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Abstract

We examine how to design and sequence policy instruments to safeguard vulnerable households under rising carbon prices. We focus on the European Union's new Emissions Trading System for buildings and road transport (ETS2) and the accompanying Social Climate Fund (SCF), which aim to reconcile climate ambition with social protection. We develop a microsimulation-based analysis, using Poland as a case study to compare two strategies for recycling carbon revenues: direct cash transfers to households versus investments in energy efficiency and the electrification of heating. Our results show that each approach has distinct temporal benefits. Immediate transfers rapidly reduce energy poverty; in 2027, Poland's residential energy poverty incidence is 0.3 percentage points below a baseline (about 40,000 fewer households in energy poverty). In contrast, an investment-focused strategy achieves larger reductions in energy poverty after 2030 as efficiency gains accumulate. The findings suggest that an optimal policy mix must combine and sequence both measures, providing prompt financial relief to build public acceptance of carbon pricing, while channelling funds into structural improvements that sustainably lower household energy costs.

Keywords: ETS2; Social Climate Fund; energy poverty; distributional impacts; targeted transfers; energy-efficiency investments; microsimulation; carbon pricing.

JEL: Q58, H23, I32, Q41

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1. Introduction

Achieving climate neutrality by 2050 will require cuts in greenhouse gas emissions. While emissions in the electricity generation and energy-intensive industry sectors have declined significantly, in large part thanks to the introduction of the EU ETS system in 2005 (Bel and Joseph, 2015), emissions from buildings and transport have not. In order to accelerate progress in decarbonization, the EU is due to expand carbon pricing to cover emissions from fossil fuels used in the buildings and road transport sectors. This will happen in the form of ETS2, a separate cap and trade system which is set to start in 2027. However, pricing carbon, whether through taxes or a cap-and-trade system, raises fuel and heating costs, sparking concerns about affordability and equity (Boyce, 2018). These concerns have been amplified by the energy price shocks of the 2020s, which stressed the vulnerability of low-income households to energy cost inflation (Bardazzi et al., 2024). Policymakers are thus confronted with a question: how can climate policy uphold ambitious carbon pricing while protecting households from undue hardship? To answer this question, we need to know (1) the impacts of different targeting and transfer mechanisms on the scale of energy poverty, and (2) how the temporal sequencing of immediate transfers and long-term investment benefits can be effectively managed, taking into account a possible trade-off between the two types of recycling.

We answer these questions using the example of Poland, which offers a compelling case study to explore these issues. In order to alleviate the negative social consequences of the ETS2 system, the EU has decided to allocate part of the ETS2 revenue to the creation of a Social Climate Fund (SCF). Poland is poised to be the largest beneficiary of the Social Climate Fund, as almost 20% of the fund (more than €10 billion) is allocated to Poland, more than any other EU country. This reflects Poland's considerable needs and challenges in the low-carbon transition. Polish households rely heavily on coal and other fossil fuels for heating, resulting in high per-household emissions and acute air pollution problems (Sokołowski and Bouzarovski, 2022). This combination of vulnerability and proactive investment makes Poland a model testing ground for strategies to shield vulnerable households while greening the housing stock. Insights from Poland can inform other countries facing similar socio-economic and infrastructural contexts in implementing ETS2 and the SCF.

The academic literature provides a strong foundation on the distributional impacts of carbon pricing and the efficacy of various compensation mechanisms. However, important gaps remain in the context of the ETS2 and SCF. A large body of research confirms that, in the absence of compensatory measures, carbon pricing tends to have regressive distributional effects in developed economies, with low-income households bearing higher burdens relative to their income (Ohlendorf et al., 2021a). This outcome is driven by energy expenditures comprising a larger share of budgets for the poor and limited access to capital for low-carbon investments. To counteract regressivity, scholars have investigated multiple revenue recycling options. One classic idea is the "double dividend" hypothesis: using carbon revenue to cut distortionary taxes (such as labour taxes) could theoretically yield both environmental benefits and economic efficiency gains (Freire-González, 2018). Some studies find that recycling carbon revenues through tax reductions can improve overall economic welfare, though often at the cost of worsened income inequality compared to direct household rebates (Budolfson et al., 2021). By contrast, returning revenues as equal per-capita transfers tends to maximise progressivity (Fremstad and Paul, 2019). Targeted cash transfers through existing social safety nets have also been recommended to protect the most vulnerable households with relatively low fiscal outlay (Slater, 2011). Beyond transfers, allocating funds to "green" spending, such as subsidising energy efficiency, public transit, or renewable energy, is often justified on efficiency or political grounds. Investing in household energy upgrades, particularly, can reduce emissions and household energy costs in the long term, creating a sustainable exit from energy poverty (Kerr and Winskel, 2020). Recent empirical work supports the value of policy mixes: combining market-based carbon pricing with targeted subsidies or investments can yield synergistic effects in emissions reduction, greater than either instrument alone (Wu et al., 2024). However, these strands of literature have typically been studied in isolation, either focusing on single-policy scenarios or evaluating static outcomes. The specific context of the EU's ETS2 plus SCF, which combines pricing with a substantial social investment fund, has not yet been deeply analysed in academic research.

Our contribution to the literature is threefold. First, we systematically compare the main policy options for revenue recycling under the SCF, including targeted transfers and subsidies for home energy renovations and assessing their distributional and efficiency trade-offs. Prior studies have typically examined these instruments separately. For example, Antosiewicz et al. (2022) analyse a lump-sum rebate versus a labour tax cut in Poland and highlight a trade-off: recycling carbon revenue via tax cuts can boost employment and GDP but tends to increase inequality relative to a lump-sum household transfer. Other work emphasises that universal rebates or direct transfers favour poorer households, making the policy more progressive (Pizer and Sexton, 2019). In contrast, energy price subsidies or tax exemptions often favour higher-income consumers who use more energy (Landis et al., 2019). We build upon and unify these insights by identifying combinations of policy instruments that can simultaneously improve equity and maintain efficiency.

Second, we provide the first empirical micro-level assessment of the EU's ETS2 and Social Climate Fund in action, with Poland as a case study. We employ a microsimulation model linked with inputs from a general equilibrium scenario to quantify the impacts of ETS2 on households across the income distribution, and to evaluate how different SCF spending strategies can mitigate adverse outcomes. Earlier analyses of carbon pricing in Poland and other coal-intensive economies (e.g. using carbon tax simulations) have yielded important insights into general distributional effects (Berry, 2019; Fried et al., 2018; Ohlendorf et al., 2021b; Rausch et al., 2011; Wang et al., 2016) and the role of compensation. However, those studies broadly examined hypothetical policies or stylised recycling schemes in isolation, without the benefit of observing an actual policy framework like ETS2/SCF. Our study moves beyond prior work by incorporating the specific design features of ETS2, notably its focus on residential fuel emissions, and by directly analysing the policy instruments enabled by the SCF. Namely, we include an analysis of transfers versus retrofit investments within the context of the same country. By simulating scenarios with and without these measures, we can identify how each approach buffers vulnerable households in the face of rising carbon costs. To our knowledge, this is the first research to project household-level outcomes under ETS2 using nationally representative data and to estimate the potential of the Social Climate Fund to alleviate energy poverty. The case of Poland provides especially policy-relevant evidence, as it illustrates outcomes for the member state receiving the most considerable SCF support and facing significant transition challenges.

