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2. PRIJAVA TEME DOKTORSKE DISERTACIJE

Opći podaci i kontakt doktoranda/doktorandice	
Titula, ime i prezime doktoranda/doktorandice	Ivana Rogulj
Nositelj/Nositelji studija	**SVEUČILIŠTE U RIJECI, EKONOMSKI FAKULTET**
Naziv studija	**Doktorski studij ekonomije i poslovne ekonomije**
Matični broj doktoranda/doktorandice	
Ime i prezime majke i/ili oca	Emilija i Mate Stanić
Datum i mjesto rođenja	04. siječnja 1983.
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ŽIVOTOPIS DOKTORANDA/DOKTORANDICE

Ivana Rogulj, rođena je 04. siječnja 1983. godine u Splitu, osnovnu školu i jezičnu gimnaziju završila je u Omišu. 2007. godine diplomirala je na Fakultetu elektrotehnike i računarstva u Zagrebu, smjer Elektroenergetika, usmjerenje Energetski sustavi. Završila je Poslijediplomski interdisciplinarni specijalistički studij Ekoinženjerstvo Sveučilišta u Zagrebu s temom vezanom uz utjecaj obnovljivih izvora energije na neposredni okoliš. Završila je Poslijediplomski specijalistički studij (MBA) Ekonomija energetskog sektora s temom „Razvoj obnovljivih izvora energije male instalirane snage u Republici Hrvatskoj: analiza okruženja i prijedlozi poboljšanja". 2020/21. godine upisuje doktorski studij. Do sada je objavila više radova i koautorica je jednog poglavlja u knjizi u Routledge izdanju.

Tijekom diplomskog studija bila je stipendistica Hrvatske elektroprivrede te se po studiju 2007. godine zapošljava u tvrtki HEP ESCO d.o.o. na investicijskim projektima energetske učinkovitosti. Od 2013. do 2020. godine radi u organizaciji Društvo za oblikovanje održivog razvoja na projektima čija su tema dekarbonizacija i učinci dekarbonizacije, a od 2020. u međunarodnom istraživačkom „think tank-u" Institutu za klimatsko- energetske politike iz Amsterdama, na klimatsko - energetskim politikama Europske unije. Završila je edukaciju za CBA, energetske preglede, međunarodnu certifikaciju na području mjerenja i verifikacije učinaka projekata energetske učinkovitosti i jednogodišnju školu Experta za upravljanje projektima financiranima putem Europskih fondova. Predsjednica je Upravnog odbora Udruge DOOR, članica je međunarodnih savjetodavnih odbora u struci. Autorica je brojnih studija, lokalnih i regionalnih energetskih planova, priručnika i analiza. Trenutno koordinira i/li radi na šest velikih znanstveno stručnih europskih projekata i brojnim studijama. Svakodnevno koristi poslovni engleski jezik.

1. NASLOV PREDLOŽENE TEME

1.1. Hrvatski

Evaluacija učinaka politika dekarbonizacije energetskog sektora na ugrožene potrošače energije

1.2. Engleski

Evaluation of the impacts of energy decarbonisation policies on vulnerable energy consumers

1.3. Područje/polje

Društvene znanosti / ekonomija

1.4. Ključne riječi (minimalno pet riječi)

Energetske politike, dekarbonizacija energetike, energetsko siromaštvo, ugroženi kupci, socioekonomska obilježja, energetska učinkovitost, ne-energetske (višestruke) dobrobiti

2. PREDLOŽENI ILI POTENCIJALNI MENTOR/MENTORI

2.1. Mentor/i

Titula, ime i prezime	*Ustanova, država*	*E-pošta*
Prof.dr.sc. Saša Žiković	**Ekonomski fakultet, Sveučilište u Rijeci, Hrvatska**	sasa.zikovic@efri.uniri.hr

2.2. Komentor

Titula, ime i prezime	*Ustanova, država*	*E-pošta*

3. OBRAZLOŽENJE TEME

3.1. Sažetak na hrvatskom jeziku
(maksimalno 4000 znakova s praznim mjestima)

Za evaluaciju politika, a posebno dekarbonizacije, obično se koristi analiza prosječnog učinka politike (ATE). Koristi se za mjerenje utjecaja intervencije (politike) na željeni rezultat i predstavlja prosječnu razliku među rezultatima kod onih koji su ciljna grupa neke politike i onih koji nisu te opisuje sveobuhvatni učinak politike. Takva metodologija propušta uzeti u obzir utjecaje na različite socioekonomske skupine, takozvani distribucijski ili heterogeni utjecaj. Distribucijska analiza uključuje procjenu kako ista intervencija djeluje na različite skupine. Npr. ista politika koja bi mogla biti pogodna za tvrtku srednje veličine, može u maloj tvrtki izazvati dodatne troškove i značajno negativne efekte. U slučaju ovog specifičnog istraživačkog problema, politika koja je pogodna za opću populaciju, može rezultirati negativnim učincima na ranjive skupine, a zbog potrebe da im se pomogne dodatnim financiranjem, rezultirati negativnim učincima na javni proračun. U istraživanju će se razviti i testirati metodologija za procjenu distribucijskih učinaka, ciljani potrošači su ugroženi potrošači energije, odnosno energetski siromašni, oni u situaciji da trpe specifične posljedice nedostupnosti odgovarajućih energetskih resursa (sukladno onome što se smatra očekivanom razinom udobnosti za njihovu okolinu). U slučaju Europske unije (EU), te ciljne skupine su energetski siromašna kućanstva i ugrožena mikropoduzeća, uz određeno preklapanje ovih dvaju skupina. Odabrani su zato što ih najnoviji zakonodavni okvir smatra najosjetljivijima na posljedice promjena cijena energije.

Za razliku od ranjivosti kućanstava na energetsko siromaštvo, gdje se indikatori definiranja skupine dugo istražuju, ranjivost mikropoduzeća tek treba definirati. Dio istraživanja posvećen je pregledu literature, meta-analizi i statističkoj analizi podataka, strukturiranim intervjuima stručnjaka, prikupljanju podataka za studije slučaja, s ciljem otkrivanja korelacije između odrednica malih poduzeća koje utječu na njihovu ugroženost, a time i izradu indikatora ugroženosti (ranjivosti) poslovnog sektora i razlikovanje poslovnog rizika od rizika od energetskog siromaštva.

Stoga je razvijena hipoteza i pomoćne hipoteze:

H: Propusti u procjeni distribucijskih učinaka politike na ugrožene potrošače prije provedbe politika dekarbonizacije, imaju utjecaj na njihovu ranjivost, ali i ukupnu uspješnost samih politika.

Nedostatak evaluacije mjera dekarbonizacije energije ima neosporan makroekonomski utjecaj, vidljiv kroz potrebu za dodatnim financiranjem kako bi se ublažili negativni učinci politika na ugrožene potrošače. Udio ugroženih potrošača i njihove potrošnje energije u ukupnoj potrošnji energije dovoljno je značajan da promijeni ukupne učinke politika ako se ne uzme u obzir. Uspjeh mjera dekarbonizacije energije oblikovan je socioekonomskim i demografskim karakteristikama krajnjih potrošača.

AH1 Postoje signifikantne razlike u rezultatima procjene utjecaja politika ako se neenergetski učinci na ranjive skupine (na primjer: troškovi zdravlja u kućanstvima ili promjena u potrebnim troškovima održavanja u tvrtkama) uzimaju u obzir.

AH2 Postoji signifikantna statistička veza između odrednica mikro poduzeća i njihovog statusa ugroženog kupca energije.

Poslovni ekosustav poduzeća značajno utječe na osjetljivost na promjene cijena energije. Veličina i vlasništvo poduzeća važne su odrednice ugroženosti.

Razvijene i(li) korištene metodologije:

- Dosadašnja iskustva i znanja vezana uz definirani istraživački problem prikupljena i analizirana klasičnim znanstvenim metodama: induktivno i deduktivno zaključivanje, analiza i sinteza postojećih informacija, apstrakcija i konkretizacija, generalizacija i specijalizacija, deskriptivna i komparativna analiza,
- Prikupljanje podataka (EUROSTAT, Anketa o potrošnji kućanstava, OECD, Strukturna poslovna statistika, nacionalni izvori podataka, ankete),
- Interpretativna analiza politika (na nacionalnoj i EU razini), strukturirani i polu-strukturirani intervjui stručnjaka, radionica s vodećim stručnjacima u području,
- Razvoj i korištenje ekonomskog modela energetske tranzicije za izračun makroekonomskih učinaka uvedenih politika,
- Matematičke metode poput ekstrapolacije i linearne regresije,
- Izračunavanje kompenzacijske varijacije kao mjere promjene blagostanja,
- Pregled literature korištenjem SALSA metodologije,
- Analiza kvalitativnih doprinosa pomoću NVivo ili drugog softvera za kvalitativnu analizu,
- Deskriptivna statistička analiza prikupljenih podataka,
- Regresijska analiza korištenjem R-a s djelomičnom analizom korelacije,
- Korištenje MICAToola – alata za kvantifikaciju makroekonomskih učinaka politika dekarbonizacije (kandidatkinja je koautorica alata)
- Korištenje mikroekonomske i analize troškova i koristi s integracijom ne-energetskih koristi za poduzeća (u razvoju, kandidatkinja je koautorica alata)
- Mikrosimulacija za određivanje učinaka na ranjiva mikropoduzeća (alat će se utvrditi)

Nužnost ovoga istraživanja je višestruka: dio ranjive skupine nije definiran, iako je već spomenut u zakonodavstvu; novouvedena politika utječe ili na promjene cijene energije ili promjene u potrebnim investicijama, a oboje ima utjecaja na krajnje potrošače; rezultati bi pomogli u planiranju i promjena u politikama, ali i definiranju potrebne pomoći ovim skupinama potrošača, a time i ukupnog troška za društvo.

Za buduća istraživanja potrebno je fokusirati se i na različitost u cjenovnoj elastičnosti potrošnje energije i ponašajnu različitost u investicijama u različitim socio-ekonomskim skupinama.

3.2. *Sažetak na engleskom jeziku*
(maksimalno 4000 znakova s praznim mjestima)

The evaluation of decarbonisation policies' is usually done using Average Treatment Effect (ATE). It is used to measure the impact of a policy intervention on an outcome of interest and represents the average difference in outcomes between those who receive the policy intervention and those who do not and describes the overall effects of policies. What it misses is including distributional impacts on different socio-economic groups. Distributional effects (heterogeneous effects) go beyond the average impact to explore how the treatment effect varies across different subgroups within the population. This involves examining the distribution of treatment effects to understand who benefits from the intervention. For example, the same policy which could be beneficial for medium. -size company, could induce additional costs or burdens in smaller companies. This might result in the adverse effects on vulnerable groups, and because of the need to help them with additional funding, resulting with adverse effects on the public budget. In this research, the methodology for evaluation of distributional effects will be developed and tested, targeted consumers are those vulnerable to energy poverty, or energy vulnerable, those in the situation of suffering specific consequences of unavailability of adequate energy resources (in line with what is considered expected level of comfort for their surroundings). In the case of European Union (EU), these target groups are energy poor households and vulnerable micro-enterprises, with certain overlap of these two groups. These groups are chosen as the newest legislative framework considers them most vulnerable to consequences of energy price changes.

As opposed to household vulnerability to energy poverty, where the indicators of the group definition have been long researched, the vulnerability of micro-enterprises has yet to be defined. So, the part of the research is dedicated towards literature review, meta-analysis and data statistical analysis, structured interviews of experts, data collection for case studies, aiming at finding out the correlation between specific ecosystem and internal determinants of small companies affecting their vulnerability and with that drafting the indicators of energy vulnerability in business sector and differentiating business risk from risk of poverty.

Therefore, the research hypothesis and auxiliary hypotheses have been developed:

H: Failing to evaluate distributional policy effects on vulnerable consumers prior to implementing decarbonization policies, has impact on their vulnerability and substantial impact on the success of the policy.

The lack of evaluation of energy decarbonization measures has an undeniable impact on the economy, as evidenced by the need for additional funding to mitigate the adverse effects on vulnerable consumers. The ratio of vulnerable consumers and their energy consumption in the total energy consumption is significant enough to change total effects of policies if taken into consideration. The success of energy decarbonization measures is shaped by the socio-economic and demographic characteristics of the final consumers.

AH1 There is a significant difference in results of evaluation of impacts when non-energy effects on vulnerable groups (for example: costs of health, change in operational costs for maintenance) are taken into consideration in comparison to when they are not.

AH2 There is a statistically significant relation between determinants of micro-companies and their vulnerability to the effects of energy prices change.
Company's business ecosystem has significant effect on the vulnerability to changes in energy prices, The size and the ownership of the company are important determinants of energy vulnerability.

To test the hypotheses, several methodologies are or will be developed and employed:

Methodologies developed and used:

- Previous experiences and knowledge related to the defined research problem gathered and analyzed using classical scientific methods: inductive and deductive reasoning, analysis and synthesis of existing information, abstraction and concretization, generalization and specialization, proof and objection, descriptive and comparative analysis,
- Data collection (EUROSTAT, Household Budget Survey, OECD, Structural business statistics, national data sources, surveys),
- Interpretive policy analysis (on national and EU levels), structured and semi- structured interviews of experts, workshop with high-level experts in the field,
- Development of *Economics Energy Transition Model* to calculate macroeconomic effects of introduced policies.
- Mathematical methods like extrapolation and linear regression,
- Use of the *Compensating Variation as a Measure of Welfare Change* (Chipman, 1992),
- Literature review using SALSA methodology,
- Analysis of expert inputs using NVivo or other qualitative analysis software,
- Descriptive statistical analysis of data collected,
- Regression analysis with partial analysis of correlation, using R
- Use of MICATool – tool for quantification of macroeconomic impacts of decarbonisation policies (*PhD candidate is co-author of the tool*)
- Use of microeconomic and cost-benefit analysis with integration of companies benefits (*in development, PhD candidate is co-author of the tool*)
- Micro-simulation for determination of effects on vulnerable micro-enterprises (tool to be determined)

The need for this research has been obvious from several points of view: the part of the vulnerable group is not defined, but is targeted in legislation; the new introduced policy influences either changes of energy price or changes in needed investments, both of which have impacts on final consumers; the results would help the planning of both changes in policies but also needed assistance towards this groups and with that, the total cost to society. Research wise, this opened additional questions to be targeted, how is the price elasticity of energy demand different among different socioeconomic groups and does this change macroeconomic results dramatically; and how investment in energy upgrades looks like in vulnerable groups and how that part affects future implementation of legislation. These are important future research questions.

3.3. Uvod i pregled dosadašnjih istraživanja
(preporučeno 7000 znakova s praznim mjestima)

Greenhouse gas (GHG) emissions, which include CO_2 emissions, are one of the main drivers of the climate change. Given the growing issue of climate change, environmental degradation, and the resulting inequalities (Schot & Kanger, 2018), the EU through its European Green Deal (EGD), proposed a set of objectives, measures, and mechanisms to promote a just, efficient, and competitive transition to a climate-neutral EU by 2050. The energy transition is one of the most important development segments of the EU for the period up to 2030, and includes the goals of reducing greenhouse gas emissions, increasing energy efficiency, and enhancing the use of the renewable energy sources. Forty-plus years of research on the topic have focused on many aspects of energy transition, in particular energy efficiency, showing its micro-level influences on disposable income or productivity, but also multiple-countries scenarios and technological developments changing courses of energy consumption.

Thoughtfully crafted policy interventions, as well as decarbonisation measures, consistently appear to contribute positively to economic welfare. (Saunders, 2021)

Looking at the same objectives from different perspective, energy transition and decarbonisation policies change import dependencies and global energy relations. (Yang & Qian, 2023) This fact became utterly important during the past two years and the threat to supply security through the Ukrainian war. Unstable prices of energy and unstable sources of imports have shown the burden that consumers endure even if they are not energy-intensive, with that the burden to public funds dedicated to help the consumers, when trying to keep the economy stable. (UN Global Crisis Response Group (GCRG), 2022) Some countries are especially vulnerable to these circumstances, depending on their market composition (the lack of access to energy supply alternatives on infrastructural and market level), building ownership (affecting the possibility for interventions in the private-owned buildings) energy import dependences, macroeconomic indicators, and the capacities of the social protection systems.

Recognition of the target groups

Some consumer groups in those countries are in particular risk of changes in energy prices. These consumer groups were until now mostly viewed as households vulnerable to energy poverty, and particular measures have been targeted towards them. The new European Social Climate Fund (SFC) and the reference to it in the Commission Recommendation on energy poverty, for the first time, mention the vulnerability of the micro-enterprises in the same policy documents as energy poverty of households, putting small vulnerable consumers together, as specific target group of the policies. (European Commission, 2023:b), (European Commission, 2023) Article 2 of the SCF Regulation outlines possible definitions for energy poverty, transport poverty, micro-enterprises, vulnerable households, and vulnerable transport users, but the definition of vulnerable micro-enterprises is still not clear.

