill support as designed under social policies is considered as substantial as the objective is to address poverty as a whole (BMWi 2012). However, this approach has been criticised as insufficient (VZ 2008, Tews 2013, Tews 2014) since regardless of the broad-based social system, households are not able to maintain affordability and therefore access to a supply of energy to meet their basic need, where more than 296,000 households (representing 0.6 % of household electricity customers) unable to pay their electricity bills and over 43,000 unable to pay their gas bills were consequently disconnected from energy services in 2018 (BNetzA 2019) despite the support options available to customers in arrears (BMWi 2020b).

CHALLENGES WITH CURRENT METHODS TO SECURE THE ENERGY WELFARE OF LOWER INCOME HOUSEHOLDS

The lack of a common understanding on what energy poverty is results in fragmented approaches and discounts its significance within the energy transition debate. This is a problem because there are indications of an increasing trend in energy poverty due in part to the COVID-19 pandemic and increasing energy prices, and current strategies risk leaving lower income households behind (Dobbins et al. 2019; Bouzarovski et al. 2021; European Commission 2020a). Determining objectives, targets and the impact of policies and measures on the household sector are commonly based on modelling assessments which typically assume a homogenous population and monitoring benchmarks for policies are gauged according to average households (BMWi 2018). This oversimplifies the assumptions for the household sector and leads to one technology (and therefore policies, measures and targets) identified as the most cost-effective solution to meet a particular demand. An average household does not adequately capture the observed technological diversity and the differences in investment decisions and consumption behaviour across different types of households and does not account for barriers to actual investment behaviour on the part of this sector (Ahanchian et al. 2020; Lopes et al. 2015; Cayla and Maïzi 2015). Therefore, there is a need to differentiate between the financial and decision-making ability of different households to be able to better determine how to meet the required investment demands leading to the achievement of sector-specific renewable energy and energy efficiency targets, especially when aiming to stimulate an increase in the numbers of prosumers producing and consuming their self-generated electricity, which is contingent on the mobilisation of capital from the private sector. There is also a need to assess energy poverty by classifying the main arguments towards the recognition of and taking action on tackling energy poverty and not only for vulnerable consumers.

Methodology and modelling framework

Typically, the household sector in Germany is represented in energy system optimisation modelling exercises as one homogeneously defined average household representing all households, disaggregated only by building type or location (BMWi 2018), which oversimplifies the situation and leads to one technology identified as the most cost-effective solution to meet a particular demand. The expected contribution from the household sector towards achieving the targets hinges on energy system analyses which are performed using average households. Despite increased granularity of various attributes in the building sector (e.g., such as investor-specific barriers, ambience heat distribution, and uptake of policies and measures), recent assessments have found that the building sector does not now nor will it meet the expected targets for 2030 (Repenning et al. 2020). These additions still do not allow an assessment of energy poverty and therefore may still underestimate the impact on lower income households and overestimate the possible contributions from the household sector towards achieving the overall objectives of the energy transition. The TIMES (The Integrated MARKAL-EFOM System) model generator is a least-cost optimisation, bottom-up, technology-rich, linear-programming energy system model that can be applied to analyse the implications of a range of pathways for long-term energy investments and to identify least-cost measures to realise the climate and energy objectives of a particular region through the integration of relevant energy policies and technologies under a detailed technical and socio-economic framework (Loulou et al. 2016b; Loulou et al. 2016a). The TIMES modelling framework has a detailed representation of energy technologies and their linkages across sectors (or actors) and considers the interdependencies of the energy system. This enables the analysis of the competition and substitution effects between technologies and provides detailed results of the energy flows, capacity investments, emissions and costs. This paper applies the TIMES framework towards the development of a household sector model with high actor resolution to enable the analysis of parameters around access and affordability, which are key to account for energy poverty in an energy system model.

Through the application of a newly developed, highly disaggregated energy system optimisation model, this paper investigates the impact of the two policy approaches to address vulnerabilities in the household sector on the energy consumption patterns, emissions and energy welfare of households in the context of the energy transition in Germany.