Third, we advance the understanding of policy sequencing in climate transitions by examining the temporal dynamics of household support measures under carbon pricing. A novel aspect of our analysis is comparing outcomes under different timing strategies: one where generous cash transfers are front-loaded in the early years of ETS2, and another where investment in energy efficiency is emphasised from the start (with benefits accruing gradually). This comparison highlights the temporal trade-off between short-term relief and long-term solutions. While it is intuitively accepted that immediate compensation is important for public acceptability of carbon pricing and that structural measures are needed to reduce energy bills permanently, our study quantifies these effects and reveals how they unfold over time. We find that in the initial phase of ETS2, directing carbon revenues to direct household transfers is markedly effective in cushioning vulnerable groups: in our simulation, an immediate transfer program prevents a significant uptick in the energy poverty rate in 2027–2028 compared to a no-support scenario. By contrast, a strategy concentrating on home retrofits yields only a mild short-run improvement, since efficiency projects take time to implement and translate into savings. However, after a few years, the investment-focused approach produces greater reductions in energy poverty than ongoing transfers, because renovated homes and clean heating systems deliver sizable energy cost savings to previously vulnerable households. By 2030, we project Poland's energy poverty rate would fall below its baseline level by a larger margin under the investments scenario than the transfers scenario. We also examine heterogeneous effects by place and dwelling type. We find that transfers are particularly effective for residents of multifamily buildings, while investments deliver larger and more persistent reductions in rural areas and single-family homes. In cities, both strategies perform similarly overall, with transfers slightly better initially and investments slightly better by around 2034 as retrofits accumulate. These patterns increase the importance of sequencing and targeting in SCF design to avoid exacerbating urban–rural and tenure-based disparities. Our contribution is to provide empirical evidence for this evolution, stressing how a well-sequenced policy mix can improve the strengths of transfers and investments at different stages of the transition. These findings align with emerging policy guidance that calls for gradually phasing out temporary income support as deep decarbonization measures take hold (Bataille et al., 2016; Green and Gambhir, 2020). We go further by offering quantitative estimates of the timing and magnitude of effects.

The remainder of this article is structured as follows. Section two lays down the institutional setting of the Emission Trading System extension and the Social Climate Fund. Section three presents our methods. Section four is the results. Section five discusses the policy implications. Section six concludes.

2. Institutional setting

Our analysis is set in the context of the European Union's new Emissions Trading System for buildings and road transport (ETS2). The system is set to start in 2027, alongside a dedicated Social Climate Fund (SCF) to help offset the social impact (Ales, 2024). The ETS2 will extend carbon pricing to fuels used for home heating and vehicles, sectors previously outside the EU's flagship carbon market. While gas, heating oil, and other fuel suppliers will formally pay for emission allowances, most costs are expected to be passed through to consumers through higher utility bills and fuel prices. This raises the risk of a disproportionate burden on less affluent households, who spend a larger share of their income on energy and may lack the means to invest in cleaner alternatives. Without mitigation measures, carbon pricing in these sectors tends to be regressive, putting a higher relative burden on low-income families (Dorband et al., 2019). To prevent a political backlash against ETS2 and avoid aggravating energy poverty, the EU's Social Climate Fund will deploy some of the new carbon revenues toward vulnerable groups. The SCF is slated to provide up to €86.7 billion in targeted support during 2026–2032, funded by ETS auction proceeds and national co-financing. Its mandate is explicitly dual: to deliver immediate relief[1] and to finance long-term investments in energy efficiency and clean technologies for households. Furthermore, Member States are obliged to spend the remaining revenues from ETS2 on progressing climate goals.

Poland is set to receive the largest share of the Social Climate Fund, nearly 20% (over €10 billion), reflecting its substantial transition needs. Polish households' heavy reliance on coal and other fossil fuels for heating drives high per-household emissions and severe air pollution, leaving low-income families highly exposed to rising carbon costs on essential energy (Sokołowski et al., 2020). At the same time, Poland has emerged as a leader in residential decarbonization. For example, the government's flagship Clean Air program has earmarked over €20 billion to subsidise home energy retrofits and replace old coal boilers, one of Europe's most ambitious clean heating initiatives (Sokołowski et al., 2026). Poland's high exposure and accelerating investment put it at the forefront of implementing policies protecting vulnerable households while

[1] Member States are allowed to allocate a maximum share of 37.5% of their SCF budget on direct aid to households.

decarbonising the housing stock. Lessons from Poland are transferable to countries with similar socio-economic and infrastructural profiles as they implement ETS2 and the SCF.

The introduction of ETS2 and the SCF raises fundamental questions about policy design and sequencing that existing research has not fully answered. A central challenge is determining the optimal use of carbon pricing revenues. Should funds be used primarily for direct compensation, e.g. cash transfers or energy rebates to households, or for indirect support via investments, e.g. insulating homes, deploying heat pumps, that reduce households' carbon footprint and energy bills in the long run? Immediate transfers can directly offset the regressive impact of higher energy prices, preventing low-income households from falling into energy poverty in the short term. In fact, uniform lump-sum rebates ("carbon dividends") have been shown to overcompensate poorer households relative to their carbon costs, thereby making carbon pricing net progressive (van der Ploeg et al., 2025). Such dividends are also politically salient and can improve public acceptance of carbon taxes or ETS by visibly returning money to citizens (Muth, 2025). On the other hand, investing in energy efficiency and clean heating tackles the problem at its source by lowering fuel consumption, emissions and thus avoiding the need to pay carbon taxes in the future. Retrofitting buildings, especially the worst-performing, energy-inefficient homes often inhabited by low-income families, can significantly cut energy expenditures and emissions, yielding enduring benefits (Alba-Rodríguez et al., 2022). However, these upgrades involve upfront costs and time to implement; their benefits (lower bills, warmer homes) materialise over many years rather than immediately. This temporal mismatch between immediate costs and delayed benefits is a critical issue: households may not be able to cope with the initial investment cost without interim support, jeopardising social welfare and the political sustainability of the carbon price (Gough, 2013). Policymakers therefore face a sequencing problem: coordinating short-term relief with long-term investments to navigate the transition period when carbon prices begin to bite. While the European Commission has indicated that income support measures should be phased out as structural investments take effect, there is little empirical evidence on how different sequencing strategies perform in practice. The interplay between immediate transfers and gradual energy-saving investments in the context of a carbon price has yet to be rigorously examined, especially under real-world initiatives like the SCF.

3. Methods

Our methodology comprises a soft-linked global general equilibrium model with a microsimulation model. This approach, whereby the output of the former model is used as input for the latter, is a commonly used method to obtain disaggregated household-level results for long-term climate policy research (van Ruijven et al., 2015). In such a setup, the global model provides information about aggregate developments, which the second model then translates into developments at the micro level. This setup enables the study of issues related to the distribution of a particular variable, such as household income or inequality.

We do not develop our own global model but instead use the results provided in the "With Additional Measures (WAM)" scenario which is the more ambitious of the two scenarios described in the National Energy and Climate Plan (NECP) for Poland. This data has been prepared using a modelling suite consisting of detailed sector models and a general equilibrium model. Using this data set increases the policy relevance of our research and ensures compatibility with real-world scenarios that the Polish administration is currently developing.

We develop the microsimulation model using the Household Budget Survey data. A single run of the microsimulation model consists of recalculating households' incomes and expenditures on various energy goods for each year in the simulation horizon. The recalculation is based on the changes in aggregate incomes, prices, and volumes of energy goods consumption provided by the global model. Once the hypothetical HBS datasets for the simulation period have been generated, we calculate a range of energy poverty measures and income distribution.

To answer our research questions, we simulate three distinct scenarios. First, we calculate a baseline scenario that closely follows the developments foreseen in the With Additional Measures (WAM) scenario described in the NECP for Poland. Next, we calculate two scenarios where the Social Climate Fund is in place. The scenarios differ in the size of the budget that is allocated for direct transfers to vulnerable households and subsidies for investment in energy efficiency and electrification of heating. In the following sections, we describe the model, scenarios, input data, and energy poverty measures that we calculate.

3.1. Description of microsimulation model

The microsimulation model is based on the Household Budget Survey data, where each observed household from the survey becomes an agent in the model. The core equations of the model are responsible for updating the income Y^h of households $h \in H$ and their expenditures E_s^h on the set of energy goods $s \in S$. As input, the model requires the change in aggregate household sector income in year t, denoted by ΔY_t, the change in household sector consumption ΔV_t^s and change in prices ΔP_t^s for the set of energy carriers S. All changes are calculated with respect to the base year, which will be denoted by a star.

For simplicity, we assume an identical income growth rate for each household given by the global model. Furthermore, in certain scenarios, total household income may be updated due to direct aid transfer from the social climate fund, denoted as T_t^h. Therefore, for each household h its income is updated according to:

$$Y_t^h = \Delta Y_t \, Y_*^h + T_t^h,$$

where Y_*^h is income of household h in the base year.