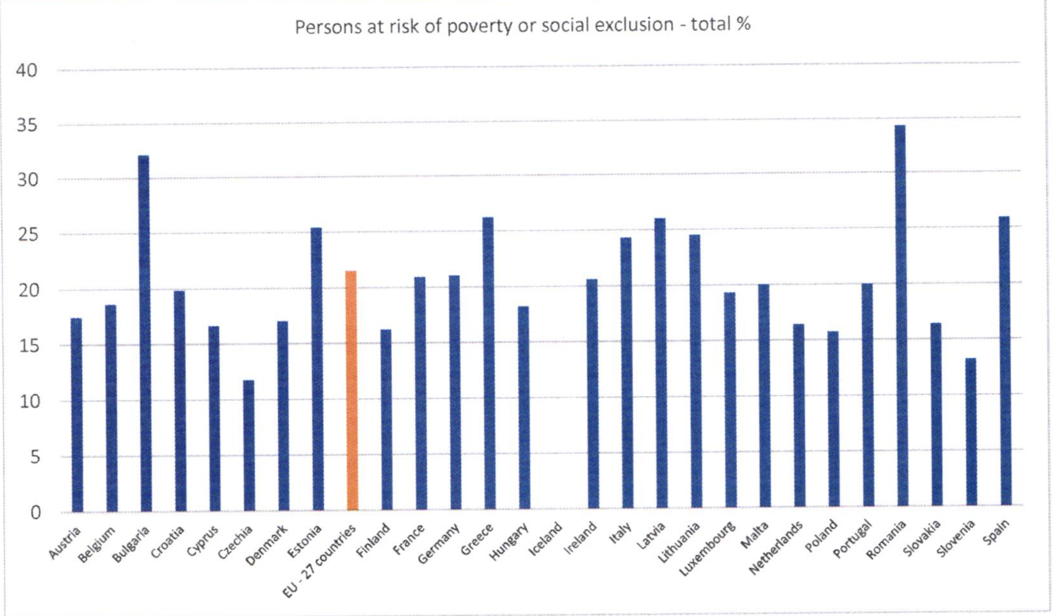
In 2022 households represented 27% of final energy consumption in the EU 27. (Eurostat, 2024) In addition to being a significant consumer of energy, they are also relevant macroeconomic aggregate in most EU countries. Diagnosing of vulnerable or energy poor groups involves measuring and monitoring their different characteristics and multiple impacts that affect them. As there is no uniform definition of vulnerable consumers, indicators are crucial, offering valuable insights into identifying and evaluating the vulnerability of those lacking access to adequate energy resources.

Table 1 Part of the recognised indicators of vulnerability to energy poverty

Indicator	Definition	Source
2M	Share of energy / transport in total expenditures / income is more than twice the national median	Household budget survey - statistics on consumption expenditure,/HBS, Eurostat
M/2	(Equivalised) expenditures on energy are less than half the national median	
LIHC	Household is at risk of poverty, i.e. expenditures are less than 60% of the national median AFTER paying for energy / transport AND share of energy / transport in total expenditures / income is larger than national median	
10%	Household spends more than 10% of income / total expenditure on heating, hot water and other activities in the building using heating oil, natural gas (e.g. cooking) or coal	
Keep home warm	Households answers "cannot keep home adequately warm"	EU statistics on income and living conditions /EU-SILC
Arrears	Household is "in arrears on paying utility bills "	
Efficiency of the building	Households living in buildings with low energy efficiency or worst-performing buildings (WPB).	National data
REPI	Rented Private Housing Energy Poverty Indicator - A composite energy poverty indicator (combining standard consensual measures of energy poverty, with a lower weighting for the share of people living in poor housing) and an indicator of the size of the PRS in a given area.	

Source: Author based on EPAH, HBS, projects author is working on.

According to Eurostat data, approximately 35 million EU citizens (approximately 8% of the EU population) were considered energy poor using the indicator of being unable to adequately heat their homes in 2020. (European Commission, 2022) This number has risen to 9.3% in 2022. There is even a more significant number of citizens in risk of poverty and exclusion, to as much as 35% in some of the European countries, while for first income quintile this number rises to 85% on the EU level.

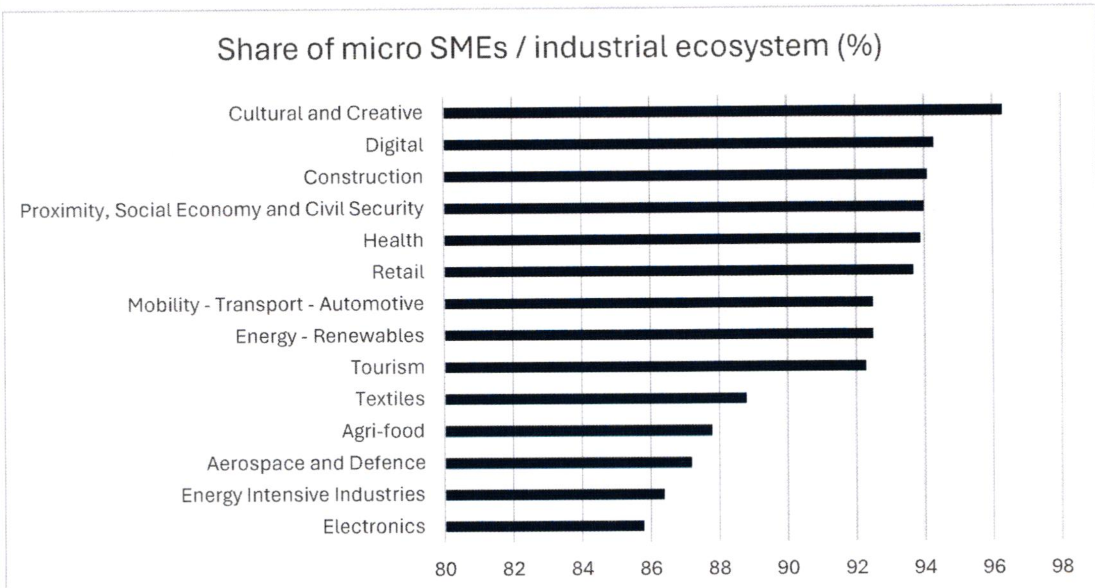


Graph 1 People at risk of poverty or social exclusion, Eurostat

Based on the later calculations in our case study using HBS data, low income and vulnerable households use 20-50% less energy, depending on the type of energy and Member State. However, to achieve adequate warmth of the household, one can argue that the poor household energy expenditure should be at least the same as average. (Champagne, et al., 2023) Otherwise, health and social consequences of inadequate living conditions contribute to the total costs to society. (Polimeni, et al., 2022) This means that we should evaluate energy expenditure of vulnerable and low-income households as a significant impact on the total household sector energy consumption. This has been recognised in specific policies targeting energy poor households, helping them get out of vulnerability. However, at the level of general energy transition policies, there has not been an adequate evaluation of effects on different socio-economic consumer groups, in particular vulnerable groups.

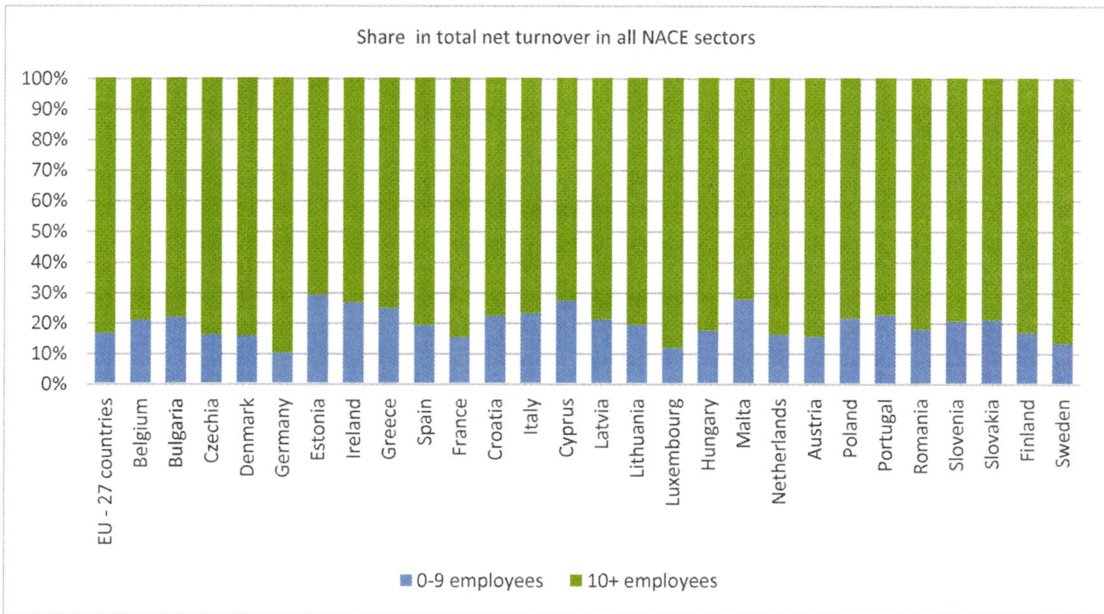
Looking into the business segment, the situation is even more complex for multiple reasons: current policies focus on larger consumers, barriers to implementing energy transition policies in all SMEs and even more micro-enterprises, and the novelty and lack of definition of vulnerability of micro-enterprises.

Micro-enterprise means an enterprise that employs fewer than 10 persons and whose annual turnover or annual balance sheet does not exceed EUR 2 million, calculated in accordance with Articles 3 to 6 of Annex I to Commission Regulation (EU) No 651/2014 (27)). The importance of micro - SMEs is shown on Graph 2, developed by JRC from the Eurostat data, where it can be seen that most European industries' ecosystems and value chains rely on the work and productivity of micro-enterprises. (Di Bella, et al., 2023)



Graph 2 Share of micro-enterprises in EU industries' ecosystems

According to the Eurostat Structural Business Statistic, share of total net turnover of micro-enterprises in Europe is also significant, almost 17% on the EU level. (Eurostat, 2024) From it, it is clear that there are significant reasons to keep micro-enterprises strong and stable.



Graph 3 Share of total net turnover of micro-enterprises in the EU countries, Eurostat SBS

As there is no specific research on barriers to energy transition and in particular energy efficiency measures in micro-enterprises, they are in this part of review viewed at as a subgroup of SMEs, facing same but even more emphasized difficulties. They are confronted with numerous competing business priorities, other investments, such as internationalization, digitalization, "just-in time" organization, etc. At the EU level, there is a lack of specific quantitative objectives and mandatory requirements for SMEs, leading to being limited to voluntary involvement. At the national level, it remains unclear how policies can be aligned, and the assistance provided is primarily informative, lacking sufficient financial support. The review of the existing barriers has already been done in the paper by (Agrawal, et al., 2023):

Table 2 Barriers to implementation of energy efficiency projects in SMEs

Detailed barriers	References
LOW CAPITAL AND DIFFICULTY TO ACCESS FINANCING	
Large capital investment requirement for energy efficiency upgrades and small funds available to SMEs for investments; longer payback period for some of the potential energy saving investment opportunity; difficulties for securing loans from banks.	Catarino et al. (2015); Thiede et al. (2013); Prasad Painuly (2009); Nigohosyan et al. (2021); Viesi et al. (2017); Lee (2015); Meath et al. (2016)
LACK OF HUMAN RESOURCES, KNOWLEDGE and AWARENESS	
The absence of internal knowledge to recognize and execute energy-saving measures, insufficient information regarding (a) energy expenses, (b) the significance and advantages of energy efficiency, and (c) outreach by technology providers to SMEs, presents a notable deficiency.	Fuchs et al. (2020); Rohdin et al. (2007); O'Keeffe et al. (2016); Kostka et al. (2013)
Small businesses do not have the resources to designate energy management responsibilities to any team member, let alone create a dedicated department or office for this purpose.	Eurochambres (2010); Sorrell et al. (2000); Henriques and Catarino (2016)

A lack of knowledge and awareness prevents SMEs from accessing any available financial schemes that support investments in energy efficiency.	Prashar (2017a); Hrovatin et al. (2021); Trianni et al. (2013); Fresner et al. (2017)
A shortage of time or an excess of other responsibilities among SME employees diminishes the priority placed on energy efficiency.	Paramonova and Thollander (2016); Henriques and Catarino (2016); Rohdin et al. (2007); Johansson (2015)

Source: (Agrawal, et al., 2023)

There was a long-term focus on decarbonisation and there are more policies focused on energy-intensive large industries in comparison to SMEs, particularly micro-enterprises. The number of SMEs (and especially micro-companies) is disproportionate to their energy consumption, which is one of the reasons why they have not yet been a priority for energy transition measures (Reuter, et al., 2021). Therefore, the EU Commission has established or supported multiple networks, projects and programmes assisting SMEs, like Covenant of Companies (including advisory services for companies and intermediaries in energy transition; expertise and support materials; visibility, recognition and incentive schemes; effective monitoring, reporting and verification systems to verify company commitments; analysis of potential synergies between businesses and local authorities) or Enterprise Europe Network (world's largest support network for SMEs). However, even the developed and EC led initiatives have unpredictable or low success, some of them already being abandoned due to the fact the effort introduced and resources involved did not result with expected outcome.

A significant existing discussion focuses on correlation between changes in energy expenses and company's profitability depending on its sector. Such changes can impact a company's expenditures due to the escalation of energy costs. Moreover, new expenses might constrain companies to maintain competitiveness, necessitating cost reductions, increased sales efforts, and/or price adjustments for their products. Holding all other factors constant, increased energy costs could lead to diminished profits for certain companies under specific conditions. If firms have not optimized the equilibrium between changes in revenue and production costs through price adjustments, they might need to explore alternative financing avenues to sustain their operations, such as seeking loans. Research shows that the size of the company affects these consequences, with smaller (and younger) companies being affected more significantly. (Herman, et al., 2023)

The major challenge in the assessment of influence of policies on vulnerable micro-enterprises is that their energy vulnerability is only recently been recognized and hence not properly addressed. Research on energy poverty and/or general vulnerability of the business sector to energy, as it is mentioned in the newest EU regulation, is practically non-existent in the literature. A review of the literature shows one very simplified working paper from Greece, aiming to evaluate the extent of energy poverty in SMEs according to research findings. (Vatikiotis, 2021) In this research, the author uses a past survey of small and very small businesses and interviews 19 energy experts in the business sector. The indicator used is the same as for the residential sector, "arrears on paying utility bills ", where around 15% of small companies have such issues. Energy data are collected and sorted in three different consumption groups, self-employed doing dispersed work (can be interpreted as mostly service crafts, for example plumbers), using commercial buildings, but having minor energy consumption (for example, hairdressers) and manufacturing. The analysis is not followed up by any scientific method but does open the question of the major diversity among target groups in sector, sizes and energy dependence. This also opens a research pre-condition, constituting the main research questions: *Which indicators should be employed to measure and analyse the energy vulnerability of micro-enterprises?*

3.4. Cilj i hipoteze istraživanja
(preporučeno 700 znakova s praznim mjestima)

Main research problem

Previous research shows that the socioeconomic status of the final consumer significantly affects the success of energy transition measures. It demonstrates that for example households in lower income brackets tend to evaluate discount rates subjectively, which significantly impacts measures due to the maturity of their repayment. For example, impoverished households use higher implicit discount rates compared to higher-income households, meaning they prefer investments with shorter repayment periods, estimating the subjective value of the implicit discount rate (IDR) for energy renovation at 45% compared to 26%, as estimated by individuals living in adequate energy conditions. This implies that low-income households might prefer (or are forced into) short-term solutions over investments, while deep insulation measures in residential sector or small companies' buildings require long-term measures. (Damigos, et al., 2021)

Additionally, the introduction of certain energy transition measures that have a positive impact on consumers with average socioeconomic status does not have a positive effect on those from other economic classes. Price elasticity of energy demand, which defines the change in the quantity demanded, in this case, energy, due to a percentage change in the price of the observed product, is extremely difficult to analyse and information is lacking.

(Labandeira, et al., 2017) provide data on average elasticities, but average elasticity does not necessarily indicate the success of implemented measures in the targeted group of households. (Charlier & Sondès, 2018) conducted research on citizens considered energy poor, and their results showed heterogeneity in households' response to changes in energy prices. They identified two groups of households that react differently and through group composition analysis demonstrated that some belong to the group of households with the highest price elasticity. These are households with high incomes, even though their share of energy costs is high. In the case of households with a high share of energy costs in their income but without high incomes, their price elasticity is low. They are unable to reduce energy consumption below a minimum comfort level, so some of the price-response policies are of unknown effect in vulnerable consumers.

