Energy Efficiency (2025) 18:105
https://doi.org/10.1007/s12053-025-10397-z

RESEARCH

Evaluating co-benefits of energy efficiency policy measures: a holistic framework with case studies from Germany

Frederic Berger · Iska Brunzema · Swaroop Rao · Florin Vondung · Peter Hachenberger · Barbara Schlomann

Received: 23 May 2025 / Accepted: 6 November 2025

Abstract Ex-post evaluations of energy efficiency policy measures have traditionally focused on direct impacts such as greenhouse gas (GHG) emissions reductions and energy savings. However, rising interest in the broader economic, social, and environmental ramifications of these policies is reshaping evaluation priorities. Notably, alleviation of energy poverty has emerged as a critical co-benefit to be measured, driven by rising energy prices and, in turn driven partially by measures such as the EU Emissions Trading System (EU-ETS). This has resulted in new reporting obligations at both national and European levels. Building on the impact evaluation methodology for energy efficiency policy measures established by Schlomann et al. (2020) that focuses on the direct environmental impacts, the present work presents a transparent, replicable, and robust approach to assess broader policy co-benefits. We focus on fiscal policy instruments and illustrate this with two key co-benefits: employment effects and social benefits. To demonstrate this, we analyse two German programmes, the Environmental Bonus for Electric Vehicles (Umweltbonus) and the Federal Funding for Efficient Buildings (BEG), as case studies. These illustrate how to qualitatively and quantitatively evaluate the effect of policy measures in terms of their co-benefits, specifically additional employment, skill intensity, alleviation of energy poverty (2M), and distributional effects, offering a nuanced understanding of these growing concerns. This paper therefore provides a comprehensive evaluation framework that integrates traditional metrics of direct impacts with assessments of social, economic, and environmental impacts. This holistic approach supports policymakers in understanding the wider implications of energy policies and enables informed, evidence-based decision-making.

Frederic Berger and Iska Brunzema contributed equally to this work.

F. Berger · I. Brunzema (✉) · P. Hachenberger · B. Schlomann
Fraunhofer Institute for Systems and Innovation Research, Karlsruhe, Germany
e-mail: iska.brunzema@isi.fraunhofer.de

F. Berger
e-mail: frederic.berger@isi.fraunhofer.de

P. Hachenberger
e-mail: peter.hachenberger@isi.fraunhofer.de

B. Schlomann
e-mail: barbara.schlomann@isi.fraunhofer.de

F. Berger
Utrecht University, Utrecht, Netherlands

I. Brunzema
Heidelberg University, Heidelberg, Germany

S. Rao
EIFER - European Institute for Energy Research, Karlsruhe, Germany
e-mail: swaroop.rao@eifer.org

F. Vondung
Wuppertal Institute for Climate, Environment and Energy, Wuppertal, Germany
e-mail: florin.vondung@wupperinst.org

Published online: 22 November 2025

Keywords Energy efficiency policy · Co-benefits · Ex-post evaluation · Energy poverty · Transport poverty · Employment effects

Introduction

Ex-post evaluations of energy efficiency policy measures mostly concentrate on environmental impacts such as greenhouse gas (GHG) emissions reductions and energy savings, which often are the main objectives of these policies. However, growing awareness of the broader economic, social, and environmental ramifications of energy efficiency policies is reshaping evaluation priorities. A comprehensive and holistic methodological approach for assessing energy efficiency policies is essential to capture all their relevant impacts.

Energy efficiency policies tend to generate co-benefits, meaning positive outcomes resulting additionally to the primary objectives of reducing energy consumption and GHG emissions (Fawcett & Killip, 2019; Ryan & Campbell, 2012; Ürge-Vorsatz et al., 2016). These co-benefits include social impacts, such as enhanced public health through improved air quality and indoor climate or reduced energy costs for consumers, economic effects like increased energy security by reducing dependence on fossil fuel imports or value added, and environmental impacts such as lower local and global pollutant emissions (Campbell et al., 2015). However, it is important to acknowledge that energy efficiency policies can also have negative impacts; certain industries may face increased operational costs due to compliance with stringent regulations, potentially leading to reduced competitiveness, and vulnerable groups could face increased energy prices during the transition to more efficient systems, exacerbating energy poverty. Moreover, effects beyond the typically assessed use phase, such as production, transport, and disposal, can severely alter and dwarf life-cycle impacts (Ingrao et al., 2018). While this paper focuses on the benefits, understanding potential trade-offs is crucial for developing balanced and inclusive energy efficiency policies tailored to local contexts that minimize unintended consequences and ensure equitable outcomes (Cagno et al., 2019; Tenente et al., 2025; Ürge-Vorsatz et al., 2016). These co-benefits and drawbacks are conceptually similar to the spillover effect and to externalities (Davis et al., 2014; Fowlie et al., 2018; Jones, 2018).

In the European Union, the recently introduced Clean Industrial Deal[1] and the EU Omnibus Package streamline the EU's sustainability regulations to enhance competitiveness, innovation, and economic resilience while maintaining environmental commitments. Economic effects of energy efficiency policies can add to these aims. They can stimulate innovation by encouraging firms to develop and adopt new solutions. Additionally, improved energy efficiency can enhance competitiveness by lowering operational costs and increasing market adaptability. Overall, energy efficiency policies can contribute to increasing employment by creating demand for skilled labour in the buildings sector, production of (electrical) motor vehicles and similar relevant sectors (Schumacher et al., 2024).

In the past years, as highlighted in the EU Green Deal, energy poverty has emerged as a critical topic in the context of climate and energy policy. The Energy Efficiency Directive (EED) revised in 2023 defines it as "a household's lack of access to essential energy services, where such services provide basic levels and decent standards of living and health" (Directive (EU) 2023/1791). Main drivers are non-affordability of energy, high energy prices (partly influenced by economic measures such as the EU Emissions Trading System (EU-ETS), low incomes, low energy efficiency of buildings and high energy expenditure. After the Russian invasion of Ukraine, rising energy costs particularly hit low-income households (see e.g., Ahlvik et al., 2025; Gajdzik et al., 2024) and resulted in higher numbers of self-reported energy poverty in the past years (Koukoufikis et al., 2024). Both the EED and the European Social Climate Fund Regulation account for the relevance of

[1] The European Union's Clean Industrial Deal (European Commission (COM) (2025)), introduced on February 26, 2025, aims to bolster industrial competitiveness while accelerating decarbonization. Key initiatives include reducing energy costs, supporting clean technology sectors, and simplifying regulations to create a more business-friendly environment. By mobilizing over €100 billion in funding, the Deal seeks to stimulate innovation, particularly in energy-intensive industries and clean tech, thereby enhancing the EU's global industrial standing. This strategic focus on sustainable industrial practices is designed to drive economic growth and secure Europe's position as a leader in green technology.

this issue by introducing reporting obligations for energy savings in energy poor households (Directive (EU) 2023/1791) and measures and investments in support of vulnerable households and transport users (Regulation (EU) 2023/955).

The recognition of such social impacts of energy policy has led to new reporting obligations at both national and European levels, underscoring the necessity not only for a policy design acknowledging these issues, but also of a holistic approach to policy evaluation. We seek to illustrate how energy efficiency policies affect employment and social equity and to show the quantified co-benefits of such policies, particularly regarding social benefits and employment. This paper extends the evaluation framework for energy efficiency policy interventions developed by Schlomann et al. (2020), emphasizing its clarity and reproducibility in capturing both direct environmental effects and wider co-benefits. We focus on fiscal policy instruments and illustrate this with two key co-benefits: employment effects and social benefits. To demonstrate this, we analyse two German energy efficiency programmes, the Environmental Bonus for Electric Vehicles (Umweltbonus) and the Federal Funding for Efficient Buildings (Bundesförderung für effiziente Gebäude, BEG), as case studies.