Household expenditures on energy goods are updated according to consumption volume and price changes. We first take into account changes in consumption. We assume that changes in the aggregate consumption of fossil fuels, that is for $s \in S^f = \{gas, oil, coal\}$ are linked to replacing the fuel with electricity in the form of a heat pump. In the following equations, we use the fact that the NECP assumes a constant decrease in their consumption. We sample the given proportion of households who use fuel s and set their expenditures on fuel s to zero and increase their expenditures on electricity. When updating the expenditure on electricity, we assume that it will change by a factor of $c_{s,ele}$, which reflects the relative price of a unit of heat energy provided by fuel s, relative to a unit of energy provided by a heat pump. To sum up, if $r < 1 - \Delta V_t^s$, where $r \sim Unif(0,1)$, then:

$$E_{ele,t}^{h,v} = E_{ele,*}^h + E_{s,*}^h \, c_{s,ele},$$

and,

$$E_{s,t}^{h,v} = 0$$

Where $E_{s,*}^h$ is the base expenditure of household h on fuel s. For remaining fuels $s \in S^{nf} = \{ele, wood, heat\}$ we assume that all households proportionally change their consumption of the given fuel, and so their expenditure is updated as follows:

$$E_{s,t}^h = E_{s,*}^h \, \Delta V_t^s$$

We also take into account the change in household expenditure on energy goods due to changes in their prices. Here, we simply assume that expenditures of households change by the same proportion:

$$E^h_{s,t} = E^{h,v}_{ele,t}\,\Delta P^s_t.$$

We simulate three scenarios: a baseline or business-as-usual scenario, a transfer scenario and an investment scenario (Table 1).

Table 1. Scenario descriptions

Scenario	Description
Baseline scenario	In the base scenario, we assume that the trajectory of income, prices, and use of fossil fuels follows the assumptions of the WAM scenario in the NECP for Poland. The prices of fossil fuels include the increase resulting ETS2, but the SCF is not used.
Transfer	In this scenario, we assume the introduction of the Social Climate Fund. The SCF budget is spent according to the government's plan for public consultation: on direct aid to vulnerable households and as subsidies for green investments.
Investment	In this scenario, we assume that the part of the SCF budget dedicated to direct aid for households is reallocated to subsidise green investment.

Source: own elaboration.

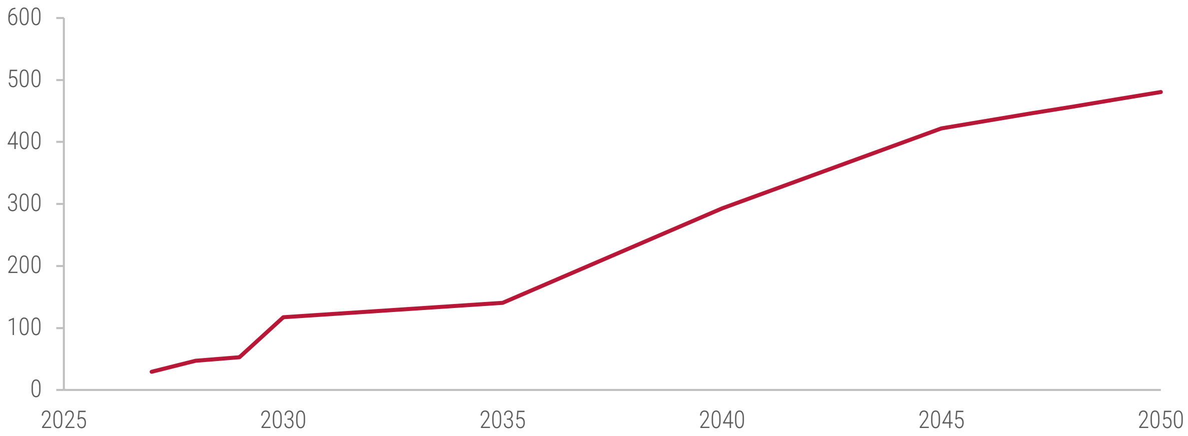
3.1. Data sources

We use the Household Budget Survey dataset for Poland for the year 2023 as the base for the microsimulation model. This dataset comprises several data tables that contain information on a representative set of approximately 28,000 households, their 68,000 household members, and their expenditures on goods according to the COICOP classification. We use data on total household income (variable *DOCH*) and expenditures on the main elements of category 04.5: *Electricity, gas, and other fuels*. We distinguish sets $s \in S$ composed of 6 fuels and energy carriers: electricity, gas, liquid fuels, coal, wood and other solids, and heat energy. In addition, we use several socio-economic variables to break down results for different types of households.

We use the following variables from the global model to develop the NECP. First, we use the total aggregate household income change in year t relative to the base year 2023, which we denote by ΔY_t. Second, we use the predicted changes in household sector consumption ΔV^s_t, ($\Delta V^s_{2023} = 100\%$) and prices ΔP^s_t, ($\Delta P^s_{2023} = 100\%$) relative to 2023 for the same set of energy carriers $s \in S$ that we distinguish from the HBS dataset. This choice allows for direct mapping of data between models. Finally, we use the assumptions regarding the price of allowances in the ETS2 system.

We highlight the main assumptions from the NECP in Figures 1-4. The NECP assumes that the price of allowances does not exceed 50 EUR per ton in the first three years of the functioning of ETS2. In the first half of the following decade, prices sharply increased by 110-140 EUR and after 2035, they increase quickly and reach 480 EUR in 2050. This price trajectory is directly reflected in the price of fossil fuels, which are presented in Figure 2. While the base price of fossil fuels is assumed to decrease slightly over the following decades, the ETS2 system causes an overall significant increase. This is especially evident in the price of the most carbon-intensive fuel, with coal seeing an almost 5-fold increase until 2050. The price of electricity and district heat, which is already covered by the EU ETS will see an increase in the coming years. However, with continued decarbonization of this sector, which allows to avoid paying for the price of allowances, prices will drop below current levels as early as 2034.

Figure 1. Assumed price trajectory for price of allowances in ETS2 system (Prices in EUR2023)



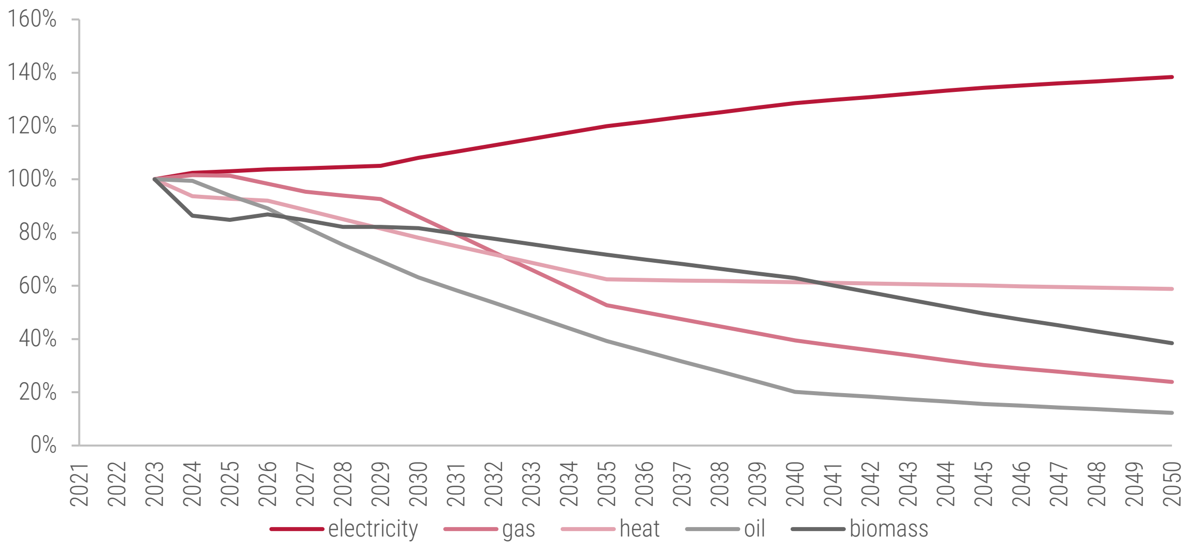
Source: own elaboration based on NECP data.