If decarbonisation does not come from switching fuels (using on-site renewable energy) or enhancing energy efficiency, it must be a result from decreased energy usage. Given that the target demographic is vulnerable and low-income, while some energy savings may arise from behavioural efficiency measures, the majority would likely stem from simply using less energy, even at the expense of comfort, leading to economic and social strain. This could push more low-income households into vulnerability, affecting their ability to pay bills, reducing comfort levels (such as warmth), and ultimately impacting the health and social well-being of the household.

The primary obstacle to structural change (such as upgrading buildings or heating systems for energy efficiency) is the challenge low-income groups face in financing upfront costs without adequate compensation mechanisms in place.

As visible from the analysis, there is a need to research and evaluate the impacts of different energy decarbonization policies on the vulnerable consumers. Therefore, the hypotheses this research will be built upon is the following:

H: Failing to evaluate distributional policy effects on vulnerable consumers prior to implementing decarbonization policies, has impact on their vulnerability and substantial impact on the success of the policy.
The lack of evaluation of energy decarbonization measures has an undeniable impact on the economy, as evidenced by the need for additional funding to mitigate the adverse effects on vulnerable consumers. The ratio of vulnerable consumers and their energy consumption in the total energy consumption is significant enough to change total effects of policies if taken into consideration. The success of energy decarbonization measures is shaped by the socio-economic and demographic characteristics of the final consumers.

AH1 There is a significant difference in results of evaluation of impacts when non-energy effects on vulnerable groups (for example: costs of health, change in operational costs for maintenance) are taken into consideration in comparison to when they are not.
AH2 There is a statistically significant relation between determinants of micro-companies and their vulnerability to the effects of energy prices change.
Company's business ecosystem has significant effect on the vulnerability to changes in energy prices, The size and the ownership of the company are important determinants of energy vulnerability.

3.5.Materijal, metodologija i plan istraživanja (preporučeno 6500 znakova s praznim mjestima)

A research methodology has been developed, including all steps of the research development. Furthermore, these steps have been described with separate methodologies, developed models, analytical tools, case studies and introduction to existing and future results interpretation. This includes integrating the research into papers (to be) published.

Definition of the target group

The introduction has shown the general reasons why this research is important and how the relevant target groups have been chosen. The decarbonisation targets in Europe are high and vulnerable consumers represent a very relevant part of total energy consumption (for vulnerable households, we can easily evaluate this number, whereas for micro-enterprises we can assume it based on the size of the target group). Therefore, to achieve the decarbonisation targets, it is relevant that introduced policies: *I. Do not omit those groups, II. Do not introduce additional burdens towards the groups, III Do not introduce new burdens to the society.*

PAPER 1: IMPACTS OF DECARBONISATION POLICIES ON VULNERABLE HOUSEHOLDS

The objective of the first paper is to develop the mathematical model and use it to test the effects of decarbonization policies on vulnerable households.

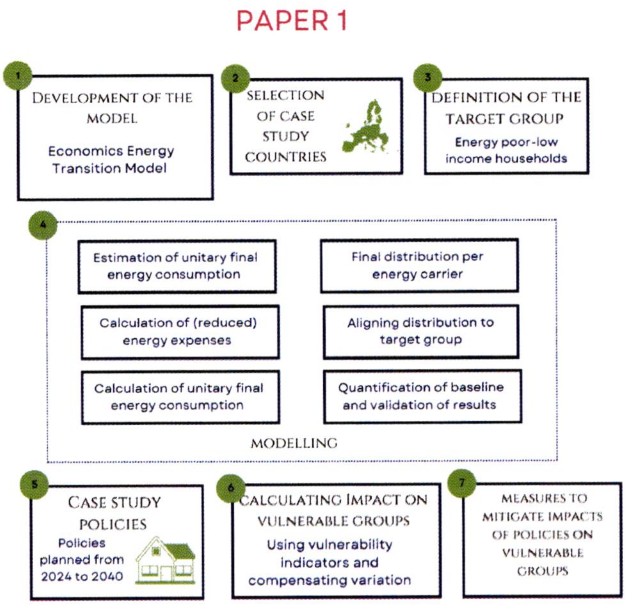


Figure 1 Structure of research for Paper 1

Methodologies development in Paper 1:

- Development of *Economics Energy Transition Model* to calculate macroeconomic effects of introduced policies.

Methodologies use in Paper 1:

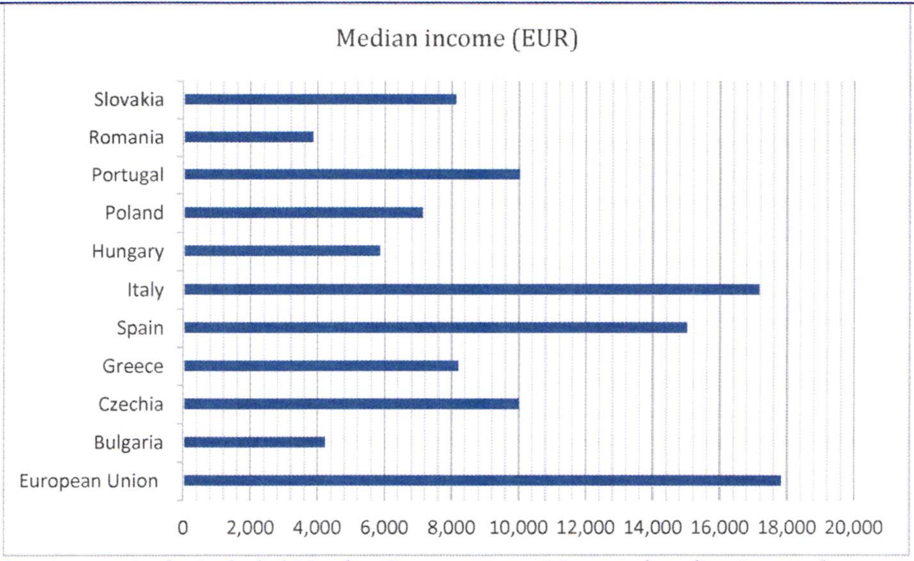
- Previous experiences and knowledge related to the defined research problem gathered and analyzed using classical scientific methods: inductive and deductive reasoning, analysis and synthesis of existing information, abstraction and concretization, generalization and specialization, proof and objection, descriptive and comparative analysis,
- Data collection (EUROSTAT, Household Budget Survey, OECD, national data sources),
- Interpretive policy analysis (on national and EU levels), structured and semi- structured interviews of experts,
- Mathematical methods like extrapolation and linear regression,
- Use of the *Compensating Variation as a Measure of Welfare Change* (Chipman, 1992),

1. Development of the model

We (PhD candidate with colleagues) develop an energy model to calculate macroeconomic effects of introduced policies. More sophisticated models can be found in the literature, with the most notorious one being PRIMES (e3M, 2024), used by the European Commission (Directorate-General for Energy) to delineate the EU Reference Scenario 2020. Nonetheless, such complexity in modelling would be overwrought for the issue at hand and most of the existing models are closed, so cannot be adjusted for the specific use. Eight desired characteristics of the economics energy transition models include reflections on complexity and uncertainty in economics; importance of time, path and lock-in; heterogeneity and behavioral elements; interdisciplinarity; role of institutions and social context; ethical and moral philosophical aspects; finance and multiple equilibria/disequilibrium. (Hafnera, Anger-Kraavib, Monasteroloc, & Jones, 2020). All these aspects have been taken into consideration in the development of the tool, to be further used for the research. Of course, inputs from PRIMES and other scenarios have been used for the specific developed methodology. Thus, our developed tool allows for modelling practices with Eurostat data in a manner which allows also for more direct communication of results. The model is further investigated for the purpose of integration of additional options and recursion loops.

2. Case study target countries selection & relevant part of target group

This case study depended on available funding but also on the fact these countries are more likely to have higher number of vulnerable households. Graph 4 illustrates the median disposable income per Member State (MS). A comparison of the median incomes of the included MS with the average income across the EU reveals that citizens of each MS typically have lower median incomes than the EU average. In translation, these countries' citizens are affected by energy prices and consumption much more than the EU MS average.



Graph 4 Median income in the included Member States, source: Mean and median income by age and sex - EU-SILC and ECHP surveys, EUROSTAT

Within the EU, not all nations present an official, legally recognised definition of vulnerable consumers. Nonetheless, it is agreed within the literature that this intricate phenomenon will always include both economic components, such as fuel prices, and energy components, such as the energy performance of the dwelling where one household lives, and all the socioeconomic interactions that can result, such as the inability to keep the home adequately warm or transport poverty. However, this phenomenon does not only have socioeconomic ramifications but, for example, also environmental ones. Indeed, households in a situation of energy poverty will utilise more outdated forms of technology for energy consumption, resulting in more environmental harm. The energy status of a household is closely related to its energy efficiency (Thomson, et al., 2017), with the latter being defined as the needed energy to power one household to generate a certain energy output.

Low-income groups are more probable to become energy poor (Deller & Price, 2018) to the extent that the gravity of one household's energy burden is often considered as a solid predictor of which groups will be affected by energy poverty (Bouzarovski, 2014). For this reason, this segment of society is the focus of evaluation. An extensive array of studies has been undertaken to thoroughly examine the multifaceted factors that contribute to the pervasive issue of energy poverty. These detailed investigations delve into crucial aspects such as financial market participation, energy efficiency, and the significance of human capital. By delving into these critical dimensions, these studies provide invaluable policy insights that not only shed light on the root causes of energy poverty but also offer practical recommendations to address and overcome this pressing challenge. Therefore, in this research, low-income groups were considered as all those households correspond to the first income decile.

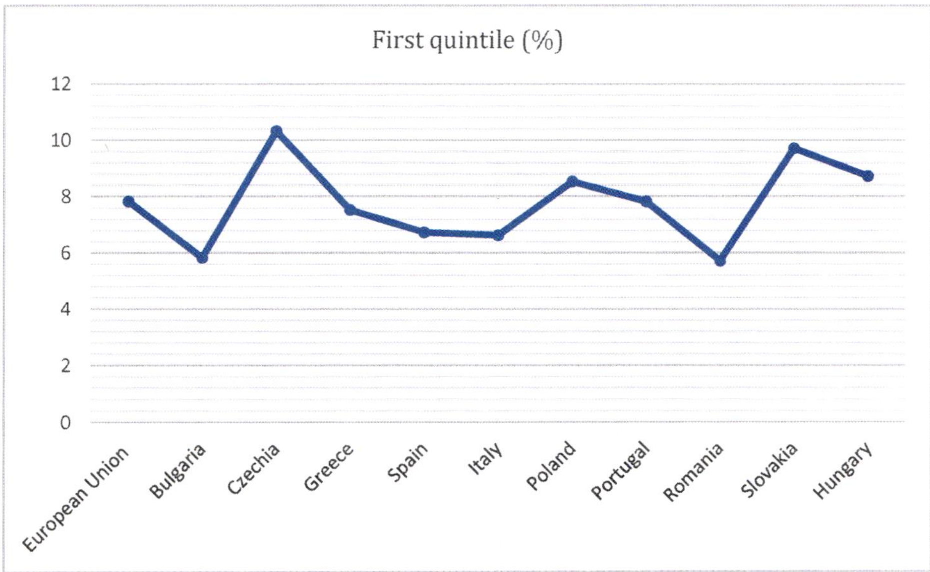


Figure 2 Percentage of the citizens in the first income quintile, source: Distribution of income by quantiles - EU-SILC and ECHP surveys, EUROSTAT

3. Energy transition economic modelling

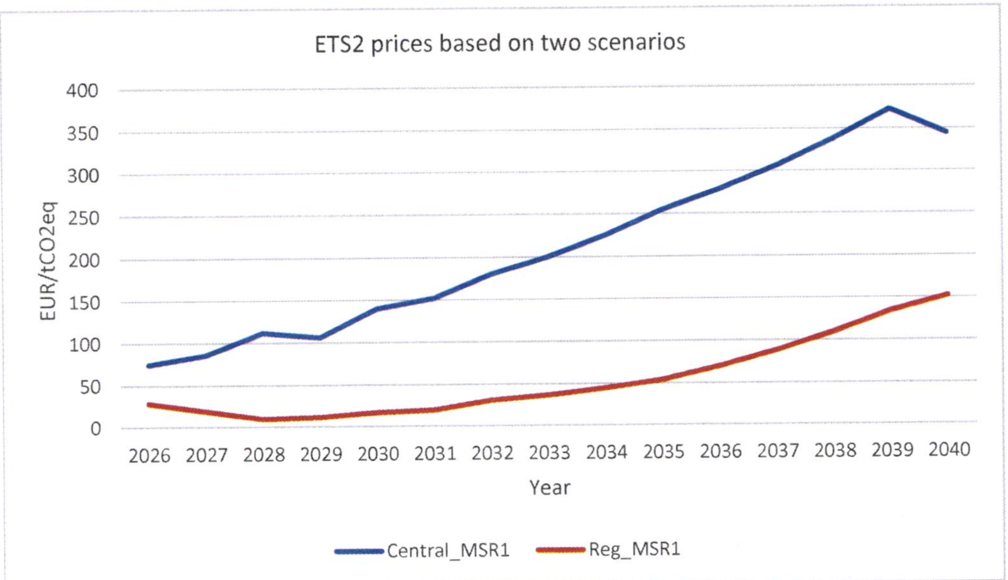
Assumptions include the energy prices from the first semester of 2022 for each fossil fuel type and electricity. Emission trading prices originate from the EU recommendations to member states (September 2022), results from PRIMES. Fossil fuel prices are from the EU Reference Scenario 2020 2019–2050 (heating oil, natural gas, coal, and LPG). Price elasticity of energy demand, due to the unavailability of data for price elasticities of low-income households' energy demand, an average elasticity is used. This approach has its negative sides but is a consequence of no research on distribution of elasticities. (Charlier & Kahoul, 2018) show that energy poor households for our target group do not have high elasticities of energy demand. Therefore, our assumption of average elasticities coming from ETS2 introduction, in the case of low-income households, would mean that the consumption decrease comes without private investments in energy efficiency and thus only from a reduction in thermal comfort.

Data collection and building of the Business-as-Usual scenario: Based on the Eurostat final energy data of the total disaggregated final energy consumption of households, unitary final energy consumption per household for different uses is estimated. This energy consumption per household per energy carrier is scaled to the consumption of poor households using HBS data on energy expenses per decile. If needed, and based on expert consultations used, utilised energy carriers are adjusted from average to low-income households in the country. After all these adjustments the energy consumption was quantified and validated.

4. Choice of decarbonisation policies to evaluate

In this case, testing of the methodology means introduction of three policies that are announced at the same time:

- Directive (EU) 2024/1275 (*in force from 24 April 2024*) on the energy performance of buildings, phasing out of fossil fuel boilers: a gradual phase-out of stand-alone boilers powered by fossil fuels, starting with the end of subsidies to such boilers from 1 January 2025
- Directive (EU) 2024/1275 (*in force from 24 April 2024*) on the energy performance of buildings, Minimum Energy Performance Standards (MEPS), assumed methodology of introduction is used based on announced in the directive proposal,
- EU Emissions Trading System extension (ETS2) As part of the 2023 revisions of the ETS Directive (*in force from 01 March 2024)*, a new emissions trading system named ETS2 was created, separate from the existing EU ETS. This new system will cover and address the CO2 emissions from fuel combustion in buildings, road transport and additional sectors. The carbon price set by the ETS2 will provide a market incentive for investments in building renovations and low-emissions mobility. The ETS2 will become fully operational in 2027. The estimated ETS2 prices are a result of a study conducted by Vivid Economics. (EEA, 2021) Two existing scenarios from Vivid Economics are evaluated for the purpose of modelling the electricity price evolution until 2040.



Graph 5 Scenario for the evolution of ETS2 price until 2040

Stemming from the proposed measures, six different scenarios were developed. A linear calculation logic is applied based on the estimation of the final energy consumption by end-use (e.g., space heating, space cooling, and domestic hot water) for six different time intervals separately up to 2050 (e.g., 2019–2025, 2026–2030, 2031–2035, 2036–2040, 2041–2045, and 2046–2050), taking into consideration: (1) The increase in energy prices, as resulted by their forecast increase until 2050 and the imposition of carbon price (ETS2) and the subsequent reduction in the final energy consumption in accordance with the price elasticity of the energy demand. (2) The implementation of energy efficiency interventions and the delivered energy savings due to the implementation of the examined policy measures (MEPS and phasing out of fossil fuel boilers).