DISAGGREGATION

Disaggregating a model to more specific user profiles is very data-intensive, especially in the case of this bottom-up energy system model, where each actor will need to be defined in terms of demands, technologies, buildings and the associated socio-economic projections. Disaggregation is also the cornerstone for integrating consumer investment and consumption behaviour, particularly with regard to developing policies to improve the electricity consumption of households through energy efficiency measures (Jones et al. 2015; Gouveia et al. 2015; Sütterlin et al. 2011) or to account for other socio-economic factors, location, consumer or occupant-related behaviour (Jaccard 2015; Tomaschek et al. 2012; Reveiu et al. 2015; Li and Just 2018; Druckman and Jackson 2008; Leroy and Yannou 2018). The basis for modelling households as actors is the statistical investment and consumption behaviour by end-use for households in order to adequately capture and assess the socio-economic parameters (Destatis 2013a).

As shown in Figure 1[1], the final model disaggregation includes income group, tenure status and building type specific profiles, energy service demands and technologies. The energy service demands are determined exogenously for each profile-defined building and are based on techno-economic assumptions for the development of technologies and the political and socio-economic framework as the key drivers for demand. This model is dynamic in that the population can shift into other income groups and buildings over time, thereby allowing a better representation of the shifts in energy demands precisely because the demands are directly related to the defined socio-economic profile.

1. 1. Income groups are disaggregated by monthly income per household R1:<€900, R2: €900-1500, R3: €1500–2000, R4: €2000–2600, R5: €2600–3600, R6: €3600–5000, R6:>€5000; Location by U=Urban, R=Rural; Tenure by O=Owner, T=Tenant, Building type by M=Multi-family home, S=Single-family home, Building age by E=Existing, N=New.

BUDGET CONSTRAINTS

Income, expenditure patterns and available savings are key factors in affordability of household energy services (Cayla et al. 2011; Kaza 2010; Longhi 2015; Alberini et al. 2011; Vassileva et al. 2012). Available capital is essential to cover the costs of consumption as well as the investment costs of new or alternative technologies and measures. Modelling affordability is about: i) understanding and incorporating the dynamics within income groups and within the profiles, ii) reflecting the affordability of each profile according to the budget constraints, iii) reflecting the present value of future cash flows through the application of appropriate discount rates, and iv) incorporating the applicable coping mechanisms to meet needs with limited budget, such as extending the technical lifetime of technologies and/or buying second-hand appliances – which have lower upfront, but higher operating costs. The model restricts the financial ability of households to invest in the high upfront cost of appliances to better reflect the actual potential in overall capital investments by determining the overall available budget per profile based on statistical analysis of the disposable income, savings, GDP and typical investment patterns (Destatis 2018; IMF 2019b, 2019a).

Based on (IMF 2019a), the GDP per capita in Germany increases by 81.4 % between 2013 and 2060 from €36,948 2015/cap to €67,0715 2015/cap. With a total available capital (actual investment and consumption expenditure plus available savings) of €179 billion in 2013, the distribution across income groups is projected to increase to €631 billion in 2060 (Dobbins In preparation). The majority of the wealth in the household sector resides in the upper two income groups. This available capital is further distributed per defined profile within each income group according to projections of the shares of households and population. These figures are used to define the budget restrictions for each actor group in the model described in the next section. The overall household energy budget is considered by including this into the assessment for households service needs. This additional disaggregation better reflects the holistic financial and decision-making power of specific actors in the household sector and is previously not reflected in modelling assessments for long-term energy planning in Germany. The investment limitations are represented with household budget constraints for each defined profile based on the available savings for each income group. This budget constraint represents the statistically available savings for each income group and is considered as the potential available budget that households could invest in more efficient or renewable-based end-use technologies (heating, water heating, lighting, other appliances), retrofit the building and small-scale PV rooftop power generation (playing a role as prosumer).