Figure 2. Price growth of basic energy carriers in NECP in the base scenario and with ETS2 prices included (2023 = 100%).

Source: own elaboration based on NECP data.

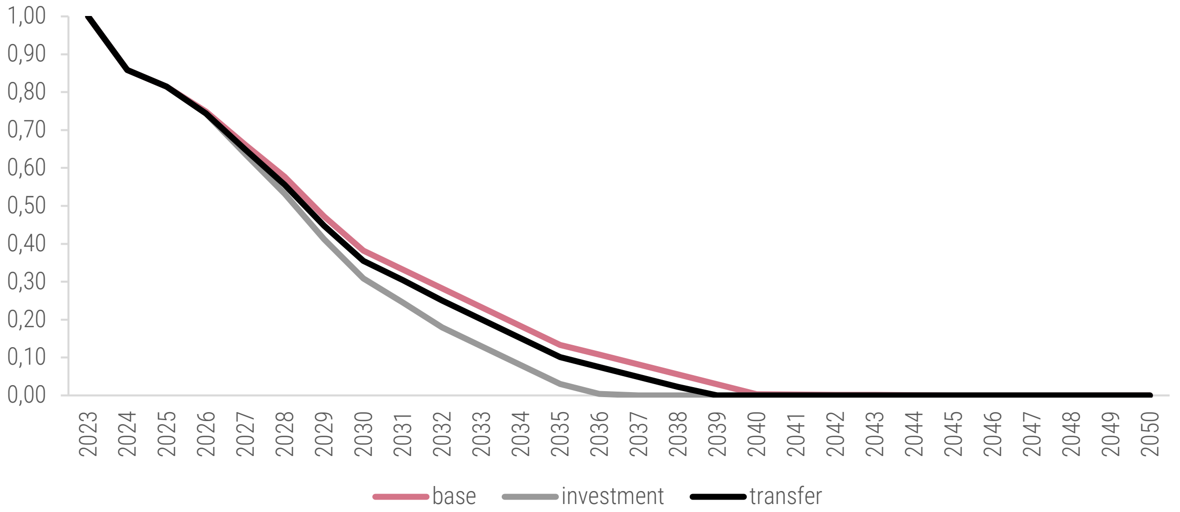
The NECP assumes that the use of all energy carriers, except for electricity will, decrease in the next 25 years. The two main drivers behind these projections are the electrification of heating and transport and increases in energy efficiency of buildings. Unfortunately, the information provided by the NECP does not allow for the quantification of their relative relevance. In the case of district heating and biomass, the more dominant driver are probably investments in energy efficiency of buildings. This is due to the fact that very few households switch away from district heating. Furthermore, these heating sources are not covered by the ETS2 on current policy does not incentivise switching to alternatives. The opposite can be said for fossil fuels, which are being pushed out of the energy mix by current policy.

Figure 3. Household consumption of main energy carriers for all scenarios (2023 = 100%).



Source: own elaboration based on NECP data.

Figure 4. Household consumption of coal under the three scenarios (2023 = 100%).



Source: own elaboration based on NECP data and the SCP.

Finally, we use data from the Polish Social Climate Plan to calibrate the investment and transfer scenarios. The two main elements of the SCF are the direct aid component, which has a total budget of 5.7 billion EUR, and the investment subsidy component, which has a budget of 3.1 billion EUR.

Direct aid is given to households whose monthly per capita income is below the threshold of 2275 PLN, or approximately 530 EUR. It is distributed evenly in the first phase of ETS2's operation, 2027-2032. The budget allows for an annual transfer of approximately 830 PLN, or 195 EUR.

The investment component will be used to fund the "Clean Air" program, which was introduced in 2018 and is used to subsidise investment in energy efficiency of buildings and the replacement and modernisation of heating systems. The program offers to subsidise a share[2] of a household's investment based on their income. In our study, we make two simplifying assumptions regarding how the money is allocated. First, we assume that the program finances 100% of the investment cost. Such an assumption allows us to quantify the Clean Air program's pure, real economic effect without discussing co-financing options and possible crowding-out effects. Second, we assume that the money is used to finance buildings' thermal insulation, which decreases energy demand and replaces coal furnaces with heat pumps[3]. With these assumptions, the budget of 3.1 billion EUR allows for a complete renovation of approx. 95,000 households, while the budget allocated for direct aid would allow for renovating an additional 175,000 households. The resulting use of coal by the household sector for the three different scenarios is shown in Figure 4. We notice that even in the BAU coal is used only until 2040, and the additional investment present in the two scenario allows for a quicker replacement of this fuel.

3.2. Description of energy poverty metrics

Our main energy poverty indicator is the Low Income High Cost index, adapted to Polish data (Sokołowski et al., 2020). We analyse households $g = 1, \dots, G$ from a nationally representative survey. All descriptive statistics and distributional cut-offs are computed with survey weights w_g. To construct benchmarks for required energy spending, each household is assigned to a strata $S(g)$ defined by its building type, construction period, and primary heating system. This stratification captures characteristics rather than idiosyncratic behaviour.[4]

Required electricity spending is proxied by the weighted mean of observed per-capita electricity outlays within each cell, scaled by household size. Let e_i be per-capita electricity spending for household i and $\bar{e}_S = \frac{\sum_{i \in S} w_i e_i}{\sum_{i \in S} w_i}$, the cell-specific weighted mean for cell S. Household g hypothetical electricity bill is:

$$H_g^E = \bar{e}_{S(g)} N_g$$

with N_g the number of people in each household. Electricity is tied largely to headcount (appliances, lighting, plug loads), so a per-capita norm minimises bias from dwelling size; adopting a per-m² norm here would

[2] Depending on household income, the program finances 40%, 70% or 100% of the total investment cost.

[3] The current version of the Clean Air program can be used to finance the replacement of both gas and coal furnaces with heat pumps or biomass furnaces. We do not model conversions to gas because these are no longer supported in the program and, in any case, require local distribution infrastructure that is missing in many areas, which would unduly restrict applicability. We also do not model biomass boilers. Incorporating them would require detailed regional fuel-price and data that we cannot observe consistently, introducing unmodelled heterogeneity into costs and impacts.

[4] Two equivalence scales are used, each where it is conceptually most appropriate. For energy needs and the residual-income comparison we adopt the fuel-poverty (FP) scale $s_g^{FP} = 0.58 + 0.42 max\,(0, A_g - 1) + 0.2 C_g$, where A_g and C_g denote the numbers of adults (14+) and children (<14). For ranking households in the general income distribution we use the modified OECD scale $s_g^{OECD} = 1 + 0.5 max\,(0, A_g - 1) + 0.3 C_g$. Using the FP scale in the residual-income test ensures that both energy "needs" and disposable resources are put on the same equivalised footing; the OECD scale is reserved for the broader notion of structural low income.

misstate needs for large families in small flats. Moreover, electricity spending are captured by the inclusion of the primary heating system variable, as $\bar{e}_{S(g)}$ reflects those higher loads.

Required space-heating is treated differently because heat demand primarily scales with the heated floor area and the building's thermal performance. Let c_i be observed heating cost per m² and $\bar{c}_s = (\sum_{i\in S} w_i\, c_i)/(\sum_{i\in S} w_i\,)$ the cell-specific weighted mean. We define the household's heated area:

$$A_g^{heat} = \begin{cases} area_g, & if\ the\ dwelling\ is\ not\ under-occupied, \\ \theta_g \times area_g, & if\ over-metraged, with\ \theta_g \in (0,1], \end{cases}$$

where θ_g is the reported heated share, applied only when the dwelling exceeds the EU under-occupied building threshold.[5] The hypothetical heating bill is then

$$H_g^H = \bar{c}_{S(g)} A_g^{heat}$$

Downscaling only for under-occupied dwellings avoids penalising small homes that already heat their full area, while recognising that very large homes often do not.