5. Impact analysis of vulnerable groups + external benefits

After the implementation of the three proposed policies, the evaluation of changes in the status of low-income groups regarding energy poverty indicators relies on both quantitative and qualitative measures. To assess the impact of these changes comprehensively, the redundancy of indicators is initially examined. High redundancies between indicators suggest that changes have influenced household status based on both measures. (Sokołowski, et al., 2020) It is generally observed that the ability to adequately heat homes and other comfort-related indicators are closely associated with building quality and expenditure as a proportion of income. Utility bill arrears primarily result from pricing factors but are also influenced by income and building issues, leading to difficulties in maintaining household warmth. Therefore, distributional aspects of the evaluated policies on low-income households for every scenario are described using three factors (energy costs, income, and energy efficiency), where the quantified adverse effect of policies is based on the income dimensions. (Tundys, et al., 2021) Compensating variation is used as an index, which explains the amount by which the mean total expenditure of low-income households would have had to increase/decrease in the target year (for instance 2030, 2040, 2050) to have maintained the baseline year ratio of absolute expenditure in relation to the overall mean energy expenditure in the target year. However, since the introduction of some policies does not add to the total energy expenditure but rather introduces new costs of the investments to households, the amount of how much the income would have to increase for a specific household to keep the same welfare level is calculated. Regarding the specific income evolution, it was extrapolated from the existing historical data on income of the target vulnerable household group.

$$B = p_y y + p_x x + p\_i\, i = Y + p\_x\, x + p\_i\, i$$

$$x = energy, p\_x = price\ of\ energy \rightarrow p\_x\, x = energy\ expenditure$$
$$i = investment, p\_x = price\ of\ investment \rightarrow p\_i\, i = total\ cost\ of\ investment$$
$$y = other\ household\ needs, p\_y = price\ of\ other\ needs$$
$$= considered\ constant\ in\ our\ case$$
$$B = total\ budget\ of\ the\ household\ (we\ refer\ to\ it\ as\ household\ income)$$
$$Y = disposable\ income\ after\ energy\ \&\ investment\ expenditure$$

$$Y = B - p\_x X - p\_i\, i$$

$$Y\_B = disposable\ income\ after\ expenditure\ in\ baseline\ scenario$$
$$Y\_Sx = disposable\ income\ after\ expenditure\ in\ evaluated\ scenario$$

$$CV = Y\_B - Y\_Sx$$

Equation 1 Calculation of the compensating variation

Results have been published in a paper. (SCOPUS, SCIE Q1):
Rogulj, I.; Peretto, M.; Oikonomou, V.; Ebrahimigharehbaghi, S.; Tourkolias, C. Decarbonisation Policies in the Residential Sector and Energy Poverty: Mitigation Strategies and Impacts in Central and Southern Eastern Europe. Energies 2023, 16, 5443. https://doi.org/10.3390/en16145443

Paper 2: Correlation between determinants of micro-enterprises and their energy vulnerability

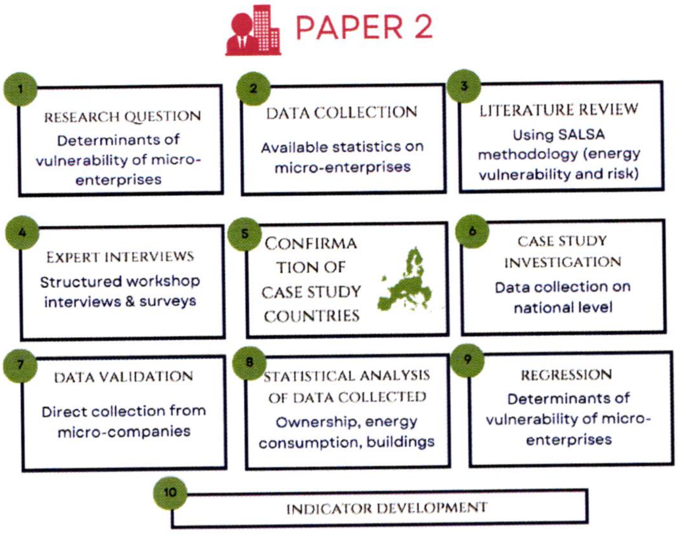


Figure 3 Structure of research for Paper 2

Methodologies to be used or developed in Paper 2:

- Previous experiences and knowledge related to the defined research problem gathered and analyzed using classical scientific methods: inductive and deductive reasoning, analysis and synthesis of existing information, abstraction and concretization, generalization and specialization, proof and objection, descriptive and comparative analysis,
- Literature review using SALSA methodology,
- Structured interviews, workshop with high-level experts in the field,
- Analysis of expert inputs using NVivo or other qualitative analysis software,
- Data collection (EUROSTAT, Structural business statistics, national data sources, surveys),
- Descriptive statistical analysis of data collected,
- Regression analysis with partial analysis of correlation, using R,

1. Research problem definition

To define energy vulnerable micro-enterprises, the sole definition of the energy vulnerability of businesses must first be investigated. A conceptual understanding of the definition of energy poverty in companies needs to be somehow operationalized using different metrics. For vulnerable households, it was much easier to define energy vulnerability as it is directly linked to economic vulnerability and poverty and there are many more disaggregated data already collected. In the research of energy poverty in households, indicators are expenditure (costs share etc.), consensual (survey on conditions) or outcome based. (Trinomics consortium, 2016) In the case of micro-enterprises, the complexity comes from the links between the micro-enterprise and quasi employed/ owner in energy poverty, where it is not easy to differentiate the household from the business consumer. Other challenges include a very sector – specific energy dependence and energy consumption, so the indicators of energy consumptions need to be disaggregated and distributed by sectors. (For example, it would be normal that car-washing service has 40% of their expenditure coming from energy, while it would be questionable for a plumbing craftsmanship.)

Table 3 Draft version of possible indicators of vulnerability of micro-enterprises, prior to detailed research

Indicator	Definition
Expenditure-based indicators (Structural business statistics (SBS) or/and national- level data)	
EX	The share of energy in total expenditures is more x% of the national median – this indicator will depend on the total number of targeted micro-companies it covers and is sector – adjusted.
Additional possible indicators that could be used depending on national data / additional EU-level datasets	
Company sector	Type of company defines dependence on energy for production and minimum expenditure for ongoing functioning of the company.
Arrears	Companies "in arrears on paying utility bills ", according to national data
Non-ability to react to high price shocks	Linked to the total earnings of the company
Stress on labour from high energy cost	Linked to the energy poverty indicators of households

Loss in competitiveness towards larger companies due to energy	Composition of the market

As these indicators have not been previously researched or applied in the European context, appropriate additional research will be conducted.

2. Data collection for determining baseline status:

There are many questions regarding the status of micro-enterprises in the EU and their energy consumption. First, for the definition of micro-enterprises, the statistical data collection is needed from the perspective of size, income, employment etc. Structural business statistics (SBS) of Eurostat will be used as the starting point, complemented with other available data. Second step is to determine their macroeconomic role in Europe and try to gather as much disaggregated data as possible. This would include sorting by NACE, type of employment and, what is most important, type of ownership. A descriptive statistic will be used to describe both what is available and what is the data status.

3. Systematic literature review and analysis (SALSA):

A systematic literature review will be used to search and analyse the concept of vulnerability to energy poverty of businesses, using SALSA research framework. The review will be supported by PRISMA checklist. The objectives of the review are:

- Concept of energy risk, vulnerability etc. in businesses – is it and how defined until now;
- Understanding the definition of energy poverty and business risk in the same context;
- Situations where the household and micro-enterprise overlap.

After the first "pre-search", the concepts and keywords will be developed to capture the essence of the needs for further research. The first summary of findings and results analysis will be further developed as input to expert validation.

4. Expert semi-structured interviews/ workshop and survey on the concept

A workshop and a survey will be prepared for experts to evaluate the proposed concept of micro-enterprises vulnerable to energy poverty. This will be done during the European Council for Energy Efficient Economy high – level yearly conference[1] , with a total of 400 participants, experts, and scholars in the field. It is expected that at least 50 representative survey responses (representative by type of background, affiliation, experience, and country), will be collected and that at least 10 to 15 participants will give feedback during structured interview-workshops. This will serve as input to final evaluation of important determinants of vulnerability and indicators' development.

5. Case study selection

Case study will be aligned with previous research *Bulgaria, Czechia, Greece, Spain, Italy, Poland, Portugal, Romania, Slovakia, Hungary*, or at least most of the included countries, based on the data availability and responsiveness of the experts included in case study investigations.

6. Case study investigations:

A combination of data collection via surveys and semi-structured interviews will be exploited in the case study countries. Several project cooperations will be used for such intervention (*DEESME, DEESME 2050, JUSTEM, ENSMOV+, RENOVERTY, Audit2Measure, etc.*). The targeted stakeholders are national energy agencies or authorities having the same role, national chambers of commerce and business associations, energy suppliers, national statistics' offices, national experts. This part of research serves to determine the logic of the determinants, as for the interventions to make sense, there has to be national data desegregation.
The research will include the questions on the:

- data availability regarding disaggregation of energy statistics per size of company,
- sectoral structures in micro – enterprises,
- ownership distribution and employment distribution (to detect quasi-employment as a double risk to energy poverty),
- differentiation of type of building (commercial, household);
- differentiation of utility bills for businesses that are located in the same house /building as household,
- who has asked for energy assistance during energy crises (type, NACE, size of companies),
- was anything done yet in terms of assistance towards vulnerable,
- other questions that come up during expert workshop and survey.

[1] eceee.org/summerstudy/about/

7. Data collected for validation via survey

Due to experience working with small companies, the candidate is aware of the low responsiveness of small enterprises on the open type surveys for data collection. Therefore, the survey will serve for separate statistics, but multiple sources of data collection will be used.

Data collected will include sector, energy consumption, ownership of company, building status (office, manufacture), ownership of building, link of business and household (is the business placed in the household), energy dependence and perceived risk.

The means of distribution will be LinkedIn and project-related channels. Steps included are using the LinkedIn (professional) tool, which is a subscription-based service offering a free trial period, search for companies who are part of the survey population. Next step is sending the first contact and the request to participate, and upon that the survey from a different platform. (Baltar & Brunet, 2012). Above used project-related experts will also be involved in the survey distribution.

8. Descriptive statistical analysis sector, size, ownership and vulnerability

Descriptive statistics will be used to describe the status of micro-enterprises from the perspective of above-mentioned determinants.

9. Regression analysis (Multiple Linear Regression and partially Hierarchical Linear Models) in R, including regression adjustment and control for confounding variables.

The expected sample size will be at least 200 representative micro-enterprises included (representativeness is considered based on previously described sampling). Based on the sample size and data characteristics regression analysis will be performed in order to single out the significant company determinants influencing the energy vulnerability.

10. Proposal of indicators:

Starting from possible indicators drafted with having energy poverty of households in mind, status of companies, data availability, national information and all other data collected will be taken into consideration for the re-evaluation and development of possible first version of indicators. They will be supported by detailed description of type, data needs, influences, and policy use.

<u>Plan is to publish the paper in the Energy Economics (Social Sciences Citation Index, IF 12.8), *Special Issue: Navigating Uncertainties towards Just Energy Transitions, deadline end 2024.*</u>

PAPER 3: ENERGY MODELLING AND MICRO-SIMULATION OF ENERGY POLICY IMPACTS ON VULNERABLE MICRO-ENTERPRISES AND RESULTING POLICY IMPLICATIONS

The development of this paper highly depends on the results of paper 2, so some parts like calculations, determination of impacts or policy implications can be different based on these results.

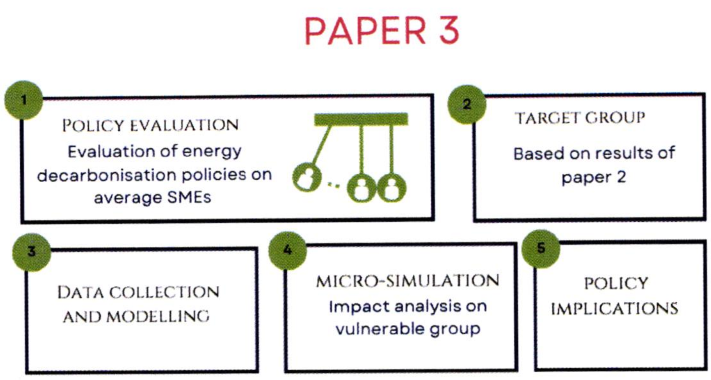


Figure 4 Structure of research for Paper 3

Methodologies to be used or developed in Paper 3:

- Use of MICATool – tool for quantification of macroeconomic impacts of decarbonisation policies (PhD candidate is co-author of the tool)

- Use of microeconomic and cost-benefit analysis with integration of companies benefits (in development, PhD candidate is co-author of the tool)
- Employing and adjusting previously developed *Economics Energy Transition Model,*
- Micro-simulation for determination of effects on vulnerable micro-enterprises (tool to be determined)

1. Evaluation of energy decarbonisation policies on average group of SMEs

Starting point for the research on relevant policies whose impact on vulnerable groups is to be evaluated, will be both the legislative train of the European Parliament (European Parilament , 2024) and the overview of the existing policies directed towards SMEs. (Herce, Martini, Toro, Biele, & Salvio, 2024). Policies that are planned, in implementation, in the legislative train planning, will first be evaluated on the whole SME group. This will be done through literature review that shows difference-in-difference of similar policy evaluation, evaluation of macroeconomic impacts of policies and microeconomic impacts on companies. Macroeconomic impacts include impact on GDP, employment, energy prices, public budget and others. To evaluate them, the MICATool[2] will be used. MICAT is the methodology developed by a project the author participated in with the aim to quantify and monetize non-energy effects of decarbonisation (specifically energy efficiency) effects, including macroeconomic effects.

Ongoing research by the PhD candidate and colleagues will be considered for microeconomic part. (Sangiorgio, et al., 2024) It shows there are undeniable impacts of energy transition measures (in this case energy efficiency) on the businesses (micro-companies included) beyond the scope of basic energy (money) savings, counting in as total impacts of energy efficiency policies on SMEs. Assuming these investments were put in place to increase energy efficiency of SMEs, an increase in income could also occur resulting from direct (increased workforce productivity) and indirect (positive perception of clients) effects of a series of multiple benefits integrated as part of the business model.

If they are generally considered efficient for small enterprises, they will be chosen to also evaluate distributional impacts for this specific group (energy vulnerable micro-enterprises). It is possible that the same policies will be used as for the assessment of impacts on vulnerable households (for example ETS2), depending on their efficiency in business sector.

2. The part of target group to be investigated

Will be decided upon finalisation of paper 2.

3. Data collection and modelling

A model for the calculation of baseline energy expenditures in targeted consumer groups and future evaluation of policy influence will be adjusted to the target group, only in the means of how data and policies are integrated. There will be probably a need for sectoral disaggregation of outputs, but it will be decided when developing indicators. This could be linked to size, net turnover, ownership, NACE code etc. Data collection will include Structural Business Statistics (EUROSTAT) and national datasets. Data collected in companies from the projects the candidate is working on will be used for validation of any needed assumptions.

For some assumptions, the same data will be used as for the implemented macro-modelling, but updated as opposed to 2022 numbers, or if the projections have been in any way changed based on newer existing data and estimates. The adjustment of the energy consumption and types of carriers that are specific for vulnerable micro-enterprises in comparison to average enterprises and the evaluation of possible major differences in elasticities or other police responses.

4. Impact analysis on vulnerable groups – micro-simulation

After the implementation of the proposed policies, the evaluation of changes in the status of the vulnerable micro-enterprises using vulnerability indicators will rely on micro-simulation. Scenarios will be developed, and calculation implemented. Depending on the final indicators, the appropriate calculation method will be used. The results will include policy implications.

Aim is to publish this paper in Energy Policy (Social Sciences Citation Index, IF 9) during 2025.

3.6. Očekivani znanstveni doprinos predloženog istraživanja
(preporučeno 500 znakova s praznim mjestima)

Implementation of the research results:

- The most important contribution of this research is that it is targeting real recognized policy problem, developing methods to reduce burden to the vulnerable groups, but also to the society and national economies long term.

Methodological contribution - Methodologies developed in this research:

[2] MICAT - Multiple Impacts Calculation Tool (micatool.eu)

- Development of *Economics Energy Transition Model* to calculate macroeconomic effects of introduced policies.

