A methodology to insert end-users behaviour in energy efficiency scenario modelling[13]

by

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Abstract

Deviations from the fulfillment of Energy Efficiency (EE) targets are attributed mainly to barriers created by the behavioral patterns of end-users. The methodology, based on the Analytical Hierarchy Process (AHP), concerns the calculation and interlinkage of the total impact factors of behavioral barriers demonstrated by end-users with the input drivers in the EE modeling. Two sets of behavioral barriers for buildings and transport are provided. Comments, advantages and disadvantages are discussed in the conclusions.

Keywords

Energy efficiency, behavioral barriers, impact factor, energy modelling.

1. Introduction

Energy Efficiency (EE) consists one of the main pillars of efforts to mitigate climate change (IEA, 2014; Energy Efficiency Financial Institutions Group, 2015). There is plethora of policy instruments that support the penetration of EE technologies and practices. Different types of barriers, particularly those linked with end-users behaviour, affect negatively the achievement of such targets (McCollum L. David et al., 2016; European Commission, 2015a, 2015b; European Environmental Agency, 2013). As a consequence, EE policies and measures do not deliver the expected benefits (such as energy savings, reductions in Greenhouse Gases (GHG), employment, poverty alleviation etc) (UNEP, 2014; IEA, 2014).

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According to the Energy Efficiency Communication of July 2014, the EU is expected to miss the 20% energy savings target of year 2020 by 1% - 2% (European Commission, 2015a; 2015b; 2014; European Commission – Directorate - General for Energy, 2012). In 2014, three Member States (Estonia, Malta and Sweden) had not achieved sufficient savings in primary energy consumption (EEA, 2016a). Due to this fact, Malta's 2020 EE target, expressed in final energy consumption, was increased in 2015 from 0.493Mtoe to 0.547Mtoe, becoming less ambitious since this amount is increased instead of being reduced even more (European Commission, 2015a). The Dutch Government lowered its initial reduction target from 30% to 20% (Vringer K. et al., 2016). Three other EU Member States (Germany, Lithuania and Slovakia) had not succeeded in their efforts of reducing sufficiently their final energy consumption so as to remain below their linear trajectory (EEA, 2016b).

Currently, efforts are focused in overcoming existing barriers and increasing the sophistication of energy and economic modelling (European Commission (EC), 2015b; 2014). Key insights in the outcomes of such efforts can guide the effective design and implementation of end-user-focused strategies and public policy interventions to improve the level of EE interventions (by adopting technologies or practices) (Frederiks R. et al., 2015; UNEP, 2014).

Forward-looking models are used for medium-to-long-term scenario analyses, aiming to support relevant policy options; some of these models are designed to consider both technological, economical and socio-behavioral elements in developing the scenarios (McCollum L. David et al., 2016; Knoblocha F., Mercure J.-F., 2016). Bridging the gap between these elements has historically been presented as a challenge (McCollum L. David et al., 2016). Demands of improving the design of models so as to become more 'realistic' by incorporating features observed in the real world are increasing (McCollum L. David et al., 2016). One group of such features of the 'real world' relates to human behaviour. Barriers, related to end-users' behaviour, need to be incorporated in forward looking EE modelling after being identified and analysed (McCollum L. David et al., 2016; EC, 2015a, 2015c; EEA, 2013).

The aforementioned demands are based on the following arguments (McCollum L. David et al., 2016):

i) Models lacking behavioural realism are restricted in evaluating energy efficiency policies and other influences on end-user demand;
ii) Improving the behavioural realism of models consequently affects policy-relevant model analysis of EE as part of the climate change mitigation efforts.

However, current modelling of behavioural features in energy-economy and integrated assessment models is relatively limited (McCollum L. David et al., 2016). Models and particularly Integrated Assessment Models (IAMs) represent the behaviour of consumers or energy end-users through economic relationships: energy demand as a function of price, technology investments to minimize levelized costs, etc (McCollum L. David et al., 2016).

