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ORIGINAL ARTICLE

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Incorporating barriers in scenarios for energy efficiency improvement and promoting renewable energy in the Bulgarian residential sector

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Abstract The progress in achieving targets for energy efficiency (EE) and renewable energy sources (RES) is hindered by a set of barriers linked with the end-users (social, educational, cultural, economic, and institutional), but previously, the effect of these barriers was only rarely quantified and no comprehensive methodology to do so is available. This paper, through a step-by-step methodology, examines the development of scenarios for the Bulgarian residential sector until 2030, focusing on the combination of available – for this sector – EE and RES technologies, after incorporating these barriers with the use of the HERON Decision Support Tool (HERON-DST). Two more research tools are used, LEAP (modeling tool) and AMS (multi-criteria evaluation method). Six different scenarios, three of which address barriers, were developed for LEAP. All scenarios are evaluated with the AMS method against a set of criteria/sub-criteria regarding their overall performance under the particular national framework. This results in the identification of the most appropriate (EE/RES) scenario for the country, i.e., addresses behavioral barriers and performs better (one with the highest AMS score) than the others under the particular national framework. This scenario promotes building shell improvement, efficient heating, and cooling in the Bulgarian residential sector. Its policy mixture mainly through financial incentives and more demanding building codes handles social, institutional, and economic barriers linked with end-users behavior. Conclusions concern the methodology, its outcomes, and future use.

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Introduction

Global efforts for mitigating climate change through the reduction of greenhouse gasses target the accelerated deployment of renewable energy sources (RES) and the adoption of energy efficiency (EE) measures (Irena, 2017, 2018; Hesselink & Chappin, 2019). In this frame, the EU aims to achieve by 2030 a 32% RES share, compared to less than 18% in 2017, and a 32.5% EE improvement (European Commission, 2020).

These efforts are linked strongly with the residential sector which is characterized as an important sector for contributing to the internationally set climate targets of the Paris Agreement due to a globally growing population and its increasing energy demand

(Hesselink & Chappin, 2019). Together, buildings and construction sectors have a 36% share in global final energy use and 39% of the energy-related carbon dioxide (CO_2) emissions including upstream power generation (International Energy Agency and the United Nations Environment Programme, 2019; Irena, 2018; UN Environment, 2017).

Almost the same shares are recorded at the European level. The EU building sector absorbs 40% of final energy, and almost 75% of EU buildings are energy inefficient (EC, 2019a). About half of the EU-28 building stock needs to be renewed or some of their equipment retrofitted over time because of being built before 1970 with limited EE considerations and no RES requirements (IRENA & EC, 2018). According to another study (BPIE, 2018), more than 97% of the EU buildings need to undergo energy refurbishment. At the national level and for the period 2012–2016, only 0.4–1.2% of the stock was renovated annually (depending on the Member State) (EC, 2019b). In 2017, the EU residential sector represented 27% of the final energy consumption (Eurostat, 2019).

As for RES, their contribution to the total final energy demand of EU buildings was 22% in 2015. Almost half was attributed to biomass, and the other half to electricity and district heat derived from RES. The contribution of solar thermal was relatively small (2% of renewable consumption) (IRENA & EC, 2018). The most common RES technologies to deliver heating/cooling services in households and become part of the energy renovation[1] are solar thermal, biomass boilers, and high coefficient of performance heat pumps (European Commission, 2016). The penetration of RES technologies depends on several factors, including building stock turnover. Estimations refer to a possible double final consumption of RES in EU buildings by 2030 compared to 2010 levels (IRENA & EC, 2018).

The difference between what is expected and what is or will be recorded is actually attributed to the existence of barriers (Nehler et al., 2018; Lawrence et al., 2018; Mavrakis & Konidari, 2017; Lee, 2015; UNEP, 2014; IEA, 2014). The implementation of EE measures for buildings is constrained by technical, structural, economic, social, and behavioral barriers (Hesselink & Chappin, 2019; Di Foggia 2018). Same situation for RES penetration (Frangou et al., 2018; Colmenar-Santos et al., 2018; Horváth & Szabó, 2018). Papers for estimating in numbers the impact of these barriers are very few (Mavrakis & Konidari, 2017). Furthermore, there are a limited number of papers about EE and RES scenarios for Bulgaria (Nikolaev & Konidari, 2017), with none of them incorporating in scenarios on the numerical impact of behavioral barriers (social, cultural, educational, economic, and institutional).

Under this context, the paper (i) presents the already evaluated impact of behavioral barriers for the examined case, (ii) incorporates these barriers in energy modeling using the HERON Decision Support Tool (HERON-DST), (iii) develops scenarios with LEAP for the case study of the Bulgarian residential sector focusing on the combination of available EE/RES technologies and policy instruments for reducing the impact of selected barriers, and (iv) evaluates the policy mixtures of the developed scenarios with the AMS evaluation method.

The first step allows policymakers to realize among barriers those that impact more negatively than others the implementation of policy instruments and the achievement of desired EE/RES targets. The term “behavioral barriers” refers to all types of barriers – social, cultural, educational, economic, and institutional – linked directly or indirectly with the behavior of the end-users toward an EE/RES technology or policy. This realization is useful for the development of scenarios since they acquire a concrete perspective. Until now, their development is based on a vast range of options in targets, technologies, and policy mixtures. Now, these are limited to a specific set of EE/RES technologies and their respective supporting policy mixture that confronts selected behavioral barriers. Depending on the selected by the policymaker set of behavioral barriers that are to be confronted, these developed scenarios demonstrate whose expected outcome is closer to the desired target and after evaluation which is more feasible according to national strengths and weaknesses.

The Bulgarian residential sector was selected because of the following.

i) Its intensity in terms of energy consumption per capita increased by 20% during 2005–2017. This

[1] That is, replacement or first-time installation of water heater with a solar thermal collector on the roof (EC 2019a).

number is the highest among all Member States and in contrast with the overall EU decrease of 12% in the period (European Commission 2019c).

ii) It is the main energy consumer within the national buildings sector (Sustainable Energy Development Agency, 2018b). Also, it is the third largest sector in terms of final energy consumption (24%), after transport (35%) and industry (28%) (Fahy et al., 2019).

iii) The country has high population shares in energy poverty (linked with the inadequate implementation of EE measures). It is indicative that in 2017, around 63.5% of the most socially deprived households were still unable to keep their homes warm (European Commission, 2017 and Eurostat, 2017a). This percentage is lower compared to that of 2005 which was 79% but remains significantly above the EU average of 23% and makes Bulgaria the worst performer in the EU on that metric (European Commission 2017).

iv) "Energy efficiency is the highest priority in the energy policy of the country" according to the Energy Strategy of the Republic of Bulgaria by 2020. On this basis, ambitious targets are set for improving EE (Sustainable Energy Development Agency, 2018a).

v) The household energy mix has a relatively high share of RES (second-most important fuel source). The most commonly used fuel for heating is wood (59%) (Fahy et al., 2019).

The paper offers a new methodology for (i) incorporating the barriers due to the behavior of end-users in the formation of energy policy scenarios and (ii) reducing the calculated deviation between the EE/RES target of a developed scenario and of the target that is set for a specific year. The main point is to show through the Bulgarian case study how this innovative approach is applied. The outcomes of this work will answer questions raised by scholars, i.e., which technologies need to be adopted by households (Hesselink & Chappin, 2019), which barriers are more persistent in stopping households from adopting EE/RES technologies (Hesselink & Chappin, 2019; Dubois et al., 2019), or which policies to select in materializing behavioral changes or reducing barriers (Dubois et al., 2019; Horvath & Szabó, 2018). The paper is structured as follows. The next section is devoted to the Bulgarian residential sector and to the respective policy framework. The "Methodology" section concerns methodology. The "Results and their evaluation" section refers to the scenario results and their policy evaluation. The last section is about the discussion of outcomes and conclusions.

Bulgarian residential sector

General information

In 2017, there were 3.95 million dwellings (NSI 2018a). Residential buildings were 2.07 million, out of which 45% were constructed until 1960, another 45% between 1961 and 1990, and only 10% after 1990 (NSI, 2018b). According to the 2011 census results (NSI, 2011), 49% of the dwellings were in single-family buildings and the remaining in multi-family buildings[2]; 68.6% of these dwellings were inhabited (NSI, 2011). It is reasonable to assume that energy is consumed only in the inhabited dwellings.

Among the inhabited buildings, 97.5% are privately owned and almost all of them are owned by individuals (NSI, 2011). In multi-family buildings, individual owners usually undertake partial energy refurbishment measures (replacement of windows, wall insulation, etc.) limited to their own dwelling unless they apply for a grant (e.g., under the Energy Efficiency of Multi-Family Residential Buildings National Programme) in which case they need to comply with the grant requirements to refurbish the whole building.

Energy consumption

The residential sector represents a substantial part of Bulgaria's final energy consumption. Its share has gradually declined from 26% in 2011 to 24% in 2017 (NSI, 2019). Its energy consumption during the period 2011–2017 is shown in Fig. 1.

The figure shows a decrease in the sectoral energy consumption during the period 2011–2014, followed by a moderate increase until 2017. In 2017, the main

[2] The single-family buildings are considered to have 1–3 dwellings, while the multi-family ones have 4 or more dwellings.

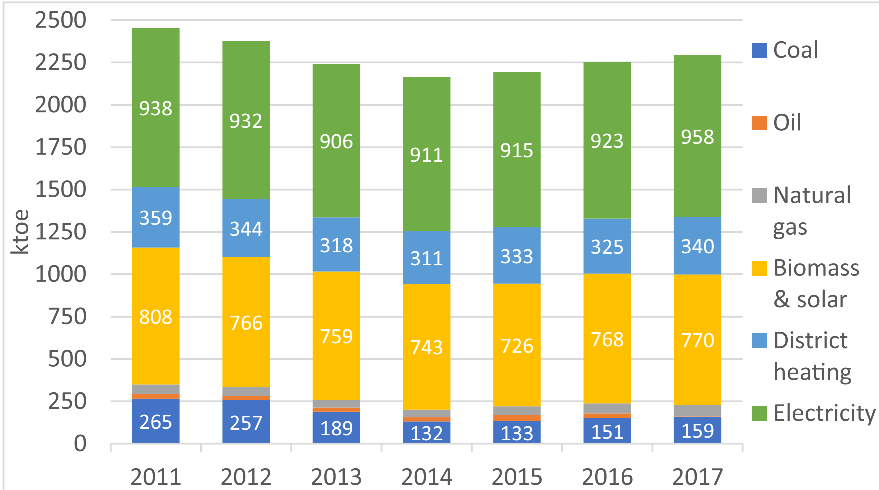

Fig. 1 Residential sector energy consumption 2011–2017 by fuel. Source: NSI, 2019

energy carriers are electricity (41.5%), biomass, and solar (33.5% together, of which 33% biomass and 0.5% solar), followed by district heating (15%), coal products (7%), and natural gas (3%). During the period 2011–2017, electricity and natural gas shares increased, but were balanced by the slight decrease in oil and coal shares.