Experimental contribution - Scientific methods used in research implementation:

- Previous experiences and knowledge related to the defined research problem gathered and analyzed using classical scientific methods: inductive and deductive reasoning, analysis and synthesis of existing information, abstraction and concretization, generalization and specialization, proof and objection, descriptive and comparative analysis,
- Data collection (EUROSTAT, Household Budget Survey, OECD, Structural business statistics, national data sources, surveys),
- Interpretive policy analysis (on national and EU levels), structured and semi- structured interviews of experts, structured interviews, workshop with high-level experts in the field,
- Mathematical methods like extrapolation and linear regression,
- Use of the *Compensating Variation as a Measure of Welfare Change* (Chipman, 1992),
- Literature review using SALSA methodology,
- Analysis of expert inputs using NVivo or other qualitative analysis software,
- Descriptive statistical analysis of data collected,
- Regression analysis with partial analysis of correlation, using R,
- Use of MICATool – tool for quantification of macroeconomic impacts of decarbonisation policies (*PhD candidate is co-author of the tool*)
- Use of microeconomic and cost-benefit analysis with integration of companies benefits (*in development, PhD candidate is co-author of the tool*)
- Micro-simulation for determination of effects on vulnerable micro-enterprises (tool to be determined)

Inputs for future research:

- Recognition of the need for the evaluation of price elasticities among low-income groups: It is important to delve into the non-linear effects of policy scenarios. Factors such as wealth distribution and income disparity should be examined to attain accurate elasticities, as different countries exhibit distinct socioeconomic characteristics. Additionally, elasticities will be influenced by the fuel composition in final energy consumption.
- Determination of replacement rates for fossil fuel boilers across different income groups: Research has indicated lower rates of equipment replacement among low-income compared to other consumer groups. However, the response rates specifically for these groups are not available. In general, low-income households might exhibit slower responses to market ban measures due to their higher discount rates in comparison to the average household.

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3.8. *Procjena ukupnih troškova predloženog istraživanja (u eurima)*

50.000 EUR

3.9. *Predloženi izvori financiranja istraživanja*

Vrsta financiranja	*Naziv projekta*	*Voditelj projekta*	*Potpis*
Međunarodno financiranje	*Policies to decarbonise residential buildings, European Climate Foundation*	*Ivana Rogulj*	[signature]
	LIFE CET DEESME 2050	*Ivana Rogulj*	

3.10. *Sjednica Etičkog povjerenstva na kojoj je odobren prijedlog istraživanja (po potrebi)*

SUGLASNOST PREDLOŽENOG MENTORA I DOKTORANDA S PRIJAVOM TEME

Izjavljujem da sam suglasan s temom koja se prijavljuje.

Potpis [signature]

Prof.dr.sc. Saša Žiković

IZJAVA

Izjavljujem da nisam prijavila/o doktorski rad s istovjetnom temom ni na jednom drugom sveučilištu.

U Rijeci, . svibnja 2024. *Potpis :*

Ivana Rogulj

M.P.

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IMPACT FACTOR 3.2

CITESCORE 5.5

Article

Decarbonisation Policies in the Residential Sector and Energy Poverty: Mitigation Strategies and Impacts in Central and Southern Eastern Europe

Ivana Rogulj, Marco Peretto, Vlasios Oikonomou, Shima Ebrahimigharehbaghi and Christos Tourkolias

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Article

Decarbonisation Policies in the Residential Sector and Energy Poverty: Mitigation Strategies and Impacts in Central and Southern Eastern Europe

Ivana Rogulj [1,2,*], Marco Peretto [1], Vlasios Oikonomou [1], Shima Ebrahimigharehbaghi [1] and Christos Tourkolias [3]

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Abstract: The decarbonisation policies for the EU building stock can improve living conditions, including thermal comfort and lower energy bills. However, these measures may impose financial burdens on low-income households, reducing their disposable income and exacerbating their vulnerability. The current study investigates the impact of decarbonisation policies on the EU's building stock, with a specific focus on Minimum Energy Performance Standards (MEPS), the new Emissions Trading System (ETS2) for buildings, and the phase-out of fossil heating systems. By employing a linear, static latest version of Microsoft Excel (Microsoft 365)-based model and analyzing Eurostat data, this study quantifies the effects of these policies on energy consumption, costs, and necessary investments. Moreover, the study emphasizes their implications for low-income groups using vulnerability indicators. The findings demonstrate that a combination of MEPs, ETS2, and phasing out fossil heating systems effectively reduces energy consumption and costs across most countries. However, implementing ETS2 alone may lead to energy reduction and discomfort for low-income groups without addressing underlying demand-side issues. To address this, this study recommends the implementation of more ambitious MEPs or the provision of additional funding alongside ETS2. The phase-out of fossil fuel boilers emerges as the most cost-effective measure in the medium to long term. While MEPS and the phase-out of fossil fuel boilers improve living conditions, they also impose upfront cost burdens and reduce disposable income for low-income households. Therefore, high subsidy rates and supportive policies are necessary to ensure equitable access to investments. The main recommendations include (a) shifting financing to renewable heating systems for low-income households by 2025, addressing cost issues and policies favouring gas boilers; (b) implementing high-funding rate subsidies for energy efficiency in low-income households before 2025, with technical guidance; (c) prioritising the Energy Efficiency First principle in planning to avoid additional emissions or higher costs for low-income households; and (d) considering the energy behaviour of low-income groups in regulations, employing a combination of policies to achieve desired outcomes and ensure thermal comfort.

Keywords: energy policy; EU Emissions Trading System; fossil fuel boiler phase-out; minimum energy performance standards; energy poverty; residential sector; energy efficiency; decarbonisation policy; low-income households; Eastern Europe

check for updates

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1. Introduction

Europe's most important and threatening crisis is climate change affecting different sectors in different ways, posing uncertainties regarding the continent's future. The reduction in greenhouse gas (GHG) emissions simultaneously requires higher implementation of renewable energy sources (RES) and an improvement in energy efficiency. Buildings account for more than 40% of final energy consumption and at least 36% of energy-related GHG emissions [1]. Therefore, there is a need for renewable and less polluting energy systems for domestic and public buildings. This will result not only in the reduction in GHG emissions but also in the promotion of energy saving, tackling energy poverty, improving health and well-being, as well as creating new opportunities for growth and work. Most EU countries present low levels of energy efficiency in the residential sector due to the ageing of the buildings and the lack of renovation strategies in the last years. Hence, measures promoting the energy efficiency of dwellings in the residential sector must be advanced. This is also illustrated by the Energy Efficiency First (EE1st) principle, part of Article 3 of the new Energy Efficiency Directive (EED) recast proposal, and it "means taking utmost account of cost-efficient energy efficiency measures in shaping energy policy and making relevant investment decisions" [2]. In practice, the EE1st principle balances demand and supply options in order to prioritise the least expensive investments for the energy system from a societal perspective.

This paper aims to understand which policy measures proposed by the European Commission, aimed at decarbonising the residential sector, would have the greatest impact in reducing energy poverty among low-income households and contemporarily improving household energy efficiency in central and southern Eastern European countries.

The following paper will start with a literature review providing theoretical background on the concepts of household energy efficiency, energy poverty, and the relation of these with low-income groups; but also an explanation as to why a focus on central and southern Eastern Europe was chosen and the European energy policy framework (Section 2). This will be followed by a section illustrating the methodology chosen (Section 3), followed by an explanation of the general results obtained (Section 4). Thereafter, these will be discussed (Section 5), followed by an explanation of the entailed policy implications (Section 6), and the final general conclusions (Section 7).

2. Literature Review

2.1. Household Energy Efficiency, Energy Poverty and the Relation of These to Low-Income Groups

As recognised in the European Green Deal, 50 million citizens across the European Union (EU) do not have access to indoor thermal comfort [3]. Bouzarovski (2018) [4] (p. 1) defines energy poverty as a situation which "occurs when a household is unable to secure a level and quality of domestic energy services–space cooling and heating, cooking, appliances, information technology–sufficient for its social and material needs". Nonetheless, various definitions of energy poverty can be found throughout the literature. This can be traced back to its multifaceted nature, as energy poverty is a socioeconomic issue that presents many ramifications. For this reason, definitions vary also across countries, dictated by national socioeconomic conditions which play an important role in defining energy poverty. Within the EU, not all nations present an official, legally recognised definition. Additionally, energy poverty is unevenly distributed across Europe, with eastern and southern regions presenting higher prominence of the latter [5]. This is also due to the environmental and geographical factors of one location which will inevitably affect its vulnerability to energy poverty [4]. Nonetheless, it is agreed within the literature that this intricate phenomenon will always include both economic components, such as the fuel prices, and energy components, such as the energy performance of the dwelling where one household lives, and all the socioeconomic interactions that can result, such as the inability to keep the home adequately warm. The importance of energy performance is enhanced trough regulation and existing building codes [6]. However, this phenomenon does not have only socioeconomic ramifications but, for example, also environmental ones. Indeed, households in a situation of energy poverty will utilise more outdated forms of technology for energy consumption, resulting in more environmental harm.

Energy poverty is closely related to household energy efficiency [7], with the latter being defined as the needed energy to power one household to generate a certain energy output [8]. Improving energy efficiency in general is one of the main objectives of the European Green Deal, with a set target of achieving at least 36% in energy efficiency by 2030 [9]. Energy refurbishments of buildings could reduce energy poverty and concurrently increase household energy efficiency [10]. In fact, measures aimed at tackling energy poverty from the demand side have the potential to alleviate energy poverty while providing direct and tangible benefits to the residents [11]. In addition, greenhouse gas emissions, total energy consumption, and consequently energy expenditures could be lessened [10]. Nations that present a higher range of low-quality and energy-inefficient dwellings tend to present higher levels of energy poverty (and vice versa) [12]. In fact, higher expenditures will result from more inefficient buildings (e.g., low thermal insulation). Another correlation that is found is that residents living in energy inefficient households present below-average disposable incomes [12]. In a similar way, low-income groups are more probable to become energy poor [13] to the extent that the gravity of one household's energy burden is often considered as a solid predictor of which groups will be affected by energy poverty [11]. For this reason, this particular segment of society was the focus of the present study.

An extensive array of studies has been undertaken to thoroughly examine the multifaceted factors that contribute to the pervasive issue of energy poverty. These meticulous investigations delve into crucial aspects such as financial market participation, energy efficiency, and the significance of human capital. By delving into these critical dimensions, these studies provide invaluable policy insights that not only shed light on the root causes of energy poverty but also offer practical recommendations to address and overcome this pressing challenge.

Among these studies, Cheng et al. [14] conducted an insightful investigation on the impact of financial market participation on household energy poverty. Using data from the 2015 Chinese General Social Survey, their findings suggest that engaging in financial markets significantly reduces energy poverty, primarily through the mediation of future expectations. However, the study also reveals that higher financial risk weakens the effect of future expectations on energy poverty by destabilising household finances. Consequently, promoting financial market participation emerges as a potential avenue for alleviating household energy poverty.

Another noteworthy study by Moteng et al. [15] explores the mechanisms through which sanctions affect energy poverty, highlighting the significance of factors such as human capital, energy efficiency, income inequality, and economic growth. By identifying these interconnected mechanisms, the study offers valuable policy insights that can inform policymakers in designing effective strategies and interventions to tackle energy poverty.

Collectively, these studies contribute to a robust foundation of knowledge for policymakers, enabling them to devise and implement targeted strategies, programs, and interventions that can effectively alleviate energy poverty and improve the overall well-being of affected communities.

2.2. *Delineation, Explanation, and Selection of the Case Studies*

The present research analyses seven countries from central and southern Eastern Europe, as these two regions were found to be particularly characterised by energy poverty. Eastern European states are additionally affected by a late liberalisation of the energy market, a historically unstable energy supply mix, and inefficient thermal insulation of buildings [5]. The countries analysed include Bulgaria, Czechia, Greece, Hungary, Poland, Romania, and Slovakia. As most EU member states, they opted to alleviate the higher burden of energy costs with price regulations, energy bill assistance, as well as tax reductions on the energy bills. Nevertheless, these are not considered as structural measures for the low-income groups and thus should be combined with energy efficiency upgrades and measures for decarbonising the space heating facilities. Moreover, the higher upfront costs of energy efficiency investments combined with the well-known and documented structural barriers do not make energy efficiency a key priority of low- and middle-income groups, notwithstanding the shortened payback period of these investments due to the higher energy prices. The households' reduced disposable income (due to the higher energy prices) is hampering the possibility of investment in refurbishments and clean heating solutions, while the incumbent fossil fuel subsidies further delay such investments. Therefore, if the available funding, such as subsidies on energy efficiency and heat pumps, is not increased for the low-income households, the energy crisis and inflation may even delay energy efficiency investments to remove fossil-fuel-heating in such households. Hence, to counter such trend, a complementary package of supporting measures which includes financial, informational, and technical measures from the national and local authorities is needed to help accelerate energy efficiency investments and finally switch to clean and sustainable space heating.

An interesting aspect to consider is the country's dependence on imported gas and the share it has in its final energy consumption and other energy end-uses. The dependence on imported gas influences the energy price, and with it, the member states' new expenditures to cover the energy costs of households via bill aid. Various figures related to gas utilisation in the considered countries are presented in Table 1. In addition to the analysed countries, France and Germany, Europe's richest countries, are also presented in this table. This is done to see the extent to which economic and geographic indicators play a role. It can be seen how Romania presents the lowest dependency on Russian gas (even lower than France and Germany). Interestingly, Bulgaria is the only country presenting a lower gas share when considering only household energy consumption rather than the total final energy consumption. This table shows how every country's data in relation to natural gas is unique and how data cannot be easily generalised. With regards to electricity generation, Greece stands out with almost 40% of gas share in its electricity production. Stemming from this data, various scatterplots relating to general gas import dependency and the different gas shares per end-use were delineated for the analysed countries (Figure 1).

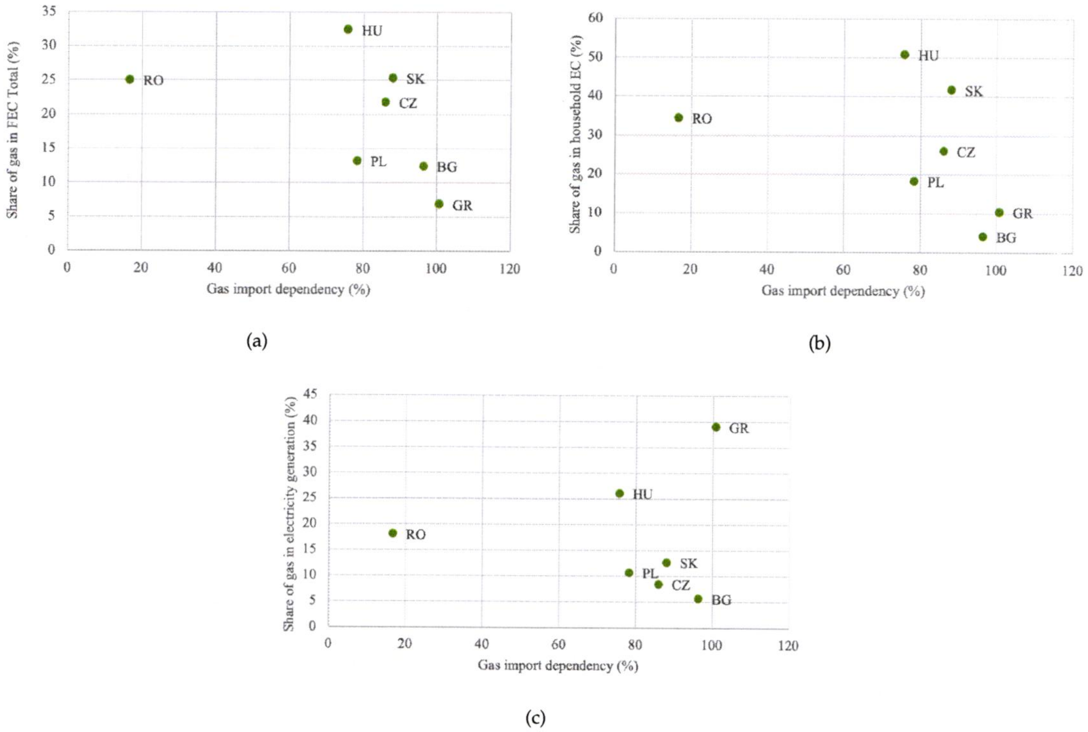


Figure 1. Comparing graphically the dependence on gas per energy end-use per country compared to its gas import dependency. (**a**) Share of gas in final energy consumption compared to gas import dependency. (**b**) Share of gas in household energy consumption compared to gas import dependency. (**c**) Share of gas in electricity generation compared to gas import dependency.

Table 1. Comparing graphically the dependence on gas per energy end-use per country compared to its gas import dependency.