End-user behaviour is complex and rarely follows traditional economic theories of decision-making (McCollum L. David et al., 2016; Frederiks R. et al., 2015; Knoblocha F., Mercure J.-F., 2016). End-users patterns of energy consumption are influenced by social-cultural-educational (status quo, social interactions etc), economic (risks of investment, financial incentives) and institutional factors (split incentives, hassle factor etc) that are characterized as barriers (Vringer K. et al., 2016; Frederiks R. et al., 2015; UNEP, 2014).

Consequently, a methodology inserting end-users' behavior into forward looking EE modeling adds value in efforts to have more reliable EE modeling.

2. Methodology

2.1. Concept

Developed scenarios for EE include as key drivers (or assumptions) the penetration of EE technologies (Building shell improvement, efficient heating and cooling, heat pumps, more efficient vehicles, etc.) and their supportive policy package (energy labelling, building standards, fuel taxes etc) (IEA, 2013; European Communities, 2006). The assumed shares of such technologies combined with the appropriate policy instruments form the synthesis of various scenarios developed with the use of energy models such as LEAP, MARKAL, TIMES, POLES etc (Bhattacharyya C. S. and Timilsina R. G., 2010).

The EE target set for a country depends on the aforementioned combination and the consumers' habits and behavior (IEA, 2013). Each national economic sector has its own EE targets or assigned contribution to the national EE target. Simultaneously, each sector has its own set of barriers towards EE issues (Hochman G. and Timilsina G. R., 2017; Trianni A. et al., 2016; Johnson H. and Anderson K., 2016; HERON, 2015a; HERON, 2015b). Depending on the rationality of these scenarios, assumptions are adopted for overcoming identified existing barriers. Each identified barrier, due to end-users' behavior towards EE issues, has a different impact in limiting the efforts of achieving any type of energy efficiency target. Quantification of the qualitative information of identified barriers allows the numerical expression of the respective impact factors on the inputs for the forward-looking EE modelling.

The proposed methodology transforms qualitative research outcomes about barriers linked to end-users' behavior, into quantitative ones. With the use of the Analytical Hierarchy Process (AHP), comparative analysis is conducted among these barriers due to end users' behavior towards technologies, measures and policy instruments for achieving EE targets. This process reveals and quantifies the negative impact of each barrier on the set of the assumed targets, in EE modeling. Mathematical expressions using the calculated impact factor of barriers provide numerical inputs to energy modelling reflecting the deviation from the set EE target due to end-users' behavior. Once the procedure is completed, the policy maker can modify accordingly the available inputs so as to reduce the calculated deviation.

2.2. *Rationale for the AHP choice*

The selection of the AHP allows pair-wise comparisons among the objects that need to be assessed (either criteria/sub-criteria, alternatives, options or barriers). Furthermore, it has the following advantages:

- *AHP is justified mathematically* (specifically, it is mathematical theory of value, reason and judgment, based on ratio scales) (Eakin H., Bojorquez-Tapia L.A., 2008; Kablan M.M., 2004).
- *AHP presents better the problem.* Its main advantage is the decomposition of the problem into elements (Ishizaka A., Labib A., 2011; Berrittella et al., 2008). Its hierarchical structure of criteria allows users to focus better on specific criteria and sub-criteria when determining the respective weight coefficients through pairwise comparisons (Ishizaka A., Labib A., 2011).
- *AHP allows pairwise comparisons*. Psychologists argue that it is easier and more accurate to express one's opinion only on two alternatives[14] than simultaneously on all (Ishizaka A., Lablb A., 2011). Additionally, the usage of pairwise comparisons does not require the explicit definition of a measurement scale for each attribute (Bozdura F.T. et al., 2007).
- *AHP offers guidelines in defining the weight coefficients and has a consistency test*. "*The AHP approach employs a consistency test that can screen out inconsistent judgments, which*

[14] Since two alternatives form the pairwise comparisons of AHP

makes the results reliable." (Bongchul K. et al., 2017; Kablan M.M, 2004).