While we outline various methodological approaches to assessing co-benefits, this paper does not aim to resolve the associated methodological challenges or propose alternative frameworks. Rather, our objective is to apply an existing framework and demonstrate its applicability going beyond its original aim of addressing mainly GHG emissions reduction and energy savings and highlight its practical relevance in evaluating social and economic co-benefits. In contrast to broader tools such as the MICATool[2] or the earlier COMBI tool,[3] which offer multi-level assessment of multiple benefits, our paper emphasizes transparency and policy specificity. A key contribution lies in comparing simpler, assumption-light indicators with more elaborate, data-intensive metrics. This comparison illustrates the trade-offs between accessibility and analytical depth and underscores the importance of flexibility in selecting indicators that suit the policy context and data availability. By integrating co-benefits into a structured and replicable impact model, we aim to support more comprehensive evaluations of energy efficiency policies, enabling policymakers to consider not only environmental outcomes, but also broader socio-economic implications.

[2] The Multiple Impacts Calculation Tool (MICATool) is an online tool developed in the EU-funded MICAT and SEED MICAT projects, aimed at policy makers, practitioners and evaluators to support in assessing multiple impacts of energy efficiency policy interventions, see here: https://micatool.eu.

[3] The COMBI tool was an online tool developed in the EU-funded COMBI project. A comprehensive multiple impact indicator set was developed and applied to the EU's 2040 energy efficiency target. The tool has been decommissioned, relevant publications and methodologies can still be found here: https://micatool.eu/seed-micat-project-en/publications.php.

Impact model

With the aim to assess not only GHG emissions reductions and energy savings, but also the broader socio-economic co-benefits of energy efficiency policies, we are building on the impact evaluation methodology for energy efficiency policies developed by Schlomann et al. (2020). The impact model (see Fig. 1) provides a transparent and replicable framework to assess energy savings and greenhouse gas emissions reductions. It follows a structured logic that can be applied to different types of measures with the respective indicators being adjusted based on the requirements. The model begins with the input of financial or administrative resources allocated to policy measures. These inputs translate into outputs, which are the triggered activities and may include the number of funding cases, number of consultancy services provided to households, or triggered investment in energy-efficient technologies, renovations, or advisory services. From these outputs, the model assesses policy outcomes, such as the number of installed systems, increased knowledge or realised energy savings. These outcomes are subsequently linked to the broader long-term impacts, including reduced final energy consumption, employment effects or reduced energy expenditure.

The indicators in the different steps of the impact model can vary based on the type of measures, namely financial (e.g. grants, rebates), fiscal (e.g. tax credits, levies), informational (e.g. energy consultancy, information campaigns) and regulatory measures (e.g. minimum standards, bans). The methodological approach primarily targets greenhouse gas emissions

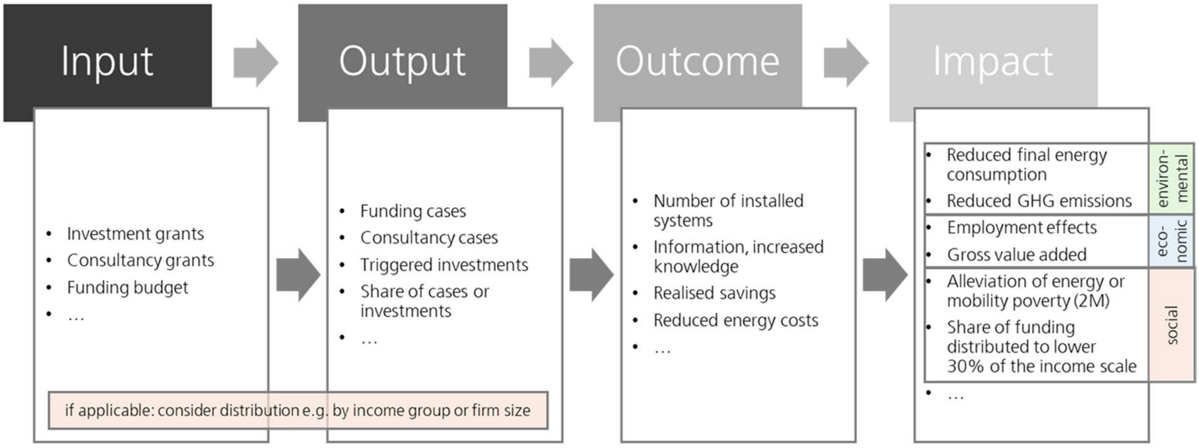

Fig. 1 Impact model for the evaluation of energy efficiency policies, adjusted based on Schlomann et al. (2020)

reductions and energy savings as the impact of energy efficiency policies. To assess a measure's broader co-benefits, e.g. its impact on the alleviation of energy or transport poverty or employment effects, a number of indicators could be used. We aim at using indicators that are in their structure applicable to all sectors and types of measures for which the respective effects are relevant, ensuring the provision of comparable results. We propose a set of standardised yet flexible indicators that capture broader social and economic dimensions. These include, for example, the share of households lifted out of energy or transport poverty (based on income-expenditure thresholds such as the 2M indicator as well as the share of funding distributed to lower 30% in income rank), the number of jobs created, and changes in household disposable income or firm-level competitiveness.

When socio-economic indicators such as income or firm size are used, e.g. to assess distribution across certain groups, they need to be already considered at the input and output levels of the model. Since the indicators at these levels are determined by the type of policy intervention rather than by the type of effect being assessed, there are no dedicated social input or output indicators. However, taking relevant socio-economic dimensions into account from the start is essential for meaningful analysis of distributional effects later in the model. For example, disaggregating funding cases or triggered investments by income group or firm size at the input and output stages allows for a more accurate identification of vulnerable groups or those particularly benefiting from or disproportionately burdened by specific measures. As shown in Fig. 1, such socio-economic indicators are transversal to the model and must be integrated early to ensure robust and relevant assessments.

Methodology

To showcase approaches but also difficulties linked to an extension of the evaluation framework, this study exemplarily assesses two potential co-benefits of energy efficiency programmes: employment effects as well as distribution effects and alleviation of deprivation. While the broader framework introduced here is designed to be applicable to various policy types, this paper limits its empirical focus to fiscal measures. These instruments provide a valuable lens through which to examine co-benefits, but they also highlight the complexities involved in evaluating indirect and multidimensional outcomes.

The varying nature of co-benefits, spanning social, economic, and environmental dimensions, presents methodological challenges as these different types may interact with energy efficiency programmes in distinct ways. We use different approaches with different levels of complexity, showing not only the necessity of well-defined indicators and aims, but also bridging the gap between scientific requirements and applicability based on data availability and temporal, financial or personnel restrictions in administrative institutions. The study highlights the methodological difficulties in capturing the full scope of co-benefits and offers insights into how these can be systematically evaluated to ensure more comprehensive policy assessments.

Employment effects

To assess the impacts of measures on the labour market, the analysis of additionally created employment is the most trivial approach. Yet, while certain sectors would benefit from additional employment, several trades already suffer from labour shortages. Hence, it is also worthwhile to analyse the type of jobs created with a policy measure. In this study we assess both the raw number of additional employment as well as their skill intensity and relevant market labour situation.