The model takes into account the limitations in available budget to each actor group through the implementation of profile-specific budget constraints. The budget constraints for each profile are calculated based on available statistics on income-specific typical investment in energy appliances, energy improvement investments and savings (Destatis 2013b). The budget restriction is applied to each actor group through a user constraint on the investment and consumption costs (Ahanchian et al. 2020). This budget constraint is applied to all investments in owner-occupied households. Similarly, the budget constraint is included for tenants, but applies only to technologies which they have the decision-making power to replace and therefore excludes heating, water heating and PV technologies as well as building renovations. Instead, these investments include a higher discount rate to represent the apprehension of landlords to make costly investments in proper-

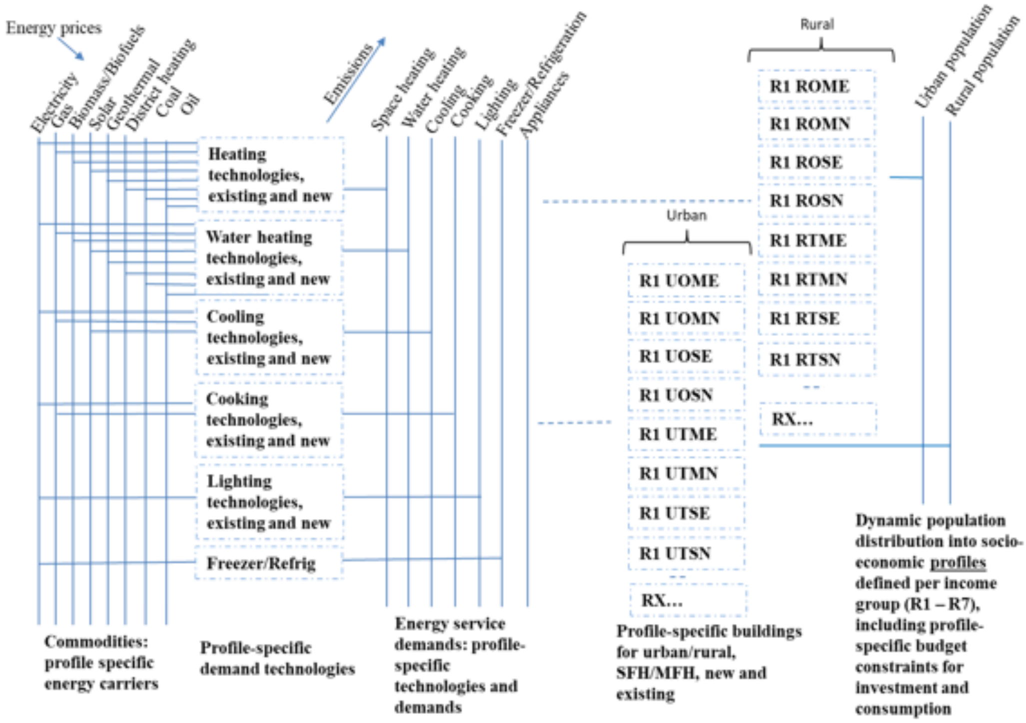

Figure 1. Reference Energy System for the household sector in TAM-Households.

Table 1. Scenario description: Disaggregation and energy poverty vs. vulnerable consumers.

Common socio-economic framework (GDP, population growth, energy prices, etc.)	
AGG	Aggregated, all expected policies implemented
TAM-HHs/REF	Disaggregated, all expected policies implemented, budget constraints with all investments paid upfront
EP	REF + financial aid for energy efficiency measures in buildings and space heaters to address energy poverty; technology-specific investment subsidisation at 20%-35% of upfront capital for lowest three income groups (those with negative monthly savings)
VC	REF + financial aid for bill support to maintain vulnerable consumers; electricity consumption subsidised; payment of carbon tax expenses excluded from budget constraint) for lowest three income groups

ties from which they may not derive a benefit, as outlined by the landlord/tenant dilemma (Bouzarovski et al. 2018; Griffiths and Causse 2010).