- *AHP is suitable for incorporating the preferences of relevant decision makers/stakeholders regarding the importance of the criteria/sub-criteria* (Bongchul K. et al., 2017; Fikret K.T., et al., 2016; Ananda J., Herath G., 2009). Due to this advantage, it has been widely used in energy management, business, maintenance engineering, and medical & health care, strategic planning etc (Da A. et al., 2017; Madeira G. J. et al., 2016). Reservations, though, are expressed that the method may be impractical for a survey with a large sample size of as 'cold-called[15]' respondents, because they may have a great tendency to provide arbitrary answers, resulting in a very high degree of inconsistency (Wong K.W.J., Li H., 2008). But there are scholars that support that it can handle uncertain, imprecise and subjective data (Srdjevic B., Medeiros Y.D.P., 2008; Petkov D. et al., 2007).

- *AHP allows qualitative and quantitative approaches for solving a problem* (Madeira G. J. et al., 2016; Kilincci O., Onal S.A., 2011; Wong J.K.W., Li H., 2008; Duran O., Aguilo J., 2008). The user can deal in this way the inherent subjectivity of the selection process. Pair-wise comparisons are quantified by using a scale (Stefanovic G. et al., 2016).

- *AHP has high popularity.* Comparative analysis of Multi Criteria Decision Analysis (MCDA) approaches has indicated AHP to be the most popular compared to other methods due to its simplicity, easiness to use and great flexibility (Nasirov S. et al., 2016; Kilincci O., Onal S.A., 2011; Ho W. et al., 2010; Srdjevic B., Medeiros Y.D.P., 2008; Duran O., Aguilo J., 2008; Babic Z., Plazibat N., 1998).

  The method reproduces what seems to be a natural method of human mind in perceptions and judgements (Madeira G. J. et al., 2016). It does not require explicit quantification of criteria (Zietsman D., Vanderschuren M., 2014). The users may directly input judgment data without getting into the mathematical background (Duran O., Aguilo J., 2008).

- *AHP has been used only for the determination of the importance of criteria/factors* (alone or in combination with other multi-criteria decision analysis methods) (Kuruoglu E. et al., 2015; Kumar S. et al., 2015; Andrejiova M. et al., 2013).

2.3. Outline and steps

The methodology, based on the AHP, develops a road map consisted of six steps. It starts with "Mapping, categorization and merging behavioral barriers" (step 1), proceeds with the "Development of the AHP tree and matrices" (step 2), the "Calculation of weight coefficients" (step 3), the "Definition and calculation of the Impact Factors of barriers" (step 4), the "Linkage of Impact factors of barriers with technologies and policies (step 5) and concludes with the "Incorporation of the Total Impact Factors in the forward-looking EE modelling" (step 6).

Step 1: Mapping, categorization and merging of behavioral barriers

The mapping of barriers linked with end-users' behavior towards EE issues is defined by the requirements of the EE scenario modelling (sector and EE technologies). Barriers are sought through: i) Bibliographic research (National Action Plans, Strategies, National Communications, reports from target groups (associations of household owners, chambers, projects etc), published papers); ii) interviews or questionnaire survey (Hochman G. and

[15] A telephone call or visit made to someone who is not known or not expecting contact.

Timilsina R. G., 2017; Chiaroni D. et al., 2016; HERON, 2015a; 2015b).

The identified barriers, with the same basic characteristics, are categorized into main groups and sub-groups. Each main group is divided into subgroups if there is a large number of identified barriers. Based on literature research three main groups are foreseen for barriers linked with end-users' behavior: "Social-Cultural-Educational" (S-C-E), "Economic" (EC) and "Institutional" (IN) (Nasirov S. et al., 2016; UNEP, 2014; IEA, 2014, 2013; EEA, 2013; Energy Communities, 2006). The first group is divided into three sub-groups "Social (S)", "Cultural (C)" and "Educational (E)".

Barriers with the same content; behavior or same manner in being handled, are merged into one barrier with a common title. This action is necessary so that the final set of barriers is complete, non-redundant, minimalistic, non-overlapping, mutually independent, decomposable (Zietsman D., Vanderschuren M., 2014; Makropoulos C.K. and Butler D., 2006).