After 2011, the residential economic consumption steadily increased, while the sectoral energy intensity steadily declined (SEDA, 2018a). The specific reasons for the consumption increase after 2014 are as follows (SEDA 2018a):

- higher living area per person,
- higher use of electric appliances, and
- higher energy comfort, both during the winter and summer periods.

Heating represents about 70% of the sectoral energy consumption (MEE 2014), although, for the period 2011–2017, the average annual heating degree-days (2504) were notably below the EU ones (3016) (Eurostat, 2018), and 39% of residents were unable to maintain heating comfort in 2016, due to material deprivation status (Eurostat, 2017b).

Energy efficiency improvement and RES potential

In the 2011 census, only 15.5% of the Bulgarian dwellings had external wall insulation and 29.0% EE windows (NSI, 2011), which indicates the poor overall energy performance of the building envelope in the national residential sector. The energy refurbishment of the multi-family buildings with poor energy performance is calculated to save on average 35.5% of their energy consumption, provided that after the refurbishment, energy certificate Class C (191 – 240 kWh/m^2 primary energy) is reached (SEDA, 2011). According to the Ministry of Regional Development, the results from nearly 50 thousand dwellings renovated to Class C in 2017 showed an average of 8350 kWh annual energy savings per dwelling (MRDPW, 2018).

A study points out two important measures for energy improvements in Bulgarian households: improving the poor energy performance of the building envelope and motivating consumers to save energy (Koleva & Mladenov, 2014). Regarding energy transformation, important energy saving potential can be realized by improving the low efficiency of biomass and coal stoves (MEE, 2014), which would result in multiple benefits – environmental, social, economic, and wider resource availability for energy needs. In this context, the future development of biomass energy utilization would require efficient and modern technologies (Koleva & Mladenov, 2014).

There are several studies that assess the theoretical and technical potential of renewables that can be used in households, such as biomass, solar, and geothermal energy Koleva & Mladenov, 2014; BSREC, 2012; MEET, 2009). The studies demonstrate that the technical potential of all of these resources is much higher than their current utilization.

Available end-use EE and RES technologies for households

The main technological options available to Bulgarian households to improve EE and increase the RES share (Nikolaev & Radulov, 2016) are as follows:

- **building shell improvements**: measures to improve the energy performance of walls, windows, roof, and floor;
- **sustainable heating technologies**: replacement of the direct use of electricity and inefficient biomass and coal burning technologies with electrical heat pumps, natural gas, district heating, solar thermal, and efficient biomass utilization technologies;
- **efficient air conditioning**: introduction of efficient (average seasonal coefficient of performance (SCOP) of 4,0) heating and cooling through reverse air conditioners;
- **efficient lighting:** replacing incandescent and fluorescent lamps with efficient LEDs;
- **efficient appliances**: all efficient energy-consuming devices are considered, except for those used for space heating, air conditioning, and lighting (for avoiding overlaps with the above technologies).

Policy framework

National objectives

The draft Integrated National Energy and Climate Plan (NECP) of Bulgaria sets the following national targets for 2030 (Ministry of Energy, 2019):

- energy saving target of 27%, compared to the country's projection for 2030 in the 2007 EU Reference scenario;
- RES share of 25% (to be increased to 27%, following EC feedback) in the gross final energy consumption, i.e., expected shares of RES in the electricity, heating, and transport, respectively, 17%, 44%, and 14%.

The 2030 energy saving target is substantially below the overall EU ambition of 32.5% (non-binding at the Member State level), as set out in the revised EE Directive (2018/2002/EU). Similarly, the national RES target (25% in 2030 compared to 16% in 2020) involves less progress than the overall EU target (32% in 2030 compared to 20% in 2020) (European Commission, 2018).

Policy instruments Policy instruments (PIs) are the means, practices, or techniques used by governmental/public authorities to support policies for achieving a predefined set of goals (Hiroshan & Chandrashekar, 2019). They are also characterized as interventions in markets or, more broadly, society designed by these authorities for all target groups linked with the solution of an emerged problem. There are five major types of PIs: legislative and regulatory, economic and fiscal, agreement-based or co-operative, information – communication and knowledge – innovation (Bouwma et al., 2016). Important implemented PIs concerning EE and RES for the Bulgarian residential sector are as follows:

- requirements for the energy consumption and energy performance of buildings, set in the Bulgarian Regulation E-RD-04–2 of 22.01.2016;
- building obligations for the use of renewable energy in new buildings, according to the Bulgarian Energy from Renewable Sources Act, amended on 18.07.2017;
- efficiency standards for appliances, with regard to the Commission Regulations implementing Ecodesign Directive 2009/125/EC and labeling of electrical appliances, according to Regulation (EU) 2017/1369 of 04.07.2017;
- labeling and ecodesign requirement concerning space heaters, water heaters, and solid fuel boilers included in Commission Regulations 811/2013 of 18.02.2013, 812/2013 of 18.02.2013, 813/2013 of 2.08.2013, 814/2013 of 2.08.2013, 518/2014 of 05.03.2014, 2015/1185 of 24.04.2015, 2015/1186 of 24.04.2015, 2015/1187 of 27.04.2015, 2015/1188 of 28.04.2015, and 2015/1189 of 28.04.2015;
- individual billing of heat supply in multi-family residential buildings (MEE, 2014);
- obligatory control of air conditioning and water heating systems, according to the Bulgarian Regulation RD-16–932 of 23.10.2009;
- individual targets for the energy suppliers with annual sales of electricity or heat exceeding 20

GWh, gas exceeding 1 million m^3, or non-transport liquid fuels exceeding 6500 tons to achieve energy savings amounting to 1,5% of their annual sales in 2018, 2019, and 2020 (EEA 2018).

There are also economic and fiscal instruments for EE/RES in households:

- National Programme for Renovation of Residential Buildings, providing up to 100% grant for the energy renovation of multi-family buildings (MRDPW, 2018) and with a total capitalization (as of the end of 2017) of 2 billion BGN (1.02 billion euros)[3];
- Residential Energy Efficiency Credit Line (REECL), combining loans and limited grants either for the comprehensive home renovation or for individual EE / RES measures in homes;
- Energy Efficiency and Renewable Sources Fund (EERSF), providing technical assistance, loans, and guarantees for energy renovation of residential buildings;
- property tax exemption for up to 10 years for high-energy performance buildings constructed before 2005, as stipulated in the Bulgarian Excise Duties and Tax Warehouses Act. The concrete period depends on both the energy class of the building and the availability of RES utilization.

In addition to the current PIs, there are planned ones in the draft Integrated National Energy and Climate Plan (Ministry of Energy, 2019):

- establishment of favorable conditions for the development of "renewable energy cooperatives" with the participation of residential consumers;
- urban planning ensuring high penetration of renewables in residential and other areas;
- support for decentralized heat production from RES;
- informational and education about EE;
- obligatory phase-out of inefficient heating appliances using solid fuels.

[3] https://www.mrrb.bg/bg/pravitelstvoto-otpusna-na-mrrb-vtoriya-miliard-za-nacionalnata-programa-za-energijna-efektivnost-na-mnogofamilni-jilistni-sgradi/

Methodology

Steps

The proposed methodology aims to facilitate policymakers in the selection of effective policies for the promotion of EE/RES by considering and reducing the impact of behavioral barriers on EE/RES targets. Its steps are as follows:

1. mapping, merging, and grouping identified behavioral barriers for end-users of the examined sector;
2. calculation of the impact factor for each one of these barriers that prevent the achievement of the set targets for the examined sector;
3. development of scenarios and their assumed policy mixture based on the incorporated behavioral barriers and selecting the most promising combination of EE and RES technologies for the energy modeling;
4. evaluating the policy mixtures of the developed scenarios so as to conclude the most appropriate one for the national case.

The methodology is presented analytically in the next paragraphs through the examined case Tables 1, 2, 3, 4, 5, 6, and 7.

Barriers linked with the behavior of end-users (steps 1 and 2)

Step 1 was conducted under previous work. Barriers regarding the penetration of EE/RES

Table 1 WCs and respective CI for the 3 main groups of barriers

First level of barriers	WC	CI
Social–cultural–educational	0,648	0,003 < 0,010
Economic	0,230	
Institutional	0,122	

Table 2 WCs and respective CI for the sub-groups of the first main group of barriers

Second level of barriers	WC	CI
Social	0,539	0,008 < 0,010
Cultural	0,297	
Educational	0,164	

Table 3 WCs and respective CI for social barriers

Social barriers	WC	CI
Social group interactions and status considerations	0,164	0,002 < 0,010
Socio-economic status of building users	0,283	
Strong dependency on the neighbors in multi-family housing	0,283	
Inertia	0,090	
Commitment and motivation of public social support	0,090	
Rebound effect	0,090	

Table 4 WCs and respective CI for cultural barriers

Cultural barriers	WC	CI
Lack of interest/low priority/undervaluing energy efficiency	0,250	0,000 < 0,010
Customs, habits, and relevant behavioral aspects	0,250	
Bounded rationality/visibility of energy efficiency	0,250	
Missing credibility/mistrust of technologies and contractors	0,250	

Table 5 WCs and respective CI for educational barriers

Educational barriers	WC	CI
Lack of trained and skilled professionals/trusted information, knowledge, and experience	0,333	No CI for 2 × 2 matrix
Lack of awareness/knowledge on savings potential/information gap on technologies	0,667	