Total hypothetical energy need is the sum $H_g = H_g^E + H_g^H$. We equivalise this using the FP scale to obtain $H_g^{eq} = H_g / s_g^{FP}$. The weighted median of H_g^{eq} in the population, denoted $\widetilde{H}_g^{eq}$, defines the "high costs" (HC) threshold; the HC indicator is $1\left(H_g^{eq} > \widetilde{H}_g^{eq}\right)$. In the baseline implementation, $\widetilde{H}_g^{eq}$is fixed at the sample's weighted median estimated on the reference wave from 2027 in each scenario (approximately 105 EUR per month in equivalised terms).

To capture the income side of energy poverty, we construct after-housing-cost income $Y_g^{AHC} = Y_g - HCOST_g$, where H_{COSTg} aggregates rent, mandatory housing charges, and mortgage repayments. We equivalise this on the FP scale, compute its weighted median $\tilde{Y}_g^{AHC,eq}$, and set the poverty line at $PL = 0.6\tilde{Y}_g^{AHC,eq}$, following the Eurostat 60% below the median income poverty threshold.[6] Following the Hills residual-income logic (Hills, 2012), the first low-income condition holds if required energy needs would push the household below the AHC poverty line:

$$LI1_g = 1\left(\tilde{Y}_g^{AHC,eq} - H_g^{eq} < PL\right)$$

To focus on structurally low-income households rather than middle-income households with temporarily high needs, we add a second filter based on the modified OECD scale. We compute $Y_g^{eq} = Y_g / s_g^{OECD}$, form weighted income deciles, and define $LI2_g = 1$ if g falls in the bottom three deciles.

The composite low-income condition is $LI_g = 1(LI1_g = 1 \wedge LI2_g = 1)$. The final Low Income, High Cost indicator is then:

$$LIHC_g = 1(LI_g = 1 \wedge H_g^{eq} > \widetilde{H}_g^{eq})$$

All distributional cut-offs (medians, deciles) are computed with w_g.

[5] According to the Eurostat criterion, a dwelling is under-occupied if it has more than an adequate number of rooms given the composition of the household. An adequate number of rooms is defined as one common room, one room for a couple in a relationship, one room for two children of the same sex between the ages of 12-17, one room for two children under age 12 regardless of gender, and one room for every other person.

[6] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:At-risk-of-poverty_rate

4. Results

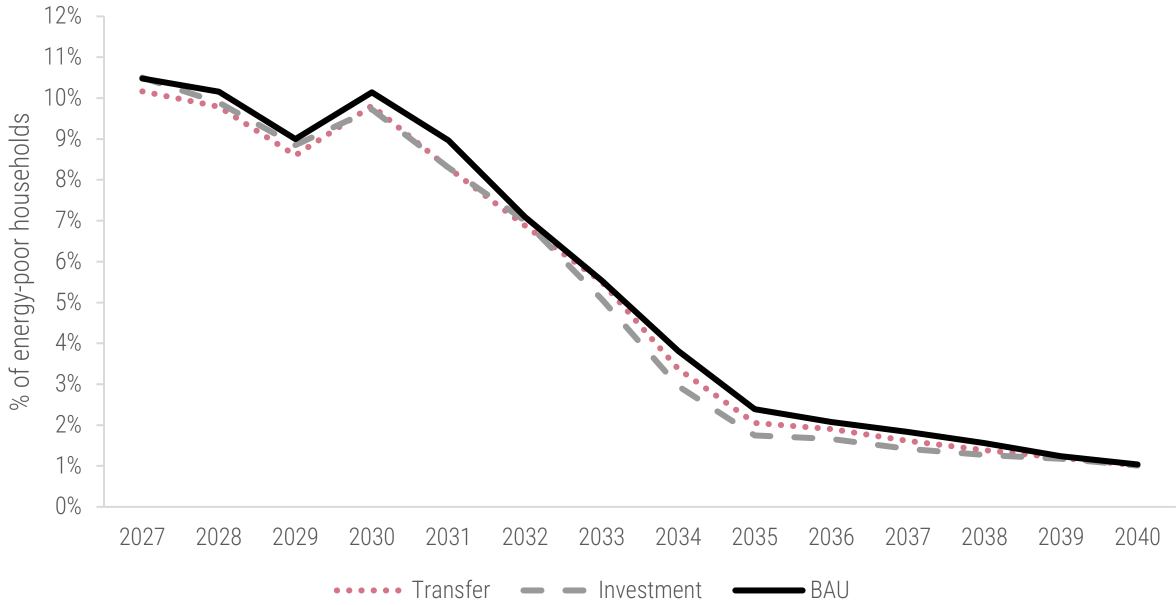
In this section, we present Poland's projected energy-poverty outcomes under ETS2 using the LIHC metric for 2027–2040, comparing the baseline scenario (BAU) with the two remaining two scenarios described in Table 1. We first report the 2027 first-year impact, showing how transfers cushion the initial distributional shock relative to BAU. We then track the evolution through the 2030s, highlighting when and how investment effects overtake transfers as renovations accumulate. We also assess the post-2032 persistence of impacts once temporary support winds down, through to 2040. Throughout, we present results as levels and differences versus BAU (percentage-point changes in LIHC), and interpret their implications for the political economy of ETS2 (acceptability and legitimacy) and for inequality, poverty alleviation, and redistribution, emphasising the complementarity of transfers (near-term protection) and investments (long-term, durable reductions).

4.3. Immediate distributional impacts of ETS2 and SCF mitigation (2027–2030)

The introduction of the new ETS2 carbon price in 2027 is projected to exacerbate energy poverty in Poland, absent countervailing measures. In our baseline (business-as-usual, BAU) scenario with no Social Climate Fund support, the share of households in energy poverty (measured by the LIHC indicator) is 10.5% in 2027.

To examine how different SCF strategies alleviate the initial shock, we compare two "With Additional Measures" (WAM) scenarios against the BAU baseline in 2027–2030: one channelling SCF revenues into direct monetary transfers for households (with an investment component), and another only investing in home energy renovations and clean heating systems. We find that direct cash transfers provide an immediate protective effect. In 2027, the energy poverty rate under the transfers-focused scenario drops to 10.2%, significantly below the baseline's 10.5% (a reduction of about 0.3 percentage points). By contrast, the investment-focused scenario yields a LIHC rate around 10.5% in 2027, similarly to BAU (Figure 5). This is an expected outcome: efficiency upgrades take time to implement and translate into lower household energy costs.

Figure 5. Scale of energy poverty in Poland 2027-2030, according to different SCF recycling scenarios (% of energy-poor households)



Source: own elaboration based on the microsimulation model and HBS data.

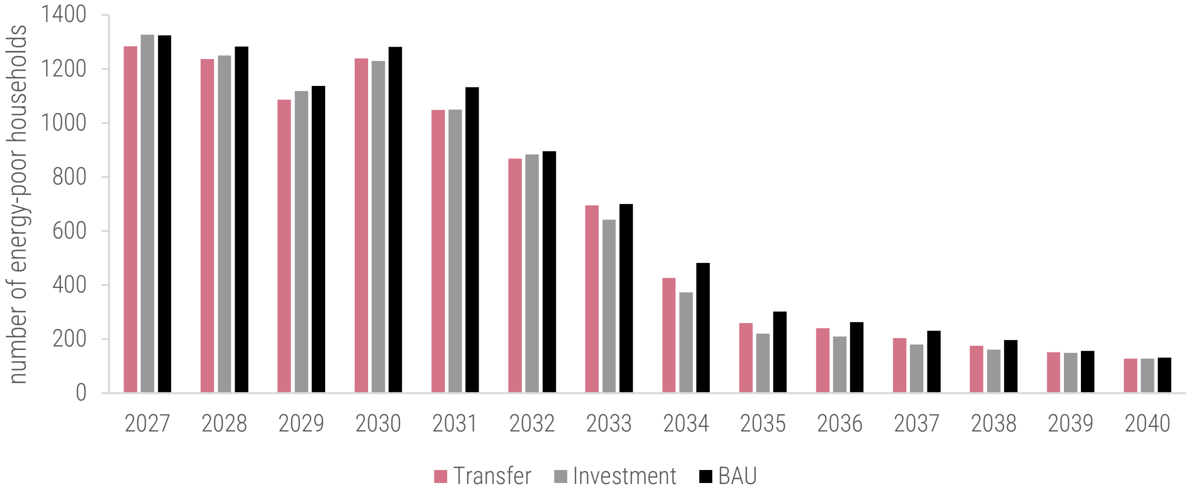
By 2028–2030, a clear divergence emerges between the two approaches to recycling the ETS2 revenues via the SCF. The transfers scenario outperforms the baseline, keeping energy poverty around 0.4–0.7 percentage points lower than BAU through 2028–2030. These cash transfers act as an immediate support, effectively compensating vulnerable households for higher fuel costs and preventing a surge in energy hardship. This cushioning effect is crucial for political and social acceptance of the carbon price: it protects consumers' living standards in the short run and builds legitimacy for ETS2. Indeed, compensating households via direct support can make carbon pricing progressive, with low-income families receiving more rebates than they pay in higher costs.