Additional employment

The most straightforward approach to assess additional employment linked to a measure is using input–output analysis. As described in Breitschopf et al. (2012), employment per investment coefficients can be calculated from input–output tables' Leontief inverse and an industry-dependent employee-to-total-supply-ratio (their calculated coefficients are also used in this study). Using these coefficient, additional employment ΔEMP_m of a measure can be estimated:

$$\Delta EMP_m = \left(1 - DW_m\right) \cdot \left[DP_{m,I} \cdot I \cdot \begin{pmatrix} k_1 \\ k_2 \\ k_3 \\ \dots \\ k_n \end{pmatrix} \cdot \begin{pmatrix} \lambda_{k,1} \\ \lambda_{k,2} \\ \lambda_{k,3} \\ \dots \\ \lambda_{k,n} \end{pmatrix} - DP_{m,L} \cdot L \cdot \begin{pmatrix} j_1 \\ j_2 \\ j_3 \\ \dots \\ j_n \end{pmatrix} \cdot \begin{pmatrix} \lambda_{j,1} \\ \lambda_{j,2} \\ \lambda_{j,3} \\ \dots \\ \lambda_{j,n} \end{pmatrix} \right] \tag{1}$$

In Equation (1), I stands for investments linked to the measure, L for potential revenue losses resulting from the measure (for instance fuel costs through energy savings or substituted technologies). The vectors k and j specify the employment per investment coefficient for a given sector i, whereas the vectors λ describe the share of investments or losses attributed to a given sector i. DW_m describes the measure's deadweight effect in percentage (quantified in the initial assessment) and $DP_{m,I/L}$ the share of the relevant products being produced domestically, for investments and losses, respectively (Heinrich et al., 2025b; Heinrich et al., 2024; Rao et al., 2024).

In this study, additional employment was assessed using the ISI-Macro model, which is an Input–Output-Model, expanded with a series of feedback loops (Sievers et al., 2019).

In this study, we have adopted this approach. The necessary statistical data on economic performance is freely available. It remains to disaggregate investments by measure and economic sector, which can then be applied to an input–output table. We have based the disaggregation on findings from the literature as well as expert assessments by Fraunhofer ISI and the Öko-Institut (UBA, 2024).

However, this approach has limitations. Since only domestic industry is considered, additional jobs might accrue in other countries. Furthermore, a measure's funding might curtail other programmes, resulting in job losses somewhere else in the economy. Finally, possible changes in income and prices are not considered either.

Skill intensity

Skill intensity refers to the composition and level of skills required or fostered within the labour market as a consequence of policy interventions. In the context of energy efficiency programmes, shifts in skill intensity may manifest through increased demand for technical, vocational, or managerial competencies, depending on the nature of the interventions. Based on sectoral and geographical heterogeneity, a policy can have different implications for skill needs. To assess effects on skill intensity, the types of jobs created need to be analysed in terms of level and types of skills required. This has been achieved by calculating the shares of employment per skill level in total employment from the statistics of the German Federal Employment Agency for the year 2019 and applying the shares to the additional employment (Bundesagentur für Arbeit, 2022). Similarly, a categorization into bottleneck and non-bottleneck professions has been adopted from Bundesagentur für Arbeit (2023).

The underlying equations are similar to Equation (1) in the previous section. Similarly, these effects have been assessed using the same Input–Output approach.

Distributional effects and energy/mobility poverty

In recent years a myriad of indicators has been developed to identify specific dimensions of social deprivation, inter alia energy and transport poverty. Moreover, methods to quantify their extent and alleviation through policy measures have been explored (Gouveia et al., 2022, 2023).

However, many of these indicators are only applicable to certain types of measures and hardly comparable across the most relevant sectors to social deprivation, the residential and the transport sector. Thus, this study uses two indicators applicable to both of these sectors, the share of funding distributed to the lower 30% in income rank and alleviation of energy or mobility poverty (2M). 2M refers to the share of energy expenditure compared to the disposable income above twice the national median and measures the financial burden of energy bills. M/2 on the other hand refers to the absolute energy expenditure below half the national median and captures underconsumption (Gouveia et al., 2022; Schumacher et al., 2025).

Those indicators were selected for two different reasons: while alleviation of energy poverty (both 2M and M/2) is the most common approach to quantify energy poverty effects of energy policy measures, the share of funding distributed to the lower 30% offers an alternative that requires no assumptions. Thus, their ubiquitousness and relevance, while mainly relying on data available from the assessments were the decisive factors for their selection (although several assumptions were still needed for 2M, as explained in the following sections). The use of the 2M indicator was favoured to the M/2 indicator (share of population spending less than half the median energy expenditure) due to the recommendation of 2M by Cludius et al. (2024) and the desired consistency and comparability between residential and transport measures.

Share of funding distributed to the lower 30%

This indicator describes the share of the assessed programme's funding going to the lower 30% in terms of household income. Thereby, it shows whether the measure shows the typical propensity to disproportionally benefit wealthier recipients. A benefit is its comparability across different measures and sectors, regardless of programmes' funding volume, number of targeted recipients, or subsidy rates.

Its calculation is straightforward, with funding distributed to the lower 30% divided by total programme funding. However, since the distribution to socio-economic brackets is disclosed as a share of recipients rather than funds, a key assumption is that the average grant is consistent across income brackets. Especially in the residential sector, where subsidies are generally defined as share of necessary investments, this assumption might not hold true, given the correlation of income with dwelling size, which, in turn, typically results in higher retrofitting costs.

The selection of the 30% threshold is due to three reasons, generally provided data for policy measures, typical funding programmes household income distribution curves, and the poverty line. Evaluation data on household income of recipients include a variety of different income bracket systems, with only one threshold used in nearly every evaluation: 2000€ net monthly household income. This threshold corresponded to the lower 29.6% of the German population in terms of income in 2018 and seems to still represent roughly 30% in 2024 (bpb, 2020; Destatis, 2025). Furthermore, around 30% in income rank seems to be the point from where on the representation of households in subsidy programmes significantly rises, as inter alia both analysed studies show. Finally, it is rather close to the German poverty line (60% of median household income), which laid at 1844€ in 2024 (Destatis, 2025). However, it is worth noting that this is merely the average poverty line, since it generally depends on the household composition (Ravaillon, 1998).

Alleviation of energy or mobility poverty (2M)

Measuring energy poverty is essential for identifying affected groups and addressing the issue effectively. In the EU, a variety of indicators is applied, capturing different aspects of energy deprivation. However, most indicators are sector-specific (mostly residential), rendering them unapplicable to several relevant measures.

An exception is the indicator 2M, which is used both for energy and mobility poverty. It categorises households as energy- or mobility-poor if their share of total expenditures spent on energy or mobility, respectively, exceeds twice the national median (Cludius et al., 2024; Gouveia et al., 2022). The idea of the indicator is to pinpoint the cause of certain households' poverty to its disproportional expenditure, in order to address it in a more precise manner. However, since costs that would rather be classified as lifestyle choices (such as numerous holidays, expensive cars, or first-class tickets) also contribute to this indicator, it is often limited to lower income brackets, although the exact threshold varies between studies.

This can then be used to examine how far a measure manages to lift households out of this kind of deprivation. The difficulty lies in the determination of monetary savings as a result of the measure and for how many households they suffice to lift them out of energy or mobility poverty.

This is the indicator used within this study, restricted to the lower 30% in terms of household income. The methodology for assessing energy poverty developed by Vondung et al. (2023) in the course of the MICAT project has been used and adapted for mobility poverty using data from the EU Household Budget Survey (COM, 2020). The key equation to estimate the number of people lifted out of energy or mobility poverty is the following:

$$\Delta EP_m / \Delta MP_m = N_m \cdot PTF_m \cdot IF_m \cdot PPA \quad (2)$$

In this equation, N_m is the number of implemented energy efficiency actions, PTF_m the share of measures in the assessed programme carried out among households of the targeted demographic, and PPA the average number of people benefitting per implemented action. IF_m specifies the impact factor, the share of households that could be lifted out of the targeted deprivation thanks to the measure. The impact factor is evaluated by assessing the deprivation gaps (i.e., by how much different households' expenditure needs to be reduced that its share in income does not exceed the 2M threshold) against the net cost savings of the measure and evaluating the share of the targeted group lifted out of their deprivation.