Table 6 WCs and respective CI for economic barriers

Economic barriers	WC	CI
Lack of any type of financial support (lack of financial incentive (public and private sector)/lack of funds or access to finance)	0,205	0,007 < 0,010
High capital costs/financial risk/uncertainty on investment/high cost of innovative technologies for end-users	0,347	
Payback expectations/investment horizons	0,114	
Relatively cheap energy and fuel prices/misleading tariff system not reflecting correct prices for energy use/EE	0,114	
Unexpected costs (hidden costs/costs vary regionally (fragmented ability))	0,069	
Financial crisis/economic stagnation	0,036	
Embryonic markets	0,114	

technologies and their supporting policies were mapped through bibliographic research and survey (HERON, 2017; Mavrakis & Konidari, 2017). Under this bibliographic research, national action plans, strategies, national communications, reports from target groups (associations of household owners, chambers, projects, etc.), and published papers concerning seven countries (Bulgaria (BG), Estonia (ES), Germany (GE), Greece (GR), Italy (IT), Serbia (SR), and United Kingdom (UK)) were used. In the first phase, the work concluded for the building sector with 28 barriers for BG, 32 for ES, 23 for GE, 62 for GR, 14 for IT, 13 for SR, and 84 for UK (HERON, 2017). This is an extended number of barriers in total, but most of them had the same or similar content and different names. So, they were merged and grouped into three main categories: (i) social–cultural–educational, (ii) economic, and (iii) institutional (HERON, 2017; Mavrakis & Konidari, 2017). The finally used names for the barriers were selected carefully so that to show the main characteristic of the barrier and to ensure its appearance in any of the seven countries for which it was identified (Table 8). Under the survey, EE/RES experts

Table 7 WCs and respective CI for institutional barriers

Institutional barriers	WC	CI
Split incentive	0,173	0,000 < 0,010
Legislation issues (lack of relevant legislation/lack of regulatory provision/change of legislation for local/ regional administrative division/complex/inadequate regulatory procedures)	0,351	
Building stock characteristics/aging stock/historical preservation	0,087	
Poor compliance with efficiency standards or construction standards/technical problems/performance gap/ mismatch	0,087	
Lack of data/information-diversion of management	0,087	
Barrier to behavior change due to problematic Implementation Network (IN)/governance framework (inadequate IN/governance framework/inadequate implementation of policy measures/poor policy coordination across different levels/cooperation of municipalities)	0,087	
Disruption/Hassie factor	0,087	
Security of fuel supply	0,043	

from all aforementioned countries were contacted by phone and e-mails and were asked to answer to a set of questions based on the outcomes of the bibliographic research, verify the identified barriers, and rank them in importance using experience and personal judgment. Collected answers were elaborated statistically.

Under step 2, the impact factor (IF) was calculated for each one of the barriers in Table 8. The IF of a barrier is defined as the AHP weight coefficient of the barrier expressing its importance to the goal of the AHP tree (Fig. 2). The authors used for the calculations the innovative HERON Decision Support Tool (HERON-DST), developed by the Energy Policy and Development Centre (KEPA) in cooperation with App-Art (HERON-DST, 2017). It is a user-friendly software which enables the quantitative transformation of the qualitative characteristics of behavioral barriers that hinder the implementation of EE/RES technologies/policies in the residential and transport sector. HERON-DST also facilitates users/policymakers in selecting the optimum combination of technologies/practices and minimizing the negative impact of barriers in the implementation of EE/RES scenarios. Two independent scientific committees of experts evaluated the tool and verified its uniqueness, reliability, and functionality (HERON, 2017).

HERON-DST includes the final set of 27 barriers specific for the building sector as the outcome of step 1 (Table 8) grouped in an AHP tree (Fig. 2). These barriers are compared pair-wised, and the importance of one barrier over the other is assessed using a 1–9 scale. Each number on this scale reflects a different level of importance, according to the analytical hierarch process (AHP) (Mavrakis & Konidari, 2017). These numbers assigned during each pair-wised comparison were based on the conducted bibliographic research and the survey, both specifically for the Bulgarian case. The rationality of understanding how important one barrier is over another was based on (i) the number of different sources that mention the barrier; (ii) the number of subsectors affected by the barrier; (c) the governance level at which the barrier is encountered (local, regional, or national); (d) its recorded duration; (e) the number of different PIs linked with the barrier; and (f) the survey outcome (Annex I in the work of HERON, 2017).

Through these comparisons (inputs from the user), HERON-DST calculates the impact factor (IF) for each one of the barriers. Details about the mathematical background of the calculations are presented in previously published work (Mavrakis & Konidari, 2017). The AHP methodology is used for the calculation of the IFs and the respective random ratios of consistency (CR*) (Mavrakis & Konidari, 2017). A matrix is consistent (outcomes reliable) if CR* < 0.10. If this precondition is not fulfilled, then, the CR* value should be adjusted. This is done by reassigning the assessments and checking again the importance of one object (here for the group of barriers) over the other (Mavrakis & Konidari, 2017). The CR* – calculated by HERON-DST using again the inputs of the user – ensures the credibility of the calculated IFs. Since most of the users of the HERON-DST are not familiar with the whole AHP methodology for simplicity reasons, the CR* is called for them as a

Table 8 Impact factors of barriers concerning the Bulgarian residential sector (HERON, 2017; Mavrakis & Konidari, 2017)

Type	Name of barrier	Impact factor
Social	Social group interactions and status considerations	**0.057**
Social	Socio-economic status of building users	**0.099**
Social	Strong dependency on the neighbors in multi-family housing	**0.099**
Social	Inertia	**0.031**
Social	Commitment and motivation of public social support	**0.031**
Social	Rebound effect	**0.031**
Cultural	Lack of interest/low priority/undervaluing energy efficiency	**0.048**
Cultural	Customs, habits, and relevant behavioral aspects	**0.048**
Cultural	Bounded rationality/visibility of energy efficiency	**0.048**
Cultural	Missing credibility/mistrust of technologies and contractors	**0.048**
Educational	Lack of trained and skilled professionals/trusted information, knowledge, and experience	**0.035**
Educational	Lack of awareness/knowledge on savings potential/information gap on technologies	**0.071**
Economic	Lack of any type of financial support (lack of financial incentive (public and private sector)/lack of funds or access to finance)	**0.047**
Economic	High capital costs/financial risk/uncertainty on investment/high cost of innovative technologies for end-users	**0.080**
Economic	Payback expectations/investment horizons	**0.026**
Economic	Relatively cheap energy and fuel prices/misleading tariff system not reflecting correct prices for energy use/EE	**0.026**
Economic	Unexpected costs (hidden costs/costs vary regionally (fragmented ability))	**0.016**
Economic	Financial crisis/economic stagnation	**0.008**
Economic	Embryonic markets	**0.026**
Institutional	Split incentive	**0.021**
Institutional	Legislation issues (lack of relevant legislation/lack of regulatory provision/change of legislation for local/regional administrative division/complex/inadequate regulatory procedures)	**0.043**
Institutional	Building stock characteristics/aging stock/historical preservation	**0.011**
Institutional	Poor compliance with efficiency standards or construction standards/technical problems/performance gap/mismatch	**0.011**
Institutional	Lack of data/information-diversion of management	**0.011**
Institutional	Barrier to behavior change due to problematic implementation network (IN)/governance framework (inadequate IN/governance framework/inadequate implementation of policy measures/poor policy coordination across different levels/cooperation of municipalities)	**0.011**
Institutional	Disruption/Hassie factor	**0.011**
Institutional	Security of fuel supply	**0.005**

consistency index (CI), attributing the core meaning of the index and facilitating them in understanding when the condition is not fulfilled. This index is used as a measure of inconsistency so as to identify (i) possible errors in the expression of the judgments and (ii) actual inconsistencies in the judgments themselves (Talib et al., 2011; Damjan et al., 2016).

The respective weight coefficients (WC) and the CIs are presented in Tables 1, 2, 3, 4, 5, 6, and 7 and the final IFs in Table 8. Indicatively, the IF for the barrier "social group interactions and status considerations" is calculated by multiplying $0{,}164 \times 0{,}539 \times 0{,}648$ (Table 8). IF is "a numerical outcome, expressing the contribution of the concerned barrier in preventing the achievement of the respective EE/RES targets." So, the IF of the barrier "split incentive" for the Bulgarian case is equal to 0.021, meaning that it contributes by 2.1% in preventing any defined EE/RES target. For another country, the IF of this barrier has a different value.

The calculated IFs allow the incorporation of barriers in energy modeling. The total impact of the

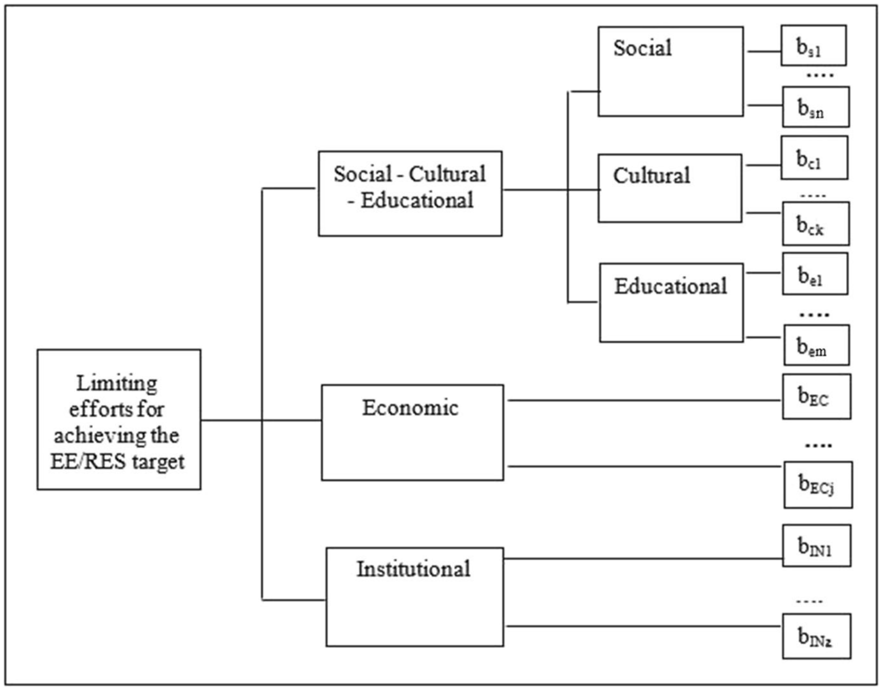

Fig. 2 AHP tree for behavioral barriers

assumed barriers on a certain technology/practice or measure is expressed by the total impact factor (TIF) also calculated with HERON-DST. Consequently, the penetration of each one of the EE/RES technologies/practices is linked with the relevant barriers through their TIFs also provided by HERON-DST (Mavrakis & Konidari, 2017). The tool provides the user with promising combinations of EE/RES technologies/practices in a hierarchical order. The user has the option to select which of the related barriers are to be tackled in view of achieving maximum or efficient progress toward targets. These promising combinations of EE/RES technologies/practices are identified based on (i) their higher number of common barriers and (ii) the lower TIF of barriers that they have as a combination of selected technologies compared to all other combinations (Mavrakis & Konidari, 2017). Mathematical details are explained in the published work (Mavrakis & Konidari, 2017).

