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Evaluating homeowners' retrofit choices – Croatian case study

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ABSTRACT

In this paper, a model of homeowners' energy efficiency retrofit choices is presented based on the database of a project implemented by the national energy efficiency retrofit scheme in Croatia during 2015 and 2016. The analysis was performed on the cleaned dataset of 4610 implemented projects in privately owned family houses.

We have analyzed available data to answer how much money consumers are willing to pay for energy refurbishment and how this corresponds to household characteristics. We have developed linear regression models for estimating costs and energy savings of different measures and have further applied multinomial and nested discrete choice models on investment choices made by homeowners. The resulting models provide estimations of willingness to pay for energy efficiency refurbishment in private family houses in relation to income class the owners belong to.

The results show that homeowners in all income classes have a similar level of willingness-to-pay for similar energy efficiency measures, with main differences being their capability to invest. With the current level of subsidies, only three of four observed measures show a significant level of free-riders. This suggests there could be a better allocation of public funds, where less money could be spent for subsidies to generate a similar amount of savings.

Furthermore, the proposed model replicates existing experience and provides insight into inconsistencies which appear when the effectiveness of implemented measures is analyzed.

1. Introduction

Energy consumption in EU residential sector, on average, accounted for 22% of the total final energy consumption in the last five years. Among the EU Member States, Croatia accounts for the highest share – 31%, and Luxembourg for the lowest – 10% [1]. That makes the residential sector an influential factor in designing energy policies, especially since the residential sector is in most cases not driven by clearly stated objectives or policy drivers. At the same time, description and modeling representation of the residential sector remains a challenge, due to the diversity of consumers and heterogeneity of their utility function.

In recent years, the importance of modeling individual consumer groups, depending on their socio-economic characteristics, has substantially increased and is the theme of growing number of studies [2–4]. The joint conclusion that arises from research is the need to respect the heterogeneity of individual consumer groups and their different preferences that need to be appropriately addressed [5,6]. One of the conclusions [6] proclaims the diversity of consumer characteristics as one of the main market barriers for implementation of energy efficiency measures.

Energy consumption modeling is implemented in line with the characteristics of households and housing units, considering the socio-economic characteristics such as income level, number of household members etc. One of the key factors in determining household consumption is the total household income, which has an immediate effect on the implementation level of energy efficiency measures. For example, when considering simulated and actual consumption in central heating, the difference between households with the highest income and those with the lowest income (both the highest and the lowest income households represent 10% of households each) is in some cases 200%. This means that the most affluent households spend three times more energy than the poorest households [7]. This difference in energy consumption is another indicator of the impact that income has on the ability and propensity of households to invest in energy-efficient appliances, heating technology change or building refurbishment.

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The heterogeneity of different end-users is evident in everyday behavior. This differing behavior influences energy consumption patterns and long-term decision-making to invest in modern technology and, in turn, requires different approaches in the appropriation of subsidies.

The aim of this paper is to show what the distribution of implemented energy efficiency measures among households would be like, depending on the level of subsidy and socio-economic parameters of households. These results can further help decision makers and energy policy implementers in deciding how to optimally allocate public funds either to achieve the greatest energy savings or to reach the established targets. With that in mind, we will also provide a guidance on the level of free-riders in case of current grant scheme and recommendations on how to alleviate them in the future. In the context of this paper free-riders are households that would implement energy efficiency measures even in the absence of the subsidy.

2. Literature review

Extensive elaboration of behavioral aspects of the transition to future energy systems was explored in [8–11] by examining energy use, context, attitudes, beliefs, values, norms, or by investigating investment decisions and household income affects [7, 12]. A large body of research also exists which evaluates incentives for energy upgrades and investments, such as socio-economic factors, dwelling, or appliance factors; some papers focus only on a specific fuel, while others take into account all energy carriers [13–18].

With either a national or local authority or any other planning entity having an energy efficiency goal set, i.e. an energy savings target such as 20% energy consumption reduction by 2020 or 27% by 2030, it is important to account for consumer behavior. Consumer behavior can be regarded as (1) everyday decisions on how to use a specific appliance or technology and (2) investment decisions when purchasing an appliance, heating technology, etc. or decisions on undertaking thermal insulation refurbishments.

Analysis of Croatian households' views on energy efficiency and barriers household owners are experiencing is provided in [19] based on the data from [20] with the conclusion that, in order for households to invest into energy efficiency measures, there needs to be some type of financial support mechanism. Authors in [21] established that strong political commitment is crucial for faster uptake of energy efficiency market, based on a survey among major stakeholders in Croatia. That conclusion is in line with results from [20] which state that over 40% of residential survey participants view subsidies for equipment or works as a desirable form of financial support measure.

The decision and choice models, that would provide information on how consumers choose products they buy [22], or which travel route they will most likely use [23, 24] are common in marketing and transport studies and have experienced a variety of modifications. A discrete choice model is also becoming an established approach to modeling user choices in energy demand modeling.

Sagebiel [25] compares two discrete choice models; random parameters logit model (RPL) and the latent class logit model (LCL), using the data from a survey on electricity supply preferences in private households. The paper aims to provide a hands-on guide to methods for selecting the appropriate discrete choice model in research when accounting for unobserved preference heterogeneity.

The paper concludes that with similar performances between RPL and LCL models, the ease of interpretation of LCL model gives it an advantage when using for informing and advising policymakers. Extensibility and possibilities for exploring methodological issues are, on the other hand, the advantages of RPL.