Case studies

To bring the outlined methodological approaches to practice, they are applied to the case studies of the Environmental Bonus and the Federal Funding for Efficient Buildings (BEG) to evaluate their respective impacts on employment and energy poverty. They are two of the most relevant measures in the demand sectors Buildings and Transport where policy measures usually directly impact households and where, in light of rising prices due to, e.g., the German CO_2-price as well as the EU-ETS 2 starting in 2027, social impacts need to be directly considered in policy making as well as economic effects, accounting for economic resilience.

Both BEG and Environmental Bonus have comprehensively been assessed ex-post (Heinrich et al., 2025b; Heinrich et al., 2024; Rao et al., 2024). In this study, we use this basis to extend the results with the aforementioned co-benefits.

Environmental Bonus

Against the backdrop of structural change in the automotive industry in Germany, the "Umweltbonus" (Environmental Bonus) was a subsidy accorded to private persons and firms who purchased or leased electric vehicles (Battery Electric Vehicles, Plug-in Hybrids, or Fuel-Cell Electric Vehicles) in Germany between 2016 and 2023. The subsidy per vehicle ranged from 4,000€ to 9,000€, with the financing coming from the German federal government as well as the car manufacturers. 2.17 million electric vehicles received a subsidy in the 7-year period, with 10.2 billion € being spent by the federal government for the programme. The subsidy ended end of 2023.

The primary objectives of the subsidy programme were to increase the uptake of E-Mobility in Germany and to contribute to GHG emissions reductions of Germany's transport sector and to support the car manufacturing industry in their transition. Given that other co-benefits were not explicitly considered in the design of the programme itself, the programme makes for a good case study for the present paper, even if in a cautionary sense, to stress the importance of considering co-benefits in the design of energy and environmental policy.

Geographically as well as across income groups, the programme showed an unequitable allocation of public resources. In a German context, this meant that the western (and economically stronger) states of the country benefited more than the eastern, economically weaker states. Additionally, due to the lack of income (or wealth) of the beneficiary as a criterion to base the amount of subsidy, the subsidy largely benefited above-average income households. An evaluation conducted in 2024 identified potential for future subsidies to explicitly consider the beneficiaries' income in the calculation of the subsidy accorded (Rao et al., 2024).

Federal funding for efficient buildings

The Federal Funding for Efficient Buildings (BEG), implemented in 2021, primarily aims to achieve energy savings and climate targets by improving the energy efficiency of buildings, particularly for Worst Performing Buildings (WPB), but also supporting the construction industry. It consists of three subprogrammes: BEG residential buildings (BEG WG) for systemic renovations of residential buildings, BEG non-residential buildings (BEG NWG) for the renovation of non-residential buildings and BEG individual measures (BEG EM) for partial renovations in either residential or non-residential buildings. Buildings renovated funded by BEG WG or BEG NWG must meet an efficiency housing standard (EH) between 85 and 40.[4] The programme targets private individuals, as well as commercial and municipal actors, with private individuals accounting for 89% of the funding recipients in 2023. However, municipalities and housing associations typically undertake larger renovations, taking up 43% of the investment volume and 38% of the funding budget in 2023 (Heinrich, Langreder, Grodeke, Alkasabreh, et al., 2025). For renovations in BEG WG and BEG NWG, low-interest loans with repayment subsidies are available, where the conditions differ based on the renovated building's EH standard. Only municipalities also have access to grants in these subprogrammes. The BEG EM funding[5] is only available as a grant variant, ranging from 15 to 30% of the total costs depending on the individual measure, with additional bonus grants bringing the funding up to 45% of the total costs depending on specific measures, such as renovation roadmaps or improvements to WPBs (BMWK, 2022). Financing is provided by the German federal government.

Results

Employment effects

The two assessed measures both show substantial employment effects, with BEG and Environmental Bonus generating 357 and 43 thousand additional full-time equivalents (FTE), respectively, as shown in Fig. 2. Beyond accounting for deadweight effects, a structural difference lies in the comparison baseline: the Environmental Bonus incentivised buyers to opt for battery-electric (BEV) or plug-in hybrid (PHEV) instead of internal combustion engine vehicles (ICE), whereas measures covered under the BEG's programmes stimulated measures that would generally not have been carried out otherwise (and if they would have, they are accounted as part of the deadweight effect). Thus, the Environmental Bonus also engenders job losses in ICE vehicle manufacturing and associated industries, offsetting some of the additional jobs from BEV and PHEV manufacturing. This results in significantly lower net employment effects of the Environmental Bonus, compared with the BEG.

However, these values do not take the type of necessary jobs into account. As Fig. 3 shows, about 21% of FTEs for the BEG and 18% for the Environmental Bonus have been generated in bottleneck professions, positions with a lack of qualified workers. While this additional employment for the Environmental Bonus is scattered rather evenly between skilled workers, specialists, and experts, additional bottleneck jobs generated by the BEG predominantly affect skilled

[4] The German efficiency housing (EH) standards are categorized as EH 40, 55, 70, and 85. These standards refer to the primary energy demand of a building in relation to a reference building defined in the German Buildings Efficiency Act, with EH40 meaning that the building needs only 40% of the primary energy required by the reference building. Additionally, the quality of the thermal insulation of the building envelope, measures by transmission heat loss, is a relevant aspect for the determination of the efficiency housing standard. For instance, the transmission heat loss in the EH 40 standard is at 55% compared to the reference building, for EH85 at 100%.

[5] Since its start in 2021, the BEG has been adjusted several times and in 2024 new funding conditions for the BEG EM were implemented with higher grants and additional and higher bonuses (including an income bonus) with a cap at 70% of the total costs. As the analyses here are based on the funding year 2023, we describe the programme based on the respective year.

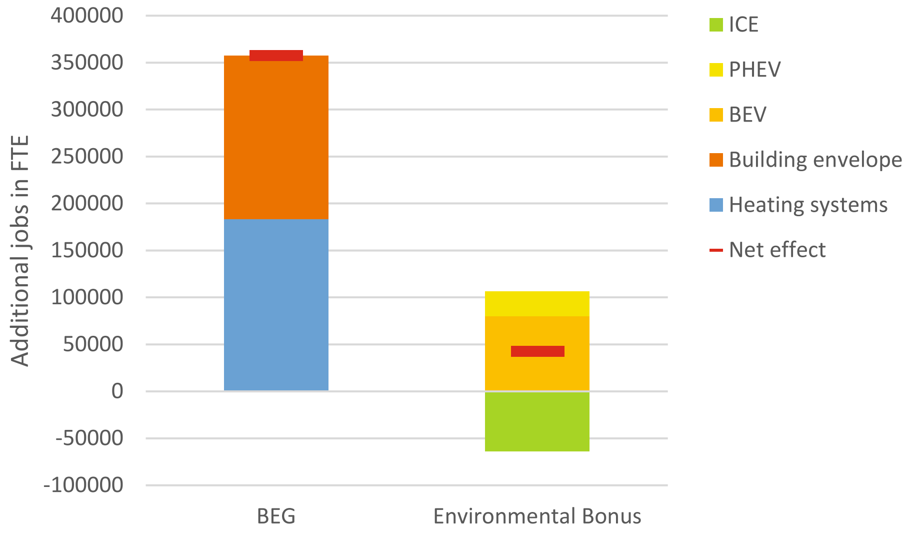

Fig. 2 Additional jobs in full-time equivalents associated with the BEG and Environmental Bonus programmes. Source: own calculations

workers, in particular handymen with a focus on plumbing and heating systems.