In this manner, combinations that are placed first in this hierarchy are more preferable to the others because efforts for minimizing the common barriers will affect the penetration of all involved technologies. So, (i) overcoming the set of these barriers as a group requires less effort compared to other combinations, and (ii) the barriers of this set will be more manageable in being confronted and will more likely allow us to reach easier the set/expected EE target compared to others (Mavrakis & Konidari, 2017). Now, outcomes are available to be used as inputs to EE/RES scenario modeling. Steps 1 and 2 were used for calculating the IFs for all seven aforementioned national cases. Calculations show the different IF values that barriers have across these cases, exactly because each country has its own particularities and perceptions.

Development of scenarios (step 3)

The Long range Energy Alternatives Planning system (LEAP) – developed by the Stockholm Environment Institute – is a widely used tool for energy policy and climate change mitigation assessment (LEAP, 2022). It can be used to (i) track energy consumption, production, resource extraction, and GHG emissions in all economic sectors (Heaps, 2016), (ii) create models of different energy systems, and (iii) support a wide range of modeling methodologies on the (a) energy demand side (bottom-up, end-use accounting techniques to top-down macroeconomic modeling) and (b) supply side (powerful accounting and simulation methodologies for modeling electric sector generation and capacity expansion planning) (Heaps, 2016).

Six scenarios were developed and modeled in LEAP for this paper. These were as follows:

A. **Business as usual (BAU) scenario:** It concerns possible current trends until 2030 with policy measures/instruments already implemented. 2030 is selected due to EU decisions on energy and climate change policy issues.

B. ***B0 scenario:*** It reflects a forward-looking path leading to the desired situation, i.e., to achieve the maximum possible amount of EE improvements and RES penetration based on the national potential. It is the synthesis of sub-scenarios, each one concerning one of five (5) household energy needs leading to EE improvements and/or increased RES use. The Bulgarian EE/RES market was investigated through bibliographic research, and only the available in-country technological options were used. More specifically:

1. Efficient heating: penetration of heat pumps (such as air-to-air, water source, and geothermal) and of highly EE/RES heating systems (biomass systems with high performance, efficient central heating systems, etc.). The sub-scenario aims the replacement of heat systems currently using direct electricity with the aforementioned ones, which are more efficient.
2. Building shell improvement (building fabric upgrade): improvement of insulation (in walls, windows, roof, and floor), resulting in decreased energy intensity of the space heating for all housing types. By 2030, the renovated buildings need to comply with the Class A energy certificate. Building shell improvement assumed targets are differentiated for single and multi-family buildings in LEAP.
3. Efficient cooling: penetration of highly EE air conditioning (up to A+++class).
4. Efficient appliances: penetration of highly EE/RES appliances including cooking devices and water heaters (energy class A++and better).
5. Efficient lighting: penetration of efficient LED (replacing incandescent and compact fluorescent lamps).

Each EE/RES technology is assumed to be supported by the respective national policy mixture (Table 9). The impact of behavioral barriers is not taken into consideration in this scenario, which is theoretically an ideal one (barrier zero – B0).

C. **B1 scenario:** It reflects the B0 scenario but after incorporating the impact of barriers whose existence prevents the achievement of the B0. With the use of the HERON-DST, the deviation from B0 (i.e., due to the impact of barriers) is now quantified.

The next scenarios (B2, B3, and B4) introduce additional policy instruments so that a specific set of barriers is addressed and preferred combinations of three EE/RES technologies are promoted. Combinations with more technologies can also be used, but for the purposes of this paper, the authors used three technologies in each scenario. Although ideally, all barriers could be addressed, it is considered that due to limited resources – financial, administrative, availability of technicians, etc. – it is more feasible to address only a few barriers simultaneously. The promising sets of addressed barriers around which the below scenarios are structured are identified by HERON-DST.

D. **B2 scenario:** It is based on the B1 scenario, but here the impact of selected barriers is minimized and justified by the assumption of introducing additional or more effective PIs. The specific set of addressed barriers is selected by the user after taking into account one of the most promising combinations of EE/RES practices/technologies presented by HERON-DST. For this scenario, the minimization of selected barriers hindering "Building Shell Improvement (BSI)" is extended to the other two additional technologies that share the selected common barriers with BSI – i.e., "Efficient Cooling" and "Efficient Heating." The assumed policy package is part of Table 9 along with barriers of minimized impact. These new values of the IFs are calculated by HERON-DST.

E. **B3 scenario:** It reflects the improved B1 scenario, looking at the second combination of EE/RES technologies/practices. Its focuses on barriers concerning "Efficient Heating." The minimization effect, due to common barriers, on the other two technologies – "Efficient Cooling" and "Efficient Lighting"– was considered too. Its assumed policy package includes PIs already assumed under B0 along with the new/enhanced

Table 9 Policy package of B2 scenario of Bulgarian residential sector

EE/RES technologies/actions	Additional PIs compared to BAU (B0 and B1 policy mixture)	Minimized impact of barriers	Additional PIs for confronting barriers and minimizing their impact
Efficient heating	-Financial incentives, e.g., REECL program (loan and grant) -Information campaigns	Common barrier with "Building Shell improvement": lack of financial support	-Widely available financial incentives, consisting of a combination of a soft loan and grant, e.g., the REECL program -Fiscal incentives (lower property tax or income taxes)
Building shell improvement (priority)	-100% grant (period 2014–2019) -Soft loan + 50% grant (period 2020–2024) -Soft loan + 25% grant (period 2025–2030) -Information campaigns	-Split incentives (institutional) -Socio-economic status of building owners (social) -Strong dependency on neighbors (social) -Poor compliance (institutional) -Lack of financial support (economic) -Legislation issues (institutional) -High costs and risks (economic)	-Regulation of owner-tenant relationship in case of renovation -Stricter legislative requirements for renovation and stricter control (i.e., penalties) of compliance -Transparent selection of renovation companies
Efficient cooling	-Financial incentives, e.g., the past REECL program (loan and grant) -Information campaigns	Common barrier with "Building Shell improvement": lack of financial support	-Widely available financial incentives, consisting of a combination of a soft loan and grant, e.g., REECL program -Fiscal incentives (lower property tax or income taxes)
Efficient appliances	-Financial incentives, e.g., the past REECL program (loan and grant) -Information campaigns -Training		None
Efficient lighting	-Information campaigns -Regulatory restrictions banning the use of incandescent lamps		None

Table 10 Policy package of B3 scenario

EE/RES technologies/actions	Minimized impact of barriers	Additional PIs for confronting barriers
Efficient heating (priority)	-Lack of experienced professionals (educational) -Lack of financial support (economic) -Misleading prices (economic)	-Training/certification of designers and installers -Improved energy tariffs (removal of subsidies, inclusion of externalities) -Widely available financial incentives for residents, e.g., REECL program (loan + grant) -Fiscal incentives (lower property tax or income taxes) -Information campaigns for residents
Building shell improvement	No minimized barriers to this technology	Same as in B0 and B1
Efficient cooling	This technology benefits from the minimization of common barriers with "efficient heating," namely, lack of financial support and misleading prices	-Improved energy tariffs (removal of subsidies, inclusion of externalities) -Widely available financial incentives for residents, consisting of a combination of a soft loan and grant, e.g., REECL program -Fiscal incentives (lower property tax or income taxes);
Efficient appliances	No minimized barriers to this technology	Same as in B0 and B1
Efficient lighting	This technology benefits from the minimization of common barriers with "efficient heating," namely, lack of financial support	Financial support for the low-income population to purchase LED (e.g., vouchers)

Table 11 Policy package of B4 scenario

EE/RES technologies/actions	Minimized impact of barriers	Additional PIs for confronting barriers
Efficient heating	No minimized barriers to this technology	No
Building shell improvement (priority)	Same as in Table 2	Same as in Table 2
Efficient cooling	No minimized barriers to this technology	No
Efficient appliances	This technology benefits from the minimization of the common barriers with "building shell improvement," namely, lack of financial support, high costs, and risks	Financial incentives, e.g., the past REECL; fiscal incentives for purchasing A + + or better appliances
Efficient lighting	This technology benefits from the minimization of common barriers with "building shell improvement," namely, lack of financial support, high costs, and risks	Financial support for the low-income population to purchase LED (e.g., vouchers)

PIs for minimizing barriers to "Efficient heating" (Table 10).

F. **B4 scenario:** It reflects the improved B1 scenario through the third most promising combination of EE/RES technologies/practices. In this scenario, the user minimizes the impact of selected barriers linked by "BSI" and considers their impact not only on that technology but also on "Efficient Appliances" and "Efficient Lighting." Its assumed policy package is in Table 11.

Scenario evaluation method (step 4)

The evaluation of the developed scenarios is carried out using the multi-criteria evaluation method AMS, a combination of three standard multi-criteria methods: analytical hierarchy process (AHP), multi-attribute utility theory (MAUT), and simple multi-attribute ranking technique (SMART) (Konidari & Mavrakis, 2007). It has been used in the evaluation of similar policy mixtures (Matsumoto et al., 2017; Nikolaev & Konidari, 2017).