Jridi et al. [26] analyzed decisions to implement three energy saving measures - solar water heaters, low-energy bulbs, and energy efficient refrigerators in Tunisia. Authors employ ordered logit and multinomial logit models. Binary logit and binary probit models were used to determine the adoption of solar water heaters; ordered logit and multinomial logit models for determination of the adoption of efficient refrigerators, and the nested model to determine adoption of energy-saving lamps.

Derakhshan et al. [27] provide a summary of advances in discrete-continuous choice modeling in transport and energy. The discrete-continuous models are an extension of the discrete choice model by accounting for effects of technology use after its acquirement. For example, in transport, a consumer decides on the type of car (discrete choice) and then how long to drive it (continuous choice).

Described models are based on indirect utility function approach and Gorman polar functional form of utility structures.

Braun applied [28] multinomial logit model to explore socio-economic parameters that influence the choice of heating type in Germany. In the paper, both house owners and renters are analyzed and compared. Construction period, as a parameter revealing some physical characteristics of the building, found to be a strong determinant of the heating type. Surprisingly, it was found that differences between income groups do not provide a strong impact on the type of heating technology installed. Due to data availability, the study could not account for the influence of capital costs nor consider renewable technologies.

Banfi et al. [29] applied binomial logit model on Swiss residential sector to estimate willingness to pay (WTP) for high energy performing single-family houses and in renting apartments. By studying stated choice experiment authors show that customers have a high preference for energy saving measures, with higher tendency to invest in ventilation system rather than investing in further façade insulation.

Similarly, Grösche and Vance [30] estimate willingness-to-pay for energy conservation among German house owners using revealed choice data from a survey. The methodological approach relies on a comparison between conditional logit, random parameters logit, and error components logit models. The results imply that, excluding hidden costs of renovation, the share of free-riders in Western Germany is roughly 50% of all households, which is similar to results by Banfi et al. [29].

Building on the above described discrete choice approach, we will evaluate consumer choices of energy efficiency measures that were implemented within the national level subsidy-providing programme. The aim of the study is to provide a framework to assess hidden costs and benefits in energy efficiency subsidy programme and to test the applicability of the method on the national subsidy providing scheme. The choice of multinomial logit and nested logit models were driven by the clarity and applicability of the selected models, ease of interpretation of resulting coefficients and applicability for calculation of willingness-to-pay. However, in the proposed approach, an extension to willingness-to-pay estimation will be provided to incorporate hidden costs and benefits.

3. Methodology

In this paper, the discrete choice model was used to evaluate decision framework employed by family house owners. The requirement for comparing different alternatives is to have all data for all alternatives and since only implemented projects were recorded in the database used, data imputation and modeling was employed based on the available data. Data imputation was needed for missing data on current thermal performance and floor area.

3.1. Data imputation and regression modeling

Costs of each alternative j, for the household i (C_{ij}) can be estimated by:

$$C_{ij} = \alpha_0 + \alpha_1 A_i + \alpha_2 EPex_{ij} \quad (1)$$

where A_i is total floor area of household i and $EPex_{ij}$ is existing energy performance level in household i for activity j, i.e. before the renovation is performed.

Specific energy savings per dwelling surface (es_{ij}) resulting from implementation of each alternative can be estimated by:

$$\log(es_{ij}) = \beta_0 + \beta_1 EPex_{ij} + \beta_2 HDD_i \quad (2)$$

where HDD_i are heating degree days for household i and log() is natural logarithm. The Eq. (2) includes building fabric and thermal performance through $EPex_{ij}$ (in kWh/m^2 in case of integral thermal refurbishment or heating system replacement, and in W/m^{2}K in case of windows replacement or wall and roof refurbishment) and climatic conditions through HDD_i and does not include other parameters, such as building services and occupant behavior, which can have a significant influence on the total energy consumption. This is not seen as a major deficiency since household owners had to decide on whether to implement EE measures based on the performed energy audit, which took into consideration specific building properties (included through EPex), climatic conditions (HDD), size of the household (number of occupants), floor area (A), and assumptions about standard household use. The assumed house use is also one of the reasons for the difference between calculated and measured energy consumption but is not captured in this decision-making process. As required by Rulebook on M&V calculations [31] only energy used for heating was calculated towards energy savings, therefore only HDD data was collected in the dataset and that is also the reason only HDD was used in the Eq. (2).

Total energy savings (ES_{ij}) for household i and measure j are then obtained by multiplying specific energy savings (es_{ij}) and floor area (A_i).

$$ES_{ij} = es_{ij} \times A_i \quad (3)$$

3.2. Discrete choice modeling

The modeling framework is based on the random utility model (RUM) framework [32] which aims to capture decision maker's choice among a set of mutually exclusive alternatives. This approach distinguishes two main components of the utility function (U); the deterministic part (V) that is observable to the researcher and random term (ϵ).