INCORPORATION OF POLICIES AND MEASURES

Policies and measures can be modelled as constraints according to particular targets (Senkpiel et al. 2020) and were modelled in TAM-Households in line with the policies and measures influencing energy use in the household sector, such as targeted greenhouse gas emissions. Methods to model energy-related policies and measures are largely adapted from TIMES-D (Fais 2015; Haasz 2017) and further developed within the Decentral project (Ahanchian et al. 2020). In TAM-Households, it was necessary to apply constraints (e.g., renovation rates, market shares for specific technologies or energy carriers) to achieve these targets for the whole sector or according to the profiles defined (e.g., homeowners, building type, location). Measures, such as subsidies, grants (financial incentives) and taxes can be included through a price reduction on the fuels or technologies for specific actor groups (e.g., income group, homeowners). Specific policies and measures modelled include the decarbonisation targets and carbon taxes implemented in the scenarios. The decarbonisation target applies a zero emissions target in 2050 whereupon the model finds the least-cost pathway to achieving this target given other variables and constraints in the model, such as the budget constraints. Environmental taxes, such as carbon taxes, are added to carbon-emitting fuels and related to the consumption by each specific actor groups represented in TAM-Households.

SCENARIO DESCRIPTIONS

To assess how lower income households cope with meeting energy needs with low incomes, a scenario analysis is conducted. These scenarios include an evaluation of the impact an energy poverty approach can have on household energy and emissions compared with the present approach for vulnerable consumers. Addressing energy poverty requires similar but different types of support compared to the approach to address vulnerable consumers. The benefits of energy efficiency have shown to improve the energy and economic welfare of households (IEA 2015). Energy efficiency directly addresses not only the causes of energy poverty but also services the overarching energy efficiency targets (Dobbins et al. 2019). However, the current approach to address vulnerabilities in the energy sector in Germany is through welfare support often reduced to bill support rather than targeted energy-specific support (Bundesamt für Justiz 2021). As it stands, social welfare beneficiaries are eligible for payment of electricity bills (up to a certain amount), heating bills (adequate for the situation of the beneficiary), and payment of the corresponding carbon tax. However, this approach contradicts the overarching targets to shift away from fossil fuel consumption and directly subsidises its consumption. Table 1 summarises the scenarios analysed for this paper. One scenario compares the costs and benefits of subsidising investment into energy efficiency (EP scenario) with a scenario where the equivalent costs of subsidisation of energy bills (consumption) and the responsibility for payment of the carbon tax are excluded from the budget constraint (VC scenario) in the lowest two income groups. The development of the carbon price per ton of CO_2-equivalent was developed according to the tax scheme developed for the Climate Protection Strategy 2030 (Vermittlungsausschuss 2019) resulting in a CO_2 tax in 2035 of the upper boundary of 200 Euro per tonne of CO2-equivalent (Harthan et al. 2020), and reaching €250_{2015} per tonne of CO_2-equivalent in 2050 to account for the expected damage cost for climate change, thereafter with a linear extrapolation to €260_{2015} per tonne of CO_2-equivalent in 2060. To drive investment in residential buildings, the funding under the Climate Programme has been consolidated as a 20 %–35 % reduction on the investment cost of renovation measures and heating technologies on specific technologies, measures and renovations that lead towards increasing renewable energy and energy efficiency (BWA 2021). In the Vulnerable Consumers scenario (VC), the electricity consumption is subsidised and the payment of the carbon tax is redirected to a third party for payment (e.g., government agency). The payment for the heating costs remains with the household in this scenario at this time because it was not possible to determine which profiles exactly benefit from this support and would distort the investment results unfavourably without the comparative price signal for the fuel type.

Results

Disaggregation within the energy model provides key insights to the expected development of investment and energy consumption patterns. When considering the differentiated needs and budget limitations of different households, the expected consumption shifts in the aggregated model (AGG) compared to the disaggregated model (REF) as shown in Figure 2 for the overall energy consumption for all households. The aggregated model overestimates the expected reduction in consumption as well as the share of renewables in the energy mix (including ambient heat, biofuels, biomass, geothermal and solar). Because the disaggregated model includes the budget constraint, the medium-term indicates the need for households to rely on biofuels to meet energy needs and comply with climate targets as they are unable to afford the costs of the infrastructure to shift to other household technologies or network solutions. To further compare the impact of subsidising investments to subsidising consumption, the energy consumption patterns are elaborated. The impact becomes visible with the VC scenario exhibiting 8.5 % less renewables and 5.8 % more fossil fuel consumption (and oil more than doubling) overall compared to the REF scenario. The subsidisation of electricity to the lowest income groups, results in electricity consumption overall increasing by 4.4 %. This underscores the differences in the approach towards providing financial support to lower income households.