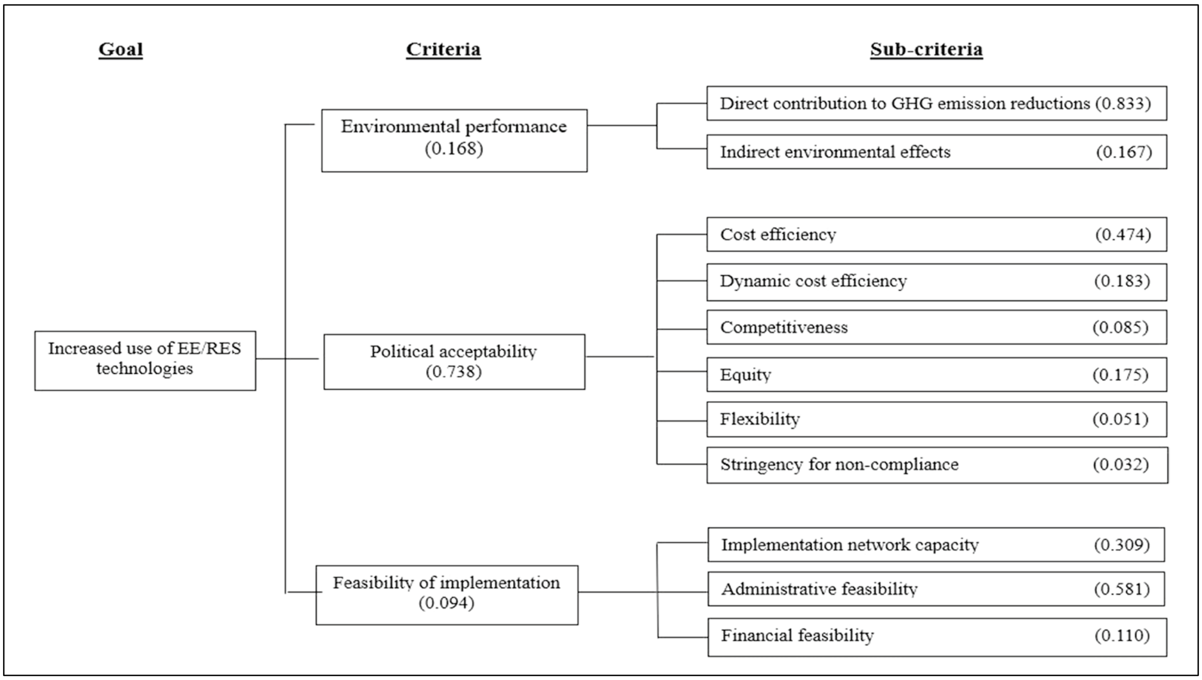

Fig. 3 AHP hierarchy in the AMS method (revised version of figures in Konidari and Mavrakis (2006, 2007)

AMS method consists of four steps. The first one is creating the criteria tree. It consists of 3 criteria – environmental performance, political acceptability, and feasibility of implementation – and 11 sub-criteria (Fig. 3). Definitions are provided in Appendix 1. Step 2 is for determining weight coefficients for criteria/sub-criteria using the method AHP. For this paper, the used weight coefficients are from already published work (Konidari & Mavrakis, 2006; Matsumoto et al., 2017; Nikolaev & Konidari, 2017) and are in parenthesis in Fig. 3. These weight coefficients reflect the cumulative global understanding – over a fifteen-year period – about the contribution of each criterion/sub-criterion in the overall effective performance of energy and climate policy instruments/mixtures (Matsumoto et al., 2017).

The third step is for grading the performance of the evaluated objects (policy instruments/mixtures, scenarios) under a criterion/sub-criterion. MAUT and SMART are used for assigning the grades. MAUT is used when there are available and credible numerical data for the evaluated objects under the examined sub-criterion. If such data are not available, then SMART is used for assigning grades for the evaluated objects based on the experience of the expert and the available qualitative information. The grades of SMART are calculated into normalized grades on the scale [0, 100], the same as the MAUT scale of grades (Konidari & Mavrakis, 2007), i.e.,

$$normalized\ grade = \frac{(\sqrt{2.51})^{m_k}}{\sum_{k=1}^{n} (\sqrt{2.51})^{m_k}} \tag{1}$$

where m_k stands for the grade assigned by the user to the object for its performance at the k sub-criterion; n is the number of evaluated objects under the k sub-criterion. The fourth step is about forming the aggregate grade for each evaluated object. First, from the previous step, MAUT and SMART normalized grades of the i-th evaluated object for the k sub-criterion ($G_{i,k}$) are multiplied by the respective weight coefficient of the k sub-criterion (W_k). The sum of all grades for the N sub-criteria under the j-criterion forms the grade of the i-th evaluated object for the j-criterion ($G_{i,j}$), i.e.,

$$G_{i,j} = \sum_{k=1}^{N} W_k G_{i,k} \tag{2}$$

Secondly, these grades ($G_{i,j}$) are multiplied with the respective weight coefficient of the j-criterion (W_j) and provide the aggregate grade. Sensitivity analysis is also performed on the final outcomes (Konidari & Mavrakis, 2007).

Table 12 Evaluation under "direct contribution to GHG emission reductions" and "indirect environmental effects"

Scenarios	Direct contribution to GHG emission reductions		Indirect environmental effects	
	Direct GHG emissions in $MtCO_2$ for year 2030	Grades under MAUT scale of AMS [0–100]	NO_x emissions in $MtCO_{2eq}$ for year 2030	Grades under MAUT scale of AMS [0–100]
BAU	1.22	0.0	4.21	0.0
B0	0.99	100.0	3.41	100.0
B1	1.12	43.5	3.85	45.0
B2	1.06	69.6	3.66	68.8
B3	1.06	69.6	3.65	70.0
B4	1.07	65.2	3.69	65.0

Results and their evaluation

Evaluation against AMS criteria

This section presents the evaluation of the developed scenarios under the respective AMS criteria/sub-criteria (Fig. 3). Criteria tree and weight coefficients of the criteria/sub-criteria are used from previously published papers (Matsumoto et al., 2017; Konidari & Mavrakis, 2007). Steps 3 and 4 of the AMS method are applied in the next sections.

Criterion 1: environmental performance

Sub-criterion – direct contribution to GHG emission reduction: For this part of the evaluation, the LEAP outcomes for the total expected GHG emissions in 2030 are used. Due to the availability of these numerical data, the MAUT part of the AMS method is applied. A linear function $y = ax + b$ is used to calculate the normalized grades on the scale of [0,100] (Konidari & Mavrakis, 2006, 2007). Coefficients (a, b) are calculated with the conditions: The scenario with the lowest amount of emissions is considered as the most effective one under this sub-criterion (grade 100 is assigned). The scenario with the highest amount of GHG emissions is evaluated as the worse one (grade 0). Data and results are presented in Table 12.

Sub-criterion-indirect environmental effects: The total environmental effects provided by LEAP are used as the base. MAUT part is used again for calculating the grades. Due to a lack of historical data, only the NO_x emissions are used. LEAP outcomes and respective grades are presented in Table 12.

Criterion 2: political acceptability

Sub-criterion – cost-effectiveness: First, the authors calculated the net cost saving per unit of energy saved for each technology – see Table 13. The net present value (NPV) per annual kWh saved (column 5) was calculated considering the investment cost per annual energy saved (column 2 – most values are from World Bank, (2018)) and the cost saving per kWh (column 4) over the technology lifetime (column 3). The energy price (column 4) represents the avoided cost due to decreased energy consumption. A discount rate of 3% has been applied to the cash flows (World Bank, 2018; The European Council for an Energy Efficient Economy (ECEEE) & Ecofys 2015; BPIE & Fraunhofer ISI, 2015). NPV per kWh saved (column 6) was calculated by dividing NPV per annual kWh saved (column 5) by the lifetime (column 3). Values in column 7 are equal to those of column 6, but expressed in a different unit.

The next step is to calculate the contribution of each technology to the total energy and cost savings of each scenario. For a given scenario, LEAP results show the energy savings due to the penetration of each technology (column 2 of Table 14). As some technologies affect others – i.e., building shell improvement, efficient heating, and efficient cooling technologies have cross-impact – the sum of all individual technology savings differs from the total scenario energy savings, so correction is applied (column 3). Then, this result is multiplied by the net cost saving of the respective technology (last column of Table 13). All calculations for EE/RES B0 scenario are illustrated in Table 13. The key technological assumptions used for these calculations are presented in Table 14.

Table 13 Cost savings for the 5 technologies/measures

Technology/measure	Investment per annual energy saved (BGN/annual kWh saved)	Lifetime[1]	Energy price (BGN/kWh)[2]	NPV (BGN per annual kWh saved)	NPV (BGN per kWh saved)	NPV (million BGN per ktoe saved)
Building shell improvement	1.135[3]	27	0.13	1.211	0.045	0.52
Efficient heating	1.82	20	0.13	0.111	0.006	0.06
Efficient lighting	1.65	15	0.16	0.252	0.017	0.20
Efficient cooling	1.52[4]	10	0.16	−0.151	−0.015	−0.18
Efficient appliances	1.79[5]	12	0.16	−0.192	−0.016	−0.19

[1]Source: Regulation E-RD-04–3 from 4.05.2016 2018

[2]Source: EWRC 2019

[3]Source: World Bank 2018

[4]Source: Methodology for the evaluation of energy savings in air-air heat pumps in buildings 2017

[5]Source: ADEME 2016

Table 14 Contribution of each technology to the total EE-B0 energy and cost savings

Technology	2030 energy saving, compared to BAU, ktoe (Source: LEAP)	2030 energy saving corrected[1], ktoe	2030 net cost saving[2], million BGN
Building shell improvement	170.3	164.2	85.4
Efficient heating	188.8	182.0	10.9
Efficient lighting	41.0	41.0	8.2
Efficient cooling	17.0	16.4	−3.0
Efficient appliances	36.1	36.1	−6.9
Sum	453.1	439.6	94.7
All technologies combined (total B0)	439.6	-	

[1]The savings from building shell improvement, efficient heating, and efficient cooling are multiplied by a correction coefficient of 0.964 due to cross-impact

[2]Calculated from an end-user perspective for simplicity. A societal perspective (excluding subsidies, excise duties, taxes, etc.) would provide more relevant results, but as the assigned grades do not depend on the absolute (but only relative) values, the deviation is negligible

The same procedure is followed for the calculation of the net cost savings of the other scenarios. Based on the net cost savings, a linear function is used again to assign the grades under the MAUT scale. Results are presented in Table 15.