Countries	Bulgaria	Czechia	Greece	Hungary	Poland	Romania	Slovakia	France	Germany
Dependency on Russian gas [16]	77%	92%	40%	64%	48%	22%	65%	24%	60%
General gas import dependency [17]	96%	86%	100%	76%	78%	17%	88%	95%	89%
Gas share in FEC [18]	12%	22%	7%	32%	13%	25%	25%	21%	27%
Gas share in household EC [19]	4%	26%	10%	51%	18%	34%	42%	28%	38%
Gas share in electricity generation [20]	6%	8%	39%	26%	11%	18%	13%	6%	16%

The scatterplots illustrate how big of a role gas plays in the energy consumption of the analysed countries and how dependent the latter are from gas-exporting partner countries. Firstly, it can be noticed how Romania can "afford" to have rather high gas consumption patterns as it imports a rather small percentage of its consumed gas. On the other hand, the country presenting the highest gas import dependency, Greece, is particularly reliant on partner countries as it produces a high proportion of its electricity from gas. Thus, even though Greece has rather low consumption patterns of gas, it is still the most gas-reliant of the analysed countries due to its high share of gas in electricity generation. Bulgaria also presents high gas import dependency; nonetheless, unlike Greece, it utilises a very small percentage of gas, and thus is not deemed as a very gas-reliant country. Poland is also another country not too reliant on gas, however on a minor scale. The other analysed countries, and in particular Hungary, can all be defined as gas-reliant.

On another note, Figure 2 shows the allocated funding (in billion EUR) in each country for tackling the energy crisis between September 2021 and October 2022. The burden on state budgets will strongly affect the possibility of member states implementing low-carbon policies. Therefore, strategic planning to develop complementary policies is of the highest relevance. Poland presents the highest budget, as expected from the largest of analysed countries both demographically and economically. Surprising is perhaps Greece, which presents the second highest budget even though having a lower economic force compared to other countries. The rest of the analysed countries seem to have an allocated budget that reflects their socioeconomic conditions.

The presented data aimed to reflect that each country presents unique gas-related characteristics with different allocated budgets. A generalisation of such starting characteristics for central and southern Eastern European nations is thus not possible. Hence, each country will be analysed on its own and only once national results are obtained will these be analysed together, considering the hereby described national characteristics.

2.3. *European Energy Policy Framework*

The EU aims to be the first continent with neutral carbon emissions by 2050 and has been at the forefront of the promotion and implementation of decarbonisation policy measures [9]. As part of this effort is the European Green Deal, which "aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use" [3] (p. 2). The proposed policy mix focuses on three key principles related to energy. Firstly, to ensure an affordable, clean, and secure EU energy supply. Secondly, to prioritise the renovation and improvement of buildings in a resource and energy-efficient way. Thirdly, to develop a fully digitalised, and interconnected EU energy market, promoting circular economy [3].

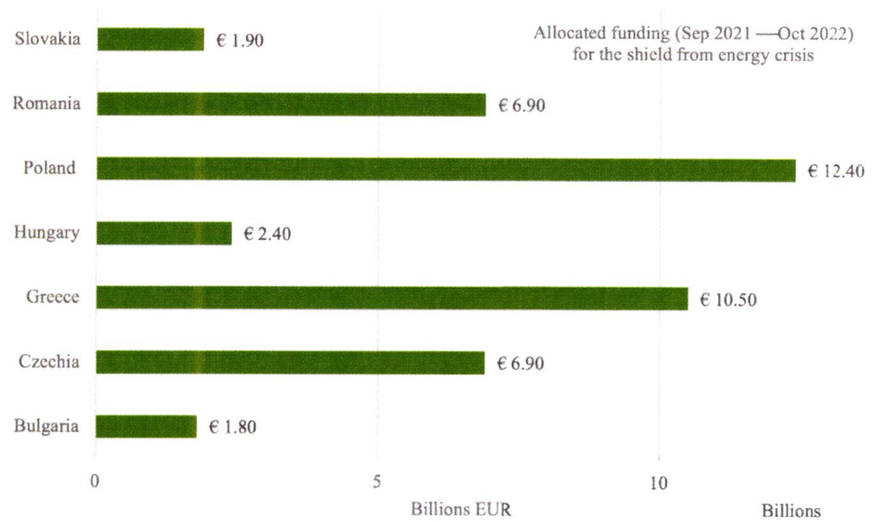


Figure 2. Governments earmarked and allocated funding (September 2021–October 2022) to shield households and businesses from the energy crisis [21].

Part of the European Green Deal is the "Fit for 55" package. This set of policy proposals also includes revisions of previous directives, such as the EED and Energy Performance of Buildings Directive (EPBD). The name of the package stems from the EU's objective of reducing by 55% its net greenhouse gas (GHG) emissions by the year 2030 compared to its 1990 levels. To ensure, a competitive and just energy transition by 2030, the package offers a careful combination of pricing, standards, support measures, and targets. Following the breakout of the war in Ukraine, the European Commission fastened its process of independence from Russian fossil fuels and thus, on 18 May 2022, presented the "REPower EU Plan" [22]. The latter foresees reducing dependence on Russian fossil fuel by further increasing some of the objectives set in the Fit for 55 package and fast-forwarding the sustainable transition. For example, the target for the renewable energy share in 2030 was increased from 40% to 45%, envisioning a doubled installation rate of heat pumps [22]. For the present research, three specific policy measures (present in the Fit for 55 package) were chosen to be analysed, simulated, and discussed. These will be further described in the following paragraphs.

2.3.1. Extension of the EU Emissions Trading System to the Residential Sector

The European Commission developed and put in force the new emission trading system (ETS2 here), which puts numbers on the fossil fuel emissions in buildings and transport sectors. It is a cap-and-trade kind of system like the ongoing ETS. It is regulated upstream, it does not directly involve buildings or vehicles but fuel suppliers, and will begin in 2026. These sectors will still be covered by the Effort Sharing Regulation, meaning member states' policies will continue to contribute to reducing emissions in the sectors. Carbon pricing is the measure that creates the market for new innovations, but the degree of this depends on (a) energy price elasticities and (b) cross-price elasticities. The impacts of the ETS price in these sectors could however generate higher costs to households, hence leading to higher energy poverty, in central and southern Eastern Europe.

2.3.2. Phasing Out of Fossil Fuel Boilers

To enable the decarbonisation of space heating and cooling in the households, the installation or sale of new fossil fuel boilers is to be phased out by 2030, plus the fossil fuel boiler lifetime. This might create a lock-in effect for households that are in the situation of energy poverty. They will use cheaper technologies due to the fact that more advanced technologies like heat pumps have higher upfront costs, despite their operational and ongoing costs being lower. To secure the avoiding of a lock-in is a policy framework that can give low-income households the possibility to switch to low-carbon heating systems. A revision of the Ecodesign and energy labelling regulation for heaters is going to lead to a downgrading of gas boilers to the low-energy (the two lowest) labels and more interest in the phase-out of the inefficient heating systems. A previous study from [23] announced that governments choose (a) natural gas for space heating, enlarging existing gas pipelines in the domestic sector, and (b) make use of subsidies for fossil fuel heating with the gas boilers, considering it an energy efficiency measure. The phasing out of fossil fuel boilers should indicate a clear timeline to avoid lock-ins and increase the costs of shifting to natural gas boilers.

2.3.3. Minimum Energy Performance Standards (MEPS)

Minimum Energy Performance Standards (MEPS) target buildings with renovations aimed at improving the energy efficiency in the residential sector reducing energy poverty, taking into account possible socio-economic differences. The EPBD recast [24] announced that the minimum energy performance standards shall at least ensure that all non-residential buildings are below (i) the 15% threshold as of 1 January 2030 and (ii) the 25% threshold as of 1 January 2034. The trajectory is expressed as a decrease in the average primary energy use in kWh/(m^2y) of the whole residential building stock over the period from 2025 to 2050. The average primary energy use in kWh/(m^2y) of the whole residential building stock needs to be at least equivalent to:

(a) The D energy performance class level by 2033;
(b) By 2040, a nationally determined value derived from a gradual decrease in the average primary energy use from 2033 to 2050 in line with the transformation of the residential building stock into a zero-emission building stock. Although evidence of the impacts of MEPS is not yet available, there was an impact assessment of the EPBD with the result that MEPS is a crucial instrument for the final energy savings and for the cost reduction, as well as for generating construction activity. The impact assessment did not isolate the impacts of MEPS on energy poverty nor did it address specificity regarding the central and southern Eastern European regions.

3. Methodology

In the following section, the methodology utilised to analyse, model, and simulate the three different considered policy measures will be explained. Firstly, it must be noted that a linear, static and Microsoft-Excel-based model was employed. In fact, the tool utilises simple predefined formulas, interconnecting various Excel sheets at the same time. More sophisticated models can be found in the literature, with the most notorious one being PRIMES, used by the European Commission and Directorate-General for Energy [25] to delineate the EU Reference Scenario 2020. The latter combines multiple objectives with different detailed constraints and, since 2016, was upgraded to include PRIMES-BuiMo (covering the residential sector), and PRIMES-Maritime (covering the maritime sector) [25]. Other models found include CAPRI, GAINS, GEM-E3, GLOBIOM, and POLES-JRC. Nonetheless, such complexity in modelling would be overwrought for the issue at hand. Thus, the simplified Microsoft Excel model was chosen, as it allows for modelling practices with Eurostat data in a simplified manner which allows also for more direct and simple communication of results. In fact, all the considered data were gathered from the Eurostat repository. The baseline year was chosen to be 2019, and a time horizon until 2050 was considered when performing simulations. Finally, as only linear and static data were examined, non-linear behaviours were not visible. Behaviours such as final energy consumption and energy price trends, which in real life are non-linear and affected by a multitude of factors, in this case will be represented linearly.

3.1. Assumptions

The Eurostat energy prices from the first semester of 2022 were considered for the separate national energy prices per fossil fuel type. Additionally, in this study, low-income groups were considered as all those households corresponding to the first income decile.

- ETS1: The estimated ETS1 prices originate from the EU recommendations to member states (September 2022) [26] as the analytical basis for updating the National Energy and Climate Plans (NECPs). The assumptions are based on the average price of EUR 80/tCO_2 eq that were reported since the beginning of 2022 and will be increasing following the expected trends as to achieve the 55% GHG reduction target and the expected energy price trends. The simulation with PRIMES is done in a way that the reductions come as response to prices and other policy drivers plus additional market considerations. Prices are then derived with iterations until achievement of the ETS cap (Figure 3).

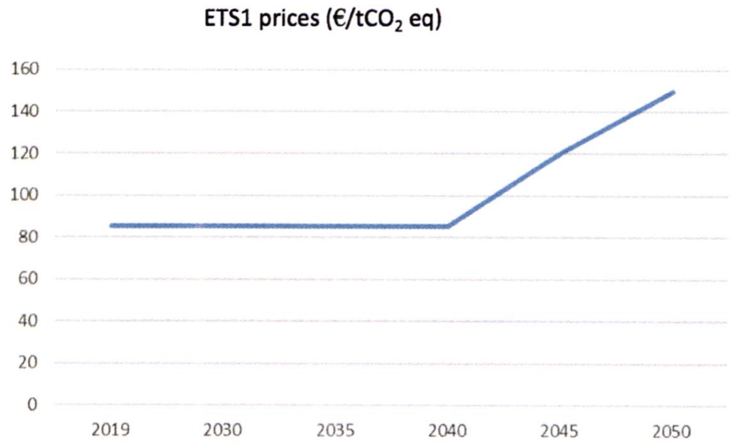


Figure 3. ETS1 price development.

- ETS2: The estimated ETS2 prices are a result of a study conducted by Vivid Economics [27] (as used in the previous study [23]). Two existing scenarios from Vivid Economics are evaluated for the purpose of modelling the electricity price evolution until 2040. Scenario 1 was used for carbon pricing policy (Central_MSR1), while the second one (Reg_MSR1) is used for their combination. The ETS2 price will remain constant after 2040 (Figure 4).

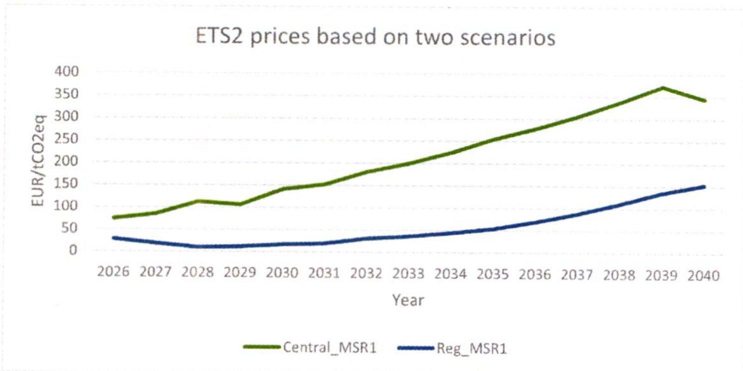


Figure 4. ETS2 prices until 2040.

- Fossil fuel prices: The EU Reference Scenario 2020 was used for the forecast of 2019–2050 fossil fuel prices (heating oil, natural gas, coal, and LPG). The estimations are derived from the EU recommendations to member states (September 2022) [26] as an analytical basis for updating the NECPs.
  Furthermore, the prices of the first quarter of 2022 (Eurostat) were used as a basis and upon that the price growths were derived (Figure 5).
- Price elasticity of energy demand: Due to the unavailability of data for price elasticities of low-income households' energy demand, an average elasticity is used. The IAEE resarch [28] shows that energy poor households for our target group do not have high elasticities of energy demand. Therefore, our assumption of average elasticities coming from ETS2 introduction, in the case of low-income households, would mean that the consumption decrease comes without private investments in energy efficiency and thus only from a reduction in thermal comfort.

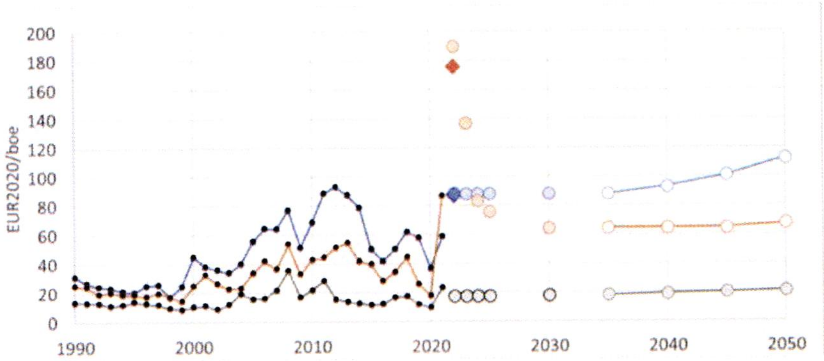


Figure 5. Envisioned fossil fuel price in the EU Reference Scenario 2020 (blue: oil, red: natural gas, grey: coal; BOE: Barrel of Oil Equivalent)

3.2. *Scenario Analysis*

Stemming from the proposed measures, six different scenarios were delineated. A linear calculation logic was applied based on the estimation of the final energy consumption by end-use (e.g., space heating, space cooling, and domestic hot water) for six different time intervals separately up to 2050 (e.g., 2019–2025, 2026–2030, 2031–2035, 2036–2040, 2041–2045, and 2046–2050), taking into consideration: (1) The increase in energy prices, as resulted by their forecast increase until 2050 and the imposition of carbon price (ETS2) and the subsequent reduction in the final energy consumption in accordance with the price elasticity of the energy demand. (2) The implementation of energy efficiency interventions and the delivered energy savings due to the implementation of the examined policy measures (MEPS and phasing out of fossil fuel boilers).

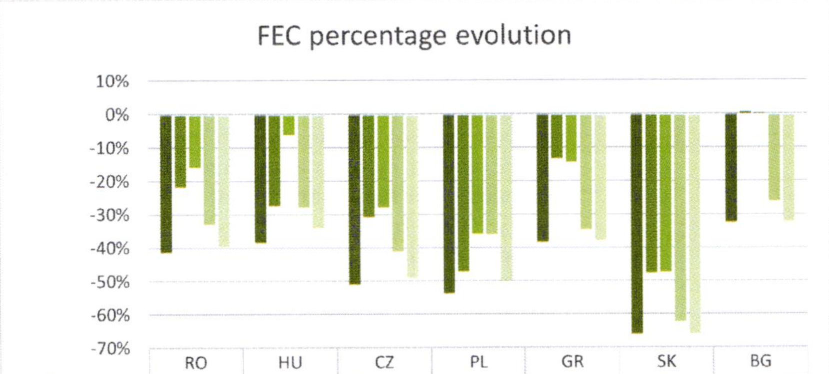
- Baseline Scenario assumes that no policy measures have been put in place (departing from the EU reference scenario) and it follows the European Commission's recommendations to member states (MSs) concerning their updating of the NECPs. This scenario is expected to present the highest energy consumption figures for all countries as no effort is made to reduce it in this scenario. On the other hand, the energy expenditure will depend on the energy mix of countries as countries presenting a higher share of fossil fuels will incur higher expenditures due to future energy price rises.
- Scenario 1 considers the implementation of the first proposed policy measure (ETS2) solely. Here, an additional increase in prices due to carbon pricing is considered. This is the same logic employed in the study [23]. An initial decrease in consumption is to be expected as the costs of fossil fuels will increase greatly. Nonetheless, this will not be a structured reform, but rather people will consume less for purely economic reasons, as they will not be able to afford energy services as before. This policy is

expected to provide undesirable results as it does not foresee a phase out of fossil fuels, but rather relies on the "market phase out" of fossil fuels for monetary reasons, a tactic which would greatly hamper low-income groups. Poland will be an exception due to its high reliance on coal and low prices of the latter, meaning that a switch to other forms of fuel could be more costly than sticking to coal. Additionally, due to its high reliance on coal, the expenditure under scenario 1 for Poland can be expected to reduce greater than in other countries.