The investment-focused scenario, on the other hand, shows only a mild short-run effect. In 2028, the LIHC rate remains at the same level as in the baseline. This suggests that investment programs alone cannot prevent an initial shock of the ETS2. However, by 2029–2030, we will already have observed the payoff of early investments: the retrofit scenario's energy poverty rate falls below the transfers scenario. For example, by 2030, the energy poverty headcount in the investment scenario is about 9.7% of households, compared to 9.8% under transfers and 10.1% in the baseline. The structural measures begin to drive the scale of energy poverty more decisively downward, as renovated homes and cleaner heating systems start cutting energy bills for formerly vulnerable families. This confirms the intuition that retrofitting creates a compounding benefit that grows over a few years, ultimately outpacing the one-off relief of cash transfers.

4.4. Long-Term trajectories and structural energy poverty reduction (2030–2040)

From the early 2030s onward, the structural advantages of the investment approach dominate the trajectory of energy poverty. All scenarios show a declining trend in LIHC incidence over the long term. This result is consistent with the assumptions present in the NECP shown in Figure 3, in particular the drop in consumption of all energy carriers except for electricity. Yet the timing and depth of poverty reduction differ. In the baseline case, energy poverty slowly declines after the initial ETS2 shock, but many households remain energy-poor through the 2030s. Our model projects the BAU LIHC rate at about 7% in 2032, falling to 4% by 2034 and only dropping below 1% of households in the late 2040s. Without efficient mitigation policies, 110,000 Polish households would continue to suffer inadequate heating or excessive energy cost burdens for over a decade into the transition (Figure 6).

Figure 6. Number of energy-poor households in Poland 2027-2030, according to different SCF recycling scenarios (% of energy-poor households)

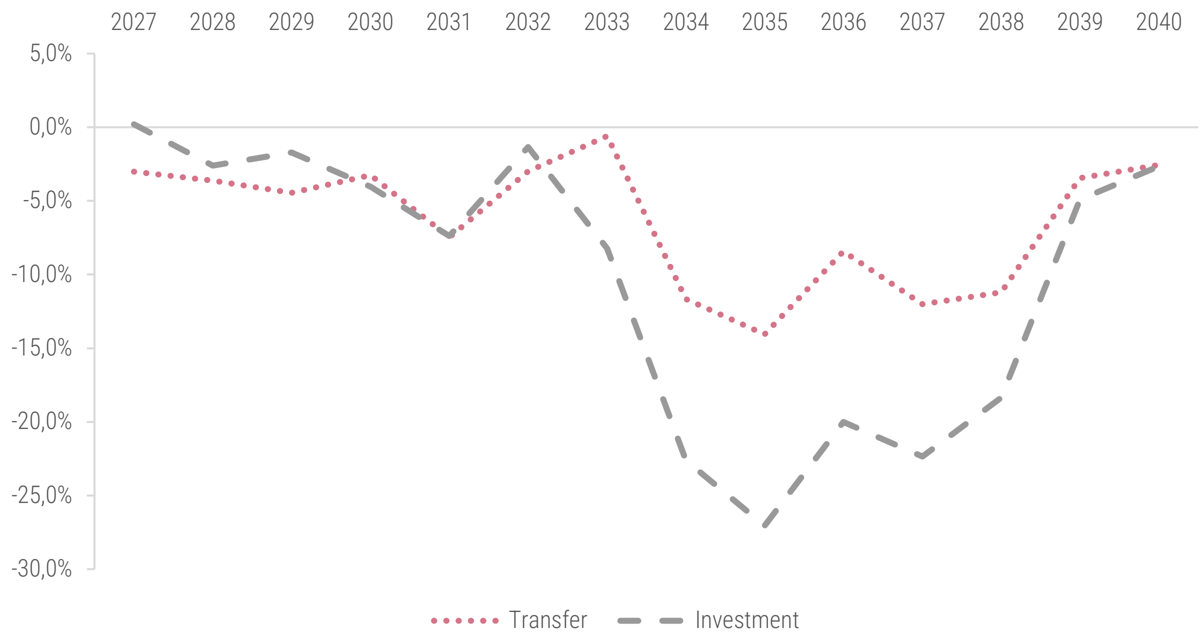


Source: own elaboration based on the microsimulation model and HBS data.

Leveraging the SCF for deep building upgrades delivers a more rapid alleviation of energy poverty after 2030. Under the investments-driven scenario, the share of energy-poor households drops to 5.1% by 2033 (versus 5.5% in BAU) and around 3% by 2034 – roughly one-third lower than that year's baseline rate. The retrofit program yields enduring reductions in household energy demand and shields occupants from carbon price exposure. As a result, the energy poverty gap between the investment scenario and baseline widens through the early 2030s. This scenario essentially front-loads the long-term benefits: once inefficient coal boilers and gas stoves, leaky homes, and other structural inefficiencies are remedied, previously vulnerable households are no longer at high risk of energy poverty. Investing SCF funds into energy efficiency and clean heat tackles the root causes of energy poverty: high energy needs and costs, thereby delivering sustained, cumulative improvements in living conditions.

The transfer scenario flattens progress in the long run. After 2030, the early advantage of transfers erodes as the effect of yearly stipends diminishes once carbon prices continue to rise. In our simulation, the transfers scenario's energy poverty rate converges toward the baseline by the mid-2030s. By 2033–2035, households in the cash support case have lost mainly their initial edge, and energy poverty remains slightly lower than BAU (by 5% or less; Figure 7). This convergence suggests direct transfers can temporarily suppress energy poverty without concurrent efficiency improvements. As prices rise and the direct payments level ceases (or loses real value), households may fall into energy stress if their homes are still inefficient. While our results only hint at a minor short-lived convergence, income support must be coupled with efforts to reduce energy costs permanently. This dynamic aligns with the SCF Regulation's requirements that any direct support be complementary to structural measures, and that investments should also target recipients of temporary aid to lift them out of energy poverty effectively.

Figure 7. Differences between SCF recycling scenarios and the BAU in Poland 2027-2030 (% deviation in the scale of energy poverty from BAU)



Source: own elaboration based on the microsimulation model and HBS data.

Beyond 2035, all scenarios trend toward very low levels of energy poverty by 2050 (under 0.5% of households), reflecting the broader decarbonisation and upgrading of housing stock over the transition. By the 2040s, our model indicates the differences between scenarios taper off, as most of the housing inefficiencies have been resolved, effectively eliminating chronic energy poverty. The baseline eventually catches up in the long run as market-driven renovations, technology adoption, and existing policies (outside the SCF) diffuse through the building stock. This convergence by 2050 highlights that carbon pricing can ultimately drive efficiency given enough time, but the social cost in the interim would be significantly higher without early interventions. The faster decline in the SCF scenarios means fewer families enduring energy deprivation during the transition years, illustrating the intergenerational equity gains from acting sooner to protect vulnerable groups.

Finally, we calculate a simple measure spanning the years 2027-2040 showing the difference in household-years in energy poverty between the transfer and BAU scenarios and the investment and BAU scenarios (Figure 8). Such a measure directly shows the trade-off between the two types of spending. For the transfer scenario, this measure is equal 473 869, with the number accumulated in the early years of the ETS2. For the investment scenario, this figure is 26% higher and stands at 597 711, suggesting that longer term benefits outweigh, at least to a certain extent, the benefits of providing direct aid.