Sub-criterion – dynamic efficiency: There are significant investment gaps in EE and RES (E3G, 2019). Innovative EE/RES technologies are not supported directly by PIs. Almost all scenarios promote moderately, but equally, the usage by the end-users of mature and innovative technologies following European and international trends. Research and development of such technologies are equally supported, too.

The B4 scenario has higher penetration rates for innovative technologies (Table 16). Its policy package is expected to support more their penetration in achieving these outcomes. If there were additional PIs targeting specifically these technologies, then the assigned grades could have been higher. The importance of additional PIs is based on the fact that households have no preference for energy options – whether it is nuclear, coal, gas, or renewables. They are mostly concerned about energy costs and not on

Table 15 Evaluation under "cost-effectiveness" and "dynamic efficiency"

Scenarios	Cost-effectiveness		Dynamic efficiency	
	Net cost saving, million BGN	Grades under MAUT scale of AMS [0–100]	Grades under SMART scale of AMS [0–10]	SMART Grades converted to grades of MAUT scale of AMS [0-100]
BAU	0	0.00	5	8.45
B0	96.4	100.00	6	13.38
B1	43.5	45.1	6	13.38
B2	78.8	81.7	6	13.38
B3	48.8	50.6	7	21.20
B4	70.7	73.3	8	30.21

Table 16 2030 Market penetration shares per technology and scenario (Source: outcomes of HERON-DST, version 1.08).

	BAU	B0	B1	B2	B3	B4
Efficient heating						
2030: share of dwellings that switch from direct use of electricity to electrical heat pumps	0%	16%	7.4%	11.0%	**13.6%**	7.4%
2030: average efficiency of biomass and coal-fired heating technologies	54%	62%	57.6%	59.2%	**60.7%**	57.6%
Building shell improvement						
2030: share of high-performance existing single-family buildings	24%	38%	30.3%	**35.7%**	30.3%	**35.7%**
2030: share of high-performance existing multi-family buildings	28%	48%	37.0%	**44.7%**	37.0%	**44.7%**
Efficient cooling						
2030: average SCOP of air conditioners	3.20	4.00	3.56	3.72	**3.78**	3.56
Efficient appliances						
Use of induction stoves by 2030	20%	50%	33.5%	33.5%	33.5%	**40.1%**
Penetration of tankless water heaters	20%	50%	33.5%	33.5%	33.5%	**40.1%**
Decrease of energy consumption in other appliances, compared to BAU	0%	– 10%	– 4.5%	– 4.5%	– 4.5%	**– 6.7%**
Efficient lighting						
2030 share of efficient LED	40%	80%	58.0%	58.0%	65.5%	**72.2%**

Numbers in boldface indicate the higher value per technology and scenario, for facilitating the reader to see the respective numbers

carbon footprint. They prefer to use electricity from the grid since regulated prices are still low and subsidized, especially when compared to the distributed RES options. They might support small RES in their homes because of proper incentives together with affordable financial options (Center for the Study of Democracy, 2018).

Due to the absence of numerical data, the AMS user assigns the grades from the SMART scale [0–10] to each scenario based on experience and available information; 10 is the highest grade that the user can assign to a scenario if according to his/her judgment the performance of the scenario under the specific sub-criterion is worth that grade. The grades are then normalized into grades of the MAUT scale (Eq. (2)) (Konidari & Mavrakis, 2006, 2007).

Sub-criterion – competitiveness: There are no available numerical data to use for comparing the performance of the policy packages of the scenarios under this sub-criterion. Grades are assigned using again the SMART scale [0–10], based on the following information and the HERON-DST outcomes.

The HERON-DST calculated (i) the expected penetration rates of the EE/RES technologies in the examined sector (quoted under B0) as these are affected by the impact of barriers and (ii) how these rates are adjusted if the impact of selected barriers is reduced (minimized). The rationality for the calculation is as follows: The initial market share (in %) of an EE/RES technology is denoted for the reference year, 0, as S_o, while that for the target year due to further penetration, p, is assumed to be

$$S = S_o + p \tag{3}$$

The term «market share» is used with a broad sense since it refers to the respective market of energy end-users depending on the examined sector or subsector of the developed scenario. So, this market can be formed by the energy end-users of the building sector in total or only those of the residential or the tertiary building subsector. When referring to the penetration of LEDs in the building sector, it is the market of all dwellings (or all energy end-users of the building sector) and the share of either selling LEDs or using them in this specific sector. If the scenario assumption refers to the residential dwellings, then the market share of this technology refers to the share of LEDs in being sold or used for lighting by the dwellings of this subsector. This concept can be used for other types of EE/RES targets also.

Because of barriers, the expected share of the technology (S_b) for the target year is

$$S_b = S_o + p_b = S_o + p^*(1 - \mathrm{TIF}) \tag{4}$$

This means that the expected penetration rate is lower in scenario B1. In the other scenarios, the IF of the confronted barriers is reduced. This change rate over time is a linear function, and the reduction of the impact factor is calculated as

$$IF_{t,i} = IF_{o,i}(1 - (\mathrm{c}/15) * t) \tag{5}$$

where $IF_{o,i}$ is the impact factor (IF) of barrier i in year $t=0$ and $IF_{t,i}$ is the IF of barrier i in year t after the implementation of a PI (or PIs) that addresses it; c stands for the assumed reduction percentage due to a PI or a mixture of PIs on the barrier; this reduction means that barrier i contributes less in preventing the achievement of the EE/RES target. For any other year than $t=0$, the $IF_{t,i}$ satisfies the condition $IF_{t,i} < IF_{o,i}$.

For reduction by 20% in the year 2030, Eq. (5) changes to $IF_{t,i}=IF_{o,i}$ (1–(0,2/15)*t) referring to a time interval of 15 years (starting from 2015 and ending in 2030 due to the importance of this year for EU) (Mavrakis & Konidari, 2017). This 20% reduction was selected as an indicative value because: (i) The mapping of the barriers (step 1, Tables 2, 3, 4, 5, 6, 7, and 8) showed that the majority of them remain important for several years despite the implementation of PIs; (ii) there are estimations of 20% higher achievement of the EE target after the implementation of behavioral measures (UNEP, 2014).

For common barriers among the EE/RES technologies, the minimization of the IF is divided equally among these technologies. Table 16 shows these lower and more realistic rates for each technology per scenario. So, if, in 2030, the assumed percentage of dwellings that will switch from direct use of electricity to an electric heat pump is 16%, due to behavioral barriers, this will be lower, reaching 7.4% in B1 or 13.6% in B3 depending on the supporting policy mixture and the confronted barriers. For assigning grades with the SMART, part the following information per scenario was also used.

Under BAU, increased market penetration is expected for insulation materials, efficient windows, and other EE/RES technologies because of the available financial support and the EE/RES requirements, e.g., for NZEBs.

Market trends show accelerated penetration of efficient boilers for firewood, wood pellets, and other solid fuels (coal) since biomass consumption (firewood, wood pellets, chips, etc.) is high. Biomass share in the final energy consumption of households was stable at 33% for the period 2013–2017 (NSI, 2019). A negligible number of straw boilers is imported, but a substantial share of efficient boilers for firewood and wood pellets is locally produced under license. The exact share of imported biomass boilers is unknown. Straw boilers are imported mainly from Denmark and wood/pellets boilers from Germany and Czech Republic (HERON, 2015).

There is growing penetration of air conditioners used for space heating since the share of households equipped with them increased from 32.6% in 2014 to 39.5% in 2018 (NSI 2019). In 2016, 100% of the air conditioners were imported (HERON, 2015).

Penetration of efficient lighting is quick, but 100% of the lamps and devices in the country are imported from China and the EU (HERON, 2015).

Investments for small RES are negatively affected due to existing cross-subsidies in the regulated

Table 17 Evaluation under "competitiveness"

Scenarios	Grades under SMART scale of AMS [0–10]	SMART Grades converted to grades of MAUT scale of AMS [0-100]
BAU	7	13.75
B0	7	13.75
B1	7	13.75
B2	8	19.59
B3	8	19.59
B4	8	19.59

Based on information in Table 16 and the above qualitative information, the authors assigned each scenario grades through the SMART part of the AMS method. Then, these were converted to grades of the MAUT scale [0, 100] (Konidari & Mavrakis, 2006) (Table 17).

Sub-criterion – flexibility: The policy package of the BAU scenario has moderate flexibility, as it provides limited compliance options (financial incentives) to the residents. The number of incentives slightly increases in B0 and B1 scenarios due to the additional policy instruments. In B2, B3, and especially in B4, further financial incentives are introduced to minimize sets of barriers (see Tables 9, 10, and 11). The assigned grades from the SMART scale are presented in Table 17.

Table 18 Evaluation under "flexibility and "stringency for non-compliance"

Scenarios	Flexibility		Stringency for non-compliance	
	Grades under SMART scale [0, 10] of AMS	SMART Grades converted to grades of MAUT scale of AMS [0-100]	Grades under SMART scale of AMS	SMART Grades converted to grades of MAUT scale of AMS [0-100]
BAU	4	7.541	5	11.21
B0	5	12.042	6	17.76
B1	5	12.042	6	17.76
B2	6	19.076	6	17.76
B3	6	19.076	6	17.76
B4	7	30.224	6	17.76

electricity sector, making consumption from the grid more attractive than investment in its own generation. Market penetration is expected to increase because of financial incentives, but there are no provisions that national manufacturers are encouraged to support and invest in these technologies (Center for the Study of Democracy, 2018).

Bulgaria has demonstrated potential for a domestic solar PV industry. Under a better regulatory framework for EE/RES, experience with and skills in solar PV could help the country re-establish a position in the RES market (i.e., selling panels in packages with maintenance to Western European neighbors) (E3G, 2019).

None of the developed scenarios can stimulate the market penetration of EE/RES technologies developed within the country. Based only on current trends and the provided financial incentives, the confronted barriers of B2-4 provide a framework likely to improve national competitiveness toward the aforementioned technologies compared to the other scenarios.