- Scenario 2 takes into account the sole implementation of the second proposed policy measure, that being the phasing out of fossil fuel boilers. In this case, it is assumed that all fossil fuel boilers (using heating oil and solid fossil fuels but also natural gas) will be phased out in 2035. It is envisioned that the actual phase-out will take 5 years and thus be de facto phased out in 2040. The investment cost per heat pump is considered to be EUR 10,000 for all countries. The energy consumption is not expected to greatly reduce as this is rather a quick and short-team measure, as the residential efficiency cannot be expected to be reduced by only improving boilers. Similarly, expenditures are not expected to greatly reduce except in countries highly reliant on heating oil (e.g., Greece) as this fossil fuel is the most expensive one with the the highest envisioned price rise.
- Scenario 3 represents the application of the third proposed policy measure (MEPS) solely. N.B. In the present report, the term MEPS is generally used to indicate the refurbishment of buildings according to some proposed standards. However, these are not necessarily the minimum requirements set in the European directive. In fact, it is hereby further assumed that 75% of all buildings will be renovated to reach energy class D by 2030, resulting in 40% energy savings and EUR 15,000 renovation costs per building. Thereafter, these buildings will be renovated to reach energy class C in 2035, resulting in 10% additional energy savings and EUR 10,000 renovation costs per building. These assumptions differ from the previous study, where it was assumed that 50% of the affected households would reach energy class E in 2030, followed by the remaining half in 2035, resulting in 30% energy savings and EUR 10,000 renovation costs per building. Additionally, it was assumed that all households would reach energy class D in 2040, resulting in 10% additional energy savings and EUR 5000 renovation costs per building. Furthermore, in this study, the same renovation costs are assumed for all considered countries (whereas in the previous study, higher renovation costs were considered for Hungary). This is expected to be the best-performing stand-alone policy as it is a structured policy improving the general efficiency of the building.
- Scenario 4 considers the combination of both scenarios 2 and 3. This scenario is expected to provide better results compared to scenario 3 in general from an energy consumption perspective. Nonetheless, when considering also expenditures, countries that are highly reliant on fossil fuels (e.g., Poland and/or Hungary) might present higher expenditures compared to scenario 3 due to the presence of more fossil fuel boilers, which, considering also the low price of fossil fuels, might not give economically beneficial results in the short term.
- Scenario 5 considers the combination of all scenarios. The combination of all three policy measures is expected to provide the best results, as it tackles the energy efficiency issue globally and from all perspectives. It greatly combines policy measures more focused on short-term gains with other ones that consider long-term gains specifically.

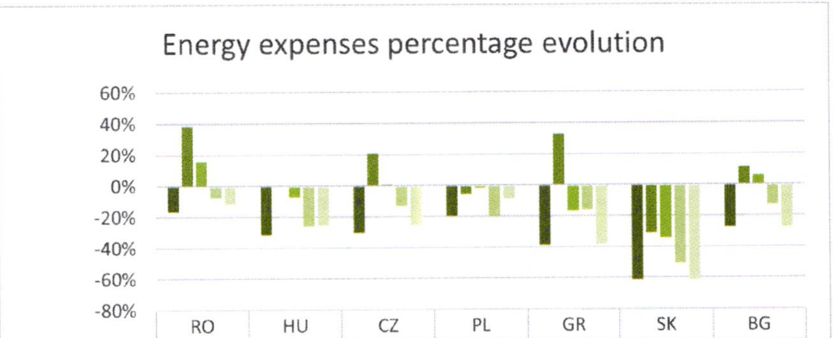
4. Results

In general, for all analysed countries, the combination of all scenarios, namely Scenario 5, provided the most desirable results in terms of final energy consumption reduction in the low-income households (without reducing thermal comfort) in 2050. Moreover, the combination of policies led to the highest reduction in energy expenses in 2050, excluding Poland, where the introduction of MEPS as a stand-alone policy resulted in the lowest energy expenses. Nonetheless, the difference in the final energy expense reduction in 2050 compared to 2019 levels for Poland between scenarios 3 and 5 was only 1%. However, this underlines Poland's great dependency on coal, as 34% of its energy consumed comes from coal (141 times higher when compared to the percentage of utilised coal in Greece). This will entail higher expenditure costs in scenario 5 due to the higher carbon costs related to the ETS2 pricing (unlike scenario 3 where the envisioned baseline fuel price increase is considered). The two graphs below (Figures 6 and 7) provide a percentage comparison of the envisioned savings in final energy consumption and in energy-related expenses from 2019 to 2050 for each country when implementing the policy measures assumed in each scenario. Essentially, the difference in values between 2050 and 2019 was expressed as a percentage, where scenario 5 provides the best results. In the rest of this section, a detailed deconstruction of the results per scenario per country can be found, differentiating between energy consumption and expenditure.



	RO	HU	CZ	PL	GR	SK	BG
Scenario 5	-41%	-38%	-51%	-53%	-38%	-66%	-32%
Scenario 1	-22%	-27%	-31%	-47%	-13%	-47%	1%
Scenario 2	-16%	-6%	-28%	-36%	-14%	-47%	1%
Scenario 3	-33%	-28%	-41%	-36%	-34%	-62%	-26%
Scenario 4	-39%	-34%	-49%	-50%	-38%	-66%	-32%

Figure 6. Resultingenergy consumption changes in 2050 compared to 2019 as a percentage per country.

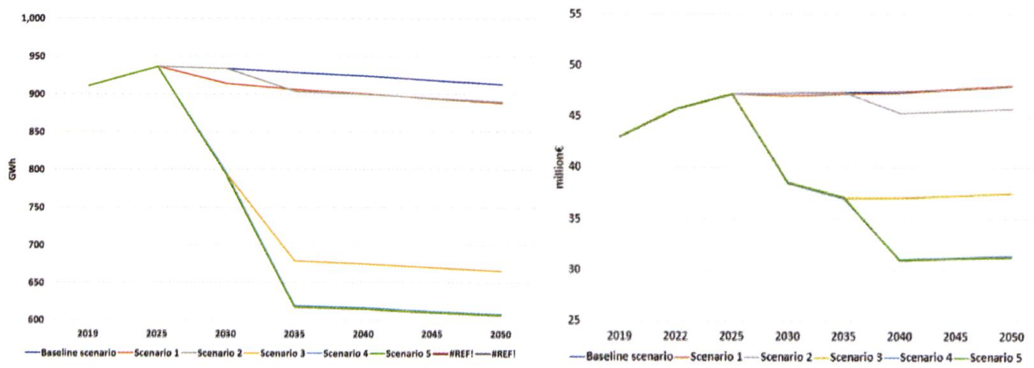


	RO	HU	CZ	PL	GR	SK	BG
Scenario 5	-16%	-31%	-30%	-19%	-38%	-61%	-27%
Scenario 1	39%	1%	21%	-5%	33%	-31%	12%
Scenario 2	16%	-7%	1%	-1%	-16%	-34%	6%
Scenario 3	-7%	-26%	-13%	-20%	-16%	-50%	-13%
Scenario 4	-11%	-25%	-25%	-8%	-38%	-61%	-27%

Figure 7. Resulting energy expenses changes in 2050 compared to 2019 as a percentage per country.

4.1. Bulgaria

Bulgaria clearly illustrates how policy measures not designed ad hoc for the country can present great counter effects. In fact, scenarios 1 and 2, together with the baseline scenario, present higher energy consumption and expenditures in 2050 compared to 2019. The case of Bulgaria clearly shows how short-term measures such as that in scenario 2 will provide only short-term gains (in this case resulting only from the initial implementation of the measure). Similarly, an unstructured measure such as that of scenario 1 will only damage low-income groups in the long run (Figure 8).

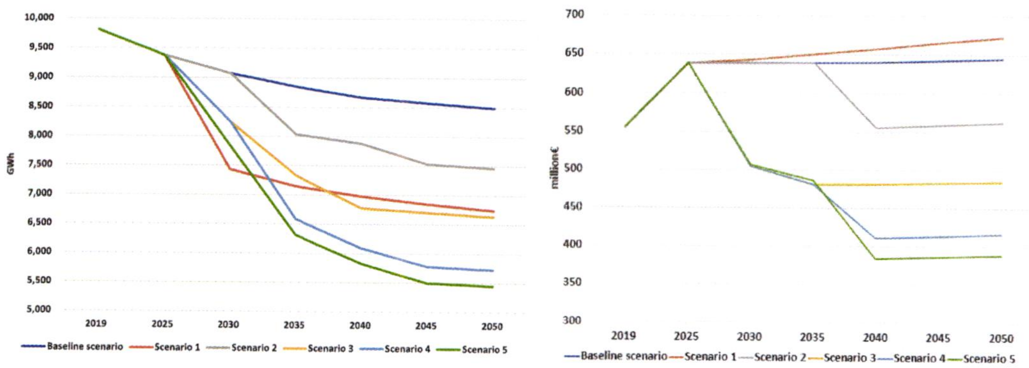


(a) (b)

Figure 8. Country analysis for Bulgaria. (**a**) Final energy consumption: comparison of different scenarios in Bulgaria. (**b**) Final energy costs: comparison between scenarios in Bulgaria.

4.2. Czechia

All proposed policies will present a reduced energy consumption in the long run in Czechia, although not a reduced expenditure. As for Bulgaria, scenarios 1 and 2 together with the baseline scenario would entail higher expenditures in 2050 compared to 2019. This is once again due to the unstructured nature of the measures. In the case of scenario 2 specifically, the gains of this measure only bring the expenditure levels in 2040 back to what they were in 2019. Nonetheless, due to rising energy prices, these will continue to rise in the period 2040–2050 (Figure 9)

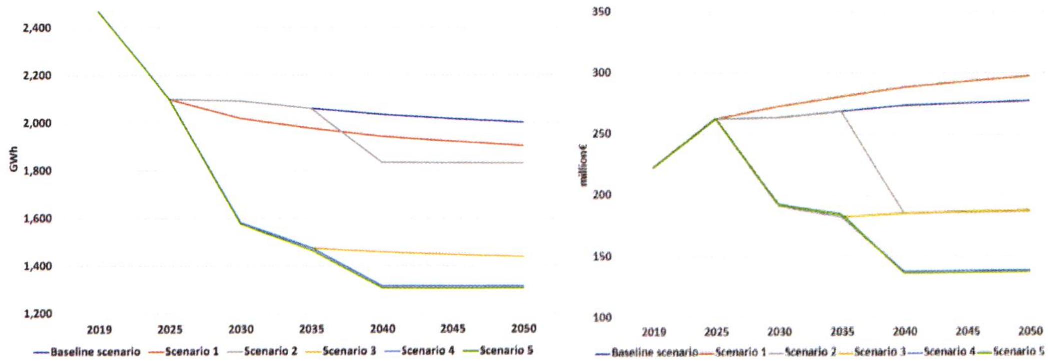


(a) (b)

Figure 9. Country analysis for Czechia. (**a**) Final energy consumption: comparison of different scenarios in Czechia. (**b**) Final energy costs: comparison between scenarios in Czechia.

4.3. Greece

All scenarios lead to lower energy consumption in Greece with only the baseline and scenario 1 leading to higher expenditures. In this case, scenario 2 leads to lower expenditures due to the high share of heating oil in Greece. In fact, this is the most expensive fossil fuel, and its phase out will thus lead to great price reductions. Specifically, in Greece scenarios 2 and 3 have the same expenditure decrease, although with the latter presenting a drastically higher reduction in energy consumption. This is preferable, as essentially in scenario 2 what is happening is a detachment from an expensive fossil fuel rather than an increase in energy efficiency (Figure 10).

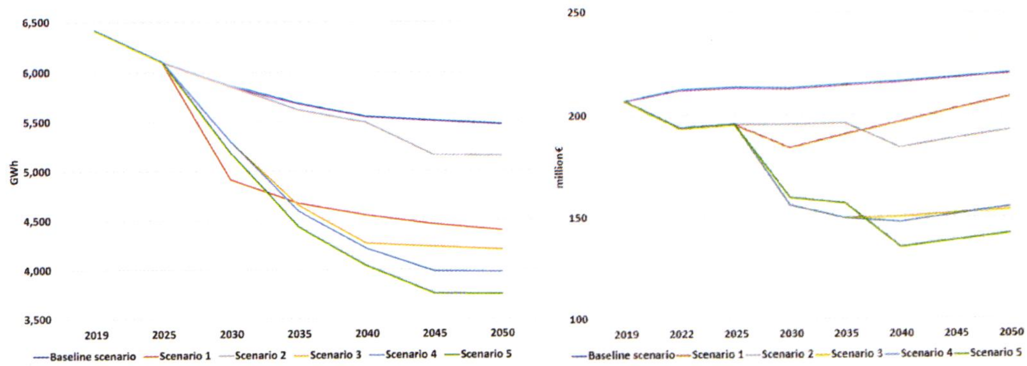


(a) (b)

Figure 10. Country analysis for Greece. (**a**) Final energy consumption: comparison of different scenarios in Greece. (**b**) Final energy costs: comparison between scenarios in Greece.

4.4. Hungary

In Hungary, the baseline scenario entails both a higher energy consumption and expenditure in 2050 compared to 2019. Interestingly, scenario 1 presents a substantial decrease in energy consumption however coupled with an increase in expenditures. This is due to a high share of gas in its final energy consumption. In fact, since it will not be possible to phase it out completely just by applying the ETS to the residential sector, low-income groups will try to reduce its consumption as much as possible although still incurring higher energy costs (Figure 11).

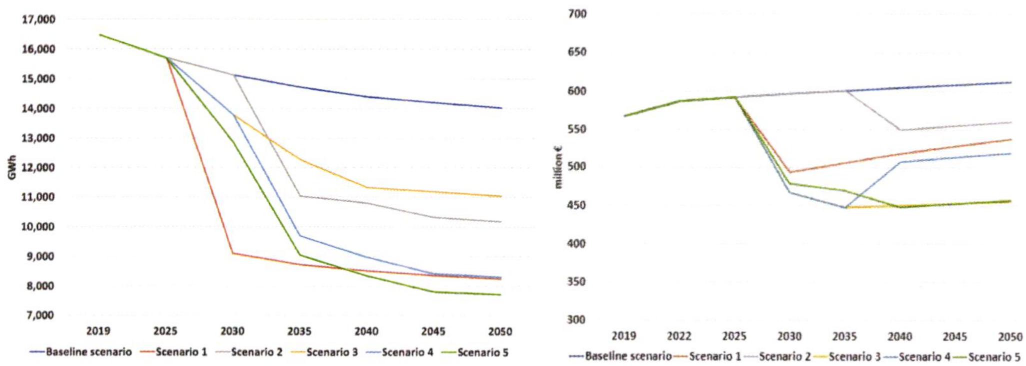


(a) (b)

Figure 11. Country analysis for Hungary. (**a**) Final energy consumption: comparison of different scenarios in Hungary. (**b**) Final energy costs: comparison between scenarios in Hungary.

4.5. Poland

All scenarios result in lower energy consumption in Poland whereas all scenarios except the baseline one result in lower expenditures. Due to Poland's high coal share in its energy mix, scenario 1 results in a greater reduction in energy consumption compared to scenarios 2 and 3. Additionally, scenario 1 presents also lower energy expenditures in 2050 compared to scenario 2. It can be thus argued that scenario 1 is effective in a greatly solid fossil-fuel-dependent country (Figure 12).

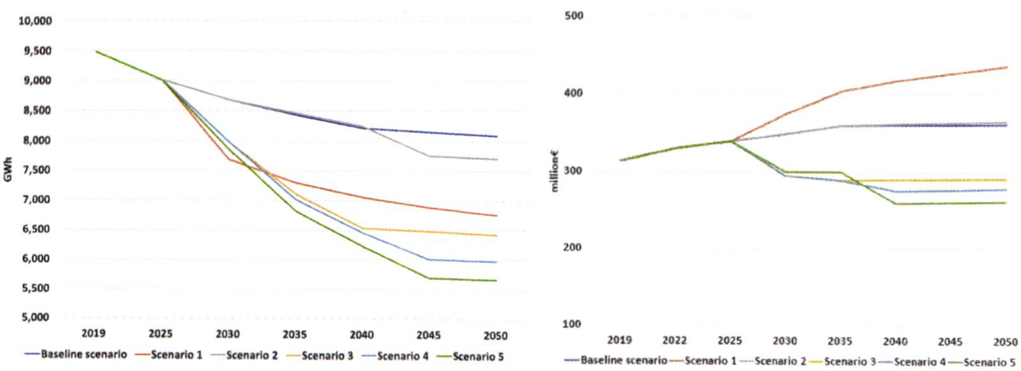


(a) (b)

Figure 12. Country analysis for Poland. (**a**) Final energy consumption: comparison of different scenarios in Poland. (**b**) Final energy costs: comparison between scenarios in Poland.