The utility derived by choosing each specific option (U_{ij}) is a function of alternative specific and individual specific characteristics (X_{ij}), and random disturbance (ϵ_{ij}).

$$U_{ij} = V_j\left(X_{ij}\right) + \epsilon_{ij} = \alpha_j + \beta_{ij} X_{ij} + \epsilon_{ij} \quad (4)$$

The probability that household i will choose the alternative j, considering its individual characteristics and characteristics of each alternative X_{ij}, is associated with the probability P that the utility of alternative j is greater than the utility of any other alternative k in the choice set with n alternatives.

$$P\left(j|X_{ij}\right) = P\left(V_j\left(X_{ij}\right) + \epsilon_{ij} > V_k(X_{ik}) + \epsilon_{ik}\right) = P\left(\epsilon_{ik} < \epsilon_{ij} + V_j\left(X_{ij}\right) - V_k(X_{ik})\right) \quad (5)$$

In multinomial logit model (MNL), with error term following the Gumbel law, the choice probability becomes:

$$P_{ij} = \frac{\exp\left(V_{ij}\right)}{\sum_{k=1}^{n} \exp(V_{ik})} = \frac{\exp\left(\alpha_j + \beta_{ij} X_{ij}\right)}{\sum_{k=1}^{n} \exp(\alpha_k + \beta_{ik} X_{ik})} \quad (6)$$

The above mentioned multinomial model comes with the restriction of independently and identically distributed (IID) error term, which is sometimes in practice violated. The IID assumption is partially relaxed in nested logit model which introduces a grouping of alternatives (called nests). The IID property holds within each nest and in general, does not hold for alternatives in different nests.

The probability equation in nested logit model becomes:

$$P_{ij} = \frac{\exp\left(V_{ij}/\lambda_k\right)\left(\sum_j \exp\left(\frac{V_{nj}}{\lambda_k}\right)\right)^{\lambda_k - 1}}{\sum_{l=1}^{n}\left(\sum_j \exp\left(\frac{V_{nj}}{\lambda_l}\right)\right)^{\lambda_l}} \quad (7)$$

In addition to multinomial logit model, a nested logit model was also applied to the dataset. That resulted in a comparison between multinomial and nested logit model.

The average marginal willingness-to-pay for energy savings, MWTP, is represented by the marginal rate of substitution of energy efficiency improvements for money, i.e. the amount of money a household is willing to exchange for energy efficiency improvement. In general, marginal change of the specific parameter in relation to another parameter can be calculated as the ratio of its parameters in the model. Therefore, marginal willingness-to-pay for energy efficiency improvement, i.e. energy savings, is:

$$MWTP = \frac{\partial investment\ cost}{\partial savings} = -\frac{\beta_{\text{savings}}}{\beta_{\text{investment}}} \quad (8)$$

This equation provides information on the marginal price (in EUR per kWh/annum) households are willing to pay to obtain or lose specific attribute k, which represents, in our case, energy savings for each specific measure.

The average willingness-to-pay is calculated by multiplying computed marginal willingness-to-pay for each household and observed energy savings:

$$WTP_i = ES_{ij} \times MWTP_j \quad (9)$$

where ES_{ij} represents energy savings, i.e. energy efficiency improvements, in kWh/annum for household i and measure j, $MWTP_j$ is marginal willingness-to-pay for measure j, and resulting WTP_i is willingness-to-pay of househod i.

4. Data

Croatia has implemented monitoring and verification scheme in form of an IT tool named SMiV (System for Monitoring, Measurement, and Verification of Energy Savings). This system serves for monitoring savings for Article 7 of Energy Efficiency Directive and is legally binding to be used as a tool for all energy efficiency measures being co-funded with public money – meaning that all institutions providing financial incentives are obliged to enter those savings into SMiV. The database[1] holds following data for all projects:

- investment cost,
- awarded subsidy,
- key thermal performance indicator before and after implementation of the project,
- total floor area of the house or area of the envelope that is being refurbished (depending on the measure),
- heating fuel source before and after refurbishment,
- location (city) where the project was implemented.

[1] The data used in this study was obtained from the database on 11th April 2017. Obtained data was prepared for analysis by removing unrealistic or unprobable values and correcting for errors in database input.

Table 1
Structure of implemented measures.

Measure's short name	Measure's description	2015		2016	
		No.	Share	No.	Share
M1	Integral thermal refurbishment	64	2.3%	66	3.3%
M2.1	Windows replacement	862	31.6%	546	27.3%
M2.2	Walls and roof refurbishment	1648	60.3%	1316	65.7%
M4	Heating system replacement	157	5.7%	75	3.7%
	Total	2731	100%	2003	100%

Data included in the analysis are comprised of four energy efficiency measures focused on improvement of thermal properties of the house. Those measures are (M1) integral thermal refurbishment of a family house (comprising of both thermal envelope insulation and refurbishment of heating system in the house), (M2.1) replacement of windows in the house, (M2.2) refurbishment of walls and roof, (M4) replacement of heating system in the house.

Public tender for energy efficiency subsidies had prescribed the following technical conditions:

- in case of window replacement, new U factor should be at least 1.1 W/m^{2}K for glass and 1.4 for glass with frame in continental climate zone, and at least 1.1 and 1.6 W/m^{2}K in the coastal zone;
- in case of wall and roof insulation, new U factor should be at least 0.25 W/m^{2}K in the continental zone, and at least 0.40 W/m^{2}K in coastal climate zone.
- thermal system replacement conditioned condensing natural gas boiler, biomass boiler, pyrolytic fuelwood boiler, or heat pump (A energy class according to Eurovent Energy Efficiency Classification).

It is important to notice that above-mentioned measures are mutually independent which means that if a household opted for thermal insulation and replacement of the heating system, that would be recorded only as an integral refurbishment, instead of recording two separate measures. In this way, a set method of calculation for the integrated measure would consider the synergies of all implemented measures and the calculated saving would be lower than if the savings were calculated for the same surface, but for all measures individually.