Figure 8. The difference in number of household-years in energy poverty relative to the BAU scenario

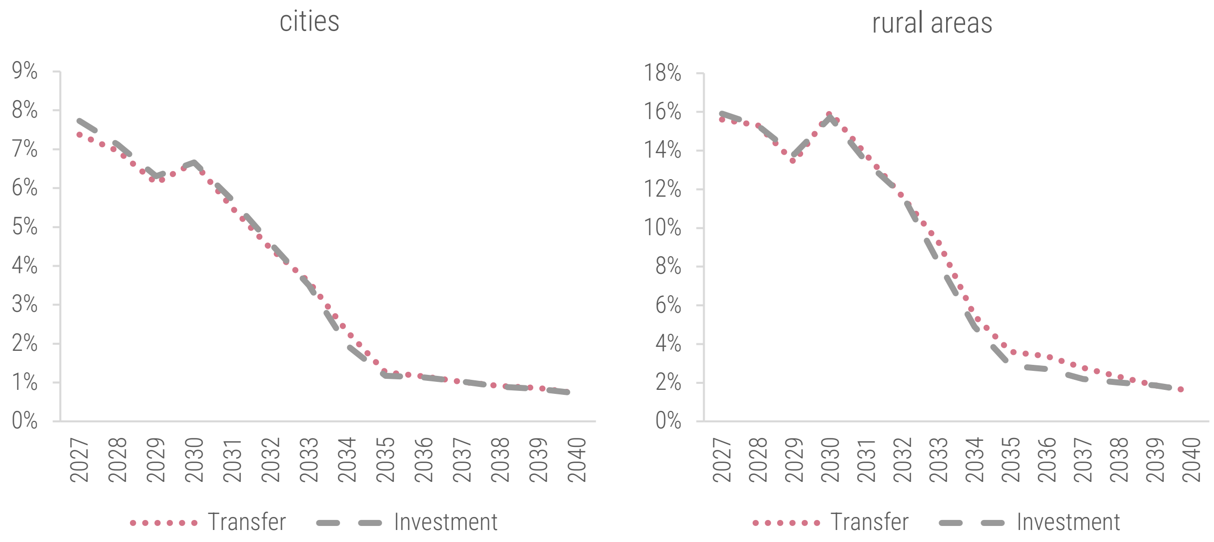
Source: own elaboration based on the microsimulation model.

4.5. Distributional heterogeneity across settlement and building types

We also analyse heterogeneities in who benefits from revenue-recycling under ETS2. Specifically, we split results by settlement type (cities and rural areas) and dwelling type (multifamily and single-family) to understand distributional consequences beyond national aggregates.

Disaggregating outcomes by settlement reveals place-based differences in how revenue recycling strategies reduce energy poverty. In cities, transfers and investments perform very similarly over the horizon, with a mild initial edge for transfers and a mid-2030s edge for investments (Figure 9).

Figure 9. Energy poverty by settlement type, according to different SCF recycling scenarios (% of energy-poor households)

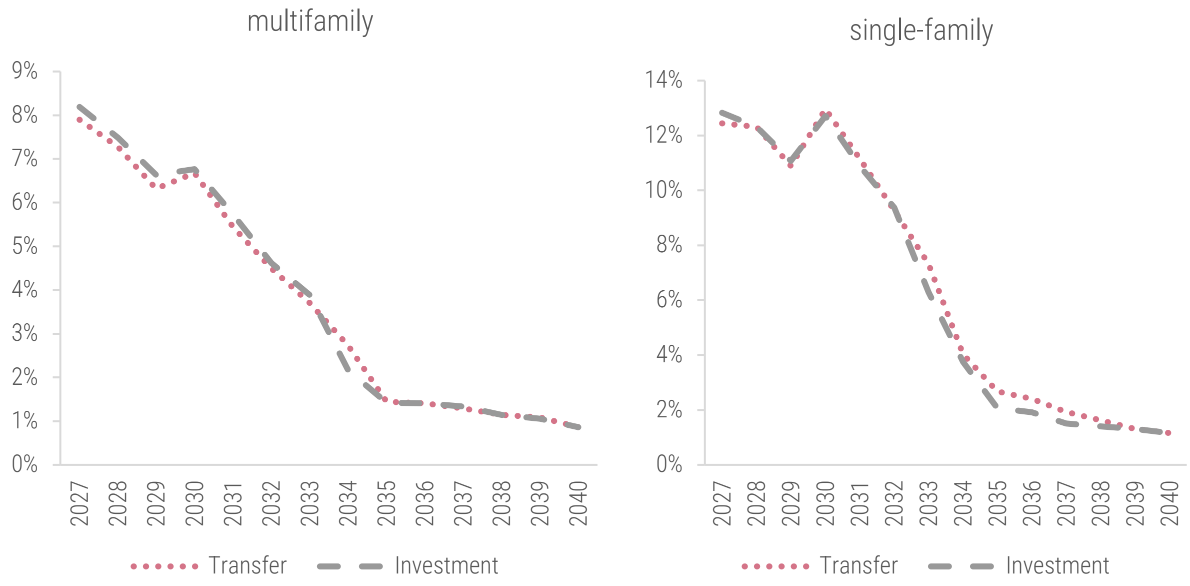


Source: own elaboration based on the microsimulation model.

In rural areas, the pattern is more clearly investment-dominant from the early 2030s onward. While 2027–2029 looks slightly better under transfers, the investment path pulls ahead once building upgrades diffuse in 2035, with small gaps persisting through 2038 and convergence thereafter. These dynamics align with our model's mechanism: transfers act immediately on disposable income, whereas investments reduce required energy with a lag but persistently.

A dwelling-type split shows that transfers work better for residents of multifamily buildings, while investments deliver larger and more persistent gains for single-family homes (Figure 10). In our model, the primary mechanism is straightforward. Investment spending accelerates the replacement of coal heating (prevalent mainly in single-family buildings) with heat pumps and improved insulation. Because coal use is concentrated in this segment, investment-driven fuel switching and efficiency upgrades yield large structural reductions in required energy and thus in energy-poverty incidence among single-family households. In contrast, multifamily stock features less coal (more district heating or gas/electric systems), so the marginal payoff of investment is smaller on average, and transfers provide more immediate and reliable relief to household budgets. Coordination frictions and ownership structures in multifamily buildings (shared envelopes, common systems and decision-making) likely reinforce this pattern by slowing deep retrofits, but the dominant channel in our results remains the coal phase-out concentrated in single-family housing.

Figure 10. Energy poverty by building type, according to different SCF recycling scenarios (% of energy-poor households)



Source: own elaboration based on the microsimulation model.

Taken together, the settlement and dwelling-type splits indicate that a uniform recycling mix risks widening existing disparities. Investment-heavy allocations will tend to favour single-family, rural homeowners, while urban multifamily residents, including a substantial group with individual heating (about 700,000), benefit more from transfers and from program designs that overcome building-level coordination barriers.

5. Discussion: complementary roles of transfers and investments for a just transition

Our results demonstrate that financial transfers and structural investments are complementary phases of an integrated strategy, not opposing solutions. The optimal pathway to a just, politically sustainable transition under carbon pricing involves sequencing and combining these measures (Meckling et al., 2017). Direct transfers are necessary in the initial phase (2027–2032) of ETS2. They provide immediate relief, prevent a surge in energy poverty, and help secure public support for the policy. This immediate shielding effect addresses the political economy concern that carbon taxes can trigger backlash if households with low incomes bear unaffordable costs (Belgioioso and Newman, 2025). The SCF was conceived precisely to shield vulnerable consumers in the short term and avoid undermining the legitimacy of climate policy. By cushioning households through upfront rebates or energy allowances, Poland can avoid a repeat of scenarios where regressive energy taxes provoked social polarisation. Moreover, because lump-sum rebates are broadly progressive, this approach enhances climate equity: it redistributes carbon revenue to households with low incomes, turning a regressive price into a progressive policy instrument (Mayer et al., 2021).