Figure 3 compares the impact on the energy consumption patterns for the lowest three income groups for the Energy Poverty (EP) and Vulnerable Consumers (VC) scenarios compared to the TAM-Households reference (REF) scenario. This describes the impact of subsidising the investment costs (EP scenario) compared to the subsidisation of consumption (VC) scenario with the reference case where neither is subsidised.

The results emphasise that while bill support is a crucial measure to assist households with acute difficulties paying energy bills, this type of measure alone is insufficient in freeing up capital for other high cost investments which would change energy consumption patterns. Across scenarios and the various socio-economic parameters (building type, tenure and location) there are wide variations in the energy consumption patterns. Overall, on average the REF scenario favours district heating and gas and include 14.6 % renewables and 29.3 % fossil fuels of the total final energy consumption. With financial support for the upfront investment costs, the EP scenario shows a shift towards the integration of renewables to encompass 26.2 % and fossil fuels are reduced to 19.6 % of total consumption with greater incorporation of biomass, biofuels and ambient heat. This increased trend of greater shares of renewables continues in tenant buildings, where the resistance to invest is decreased for landlords. However, the VC scenario shows households unable to invest and therefore continuing to consume fossil fuels heavily representing a stable 27.8 % of total consumption compared to the REF scenario. Without the effective price signal from the carbon tax, the investments do not track the same trajectory as in the EP or even the REF scenarios.

Looking at the lowest three income groups in 2035 only, a comparison of the suppressed demand and the impact of the two subsidisation variations with the reference case is undertaken in Figure 4. In the reference scenario in 2035, 6.1 million people, are in need of an additional €151 per capita in order to meet all household service demands. While the number of people affected is not reduced, the suppressed demand is alleviated in this same population set in the Vulnerable Consumers scenario (VC) due to the subsidisation of the electricity costs and the removal of the burden of the carbon tax such that this population subset would require an additional €74 per capita to satisfy all household service demands. The greatest impact in reducing suppressed demand is through the Energy Poverty (EP) scenario, which reduces the issue to affecting approximately 950,000 people. An additional €62 per capita for this subset of the population is necessary to alleviate the budget deficit.

The method with the disaggregation and budget constraints applied within an energy system model allowed the assessment of the impacts of policies on the energy use and energy welfare of different household types. The effect of subsidising investments in renewable and more efficient technologies and measures was compared to the approach of subsidising consumption. This showed that lower income households were able to overcome the investment hurdle and shifted their investment and consumption profiles to include more renewables when investment subsidies are provided, whereas the subsidisation of electricity consumption and assuming the carbon taxes for lower income households maintains the similar shares of fossil fuel consumption, which is not in line with the energy transition objectives. The evaluation of the suppressed demand showed that compared to the reference scenario, the acute bill support provided in the Vulnerable Consumers scenario halves the budget deficit which underscores the benefit and role of direct financial support to households. However, the Energy Poverty scenario reduced this problem to affecting less than one million people with almost two-thirds of the budget deficit alleviated. This methodology highlights opportunities to redistribute the funding, emphasising the need for both investment and consumption support. Policies can be further assessed to identify how best to provide acute bill support as well as investment into the household energy infrastructure, which can be better targeted to the appropriate beneficiaries. This emphasises the importance of targeted financial support and the need to identify a pathway to allowing funding to address both the underlying causes of energy poverty as well as ensure living standards are maintained or increased. Investments in infrastructure, such as energy efficiency to reduce demand or renewable energy to shift consumption to decentralised energy sources, crucially helps to build resilience in lower income households when it comes to energy price increases due to price fluctuations or rising carbon taxes.

Conclusion

Acknowledgement for the negative consequences arising from energy poverty is becoming increasingly prevalent in the energy transition discourse. The lack of recognition for energy poverty is not unique to Germany. Only a handful of countries in the EU have legislated a definition of energy poverty. This research contributed to the European understanding of energy poverty by recognising that the common approach to addressing vulnerabilities in the energy sector is typically restricted to so-called vulnerable consumers within the liberalised energy markets. This limiting stance led to vulnerabilities associated with general poverty and so measures to support vulnerable consumers are classically addressed through the social welfare system whereby little is undertaken to address the underlying causes of these vulnerabilities in the energy context. This erroneous approach means little is done to ensure lower income households can participate in and benefit from the energy transition beyond bill support and disconnection protection. European legislation is paving the way to address vulnerabilities in households beyond electricity and gas and gives credence to the importance of addressing the underlying issues leading to energy poverty.