However, a limitation of these results lies in the share of products subject to the subsidy effectively being produced in Germany. For instance, in the case of the Environmental Bonus, given that there was no restriction on the origin of the electric vehicles (and given the complex international supply chains of vehicle manufacturing in general), it is possible that a significant portion of the employment effects occurred outside of Germany. While a full discussion on employment effects is linked to discussions of global trade and is out of scope for this paper, regional and/or national effects could be estimated to inform regional policy on employment co-benefits.

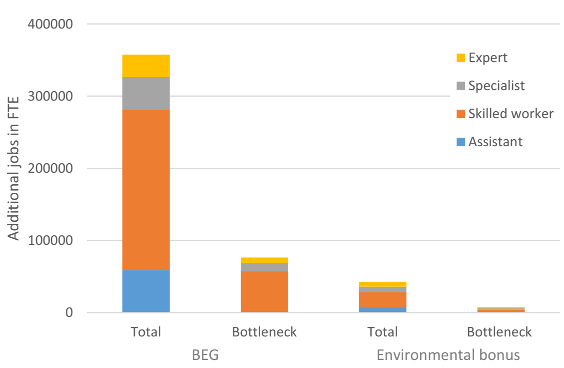

Fig. 3 Additional jobs disaggregated to job requirements in full-time equivalents for BEG and Environmental Bonus, also accounting for bottleneck professions. Source: own calculations

Distributional effects and alleviation of energy and mobility poverty

When assessing distributional impacts of both programmes, the disproportionately low share of beneficiaries from lower income ranks is remarkable. As Fig. 4 shows, only 4% of recipients of the BEG and 2% of the Environmental Bonus are among the lower 30% in terms of household income. In contrast, the upper income quintile accounts for roughly a third of BEG and half of Environmental Bonus beneficiaries.

This does not even consider the average grants to different income brackets. Given the correlation of income with household size, the BEG's generally higher subsidies per grant for higher incomes is unsurprising (Heinrich et al., 2024). This results in an even lower 3% of funds allocated to beneficiaries from the lower 30% in terms of net household income (assuming comparable measures with similar subsidy rates are implemented). A similar pattern can be assumed for the Environmental Bonus as well, where such figures are missing.

These results match an evaluation of the programme for the funding year 2023 showing that the private funding recipients are usually well-educated, working-age individuals with high incomes. The BEG WG programme is more often used by younger, higher-earning, and better-qualified people compared

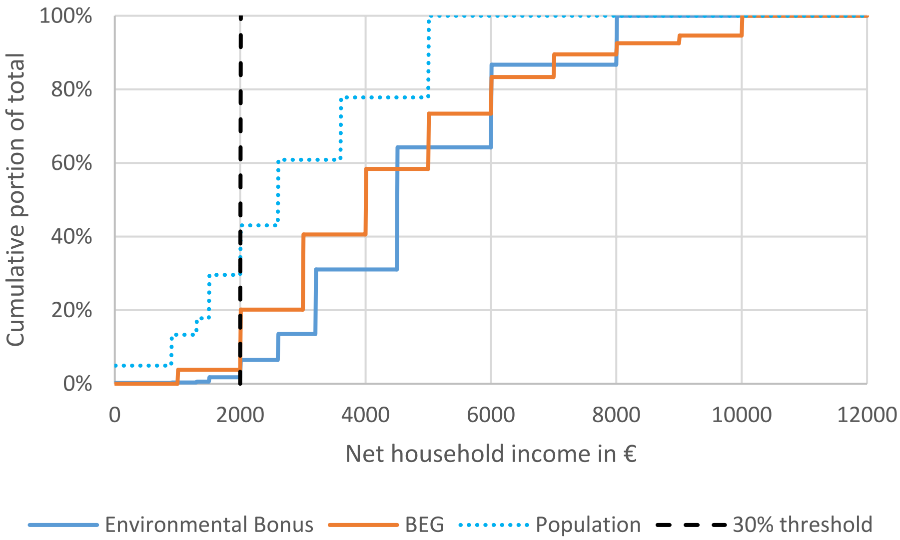

Fig. 4 Cumulative share of recipients by income bracket compared to general population (last income bracket of general population starts at household incomes of 5000€). Source: own calculations

to the BEG EM programme. In contrast, BEG EM recipients show more social diversity (Heinrich et al., 2025a). Regionally, most recipients are concentrated in the economically strongest and most populous federal states, while uptake in Eastern Germany remains low.

Another approach to assess the effects of these measures on financially constrained people is the assessment of energy and mobility poverty alleviation. At first sight, it seems like the Environmental Bonus has lifted significantly more people out of their deprivation. However, the majority of these cases is attributable to deadweight effects, with beneficiates stating they would have bought an EV anyway. Yet, at that point in time, the use of BEVs and PHEVs was generally not cost-effective compared to ICE vehicles. Thus, given this willingness to voluntarily overspend, it can be assumed that a substantial share of this group was not actually suffering from mobility poverty in the first place. However, this cannot be determined unambiguously, as EVs might have been cost-effective at an earlier stage to certain households with very frequent drivers or just a desirable expenditure that they prioritised.

The vast majority of people lifted out of energy poverty by BEG measures is attributable to individual measures (BEG EM), with only a smaller share of benefits from the systemic renovation programme (BEG WG). However, the majority of energy poverty tackling comes from retrofitting of tenements and other rented properties. This is due to the financial inability of energy poor owner-occupiers to make use of subsidies and the fact that merely 24% of energy poor households are owner-occupiers (COM, 2020). Moreover, housing associations are also eligible recipients, which tend to house more energy-poor households than private residents. Yet, given the unclear rent hike and the unknown income situation of the tenants affected by this measure, this leads to uncertainty in the result.

As a result, as depicted in Fig. 5, with roughly 45 000 people, the BEG has lifted considerably more people out of their deprivation (most of them tenants) than the Environmental Bonus, helping about 3 000 (accounting for deadweight effects). Most of

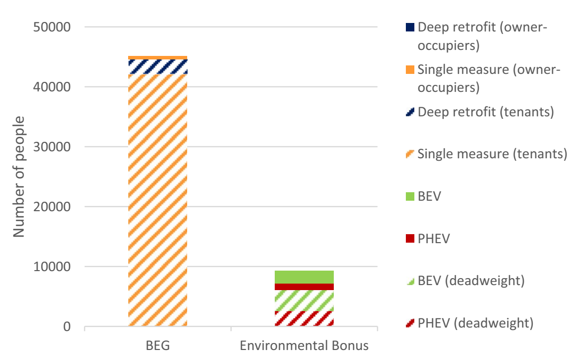

Fig. 5 Total number of people lifted out of energy and mobility poverty by the BEG and Environmental Bonus programmes, respectively. The values are disaggregated to clarify benefits to owner-occupiers and tenants, as well as those related to deadweight effects. Source: own calculations

the people lifted out of energy poverty would be tenants benefitting from their landlords involvement in the scheme. Beneficiaries that would have chosen a PHEV or BEV anyway (deadweight effect), despite higher costs without the subsidy, have been excluded from the net mobility poverty figure. Yet, given the aforementioned issues and the indicators' deterministic approach, there is considerable uncertainty with the results.