Table 1 provides the number of implemented measures per year in 2015 and 2016, and their share within each year.

Although the absolute number of implemented projects decreased in 2016, the structure or distribution of measures is similar for both years, with the highest share appertaining to the refurbishment of walls and roof, and windows replacement coming next in absolute share in total. Only those two measures account for more than 90% of implemented projects during those two years.

Due to a different level of economic development, and with the aim of providing a similar level of opportunities to all, the maximum amount of subsidy given to individual household was defined by the level of economic development of the specific administrative area. Designation of appropriate development class for each administrative area is provided by the Ministry of Regional Development, in line with the Act on Croatian Regional Development [33]. There were three levels of support for energy efficiency refurbishment, all provided by the Fund for Environmental Protection and Energy Efficiency:

- up to 80%, for administrative areas under special governmental support,
- up to 60%, for mountain area,
- up to 40%, for others.

Key indicators taken into the calculation for above-mentioned classification are unemployment rate, per capita income, budget revenues of local or regional self-government per capita, general population movements, and education rate. The classification is performed at five-year intervals, last being completed in 2013.

Table 2
Household energy prices.

Fuel	Price in EUR/kWh
Electricity	0.120
LPG	0.059
Natural gas	0.056
Heating fuel oil	0.045
Biomass pellets	0.040
Fuelwood	0.029

Since information on socio-economic characteristics of households was not collected as a part of data collection procedure, we have assigned that information through NUTS-3 level statistical data. We used data on the number of households and number of family houses in each county from [34] and average household income per capita from [35].

Fig. 1 shows NUTS 3 and NUTS 2 regions in Croatia. All NUTS 3 regions starting with HR03x belong to NUTS 2 region named „Jadranska Hrvatska" and NUTS 3 regions starting with HR04x belong to NUTS 2 region named "Kontinentalna Hrvatska". Those two administrative regions closely correlate with climate regions, i.e. heating and cooling requirements.

Table 2 provides average energy prices for households in Croatia. The prices include VAT and all relevant taxes and show a representative cost of energy for an individual household.

5. Results

Table 3 shows mean values of several parameters of the grant scheme. Total investment cost in EUR corresponds to overall investment cost; annual financial savings in EUR are result of measure implementation and equal to annual energy savings multiplied by energy price; own assets needed for the investment are equal to total investment minus provided subsidy in EUR; mean of simple payback period (SPP) for homeowners in years is calculated as years needed to payback own assets at current energy prices and projected savings; own cost of savings is equal to own assets divided by lifetime energy savings; and public cost of savings is equal to subsidy divided by lifetime energy savings. The total cost of energy savings is equal to own cost plus the public cost of savings.

When considering simple payback period, the measures with the fastest return on investment of own assets are the replacement of heating system (M4) and integrated refurbishment (M1) of the family house. With slightly higher SPP, walls and roof refurbishment (M2.1) provide a very quick return on invested funds, while windows replacement (M2.2), although popular among homeowners does not provide such a worthwhile investment as other measures.

Fig. 1. NUTS 3 regions in Croatia [36].

Table 3
Summary of the grant scheme.

Social status	Measure	Investment cost EUR	Financial savings EUR/yr	Own assets EUR	Simple payback period yr	Own Cost of savings EUR/kWh	Public Cost of savings EUR/kWh
nonPPDS	M1	19,782	2075	12,617	6.1	0.0113	0.0064
	M2.1	6019	256	3752	14.7	0.0256	0.0154
	M2.2	9770	1069	6343	5.9	0.0099	0.0053
	M4	5344	879	3458	3.9	0.0105	0.0057
PPDS	M1	17,033	1830	5012	2.7	0.0044	0.0105
	M2.1	5666	210	1987	9.5	0.0152	0.0281
	M2.2	7670	780	2291	2.9	0.0041	0.0096
	M4	3549	672	1353	2.0	0.0049	0.0080

In both administrative areas, those with a special social status (PPDS) or "areas of special state concern", and areas that are not of special state concern (nonPPDS), the total cost of energy savings during the lifetime of a specific measure is similar, the difference being only who takes over the cost. In case of social status area, the cost per unit of energy saved that is covered via subsidy is up to twice as large as the cost covered by households' own assets. In case of non-social status area, the situation is exactly the opposite – households are retaining over two-thirds of the energy savings. This is a direct result of grant scheme design which awards grants to areas of special state concern twice as high as those in the areas other than those of special state concern.

It is also important to notice the difference in own assets requirements, and hence simple payback period, between measures implemented in the administrative units with higher grant support than in municipalities with lower grant support. The difference between them has a factor of two.

5.1. Expected energy efficiency improvements and costs of investments

Table 4 shows the estimation and data imputation model. As can be seen from the table, all parameters are significant at the level of 5%, except for the interaction of M1 with total floor area and existing building performance. Log-linear model of specific energy savings (per total floor area) accounts for 80.5% of the variance in observations while the linear model of the cost function accounts for 61.7%.

Specific savings model is the deemed savings model, which provides information on how much energy will be saved based on the climate zone (HDD) and on the current thermal performance of the building (EPex). That models the characteristics of existing housing stock in Croatia.