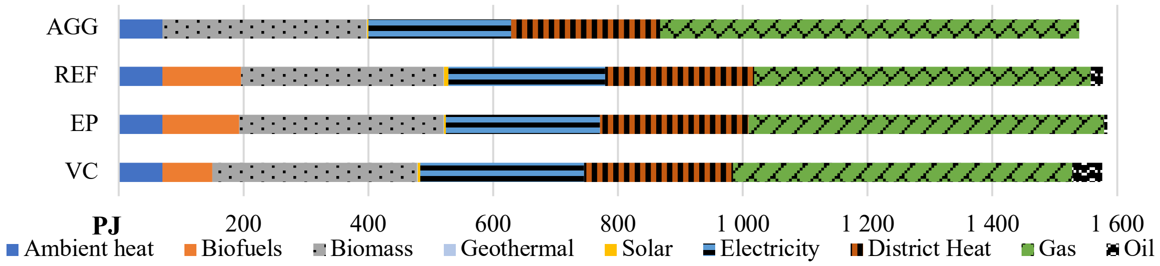

Figure 2. Final energy consumption in all households by scenario, Germany 2035.

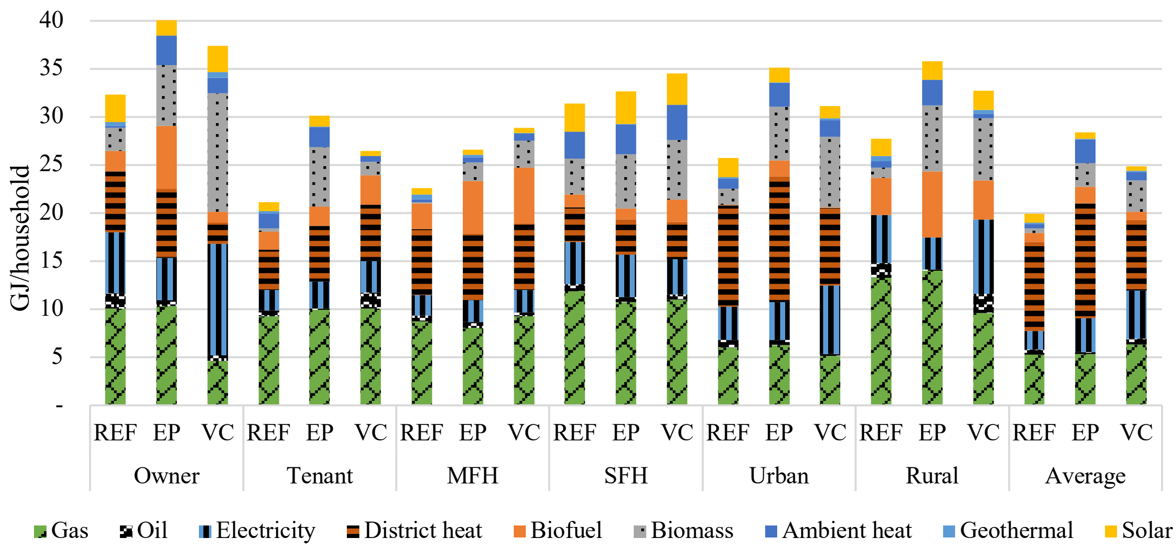

Figure 3. Comparison of the energy consumption patterns in the energy poverty and vulnerable consumers approach in the lowest three income groups, Germany 2035.
Abbreviations: REF=reference, EP=energy poverty, VC=vulnerable consumers; SFH=single family home, MFH=multi family home.