Discussion and conclusion

This study aimed to assess the impacts of energy efficiency policies on employment and energy poverty. The findings illustrate that while significant employment effects were achieved, the distribution of benefits largely favoured higher-income groups, raising concerns about equity. Both the BEG and the Environmental Bonus have generated combined employment effects of nearly half a million FTEs, although a substantial share affects bottleneck professions. In contrast, both programmes are performing poorly in terms of distributional effects, with merely 4% and 2% of funds going to the lower 30% for BEG and Environmental Bonus, respectively. Moreover, while the BEG managed to lift roughly 45 000 people each out of energy poverty, predominantly tenants, the Environmental Bonus only alleviated about 3 000 people's mobility poverty. Including these effects allows to describe the benefits of measures by pointing to more tangible effects than funding efficiency coefficients and other typical key performance indicators.

Integrating co-benefits into the impact model to be used universally can be pivotal for a more comprehensive and holistic evaluation of energy efficiency policies. The model's structured approach allows for the assessment of not just direct environmental impacts, such as greenhouse gas emissions reductions and energy savings, but also broader socio-economic benefits. By employing a transparent and replicable framework, the impact model facilitates the identification and quantification of various indicators, including employment effects and social benefits. This holistic perspective enables policymakers to weigh-in relevant co-benefits in their decisions and to consider the wider implications of policy instruments and their design, thereby ensuring that energy efficiency policies do not unintentionally exacerbate existing inequalities and underscoring the necessity of additional measures.

Moreover, the flexibility of the impact model to adapt indicators based on the type of measures employed is essential for capturing nuances of different policy interventions. While more straightforward and simpler indicators such as additional employment or the share of funding going to the lower 30% allow for a good comparison of measures, they might fall short of the necessary detail or tangibility. Nonetheless, they allow a good comparison using but a small number of assumptions. In turn, more complex indicators, such as skill intensity of additional employment and energy/mobility alleviation, have the benefit of giving more valuable insights and being more tangible. However, this comes at the cost of needing more complex models and significantly more data or alternatively assumptions, the latter leading to larger margins of error, since each additional assumed parameters comes with its margin of error. However, knowing about the shortcomings of the different approaches allows for informed decisions when deciding for the most fitting evaluation method. While more robust indicators with fewer assumptions or some closer to typical evaluation outputs would render the results more reliable, it is questionable how much scope for improvement there is without moving too far away from core energy poverty indicators. As the Energy Poverty Advisory Hub's second publication of indicators showed, newly developed energy poverty indicators tend to require more data or become more niche and less widely applicable (Gouveia et al., 2023).

These insights not only highlight the effectiveness of the impact model in evaluating co-benefits but also underscore the necessity of incorporating co-benefits into the design and evaluation of energy efficiency policies. Next to achieving environmental targets, i.e. GHG emissions reductions and increased energy savings, it allows for the recognition and understanding of the social and economic ramifications of energy efficiency measures, especially in regard of reporting obligations on national and EU level. The impact model can serve as a vital tool in this regard, providing a robust framework for assessing the multifaceted impacts of energy policies. By bridging the gap between commonly used environmental metrics and broader socio-economic considerations, the impact model enhances the capacity for informed, evidence-based decision making. In conclusion, this research contributes to the growing discourse on the importance of holistic policy evaluations in the context of energy poverty and economic resilience, which have become increasingly pressing issues in policy making, e.g. in the European Social Climate Fund and the EED.

Appendix I

In order to clarify the calculation of the indicators, this appendix briefly guides through the calculation of the effects of the Environmental Bonus.

Additional employment

The calculation is based on Equation (1), although the used coefficients are already weighted with λ and summed up (computing the relevant scalar multiplication):

$$\Delta EMP_{EB} = (1-0.37)\cdot\left[\frac{0.32\cdot 57.1B€\cdot 7.0FTE/M€}{BEV} + \frac{0.32\cdot 21.6B€\cdot 6.0FTE/M€}{PHEV} - \frac{0.35\cdot 56.0B€\cdot 5.2FTE/M€}{ICE}\right]$$
$$= \frac{80456FTE}{BEV} + \frac{26080FTE}{PHEV} - \frac{63990FTE}{ICE} = 42547FTE$$

Skill intensity

For the calculation of skill intensity, the coefficients are disaggregated to the different skill levels of occupations, differentiating between assistant, skilled worker, specialist, and expert. This results in four coefficients per industry sector, which are already weighted by allocation of investments. These combinations of sector and skill level can then be mapped to bottleneck professions using a boolean vector, specifying whether or not the combination constitutes a bottleneck profession. The following equation shows this latter calculation for expert level employment for the Environmental Bonus:

$$\Delta EMP_{EB,expert} = (1-0.37)\cdot\left[\underbrace{0.32\cdot 36.0B€\cdot\begin{pmatrix}0.013FTE/M€\\0.047FTE/M€\\0.057FTE/M€\\\dots\\0.004FTE/M€\end{pmatrix}\cdot\begin{pmatrix}1\\0\\1\\\dots\\1\end{pmatrix}}_{BEV} + \underbrace{0.32\cdot 13.6B€\cdot\begin{pmatrix}0.017FTE/M€\\0.045FTE/M€\\0.049FTE/M€\\\dots\\0.003FTE/M€\end{pmatrix}\cdot\begin{pmatrix}1\\0\\1\\\dots\\1\end{pmatrix}}_{PHEV} - \underbrace{0.35\cdot 35.3B€\cdot\begin{pmatrix}0.020\ FTE/M€\\0.044\ FTE/M€\\0.042\ FTE/M€\\\dots\\0.003\ FTE/M€\end{pmatrix}\cdot\begin{pmatrix}1\\0\\1\\\dots\\1\end{pmatrix}}_{ICE}\right]$$
$$= \underbrace{2720FTE}_{BEV} + \underbrace{844FTE}_{PHEV} - \underbrace{1969FTE}_{ICEV} = 1595FTE$$

In this example, the selected figures are the coefficients for experts in the sectors vehicle, aerospace and shipbuilding engineering, metal construction and welding, corporate organisation and strategy, and advertisement and marketing. This calculation can then be carried out analogously for the other three skill levels.

Share of funding distributed to the lower 30%

The calculation of this indicator is quite straightforward for the Environmental Bonus. The share of beneficiaries in income brackets with less than 2 000€ household income (2%) is multiplied with the bracket's average grant volume and then divided by the programme's overall average grant volume. However, in contrast to the BEG, average grants are not disaggregated by income brackets for the Environmental Bonus, rendering the last calculation step negligible in this case.

Energy/mobility poverty alleviation

In order to use Equation (2), the impact factor for the Environmental Bonus is calculated. This is done by comparing the cost-savings of both BEV and PHEV to ICE vehicles, as well as to unsubsidised BEV and PHEV (to account for deadweight effects), to the mobility poverty gaps identified from the HBS data. This has been done using the ALADIN model for all four of these options for every year of the Environmental Bonus, with each calculation resulting in an impact factor for every assessed income bracket (<900€, 900€-1300€, 1300€-1500€, 1500€-2000€) (Gnann et al., 2015). Then, for each of the four options in a given year and income bracket, the aforementioned calculation can be carried out:

$$\Delta MP_{\text{ICE}\rightarrow\text{BEV},2020,900€-1300€} = \underbrace{52026}_{N_{\text{ICE}\rightarrow\text{BEV},2020}} \cdot \underbrace{0.1\%}_{PTF_{900€-1300€}} \cdot \underbrace{40\%}_{IF_{\text{ICE}\rightarrow\text{BEV},2020,900€-1300€}} \cdot \underbrace{1.1}_{PPA_{900€-1300€}} = 26.9 \cong 27$$

From there, a total result can be calculated by summing up across all options (or only non-deadweight options), relevant years, and considered income brackets:

$$\Delta MP_{EB} = \sum_{option} \sum_{year} \sum_{bracket} \Delta MP_{EB,\, ICE\rightarrow BEV,2020,900€-1300€}$$

Acknowledgements We want to thank Daniel Speth, Luisa Sievers, Till Gnann, and Tim Wicke for their support and help to gather some of the necessary data.