Cost model provides information on the current market conditions and gives the estimation of total costs of refurbishment de-

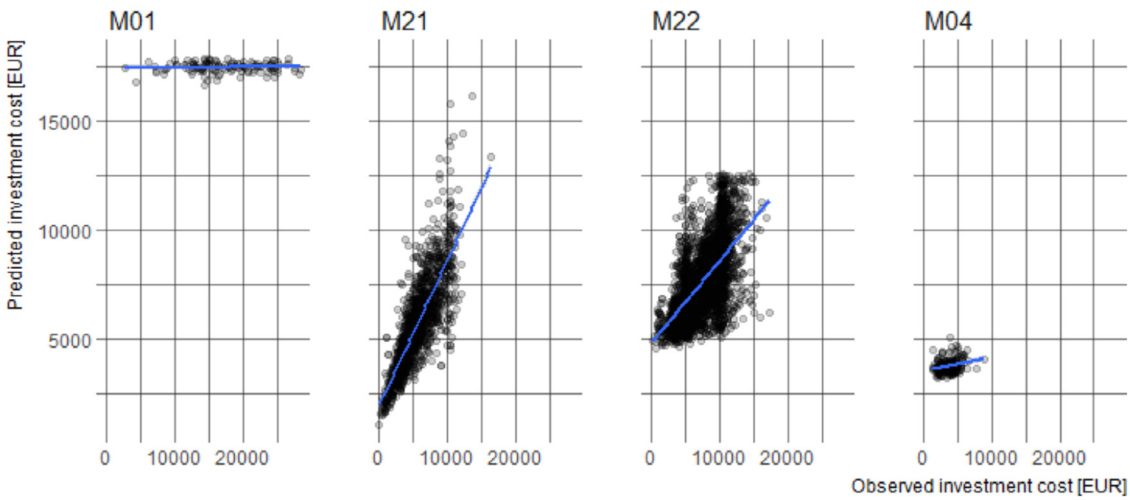

Fig. 2. Basic goodness-of-fit plot for Investment cost.

Table 4
Resulting linear regression models.

	Dependent variable	
	log(Savings/Surface)	Cost
HDD	0.001*** (0.00002)	
Categorical variables		
M1	3.206*** (0.101)	18,519.260*** (932.794)
M2.1	−2.509*** (0.102)	−18,016.120*** (974.896)
M2.2	−1.044*** (0.093)	−14,258.920*** (942.378)
M4	−1.032*** (0.108)	−15,832.370*** (1,121.946)
Interaction with A		
M1		−2.994 (3.658)
M2.1		31.016*** (0.868)
M2.2		15.487*** (0.360)
M4		5.107** (2.496)
Interaction with EPex		
M1	0.004*** (0.0004)	−2.850 (2.388)
M2.1	0.346*** (0.012)	215.424*** (63.236)
M2.2	0.817*** (0.011)	427.521*** (62.406)
M4	0.005*** (0.0003)	1.344 (1.849)
R^2	0.805	0.618
Adjusted R^2	0.805	0.617
Residual Std. Error	0.409 (df = 4594)	2,182.344 (df = 4591)
F Statistic	2,376.156*** (df = 8; 4594)	675.597*** (df = 11; 4591)

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

pending on the building's thermal performance (EPex) and on the total floor area of the building (A).

Figs. 2 and 3 present goodness of fit plots for investment cost and specific energy savings models, both in relation to specific energy efficiency measure. In accordance with the model results, both models can accompany underlying data trends but lack the complexity to accommodate for the variability and outlies in the dataset. Investment costs are shown in EUR and specific energy savings as final energy savings in kWh per total floor area in m^2.

5.2. Choice model

Parameters of two fitted models are provided in Table 5. First three parameters are intercepts for different measures and individual attributes, next is interaction with grant share, and then come coefficients of interaction between surface, current performance, savings, and level of own assets with different choices of measures.

In case of the multinomial logit model, all coefficients are highly significant ($p < 0.01$), except for M2.1 interaction with savings and own assets. Nested multinomial logit model also has all highly significant coefficients except M2.1 interaction with savings and own assets. Signs of coefficients are the same as in the case of MNL model. In nested MNL model measures were divided into two nests. Measures M2.1 and M2.2 were assigned to "demand" group and measures M1 and M4 into "integrated" group.

Table 5
Resulting discrete choice models.

	MNL	nested MNL
M2.1 intercept	30.686*** (3.317)	67.476*** (16.254)
M2.2 intercept	25.788*** (3.339)	58.286*** (15.929)
M4 intercept	20.912*** (3.606)	51.610*** (15.577)
Interaction with Grant share		
M2.1	−40.220*** (4.719)	−95.339*** (21.875)
M2.2	−33.209*** (4.759)	−82.407*** (21.275)
M4	−28.931*** (5.287)	−75.094*** (21.344)
Interaction with PerformanceOld		
M1	0.020*** (0.003)	0.034*** (0.007)
M2.1	0.473*** (0.076)	0.775*** (0.187)
M2.2	1.289*** (0.132)	2.224*** (0.496)
M4	0.021*** (0.003)	0.033*** (0.003)
Interaction with Savings		
M1 × 10^{-5}	−2.923*** (0.517)	−5.197** (2.393)
M2.1 × 10^{-5}	−5.426 (3.511)	−5.700 (5.701)
M2.2 × 10^{-5}	−5.803*** (0.857)	−10.258*** (2.264)
M4 × 10^{-5}	−4.539*** (1.484)	−8.148*** (2.438)
Interaction with Cost		
M1 × 10^{-3}	−0.818*** (0.108)	−2.010*** (0.422)
M2.1 × 10^{-3}	−0.212*** (0.039)	−0.436*** (0.125)
M2.2 × 10^{-3}	−0.205*** (0.038)	−0.384*** (0.120)
M4 × 10^{-3}	−1.697*** (0.356)	−2.865*** (0.327)
Interaction with Own Assets		
M1 × 10^{-3}	2.246*** (0.263)	5.273*** (1.185)
M2.1 × 10^{-3}	0.050 (0.075)	0.064 (0.150)
M2.2 × 10^{-3}	0.728*** (0.097)	1.301*** (0.358)
M4 × 10^{-3}	3.423*** (0.639)	5.771*** (0.660)
iv. demand		1.921*** (0.540)
iv.integrated		2.907*** (1.123)
Log Likelihood	−3830.815	−3793.129
LR Test	728.014*** (df = 22)	803.386*** (df = 24)