Sub-criterion – stringency for non-compliance The policy package of the BAU scenario is not characterized as stringent for non-compliance cases. Most of the implemented PIs do not have provisions for penalties or sanctions. Under B0, there are "regulatory restrictions for incandescent lighting" (implemented – regulatory PIs). The same assumptions are followed for the other scenarios also. Tables 9, 10, and 11 provide this information, and Table 18 includes the assigned SMART grades for this sub-criterion.

Sub-criterion-equity: Evaluation is based on LEAP outcomes. Using the MAUT procedure, grades are assigned through a linear equation again, whose

Table 19 Energy savings/cap and GHG emissions/cap for 2030 per scenario

Scenarios	2030 energy savings per capita in toe (LEAP outcomes)	2030 GHG emissions per capita in tCO_2eq (LEAP outcomes)	Grades under MAUT scale of AMS [0, 100]		
			Energy savings	GHG emissions	Average
BAU	0	0.193	0	0	0.0
B0	0.069	0.156	100	100	100.0
B1	0.031	0.177	45.1	43.5	44.3
B2	0.044	0.168	63.1	69.6	66.3
B3	0.045	0.168	64.2	69.6	66.9
B4	0.042	0.169	60.8	65.2	63.0

coefficients are calculated specifically for this sub-criterion. Results are presented in Table 19.

Criterion 3: feasibility of implementation

Sub-criterion – implementation network capacity: The entities that form the implementation network (IN) for EE/RES issues are.

a. **National level:** Council of Ministers of the Republic of Bulgaria; Ministry of Energy; Ministry of Regional Development and Public Works;
b. **Local/regional governance level:** municipalities; regions;
c. **Other actors within the national governance level:** Sustainable Energy Development Agency (SEDA); EERSF;
d. **Academic institutions and research institutes;**
e. **Contribution to the national governance level by non-governmental entities:** energy efficiency funds and credit lines;
f. **Regional/local energy agencies.**

The existing capacity of the IN is characterized as very good. More specifically, the EERSF has received, from its official launching until 2017, multiple awards and has been recognized on many occasions for its excellent performance in EE financing (ECOLONER, 2017). It operates as a public–private partnership. For the time period from mid-2006 (when it started functioning) to the end of 2016, EERSF provided EE loans to a total of 185 projects, equivalent to a total project investment of more than 41.6 million USD. It also provided partial credit guarantees or portfolio guarantees to 33 projects (13.3 million USD of total project investment). Using only its initial 15 million USD in capital, the fund catalyzed until 2017 more than 54 million USD in EE investments in Bulgaria. As of December 31, 2016, the EE investments financed or guaranteed by this entity had achieved energy savings of 107,006 MWh/year and avoided CO_2eq emissions of 83,064 kt/year (ECOLONER, 2017).

Training for energy assessors and auditors is offered by four universities.[4] However, the market of energy services (i.e., contracting for energy performance, energy supply, operational contracting, and integrated energy contracting) is still not well developed because of the difficulty to raise affordable finance, high costs of project development and procurement, administrative barriers in the public sector, and complex concept/lack of information (Nikolaev & Andreeva, 2018).

For facilitating the end-users, the energy suppliers also publish energy saving tips on their websites and, in some cases, information about the typical power consumption of the most common household appliances (Republic of Bulgaria, Ministry of Energy, 2015). Nearly all suppliers' websites feature an energy calculator, which customers can use to calculate household energy consumption (Republic of Bulgaria, Ministry of Energy, 2015).

This situation will not change under the developed scenarios unless there are structural changes. The inclusion of training programs and information campaigns improves the performance of the scenario policy packages that included them compared to that of others.

4 www.seea.government.bg/documents/univercities_list.rtf (in Bulgarian language).

Table 20 Evaluation under "implementation network capacity," "administrative feasibility," and "financial feasibility"

Scenarios	Implementation network capacity		Administrative feasibility		Financial feasibility	
	Grades under SMART scale of AMS [0–10]	SMART Grades converted to grades of MAUT scale of AMS [0-100]	Grades under SMART scale of AMS [0–10]	SMART Grades converted to grades of MAUT scale of AMS [0-100]	Grades under SMART scale of AMS [0–10]	SMART Grades converted to grades of MAUT scale of AMS [0-100]
BAU	7	11.96	6	23.89	8	26.79
B0	7	11.96	6	23.89	7	18.80
B1	7	11.96	6	23.89	7	18.80
B2	8	17.04	4	9.44	6	11.87
B3	9	30.03	4	9.44	6	11.87
B4	8	17.04	4	9.44	6	17.87

Based on this information, SMART grades were assigned using a scale [0, 10] (Table 20).

Sub-criterion – administrative feasibility: Out of the institutional barriers, "legislation issues (lack of relevant legislation/lack of regulatory provision/change of legislation)" have the higher impact (Table 1). This is reasonable since the regulatory environment for RES growth has significantly weakened, while various limitations hinder it since 2012/13 (E3G, 2019). The BAU policy package reflects these difficulties in implementation due to overlaps of responsibilities, coordination issues, and shortcomings in the legislation.

The legislation/regulatory practice does not support households and small consumers adequately to invest in small-scale renewables. More specifically, complicated procedures hamper the construction of small rooftop PV systems on residential buildings. Their construction requires obtaining a building permit. This procedure requires a supervision company to monitor the construction of the PV system, the complimentary architectural, electrical, static, and other designs subject to special approval by the municipal administration. A simplified procedure for solar capacities of less than 30 kW was allowed by the amended Land Use Planning Act. Due to changes from 2011, a building permit is not required for installing RES capacities under 30 kW on existing structures (Center for the Study of Democracy, 2018).

Due to additional financial incentives and awareness campaigns, the administrative burden, respectively, will increase under B2, B3, and B4 compared to BAU, B0, and B1. Therefore, their effectiveness is reduced which is reflected in the assigned SMART grades (Table 20).

Sub-criterion – financial feasibility: EU funding plays an important role in the economy. €568 million have been invested into clean energy during the current budget period (E3G, 2019), but there are no available official data about the cost of implementing the current policy package from the perspective of the IN. The required budget in each scenario for the implementation of the proposed PIs is not available since LEAP does not provide such features. Evaluation will be based on the rough financial requirements and the impact of related barriers. In BAU, B0, and B1, the policy package seems to have moderate performance in this sub-criterion since the necessary funds are secured.

Most administrative bodies do not have independent budgets, which preclude the implementation of EE/RES improvement measures (Republic of Bulgaria, Ministry of Energy, 2015). The process of gathering and analyzing the information received from obligated parties shows that there is a lack of sufficient funds for implementing these measures envisaged in municipal and sectoral plans and programs. However, there are some public bodies with access to several EU funds, such as EU Structural and Cohesion Funds and Horizon 2020 projects (notably Concerted Actions), to design and implement EE/RES policies. Assigned grades under this sub-criterion reflecting the aforementioned information are in Table 20.

Table 21 AMS results for each scenario

Criteria	Scenarios					
	BAU	B0	B1	B2	B3	B4
Direct contribution to GHG emission reductions (0,833)	0.00	83.30	36.22	57.95	57.95	54.33
Indirect environmental effects (0,167)	0.00	16.70	7.52	11.48	11.69	10.86
Environmental performance (0,168) – A	**0.00**	**16.80**	**7.35**	**11.66**	**11.70**	**10.95**
Cost-efficiency (0,474)	0.00	47.3	21.72	39.36	24.37	35.31
Dynamic cost-efficiency (0,183)	1.54	2.44	2.44	2.44	3.87	5.51
Competitiveness (0,085)	1.17	1.17	1.17	1.67	1.67	1.67
Equity (0,175)	0.00	17.50	7.86	11.16	11.41	10.65
Flexibility (0,051)	0.38	0.61	0.61	0.96	0.96	1.53
Stringency for non-compliance (0,032)	0.38	0.60	0.60	0.60	0.60	0.60
Political acceptability (0,738) – B	**2.56**	**51.38**	**25.40**	**41.47**	**31.65**	**40.79**
Implementation network capacity (0,309)	3.70	3.70	3.70	5.27	9.28	5.27
Administrative feasibility (0,581)	13.88	13.88	13.88	5.49	5.49	5.49
Financial feasibility (0,110)	2.95	2.07	2.07	1.30	1.30	1.30
Feasibility of implementation (0,094) – C	**1.93**	**1.85**	**1.85**	**1.13**	**1.51**	**1.13**
Total (A + B + C)	**4.49**	**70.03**	**34.59**	**54.27**	**44.86**	**52.88**

The lines in Boldface show the final scores per criterion, after the calculations with the score in the respective sub-criteria

Evaluation outcomes

The final score for the performance of each scenario is calculated (Konidari & Marvrakis 2006). AMS results are presented in Table 21. The reader can see in the last line of the table the total grades of the policy mixtures of the scenarios regarding their effectiveness in achieving the expected EE/RES targets (the higher the grade, the better the scenario). Contributions of each sub-criterion and criterion to this total grade are also presented.

Among all scenarios (except for the "theoretical" B0 which is an ideal scenario without considering the impact of barriers), the one with the highest score was B2 (score of 53.76). Compared with B1, B3, and B4, this one ranked higher in "political acceptability" because it handles better the encountered barriers (coming from the end-users behavior), although it has almost equal evaluation scores for environmental outcomes with B3. It ranked first because of a higher score compared to B3 in "cost-efficiency." Regarding "financial feasibility," it needs equal economic resources from the governmental part with B3 and B4. Its combination of EE/RES technologies, i.e., BSI, efficient heating, and cooling, is the most promising one in delivering the set Bulgarian EE/RES targets.

Sensitivity analysis of evaluation outcomes

Evaluation outcomes of Table 21 are tested for their robustness through sensitivity analysis, i.e., changes in the values of the weight coefficients for criteria A, B, and C (these changes are in Table 22). There were two main changes: (i) The value of one weight coefficient was increased by a certain percentage, while that of another one was reduced by the same percentage (cases 1–6); (ii) the value of one weight coefficient was increased, while that of another remained stable (cases 7–12). In all cases, the sum of the three values had to be 1 and all values had to remain positive. It is indicative that although most changes in the values of weight coefficients were close to 100% (in two cases, even more), the results are characterized as robust since ranking was preserved. For the cases where the increase is from 15 to 25%, one of the three coefficients reached the highest value (from 0.849 to 0.922, close to 1) without having a change in the ranking order.