Author contribution I.B. provided the idea and first developed the theoretical and methodological extension of the impact model. F.B. and I.B. developed the methodological framework and wrote the main manuscript text. F.B. calculated the effects and prepared the figures. S.R., F.V. and P.H. contributed to the manuscript and calculated relevant data. B.S. first developed the impact model and added to its extension. All authors reviewed the manuscript.

Funding Open Access funding enabled and organized by Projekt DEAL. Part of this work was funded by the European Union's LIFE Programme under the project SEED MICAT (project number 101120599, micatool.eu).

Data availability The data that support the findings of this study are partly available in public studies, some are only available upon request due to privacy laws. The data on the "Federal Funding for efficient buildings" are available in the evaluations of the subprogrammes (https://www.energiewechsel.de/KAENEF/Redaktion/DE/PDF-Anlagen/BEG/beg-evaluation-2023-beg-em.pdf?__blob=publicationFile&v=2 and https://www.energiewechsel.de/KAENEF/Redaktion/DE/PDF-Anlagen/BEG/beg-evaluation-2023-beg-wg.pdf?__blob=publicationFile&v=2). The data on the Environmental bonus are partly available in the evaluation of the programme (https://www.bmwk.de/Redaktion/DE/Downloads/E/evaluation-der-richtlinie-zur-foerderung-des-absatzes-von-elektrisch-betriebenen-fahrzeugen.pdf?__blob=publicationFile&v=4), additional data are not publicly available, but available from the authors upon reasonable request. The raw HBS data are protected and are not available due to data privacy laws, access can be requested individually (https://ec.europa.eu/eurostat/web/microdata/household-budget-survey). The data from the models ALADIN and ISI-MACRO are unpublished but are available from the authors upon reasonable request. The data on income distribution in Germany is publicly available online (https://www.bpb.de/kurz-knapp/zahlen-und-fakten/soziale-situation-in-deutschland/61754/einkommen-privater-haushalte/).

Declarations

Competing interests The authors declare no competing interests.

References

Ahlvik, L., Kaariaho, T., Liski, M., & Vehviläinen, I. (2025). Household-level-responses-to-the-European-energy-Crisis (CEPR Discussion Paper No. 19972). CEPR Press. https://www.researchgate.net/profile/Lassi-Ahlvik-2/publication/389400958_Household-Level_Responses_to_the_European_Energy_Crisis/links/67c145ef96e7fb48b9d24cea/Household-Level-Responses-to-the-European-Energy-Crisis.pdf

bpb. (2020). Einkommen privater Haushalte: kurz&knapp. https://www.bpb.de/kurz-knapp/zahlen-und-fakten/soziale-situation-in-deutschland/61754/einkommen-privater-haushalte/

Breitschopf, B., Resch, G., & Nathani, C. (2012). Methodological guidelines for estimating the employment impacts of using renewable energies for electricity generation. https://www.researchgate.net/publication/260434928_Methodological_guidelines_for_estimating_the_employment_impacts_of_using_renewable_energies_for_electricity_generation

Bundesagentur für Arbeit. (2022). Sozialversicherungspflichtig Beschäftigte am Arbeitsort nach Berufen KldB 2010 und Wirtschaftszweigen WZ 2008 sowie nach dem Anforderungsniveau: Statistik der Bundesagentur für Arbeit, Sonderauswertung mit Auftragsnummer 327653.

Bundesagentur für Arbeit. (2023). Fachkräfteengpassanalyse 2022: Deutschland und Länder - Ergebnisse Bund. https://statistik.arbeitsagentur.de/DE/Navigation/Footer/Top-Produkte/Fachkraefteengpassanalyse-Nav.html

Cagno, E., Moschetta, D., & Trianni, A. (2019). Only non-energy benefits from the adoption of energy efficiency measures? A novel framework. *Journal of Cleaner Production, 212*, 1319–1333. https://doi.org/10.1016/j.jclepro.2018.12.049

Campbell, N., Rozite, V., Lees, R., & Heffner, G. (2015). Capturing the mutiple benefits of energy efficiency. International Energy Agency (IEA). https://iea.blob.core.windows.net/assets/28f84ed8-4101-4e95-ae51-9536b6436f14/Multiple_Benefits_of_Energy_Efficiency-148x199.pdf

Cludius, J., Noka, V., Unger, N., Delfosse, L., Dolinga, T., Schumacher, K., Suta, C.-M., Lechtenfeld, R., Vornicu, A., Sinea, A., Serarols, A., García, M., Giardina, F., Lucas, K., Mohd Radzuan, H. S., Bouzarovski, S., Krawiec, K., Chrzanowski, P., & Ruciński, K. (2024). Transport poverty: definitions, indicators, determinants, and mitigation strategies. European Commission (COM). https://euagenda.eu/publications/transport-poverty

Davis, L. W., Fuchs, A., & Gertler, P. (2014). Cash for coolers: Evaluating a large-scale appliance replacement program in Mexico. *American Economic Journal: Economic Policy, 6*(4), 207–238. https://doi.org/10.1257/pol.6.4.207

Destatis. (2025). Verteilung des Haushaltsnettoeinkommens nach ausgewählten Einkommensarten. https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Einkommen-Konsum-Lebensbedingungen/Lebensbedingungen-Armutsgefaehrdung/Tabellen/einkommen-einkommensarten.html

European Commission (COM). (2020). Household budget survey. https://ec.europa.eu/eurostat/web/microdata/household-budget-survey

European Commission (COM). (2025). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. The clean industrial deal: A joint roadmap for competitiveness and decarbonisation. https://commission.europa.eu/document/download/9db1c5c8-9e82-467b-ab6a-905feeb4b6b0_en?filename=Communication%20-%20Clean%20Industrial%20Deal_en.pdf

European Union (EU). (2023). Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast), OJ L 231, 20.9.2023, p. 1–111. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ%3AJOL_2023_231_R_0001&qid=1695186598766

European Union (EU). (2023). Regulation (EU) 2023/955 of the European parliament and of the council of 10 May 2023 establishing a social climate fund and amending regulation (EU) 2021/1060, OJ L 130, 16.5.2023, p. 1–51. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R0955

Fowlie, M., Greenstone, M., & Wolfram, C. (2018). Do energy efficiency investments deliver? Evidence from the Weatherization Assistance Program. *The Quarterly Journal of Economics, 133*(3), 1597–1644. https://doi.org/10.1093/qje/qjy005

Gajdzik, B., Wolniak, R., Nagaj, R., Žuromskaitė-Nagaj, B., & Grebski, W. W. (2024). The influence of the global energy crisis on energy efficiency: A comprehensive analysis. *Energies, 17*(4), 947. https://doi.org/10.3390/en17040947

German Ministry for Economic Affairs and Climate Action (BMWK). (2022). Richtlinie für die Bundesförderung für effiziente Gebäude - Einzelmaßnahmen (BEG EM) (BAnZ AT 30.12.2022).