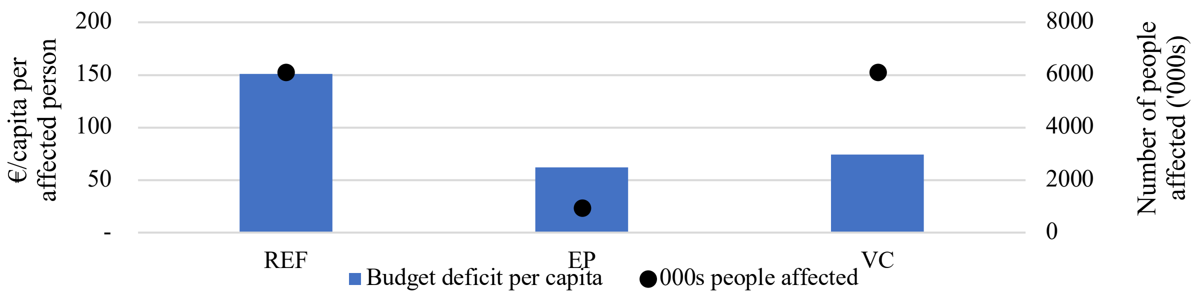

Figure 4. Comparison of the suppressed demand by scenario, Germany 2035.

This paper took the interdisciplinary approach to combine energy poverty research typically based in the social sciences with an economic-engineering method developed for technology assessment and energy system analysis, thus bridging the gap towards an integrated energy transition study. Understanding energy poverty and its role in the broader energy transition debate led to the development of an energy system optimisation model incorporating specific features, such as disaggregated profiles accounting for the lack of financial capacity or decision-making power. Parameters that are significant for understanding and integrating consideration for energy poverty in the energy planning process, such as budget restrictions for investment and consumption, are included in TAM-Households. Comparison of the results from TAM-Households including these parameters and the aggregated model revealed that unexpected fuel types enter the future mix when accounting for the full costs to the household for various heating technologies and not only taking a system view of costs. This highlights that the future energy landscape would then need alternative network extensions and a more in-depth view of these results within the overall energy system. The inclusion of both disaggregation and the budget constraints are the cornerstones to enabling an evaluation of the energy welfare of households. Disaggregation without the budget constraint forces the model to only solve for the cost-optimal system costs, while the addition of the budget constraint adds the additional model objective to also maximise the benefit to the household. This provided a platform to explore the impact of various policies and measures on lower income households.

The method developed in this paper provides a platform from which to conduct a review of the impact of various policies and measures, whether they are targeted towards lower income households or the general population. The TAM-Households model is capable of assessing the impact on lower income households and can help to shape future policy. Understanding the causes and effects of energy poverty can help to target support appropriately. The comparison between subsidising investments compared to subsidising consumption was illuminating in that it revealed that subsidising investment led to a final energy consumption in lower income household fulfilled with a greater degree of renewable energy. In contrast, and as can be expected, subsidising the consumption of electricity and assuming the responsibility for the carbon tax maintains the current energy system for the lower income households, which sees no new investments and a perpetuation of the consumption of fossil fuels. When energy consumption in households drawing social welfare continues to be subsidised, this contradicts objectives to decarbonise and effectively maintains the existing energy system. Yet by providing financial assistance towards investments, the energy poverty cycle can be broken because households reduce consumption and are less subjected to energy price fluctuations – just as the energy transition foresees. A further key outcome of the methodology enabled an analysis revealed the concept that lower income households are not in a financial position to improve their energy welfare due to suppressed demands. Households have budget deficits to meet energy consumption needs, which effectively restrict the available budget for investments. This evaluation points to the need to target support, which can improve the energy welfare of households while meeting the energy transition targets.

While this research has provided an interesting overview of the inequality within the energy system based on the perspective of household income, this can be enriched by increasing the detailed representation of the building stock and including perspectives from other socio-economic characteristics, such as household composition (e.g., elderly, single-parent households) or other factors. These additional considerations provide scope for further research where future data collection efforts systematise the triangulation of these parameters. This further highlight the needs and capabilities of different sectors of society and entrenches the need for a differentiated approach to developing policies tailored towards not only the impact of energy poverty on different consumer groups but in general as well.

Solutions to addressing energy poverty do not conflict with the objectives of the energy transition. Recognition of the issue will drive forward not only the energy transition but will benefit all households through targeted policies and measures designed to achieve the future vision and ensure no one is left behind.

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