Note: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

The signs of coefficients in both cases are the same, which is in line with the expectations. Measure M1 is used as a reference point, therefore it is missing in the intercept coefficients and interaction with the amount of grant share.

However, in the case of the nested logit model, the inclusive value of both groups are outside the [0,1] range which suggests

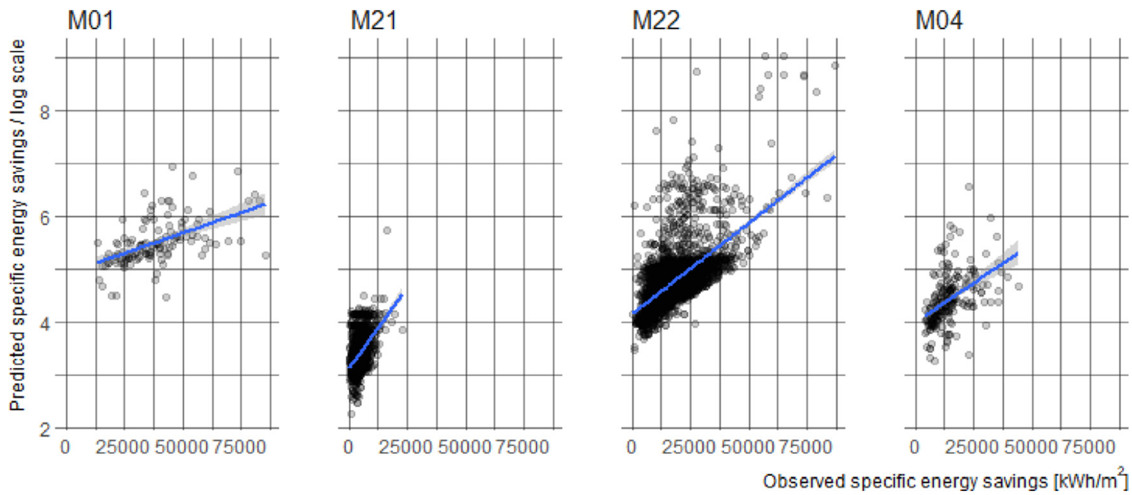

Fig. 3. Basic goodness-of-fit plot for Specific energy savings.

[37] that the model does not satisfy utility maximization. Nested model is a generalization of multinomial logit model and reduces to MNL if inclusive value equals 1.

Coefficients of interaction with Grant share are negative which corresponds to the subsidy scheme design, where grant share was used as a proxy for the level of poverty or economic development in the region. If the region was richer, the grant share was lower and with negative coefficients of Grant share that results in higher utility.

Cost variable has a negative coefficient which corresponds to lower utility in case the costs of investment are higher. It is surprising to observe negative coefficients for Savings variable and positive for Own Assets variable since it translates to the higher utility when savings are decreasing and higher utility when own assets are increasing. Negative coefficients can be explained by a threshold of minimum energy performance standard that needed to be achieved for energy efficiency to be eligible for a subsidy. That means that households were willing to achieve required energy efficiency standard, but not more than that. Given the fixed value of total investment cost, the Own Assets variable is also partially gauging household's income level, therefore the utility is increasing with the increase of the amount of own assets invested into refurbishment project It is also possible that households are viewing more expensive measures as much better and valuable. Because both models provide similar results, and MNL has formal advantages over nested MNL model in this case, in further discussion and analysis, MNL model was used.

6. Policy implications

In order to estimate the free-riding effect, an approach proposed in Grösch and Vance [30] was modified and improved. Calculated willingness-to-pay should be compared with observed and hidden costs of undergoing the refurbishment. If the WTP of the individual household for the specific energy-saving measure is greater than the sum of observed and hidden cost, the household is defined as a free-rider since it is willing to pay more than the cost of the measure and would implement that measure even in the absence of the grant scheme. It is important to notice that, although observed costs are known, the extent of the hidden cost that household is incurring is not being measured.

$$WTP + FR = oC + hC \quad (10)$$

where WTP is the willingness-to-pay, FR is the experienced value of free-riding, oC is the observed cost, and hC is the hidden cost.

Table 6
Marginal willingness to pay.