However, transfers alone are not sufficient to sustain political and social support in the long run. Without visible improvements in housing and heating affordability, the public could perceive carbon pricing as perpetually requiring compensation (Klenert et al., 2018). This is where the investment measures become essential. Our analysis shows that retrofits and clean heating investments deliver the lasting reduction in energy poverty needed to fulfil the promise of a fair transition (Desvallées, 2022). These measures tackle energy poverty at its source by lowering energy demand and decoupling households from fossil fuel expenditures. Notably, they also produce co-benefits: improved thermal comfort and health, reduced air pollution, and lower greenhouse gas emissions, which are outcomes that enhance the political sustainability of climate policy by creating tangible positive results in people's lives (Harlan and Ruddell, 2011). By 2030 and beyond, the investment scenario outperforms pure income support, validating the EU's guideline that short-term aid should pave the way for structural fixes. In practice, this means Poland's Social Climate Plan should devote a significant share of funds to insulating homes, replacing old coal boilers with heat pumps and biomass stoves, and subsidising renewable energy systems for low-income households. Such investments ensure that households are not left vulnerable to rising carbon costs again once the SCF's direct aid tapers off (the SCF is initially slated for 2027–2032).

Importantly, the sequencing of measures matters. Our results support a timeline in which income support is front-loaded at the moment of ETS2 implementation, while investment programs ramp up quickly and continue beyond 2030. This approach aligns with policy recommendations from recent studies and EU institutions. Direct support should begin when ETS2 comes into force (2027) to protect the most vulnerable immediately, whereas retrofit programs should start even earlier and scale up through the 2020s (Meadows et al., 2024). The idea is that generous transfers in the early years buy time, allowing the structural measures to take effect when the carbon price increases steeply in the 2030s. Our modelled SCF scenarios illustrate this dual-role strategy. In the first 3–5 years, transfers prevent the energy poverty rate from breaching 10% in 2027 and hastening its decline in 2028–2030. Subsequently, by 2030 and especially 2032 onward, building retrofits and clean heating investments drive a steep downtrend in energy poverty that persists even after direct payouts end. In essence, transfers create the room for structural policies to succeed, and once those structural improvements are in place, the need for ongoing transfers diminishes, validating the upfront political investment.

Combining the two SCF strategies yields the most equitable and politically viable outcome. Direct monetary transfers immediately address the symptoms of energy poverty, ensuring vulnerable households can afford energy in the short term and that the carbon pricing reform is socially just (Belaïd, 2022). Simultaneously, investment in energy efficiency addresses the causes of energy poverty, permanently lowering energy bills and carbon emissions. This dual approach ensures that climate policy in Poland not only achieves emissions reductions (through the price signal and subsequent behaviour changes) but does so in a way that shares the costs and benefits fairly across society. The SCF's design reflects this balance: up to 37.5% of funds can be used for temporary income support, while at least 62.5% is earmarked for investments that yield lasting gains. Relying on just one approach would either fail to prevent hardship in the short run (if only investments were pursued) or fail to eradicate energy poverty in the long run (if only cash transfers were used).

Additionally, the heterogeneity results suggest place- and tenure-sensitive allocations of SCF resources. In cities and multifamily stock, generous, time-bound transfers should be paired with instruments that lower retrofit coordination costs. In rural areas and single-family homes, investment-heavy allocations are likely to yield larger cumulative reductions in energy poverty because delivery is faster and agency is higher at the household level. Without such tailoring, a uniform policy could over-serve single-family owners while under-serving multifamily residents, even among those with individual heating systems, thereby entrenching disparities that the SCF seeks to erase.

In the EU climate policy design context, these findings highlight how social equity measures can be built into carbon pricing to enhance feasibility. The ETS2 and the SCF mechanisms allow member states to leverage carbon revenues for progressive redistribution and infrastructure upgrading. By combining compensation with capital investment, the EU can turn what might have been a regressive policy into a tool for reducing inequality, alleviating energy poverty, modernising homes, and ensuring low-income communities share in the benefits of climate action (Reckien et al., 2017). This approach strengthens the political coalition for decarbonisation. When citizens see that climate policy delivers warmer homes, lower bills, and financial support, they are more likely to support higher carbon prices over time (Rhodes et al., 2014). Therefore, a politically sustainable transition will not result from carbon pricing alone, but from carbon pricing with redistribution (Baranzini et al., 2017). Our analysis of SCF implementation strategies in Poland demonstrates that coupling an emissions price with well-designed social investments and transfers can achieve environmental effectiveness and social fairness.

6. Conclusion

Our paper examined how the Social Climate Fund (SCF) can recycle ETS2 revenues to protect households from rising energy costs in Poland. We compared two strategies: direct transfers and investment in energy efficiency and clean heat, and their sequencing over 2027–2050. Three results stand out. First, transfers are highly effective at cushioning the initial ETS2 shock: in 2027, the LIHC rate falls from a 10.5% baseline to 10.2% with transfers (0.3 pp reduction). Second, as retrofits accumulate, investments outperform transfers: by 2030, the LIHC rate is 9.7% under the investment path versus 9.8% with transfers and 10.1% in the baseline. Third, the long run features convergence as the stock upgrades and carbon pricing diffuses through the system; by the 2040s, differences narrow substantially. By 2050, energy poverty is below 0.5% in all scenarios. The convergence to the same level is due to the fact that all scenarios assume moving away from coal, and the SCF allows for this to happen a couple of years earlier. These findings imply that an optimal, politically sustainable design is a sequenced mix: generous, time-bound transfers to secure acceptability at entry and rapid scale-up of structural investments that permanently lower needs and bills for vulnerable households.

Our findings should be read with several caveats. First, the microsimulation depends on a range of external assumptions including carbon-price trajectories, pass-through rates, how the investment part of the SCG is spent and the timing and scale of SCF outlays; different parameterisations would shift magnitudes and sometimes the timing of effects. Second, we abstract from delivery frictions: administrative lags, contractor capacity, supply-chain bottlenecks, and take-up barriers, that could slow retrofit deployment or blunt the short-run reach of transfers. Third, behavioural responses beyond bill mechanics (comfort changes, rebound, off-program fuel switching) are simplified, which may bias near-term and cumulative savings. Fourth, energy-poverty classification inevitably reflects measurement choices (threshold anchoring, equivalence scales, treatment of dwelling characteristics); households near cut-offs are especially sensitive to these. Finally, we abstract from second round effects: for example earlier retirement of fossil fuel use would decrease the price of allowances in the ETS2 system. However, the core conclusions are robust to these uncertainties because they follow from the mechanism. Transfers act immediately on disposable income, while investments lower the required energy with a lag but persistently. This structural timing asymmetry means transfers dominate in the entry years and investments dominate as retrofits accumulate, regardless of reasonable price variation, pass-through, or delivery speed. Our comparisons also hold the fiscal envelope constant, so the results hinge on modality rather than budget size. We further reduce reliance on single-year assumptions by reporting outcomes across near-, medium-, and long-term horizons. Finally, household-level accounting links policy, dwelling characteristics, and bills consistently. This makes distributional channels transparent and aligned with broader evidence that income supports mitigating acute hardship while capital upgrades deliver durable resilience.

We see a couple of avenues for future research. Testing alternative targeting rules (e.g. income-based, LIHC-status, building-condition, place-based) and dynamic sequencing that ties beneficiaries from cash relief into retrofit programs, while explicitly modelling administrative costs and take-up elasticities, could be an important extension of our work. In parallel, incorporating richer behavioural modules and coupling the microsimulation to macro and housing-market blocks would capture comfort choices, rebound, adoption dynamics, rent pass-through, and labour-income feedbacks that shape distributional outcomes over time. Broadening the scope to jointly model residential energy and road transport would illuminate place-based burdens, especially in rural and coal-dependent areas where mobility constraints interact with heating needs. As programs roll out, ex post evaluation using quasi-experimental and experimental designs can validate ex ante projections, quantify delivery frictions, and measure the persistence of savings and co-benefits (comfort, health, air quality), feeding evidence back into SCF policy design and the sequencing of transfers and investments.

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