Step 1 based on the aforementioned sources and the findings of the HERON project led to two sets of behavioral barriers with universal use, responding to the needs of forward looking EE modelling for the sectors of buildings and transport (HERON, 2015a; 2015b; 2016). These sets are presented in the next step.

Step 2: Development of the AHP tree and matrices

The mapped and classified barriers into groups and sub-groups of step 1 form the AHP tree. Apart from the structure of groups and sub-groups, the goal (zero level of AHP tree) needs to be determined also. Goal reflects the aim of the tree which is the "limiting efforts for achieving the EE target" due to the impact of each barrier as part of this tree (Figure 1). This EE target can be based on primary or final energy consumption, primary or final energy savings, or energy intensity[16].

The next level is the first level of the AHP tree and is structured with the three main groups of barriers: i) S-C-E); ii) EC and iii) IN. The second level consists of the three sub-groups S, C and E. The other two groups do not have sub-groups (Figure 1). Under each group and sub-group, the identified and merged barriers are classified forming the third level. The two sets of barriers of step 1 with the goal are presented in Tables 1 and 2. The comparison of these two sets shows that: i) The number of classified barriers is different for one sub-group (E) and two groups (EC, IN); ii) there are common barriers between the two sets.

This structure – common for both sectors - is used to form the AHP matrices for the comparative analysis of the next steps. Columns and rows of these matrices refer to the compared *groups* or *sub-groups of barriers* or *barriers themselves* (depending on the level forming the matrix). The AHP matrices are filled in their diagonal with number "1" due to the pairwise comparison of one group or sub-group or barrier with itself. The preferable maximum number for each AHP matrix is 8x8.

Step 3: Calculation of weight coefficients

Step 3.1: First level of pair-wise comparisons

The three *groups of barriers* (S-C-E; EC; IN) are compared using the AHP matrix and scale (Tables 3 and 4). Each cell of the AHP matrix is filled after:

i) comparing the group of each row with the respective group of the column;

ii) assigning the appropriate - according to judgement - intensity from Table 4;

iii) the assignment of the intensity (judgement) is based on the following conditions:

[16] https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive

a. the first group is more important compared to the second one if the number of the identified barriers under the first group of barriers is higher compared to those under the second one;

b. the first group is more important compared to the second one depending on the level of difficulty with which it can be confronted (the more difficult, the more important);

c. the first group is more important compared to the second one if it is divided in more different sub-groups; and

d. the first group is more important compared to the second one if the available preferences of experts on EE issues clearly quote this importance.

iv) Depending on how overall important is the first group, compared to the second; the intensity is assigned by the user. The selected intensity is quoted in the respective cell. If during any comparison, the second group is more important than the first one, then the quoted intensity is 1/intensity.

Table 5 shows a filled AHP matrix where A_{ij} is the content of the cell (i,j); i refers to the row and j to the column. The element of the AHP matrix, A_{12}, expresses how more important is the first group (S-C-E), in limiting the efforts of achieving the EE target compared to the second group of barriers (EC).