Measure	MWTP EUR / kWh
Integral thermal refurbishment	0.0130
Windows replacement	1.0761
Walls and roof refurbishment	0.0797
Heating system replacement	0.0133

Additionally, WTP can be split into the energy-related effects and non-energy related benefits incurred by the investment.

$$WTP_e + WTP_{ne} + FR = iC - sub + hC \quad (11)$$

where WTP_e is willingness-to-pay for energy related benefits, WTP_{ne} is WTP for non-energy related benefits, iC is total investment cost, and sub is the amount of subsidy. Hidden costs are costs incurred by the household through their time and efforts invested into procurement and preparation of the project, additional costs of obtaining required documents, the price premium for the discomfort of the works performed on the house, etc. Non-energy related WTP consists of different benefits provided by the investment, such as visual improvements on the house after the facade is renovated or improved manipulation (or automation) of the new heating system, etc.

If non-energy benefits and hidden costs are disregarded, or assumed equal, i.e. to cancel each other out, the calculated willingness-to-pay is then compared to the observed total cost of retrofitting to estimate free riding.

If observed total cost is lower than corresponding WTP, i.e. if the household was willing to pay more than the cost of retrofitting it means that household would implement that measure in the absence of the grant as well, which counts as free-riding. If the total cost is higher than WTP, that means a household would not invest in the measure in the absence of the provided grant (Table 6).

Resulting Marginal willingness to pay (MWTP) for two most popular measures, windows replacement and walls and roof refurbishment, is higher than the average heating energy prices for households. At the same time, in case of integral thermal refurbishment and heating system replacement, it is lower even than the cheapest fuel – fuelwood.

When calculating MWTP from Eq. (8), it is important to observe that Investment variable from the Eq. (8) corresponds to Own Assets variable in the discrete choice model, since it corresponds to amount of money household is actually providing for the investment.

Table 7
Willingness to pay.

Measure	Social status	No. of measures #	Own assets EUR	Willingness to pay EUR
M1	nonPPDS	20	12617	484
	PPDS	110	5012	496
M2.1	nonPPDS	87	3703	4938
	PPDS	1314	1985	4603
M2.2	nonPPDS	260	6037	1553
	PPDS	2580	2226	1463
M4	nonPPDS	26	3458	219
	PPDS	206	1353	183

Although most users opted for walls and roof refurbishment, the measure with the highest marginal willingness to pay per annually saved energy is windows replacement. Marginal WTPs for both, windows replacement and walls and roof refurbishment, are higher than household energy prices (Table 2), which implies that households are highly valuing additional benefits in those measures (benefits other than energy savings) and that majority of free-riders will be among those measures. MWTPs of integral thermal refurbishment and heating system replacement are, in both cases, lower than energy prices which suggest that the additional discomfort of renovating has a high cost, i.e. negative MWTP.

This result indicates that besides in energy savings, households are highly interested in improving most notable and visible aspects of their living space. New glazing improves occupants' comfort of living through improved ventilation, reduced window fogging, or overall aesthetics.

Table 7 provides a comparison between resulting willingness to pay and invested own assets, divided per measure and per social status area (PPDS = social status, non PPDS = non-social status). The difference in the investment of own assets between an area with social status and those without it are caused by the different level of subsidies. On the other side, resulting willingness to pay is similar between different social status areas within the group of measures. Therefore, it is not surprising that with similar total costs and observed WTP, and with high differences in own assets needed, the majority of measures have been implemented in areas with higher grants awarded.

The free riding effect, evident from Table 7, is highly noticeable for windows replacement, which suggests there might be no need for subsidies for that measure. In case of heating replacement, the WTP is almost non-existent.

All measures provide similar WTP for areas with different level of special state concern, but as an effect of funding policy, very large discrepancies are observed in own assets needed for energy efficiency refurbishment.

Interestingly, the WTP for walls and roof refurbishment in areas of special state concern is approaching the amount of own assets needed for that investment and consequently accounts for the largest share in total investments undertaken through the grant scheme.

The reason for this distribution can be found in Table 7 which shows similar levels of WTP for all four measures in both areas of special state concern and those without, but with a very different level of investment needed for the implementation of energy efficiency measures.

However, Table 8 provides clarification for this result. In administrative areas with a lower amount of grant limit, measures were mainly being implemented by households in administrative areas with higher per capita income. In areas without special state concern, 53% of all measures were implemented by four upper-income classes, while in the case of cities with social status, the share of measures per income classes is concentrated around the mean income class, with the lowest four income classes accounting for 41%, middle class accounting for 27%, and upper five classes accounting for 32% of measures.

Since there was no information on household income in the original dataset (nor was that data collected by the national authorities) the annual per capita income for the administrative unit where the household is situated was used as a proxy value.

With the higher subsidy, more households are interested in the energy efficiency refurbishment and the distribution of households implementing measure is leaning towards middle-income households. In contrast to lower subsidies, where only higher-income households are inclined to undertake the investment. This conclusion is in line with results in Table 7 and suggests that although average WTP among household groups is similar, in case of higher subsidy more equal distribution per income class is achieved, while in the case of a lower subsidy, only the households in higher income areas can afford to implement EE measures.

Households with fuelwood as a primary heating fuel have the most implementations among the participants in the grant scheme and are mostly investing in measure M2.2, as well as all other households. Among households with natural gas, the number of measures M2.2 is dominant, but there are twice as many households with that measure implemented, then those with fuelwood as their primary heating source (Table 9).

The distribution of willingness to pay per income classes shows the flat line in both cases, in areas of special state concern, and other areas, suggesting that irrespective of the income, people are valuing their energy savings very similarly.

Interestingly, households that use fuelwood have a slightly higher WTP for all measures, which corresponds to the notion that those households are using more fuel and must put, in general, more effort and time into operational and maintenance activities. Hence, they calculate added value of comfort into the total cost.