4.6. Romania

Romania presents lower energy consumption with all suggested scenarios. Interestingly, scenario 1 performs better than scenario 2 in terms of consumption. However, in terms of expenditure, scenario 1 presents higher values even when compared to the baseline scenario. Romania is highly dependent on biomass, which was assumed to remain constant in usage and price. Natural gas being the second most used fuel, its reduction will be minimal compared to the incurred costs in scenario 1 (Figure 13).



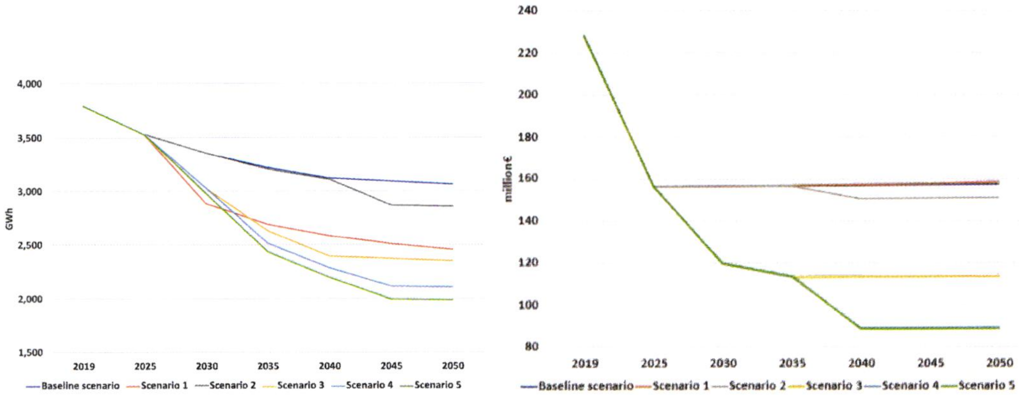
(a) (b)

Figure 13. Country analysis for Romania. (**a**) Final energy consumption: comparison of different scenarios in Romania. (**b**) Final energy costs: comparison between scenarios in Romania.

4.7. Slovakia

Slovakia presents lower energy consumption and expenditure in all scenarios. The scenarios yield similar results when comparing the energy consumption and expenditure.

Interestingly, scenarios 4 and 5 present practically the same results, highlighting how the ETS extension does not have a great influence and effect in Slovakia (Figure 14).



(a) (b)

Figure 14. Country analysis for Slovakia. (**a**) Final energy consumption: comparison of different scenarios in Slovakia. (**b**) Final energy costs: comparison between scenarios in Slovakia.

5. Discussion

5.1. Insights on the Low-Income Households Policy Specifics

How these results transfer to the specific household is evaluated using qualitative and quantitative indicators. Energy poverty indicators are well known and include five dimensions (low income compared to costs, high share of income spent on energy, inability to pay bills, housing faults, and the inability to keep warm). To avoid redundancies for precision [29], distributional aspects of the three policies on low-income households for every scenario are described using three factors (energy costs, income, and energy efficiency) [30], where the quantified adverse effect is based on the income dimensions. In addition to compensation variation showing that energy poor households without proper public funding end up with higher levels of income poverty, research [31] shows that energy poverty not only changes living conditions but also influences health, social activity and inclusion [32], local environment, education, and many other aspects of life. It is, therefore, important to also look closely at the non-energy impacts of the proposed policies that are to help with the adverse effects of transition to the low-income groups. In all the aspects of any of the policies targeting energy poverty alleviation (like evaluation or monitoring), all the indicators should be taken into consideration to avoid additional negative effects on the low-income households (Figure 15).

5.2. Insights on the Energy Retrofit and Investments

From the percentage change of the average income without financing, it becomes clear that, no matter the expenditure decreases in the medium run and the thermal comfort improves, the disposable income is too low and therefore blocks the investments, making it impossible for low-income households. Additionally, evidence [33] shows that vulnerable households use a higher discount rate compared with average, therefore choosing short-term solutions as opposed to long-term investments. Covering the upfront costs using the Social Climate Fund and additional funding directed to vulnerable groups would result in a positive change of the average income of the low-income groups and external positive effects (Figure 16).

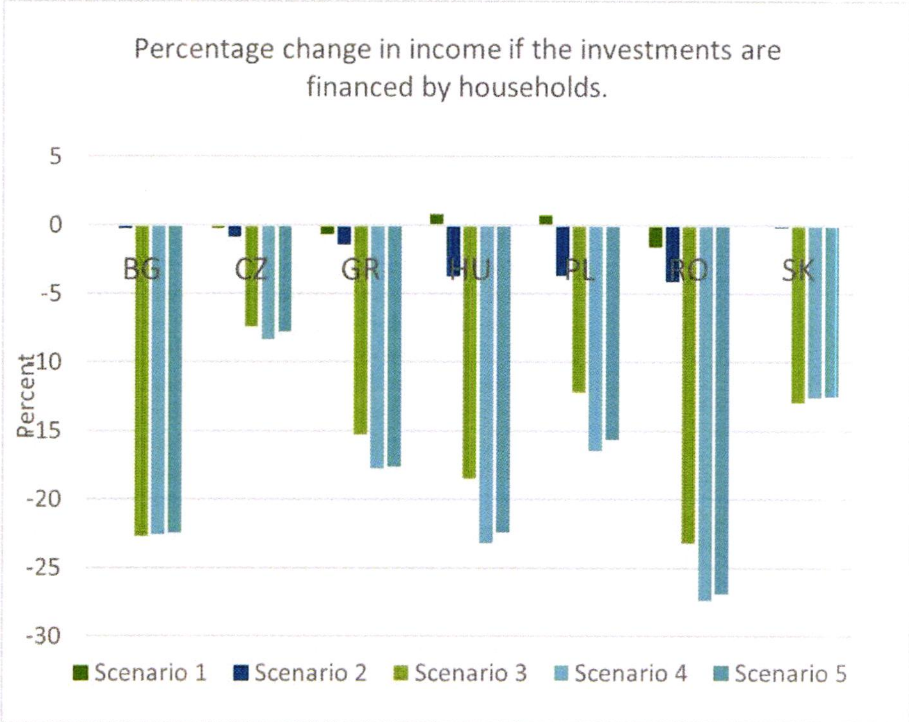


Figure 15. Percentage change in average income of the low-income group in 2050 compared to 2019 without investment financing.

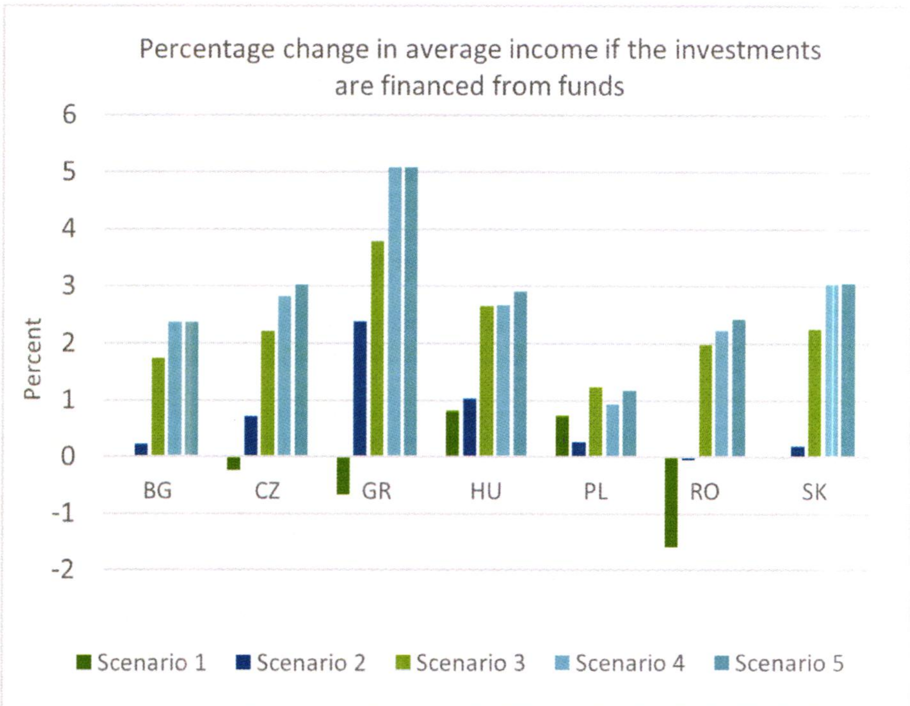


Figure 16. Percentage change in average income of the low-income group in 2050 compared to 2019 with investment financing.

6. Policy Implications

The study investigated the impacts of the recent energy policies on the low-income group of households. Based on the analyses, the following recommendations are suggested:

- The financing possibilities should be shifted from new and upgraded fossil fuel boilers to new and renewable heating systems before 2025. Phasing out of fossil fuel boilers from the market will not automatically lead to the replacement of existing fossil boilers, especially in the case of low-income households due to the existing high upfront costs as well as policies encouraging the installation of gas boilers. In the countries' short-term measures for the energy crisis (next to the income-support ones), there are still subsidies for fossil fuel use in heating as well as for installing fossil fuel heating systems, for example, in Bulgaria, Greece, Poland, and partly in Croatia. Therefore, it is important to phase out such subsidies even before 2025, as on average boilers have a lifetime of 20 years and it would require a minimum of 5 years to fully implement the phase-out (thus, to be carbon neutral by 2050, these changes would have to be made 25 years before). This process will speed up if funds are allocated for phasing out fossil fuel boilers and shifting to clean heating systems.
- Include subsidy schemes for the energy efficiency with as high as possible funding rates (total investment wherever possible) for low-income households. Measures should also include technical guidance and assistance. These subsidies should be starting before 2025, with information available for the low-income groups. It is also relevant to emphasise that the introduction of MEPS should accompany such phase-out as important in low-income households. For example, the Clean Air Program, 22.7 billion EUR, is planned to run until 2029 in Poland, providing 90% of investment costs for low-income groups of households to invest on efficient heat resources.
- Prioritise the Energy Efficiency First principle. In view of the updates of the NECPs and the new EED Article 3 (for the E1st principle), countries can benefit and start planning based on the energy efficiency requirements. Through MEPS, for instance, (when introduced with the phasing out of fossil fuel boilers) their implementation is not resulted in additional emissions, or higher costs for the low-income, despite the extra costs of the plan.
- Scenario 5 (all three measures included) provides a relevant signal and generates important effects on the consumption and energy expenditure of low-income groups. Even if we consider the phase-out as significant and cost-effective for using simplified repayment analysis, without MEPS there is no change in the quality of life and thermal comfort of the low-income households plus there is no lower energy demand and costs.
- The Social Climate Fund (for which it is obvious), the ETS2 auctioned revenues and the funding streams from Recovery and Resilience plan should include concrete energy efficiency actions for low-income citizens. In some countries, the Social Climate Fund and expected revenues from ETS2 allowances are enough for covering the cost of three measures (increased energy expenditure, investment costs for new heating and refurbishments), but only for low-income households. Part of the available funding allocated to the residential sector will focus on energy and transport poverty as a whole, thereby including a much larger number of households in each country than the specific target group of this study (the lowest income decile households). All of these programmes (even SCF in some way) include a budget for the bigger energy efficiency programs (with an average of 40–50% financing rate), with no specific support to low-income households. Those are to be financed with a higher percentage.
- Regulation is to include insight into the energy behaviour of low-income groups. There is a lack of data to determine the price elasticity and changes in energy consumption, all the behaviour changes. An incentive based on the price, ETS2, for example, results in lower thermal comfort deriving from lower energy consumption. This is why it is important to provide a good combination of policies and measures.

7. Summary and Conclusions

Despite the unavailability of data concerning energy poverty indicators from the months following the start of the Ukrainian war and price increases, a disruption of positive trends in energy poverty reduction can be observed beginning in 2021. These trends, in combination with price rises, expected inflation, risk of increased poverty, lower GDP, and weakened growth indicate the existing burden on countries to lower these adverse effects. Considering the inflation due to energy prices, energy poverty indicators will likely worsen in 2022 compared to 2021. EU member states have opted to alleviate the higher burden of energy costs with price regulations, energy bill assistance as well as tax reductions on energy bills. Nevertheless, these are not considered structural measures for the low-income groups and they should be combined with energy efficiency upgrades and heating decarbonisation. Moreover, the higher upfront costs of energy efficiency investments combined with the well-known and documented structural barriers do not make energy efficiency as a key priority of low- and middle-income groups, although the payback time of such investments is shortened due to the higher energy prices. Their reduced disposable income (due to the higher energy prices) is hampering the possibility to invest in renovations and clean heating solutions, while the incumbent fossil fuel subsidies further delay the investments in clean heating. Therefore, if the available funding, such as subsidies on energy efficiency and heat pumps are not increased for low-income households, the energy crisis and inflation may even delay energy efficiency investments to remove fossil fuels for heating in these households. To combat this, a complementary package of support with financial, technical, and information measures from the national and local authorities can help accelerate energy efficiency investments and a switch to clean heating. Additionally, the dependence on imported gas of the analysed countries varies widely. This needs to be considered when evaluating the ability of a country to react to the changes deriving from the implementation of three targeted Fit for 55 policies. The dependence on imported gas influences the energy price, and with it, member states' new expenditures to cover the energy costs of households via bill aid. However, the EU Emissions Trading System extension (ETS2) and phasing out of fossil fuel boilers will lead to the diversification of energy sources due to the requirement of cleaner sources or electrification in heating and price incentives (in the case of ETS2). A lower fossil fuel usage and therefore a lower gas import are expected due to these policies. The combination of the three policies can provide the best results both in terms of utilisation of energy and expense reduction for all countries (except Poland). When no additional policy measures were implemented, the highest envisioned energy consumption was incurred. With regards to energy expenditures, for half of the analysed countries, these would be higher when implementing the ETS2 prices than in the baseline scenario. This is due to the higher ETS2 energy prices and an inefficient phase-out of solid fossil fuels, as the latter would happen only due to higher fuel prices, without a coordinated phase-out policy measure. Moreover, new ETS2 as an alone policy measure can incur the highest energy reduction, which also results in thermal comfort loss for low-income groups, as no structural effects in the demand reduction take place. In addition, the implementation of measures aimed at improving energy efficiency in general, such as the introduction of MEPS, rather than targeting energy prices will provide more homogenous energy improvements throughout, resulting in homogenous price trends and more equally spread benefits to low-income households.

8. Recommendations for Future Research

The present study suggests several areas that could be explored in future research. These areas primarily stem from the lack of data on crucial parameters necessary for accurate calculations. The authors aim at gathering more detailed data in one EU member state (presumably Croatia) and test the developed methodology. The subsequent paragraphs delineate the key parameters that require further investigation and were not encompassed in the current research:

(a) Evaluation of price elasticities among low-income groups: Price elasticity plays a crucial role in evaluating the susceptibility of low-income households to price hikes stemming from the execution of ETS2 and other policy scenarios. It is important to delve into the non-linear effects of ETS2 and other policy scenarios, as indicated in a prior study. The response to heightened energy prices involves investing in energy efficiency measures and switching fuels or suppliers. However, low-income groups typically possess limited options, and their reduction in energy consumption primarily stems from decreased demand. Consequently, if the average elasticity is considered, any savings in energy expenditure that do not arise from fuel switches or energy efficiency measures will negatively impact the vulnerability of low-income groups. Factors such as wealth distribution and income disparity should be examined to attain accurate elasticities, as different countries exhibit distinct socioeconomic characteristics. Additionally, elasticities will be influenced by the fuel composition in final energy consumption.

(b) Determination of replacement rates for fossil fuel boilers across different income groups: Information regarding the rate of boiler replacement is necessary for calculating the overall costs of fossil fuel boilers as well as reductions in energy consumption and CO_2 emissions. Research has indicated lower rates of boiler replacement among low-income households compared to other groups. However, the response rates specifically for these groups are not available. In general, low-income households might exhibit slower responses to market ban measures due to their higher discount rates in comparison to the average household. This implies that low-income households may prefer short-term solutions or find themselves in situations where they have limited choices for long-term investments.

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