Gnann, T., Plötz, P., Kühn, A., & Wietschel, M. (2015). Modelling market diffusion of electric vehicles with real world driving data – German market and policy options. *Transportation Research Part a: Policy and Practice, 77*, 95–112. https://doi.org/10.1016/j.tra.2015.04.001

Gouveia, J. P., Palma, P., Bessa, S., Mahoney, K., & Sequeira, M. (2022). Energy Poverty National Indicators: Insights for a more effective measuring. Energy Poverty Advisory Hub (EPAH). https://energy-poverty.ec.europa.eu/system/files/2024-05/EPAH_Energy%20Poverty%20National%20Indicators%20Report_0.pdf

Gouveia, J. P., Palma, P., Bessa, S., Mahoney, K., & Sequeira, M. (2023). Energy poverty national indicators: uncovering new possibilities for expanded knowledge. Energy Poverty Advisory Hub (EPAH). https://energy-poverty.ec.europa.eu/system/files/2024-05/EPAH2023_2nd%20Indicators%20Report_Final_0_0.pdf

Heinrich, S., Langreder, N., Grodeke, A.-M., Sahnoun, M., Jessing, D., Wachter, P., Empl, B., & Winiewska, B. (2024). Förderwirkungen BEG EM 2022: Evaluation des Förderprogramms „Bundesförderung für effiziente Gebäude (BEG)" in den Teilprogrammen BEG Einzelmaßnahmen (BEG EM), BEG Wohngebäude (BEG WG) und BEG Nichtwohngebäude (BEG NWG) im Förderjahr 2022. https://www.energiewechsel.de/KAENEF/Redaktion/DE/PDF-Anlagen/BEG/beg-evaluation-2022-beg-em.pdf?__blob=publicationFile&v=2

Heinrich, S., Langreder, N., Grodeke, A.-M., Alkasabreh, M., Hoch, M., Jessing, D., Wachter, P., Maiwald, F., Empl, B., Boberach, C., & Winiewska, B. (2025a). Kurzfassung der Evaluationsergebnisse. Förderwirkungen BEG 2023: Evaluation des Förderprogramms „Bundesförderung für effiziente Gebäude (BEG)" in den Teilprogrammen BEG Einzelmaßnahmen (BEG EM), BEG Wohngebäude (BEG WG) und BEG Nichtwohngebäude (BEG NWG) im Förderjahr 2023. Prognos; Institut für Umwelt- und Energieforschung (ifeu); Forschungsinstitut für Wärmeschutz e.V. München (FIW); Institut für technische Gebäudeausrüstung Dresden Forschung und Anwendung GmbH (ITG). https://www.energiewechsel.de/KAENEF/Redaktion/DE/PDF-Anlagen/BEG/beg-evaluation-2023-kurzfassung.pdf?__blob=publicationFile&v=5

Heinrich, S., Langreder, N., Grodeke, A.-M., Hoch, M., Jessing, D., Wachter, P., Maiwald, F., Empl, B., Boberach, C., & Winiewska, B. (2025b). Förderwirkungen BEG WG 2023: Evaluation des Förderprogramms „Bundesförderung für effiziente Gebäude (BEG)" in den Teilprogrammen BEG Einzelmaßnahmen (BEG EM), BEG Wohngebäude (BEG WG) und BEG Nichtwohngebäude (BEG NWG) im Förderjahr 2023. Prognos; Institut für Umwelt- und Energieforschung (ifeu); Forschungsinstitut für Wärmeschutz e.V. München (FIW); Institut für technische Gebäudeausrüstung Dresden Forschung und Anwendung GmbH (ITG). https://www.energiewechsel.de/KAENEF/Redaktion/DE/PDF-Anlagen/BEG/beg-evaluation-2023-beg-wg.html

Ingrao, C., Messineo, A., Beltramo, R., Yigitcanlar, T., & Ioppolo, G. (2018). How can life cycle thinking support sustainability of buildings? Investigating life cycle assessment applications for energy efficiency and environmental performance. *Journal of Cleaner Production, 201*, 556–569. https://doi.org/10.1016/j.jclepro.2018.08.080

Jones, B. A. (2018). Spillover health effects of energy efficiency investments: Quasi-experimental evidence from the Los Angeles LED streetlight program. *Journal of Environmental Economics and Management, 88*, 283–299. https://doi.org/10.1016/j.jeem.2018.01.002

Koukoufikis, G., Ozdemir, E., & Uihlein, A. (2024). Shedding light: unveiling the dynamics of energy poverty in the EU. https://doi.org/10.2760/7432189

Rao, S., Schlomann, B., Grimm, A., Plötz, P., Dütschke, E., Schleich, J., Blauert, M., Stede, J., & Schaper, J. (2024). Evaluation der „Richtlinie zur Förderung des Absatzes von elektrisch betriebenen Fahrzeugen (Umweltbonus)" - Abschlussbericht (Förderzeitraum: 2016–2023, gesamter Förderzeitraum). German Ministry for Economic Affairs and Climate Action (BMWK).

Ravaillon, M. (1998). Poverty lines in theory and practice: Living standards measurement study (LSMS). The World Bank. http://documents.worldbank.org/curated/en/916871468766156239

Schlomann, B., Voswinkel, F., Hirzel, S., Paar, A., Jessing, D., Heinrich, S., Antoni, O., & Kahles, M. (2020). Methodikleitfaden für Evaluationen von Energieeffizienzmaßnahmen. Bundesministerium für Wirtschaft (BMWi). https://www.bmwk.de/Redaktion/DE/Downloads/M-O/methodik-leitfaden-fuer-evaluationen-von-energieeffizienzmassnamen.pdf?__blob=publicationFile&v=3

Schumacher, K., Appenfeller, D., Cludius, J., Kreye, K., Sievers, L., Grimm, A., & Stijepic, D. (2024). Sozio-ökonomische Folgenabschätzung zum Projektionsbericht 2024. Umweltbundesamt. https://www.umweltbundesamt.de/sites/default/files/medien/11850/publikationen/projektionsbericht_2024_fa.pdf

Schumacher, K., Noka, V., & Cludius, J. (2025). Identifying and supporting vulnerable households in light of rising fossil energy costs (TEXTE 01/2025). Öko-Institut; German Environmental Agency (UBA). https://www.umweltbundesamt.de/sites/default/files/medien/11850/publikationen/01_2025_texte.pdf https://doi.org/10.60810/OPENUMWELT-7674

Sievers, L., Breitschopf, B., Pfaff, M., & Schaffer, A. (2019). Macroeconomic impact of the German energy transition and its distribution by sectors and regions. *Ecological Economics, 160*, 191–204. https://doi.org/10.1016/j.ecolecon.2019.02.017

Tenente, M., Henriques, C., Gomes, Á., & Da Silva, P. P. (2025). A comprehensive framework for evaluating energy efficiency solutions. *Energy and Buildings, 344*, Article 115997. https://doi.org/10.1016/j.enbuild.2025.115997

Umweltbundesamt (UBA). (2024). Projektionsbericht 2024:: Bericht der Bundesregierung an die Europäische Kommission gemäß Artikel 18 der Verordnung (EU) 2018/1999. https://www.umweltbundesamt.de/sites/default/files/medien/11850/publikationen/projektionsbericht_2024_fa.pdf

Ürge-Vorsatz, D., Kelemen, A., Tirado-Herrero, S., Thomas, S., Thema, J., Mzavanadze, N., Hauptstock, D., Suerkemper, F., Teubler, J., Gupta, M., & Chatterjee, S. (2016). Measuring multiple impacts of low-carbon energy options in a green economy context. *Applied Energy, 179*, 1409–1426. https://doi.org/10.1016/j.apenergy.2016.07.027

Vondung, F., Suerkemper, F., Xia-Bauer, C., Wagner, F., Kiesewetter, G., Charalampidis, I., Vrontisi, Z., & Mzavanadze, N. (2023). Social Impacts: D2.3 Empirical basis of Social Impacts. Quantification/monetization methodology and derived impact factors. Wuppertal Institute for Climate, Environment and Energy. https://micatool.eu/seed-micat-project-wAssets/docs/publications/reports/MICAT_D2.3_social_impacts.pdf