The ratio of willingness to pay and own assets invested in a measure provides the indication of the free-riding effect. In case of non-PPDS areas, this ratio is decreasing from low-income classes to high-income classes, however, in PPDS, it is decreasing more rapidly. When comparing the coastal region of Croatia with the continental region, the figures are similar as when comparing the non-PPDS and PPDS administrative areas, because the majority of the social status areas are situated in the continental part of Croatia, and therefore have a dominant effect on the shape of the graph. Both cases show same trends as the national average, which is dominated by PPDS administrative areas in the continental part of Croatia (Fig. 4). The figure shows the ratio of WTP to own assets invested into energy efficiency actions per income class.

As household income rises, the share of WTP in own assets invested into energy efficiency actions falls, suggesting that higher income households are warier with their investments. A similar trend can be seen for all analyzed measures, whether considering WTP per own assets or WTP per average household income.

Table 8
Distribution of implemented measures per income class and administrative social status.

Social status		Income class 1	2	3	4	5	6	7	8	9	10
non PPDS	No.	0	7	20	30	66	61	49	63	30	67
	%	0%	2%	5%	8%	17%	16%	12%	16%	8%	17%
PPDS	No.	11	381	550	787	1149	564	282	279	76	131
	%	0%	9%	13%	19%	27%	13%	7%	7%	2%	3%

Table 9
Number and mean willingness-to-pay per heating fuel type.

Fuel	M1		M2.1		M2.2		M4	
	No.	WTP	No.	WTP	No.	WTP	No.	WTP
Biomass pellets	-	–	3	4866	5	1538	1	169
Electricity	4	400	81	2975	109	965	10	172
Extra light Fuel Oil	–	–	13	4979	28	1421	1	170
Fuel Oil	4	454	26	3902	36	1315	6	130
Fuel wood	39	502	417	5598	1521	1557	65	225
LPG	2	336	14	4584	20	1514	5	176
Natural gas	81	501	847	4318	1121	1408	144	174

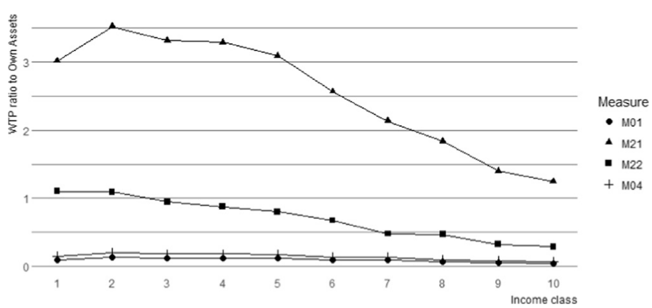

Fig. 4. Distribution of Willingness to pay per income classes.

7. Conclusion

The results provide two sets of conclusions. In case of administrative areas of special social care, there is a higher demand for financial help for house renovation, which is evident in the number of implemented projects and results in the lower amount of own assets required. It could, however, be discussed whether those renovations were implemented with the aim to reduce energy consumption, or to improve the low standard of housing. Also, there is a possibility that some of the wealthier homeowners residing in special care administrative areas also used this grant for energy efficiency improvement. Since there is no data on the social status of each individual household that was awarded the energy efficiency grant, it is difficult to make a solid conclusion.

In case of the rest of the territory, free riding is noticeable in windows replacement measure, amounting to almost 100%. Although perceived benefit is not the exact measure of free riding, it is, however, an indicator of whether the grant scheme could be improved to match the homeowner's perceived benefit and realize higher savings with less public funds.

Integrated thermal refurbishment and heating system replacement are actions without any free-riders evident through the analysis. Users of those measures have placed an additional value on non-energy benefits of the implementation.

Thermal insulation refurbishment was very well adjusted for households in administrative areas of special state concern, as their WTP closely corresponds to the amount of own assets that were needed for the investment. On the contrary, in administrative areas that are not of special state concern, and therefore with a lower amount of awarded subsidy, the WTP was four times lower than the needed assets for the investment.

Interestingly, the WTP for windows replacement was, in both types of administrative areas, higher than required investment. That suggests that household owners are probably placing an additional value on most visible non-energy benefits of the investment, such as aesthetics, reduced fogging, increased ventilation properties etc.

The performed analysis revealed some characteristics of homeowners' decision process. Most surprising revealed characteristic was that the WTP of households in social care areas is the same as in the rest of the country, and secondly, the WTP for all measures does not correlate with the general territorial income class for that administrative area.

As expected, the distribution of implemented measures is highly affected by the amount of subsidy provided. It was shown that with lower subsidies in administrative areas that are not of special state concern only upper-income households are willing to invest in energy efficiency measures. In areas of special state concern, the distribution of households is more socially equal.

The social status of the household is partially reflected in fuel used for heating, which again is reflected in implemented measures and households' willingness-to-pay.

It is, therefore, of crucial importance for policymakers to include household status and annual income into the future energy efficiency policies. Ignoring the differences among income classes might additionally deepen the social division and increase the inequality of chances.

It would be beneficial for further analyses if more elaborate data collection process would follow the award of subsidy to better understand main drivers of decisions and effects that energy policy has on different social groups. When designing new policy measures and improving the existing ones, different decision processes should be included, alongside the heterogeneity of household structure.

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Conflict of interest

Declarations of interest: none.

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