Conclusion and policy implications

The paper studied five policy scenarios for the Bulgarian residential sector. The B0 scenario is a "theoretical" and unrealistic scenario since it ignores the

Table 22 Sensitivity analysis

Sensitivity analysis case	Changes in weight coefficient of criterion			New values of weight coefficients
	1st	2nd	3rd	
1	Increase by 90%	Decrease by 90%	Modified accordingly	0.319–0.074–0.607
2	Decrease by 15%	Increase by 15%	Modified accordingly	0.143–0.849–0.009
3	Increase by 95%	Modified accordingly	Decrease by 95%	0.328–0.667–0.005
4	Decrease by 98%	Modified accordingly	Increase by 98%	0.003–0.810–0.186
5	Modified accordingly	Increase by 25%	Decrease by 25%	0.007–0.922–0.070
6	Modified accordingly	Decrease by 72%	Increase by 72%	0.631–0.207–0.161
7	Increase by 350%	Modified accordingly	Stable	0.756–0.150–0.094
8	Increase by 55%	Stable	Modified accordingly	0.260–0.738–0.002
9	Stable	Increase 12%	Modified accordingly	0.168–0.826–0.005
10	Stable	Modified accordingly	Increase 360%	0.168–0.399–0.432
11	Modified accordingly	Increase by 22%	Stable	0.006–0.900–0.094
12	Modified accordingly	Stable	Increase by 170%	0.008–0.738–0.254

presence of barriers. B0 was included only to benchmark the effect of the PIs addressing barriers in the "realistic" scenarios. Its final grade is 70 (100 would have been the grade for the perfect option), showing the upper limit for the performance of the other scenarios.

Among the "realistic" scenarios, the most promising is B2. It addresses barriers encountered for "BSI" (see Table 9), but also the effect of minimization on "efficient heating" and "efficiency cooling." The confronted barriers are social, economic, and institutional. Their IFs range from 0.011 to 0.099, with the social ones having the higher negative impact on the expected target. The assumed PIs for confronting them and reducing their IF include wider availability of financial incentives, stricter legislative requirements for renovation, and stricter control of compliance, regulation of owner-tenant relationship in case of renovation, and others (Table 9). By supporting financially low-income families in a multi-family building, the B2 policy mixture addresses the behavioral barriers "socio-economic status of building owners," "lack of financial support," and "high costs and risks." Consequently, it scored higher in "cost-efficiency" and gained "political acceptability."

The IN (mainly the national government) will need funds for overcoming the economic barriers, "lack of financial support" and "high costs and risks." This situation – penetration of EE/RES technologies needs financial support—was mentioned throughout the AMS evaluation, more specifically, at sub-criteria "cost-effectiveness," "dynamic efficiency," "competitiveness," and "financial implementation." On the one hand, the lack of funding to cover the initial investment can be addressed by public support for residents to access loans, for example, through guarantees provided to commercial banks or the establishment of a public fund. On the other hand, as indicated in Table 13, the NPV (BNG per kWh saved) of "efficient cooling" and "efficient appliances" is negative, so subsidies need to be provided to residents to make these technologies financially attractive (with a positive NPV).

B4 scored second, and this is reasonable for the following reasons. Under this scenario, a higher penetration of innovative technologies (BSI, efficient appliances, and efficient lighting) is expected (see "Dynamic cost-efficiency" in Table 21 which is 5.51 – almost double compared to that of B2). This penetration requires more investments from (i) households whose majority is energy-poor ones and (ii) the national IN which has limited financial sources as explained above for the B2 scenario. Also, the combination of "BSI" with "efficient appliances" and "efficient lighting" is less effective in "environmental performance" compared to that of B2. So, BSI with "efficient heating" and "efficient cooling" has better outcomes in this criterion. Furthermore, "efficient heating" is an essential energy service for Bulgarian energy-poor households due to climate conditions and the building characteristics as presented in the "Bulgarian residential sector" section of this paper about the national building sector.

The B2 scenario is only a policy recommendation that policymakers can consider but can be modified according to their requirements. If the B2 approach is not preferred by decision-makers, other pathways can be developed through this methodology. Depending on the needs of the policymaker, developed scenarios can target a specific EE/RES combination and look into barriers and their IFs. This combination may include three or more EE/RES technologies (HERON-DST is designed for combinations of seven EE/RES technologies). If the policymaker selects three technologies, then he/she is facilitated in understanding the different impacts of the barriers in their penetration. A differently selected set of barriers through the HERON-DST demonstrates how differently the other two technologies are affected. This can be observed in scenarios B2 and B3. The first included "BSI," "efficient heating," and "efficient cooling," while the second included "efficient heating," "efficient cooling," and "efficient lighting." In the end, in Table 14, the reader can see that the second one had a lower score than the first one, but also under which criteria/sub-criteria it scored less.

The respectively assumed set of different PIs results in other LEAP outcomes and AMS evaluation. The user decides what to explore, starting from the number of EE/RES technologies, their combination up to the barriers, and the available PIs. The scenario placed at the top of the AMS hierarchy represents the best pathway that most likely would be both effective against the set targets and efficient, considering the national circumstances. The scenario with these two characteristics ("effective against barriers" and "efficient toward national circumstances") is the most appropriate for the examined national case.

This is the main contribution of the paper, a new methodology that leads to the most appropriate scenario. This proposed methodology can be applied to other sectors and other national cases as long as the IFs are calculated based on the end-users behavior. So, the development and comparison of several policy scenarios, each addressing a different set of barriers to the penetration of EE/RES technologies, is shaped according to national circumstances each time. This allows us to identify the best policy mixture appropriate to these circumstances and effective in reducing the gap between the expected target and the actually achieved one. The methodology has been used for other national cases (Estonia, Germany, Greece, Serbia, UK). Further research for additional national cases will allow us to test it even more and understand its weakness and strengths. The set of barriers for the building sector needs to be verified again and if necessary due to a non-identified barrier to be adjusted. More EE/RES technologies need to be added to the HERON-DST and verify which behavioral barriers from the whole set of barriers are linked with each technology specifically.

The research questions quoted in the "Introduction" section are confronted. The incorporation of behavioral barriers led to the development of scenarios with more realistic characteristics and a policy mixture that can be more effective. The methodology provides reliable outcomes (due to consistency tests and sensitivity analysis). Policymakers are facilitated in (a) understanding the impact of behavioral barriers on the expected targets, (b) concluding the combination of EE/RES technologies that will have results closer to the desired target, and iii) based on the AMS outcomes they are in a position to see where a policy mixture scores lower compared to the other ones and attempt to improve it.

Future research on behavioral barriers for EE/RES technologies can explore the time development of their impact, i.e., how weak or strong their impact remains through the years and due to the implementation of applied PIs. Such outcomes will allow the better evaluation of policies and improve their effectiveness.

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Declarations

Conflict of interest The authors declare no competing interests.

Appendix 1 Criteria of the AMS

Definitions of the criteria/sub-criteria are based on the work of Konidari and Mavrakis (2006, 2007) about the AMS method.

1. *Environmental performance* – "the overall environmental contribution of the policy instrument (PI) toward the goal." Assessment under this criterion is based on its two sub-criteria:

   a. *direct contribution to GHG emission reductions* **–** **"**synthesis and magnitude of GHG emissions reductions directly referred to and attributed only to the PI";
   b. *indirect environmental effects* **–** **"**ancillary outcomes attributed only to the PI."

2. *Political acceptability* – "the attitude of all involved entities toward the PI." Assessment is performed through its six sub-criteria:

   a. *cost-effectiveness* **–** "property of the PI to achieve the goal under the perspective of a financial burden acceptable and affordable by the involved entities in using EE/RES (target groups)";
   b. *dynamic cost-efficiency* **–** "property of the PI to create, offer, or allow compliance options that support research projects, incremental and radical pioneer technologies and techniques, and institutional or organizational innovations leading to increase in EE/RES";
   c. *competitiveness* **–** "capacity of the entity to compete, under the particular PI, via price, products, or services with other entities and maintain or even increase the magnitude of specific indicators describing its financial performance";
   d. *equity* **–** "fairness of the PI in cost sharing, compliance costs, and benefits among entities for increasing RES. This equity can be divided into sector and social equity." *Sector equity* – "perceived fairness between different national sectors." *Social equity* – "perceived equity between different groups of society";
   e. *flexibility* **–** "the property of the PI to offer a range of compliance options and measures that entities are allowed to use in achieving the purposes under a time frame adjusted according to their priorities";
   f. *stringency for non-compliance and non-participation* **–** level of rigidity determined by provisions of the policy instrument toward entities that failed to comply or did not participate in its implementation.

3. *Feasibility of implementation (or enforcement)* – "the aggregate applicability of the PI linked with national infrastructural (institutions and human resources) and legal framework." Assessment is based on three sub-criteria:

   a. *implementation network capacity* **–"**ability of all national competent parties to design, support, and ensure the implementation of the PI." "The capacity of the network is based on its *trained personnel*, *technological infrastructure, credibility,* and *transparency." Trained personnel* – "national human resources capable of supporting the implementation of the PI." *Technological infrastructure* – "set of available technologies and techniques within the country that can be used for supporting implementation." *Credibility* – "the accuracy and consistency that characterize the activities of the implementation network, mainly measurements and elaboration of data necessary for implementation, promotion and steering of national compliance efforts." *Transparency* – "openness of the implementation network toward target groups in providing them with clear information for the implementation of the PI and methods of operation."
   b. *administrative feasibility* **–** **"**aggregate work exerted by the regulatory implementation network during the enforcement of the PI";
   c. *financial feasibility* **–** "property of the PI to be implemented with low overall costs by the pertinent regulatory authorities."

Appendix 2 Assessment for the instrument under a sub-criterion (Konidari & Mavrakis, 2006, 2007)

Assessment of performance	Grade by the DM	Grade equivalent to Maut Scale
Null	0	1
Slightly more than null, less than very bad	1	1.58
Very bad	2	2.51
Bad	3	4.01
More than bad less than moderate	4	6.25
Moderate	5	9.98
More than moderate less than good	6	15.81
Good	7	25.05
More than good, less than very good	8	39.69
Very good	9	62.88
Excellent	10	99.62 ≈ 100

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