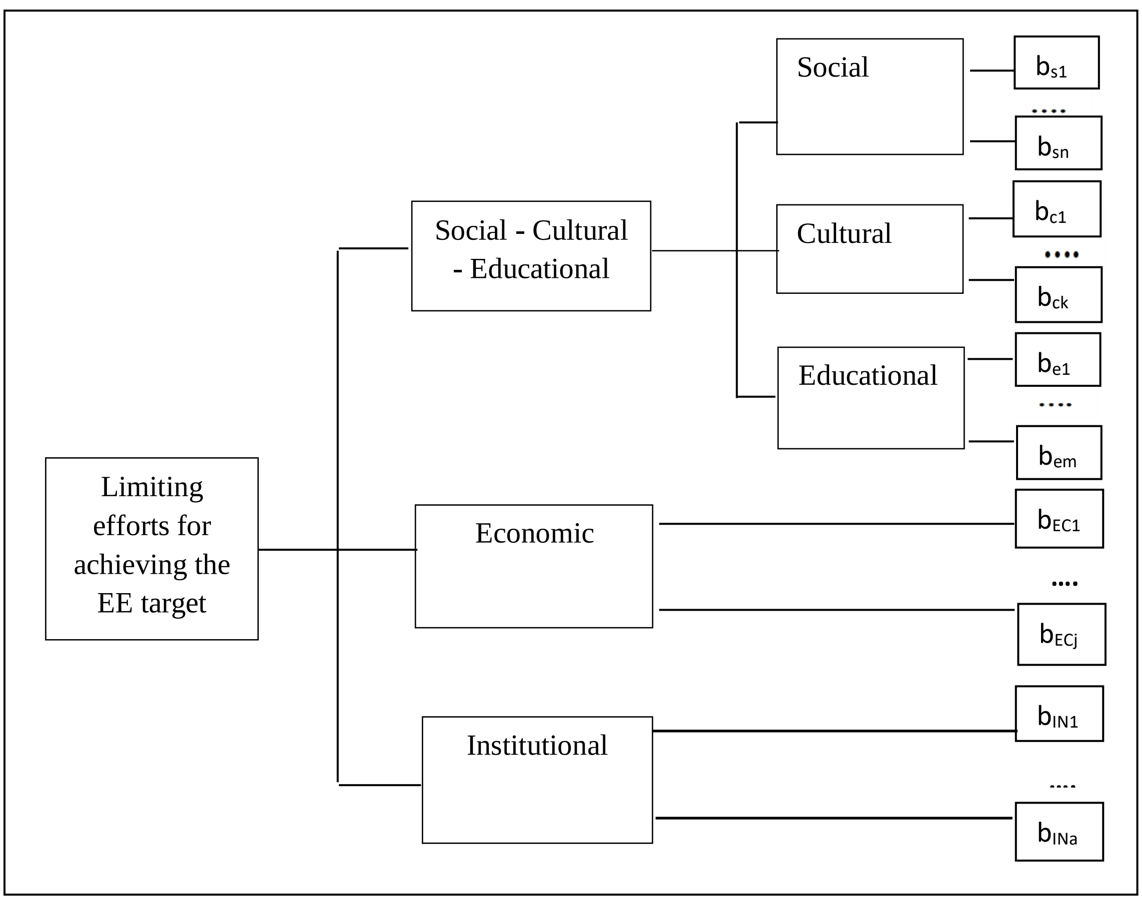

Fig 1: The AHP tree of the barriers.

Table 1. Set of behavioural barriers for the building sector.

Goal	Group	Sub-group	Barriers (b)
Limiting efforts for achieving the EE target	S-C-E	S	b_{s1}: Social group interactions and status considerations
			b_{s2}: Socio-economic status of building users
			b_{s3}: Strong dependency on the neighbors in multi-family housing
			b_{4}: Inertia
			b_{s5}: Commitment and motivation of public social support
			b_{s6}: Rebound effect
		C	b_{c1}: Lack of interest/low priority/Undervaluing energy efficiency
			b_{c2}: Customs, habits and relevant behavioural aspects
			b_{c3}: Bounded rationality/Visibility of energy efficiency
			b_{c4}: Missing credibility/mistrust of technologies and contractors
		E	b_{E1}: Lack of trained and skilled professionals/ trusted information, knowledge and experience
			b_{E2}: Lack of awareness/knowledge on savings potential/information gap on technologies
	EC		b_{EC1}: Lack of any type of financial support (lack of financial incentive (Public and Private sector)/ Lack of funds or access to finance)
			b_{EC2}: High capital costs/Financial risk/ Uncertainty on investment/ High cost of innovative technologies for end-users
			b_{EC3}: Payback expectations/investment horizons
			b_{EC4}: Relatively cheap energy and fuel prices/ misleading Tariff system not reflecting correct prices for energy use/EE
			b_{EC5}: Unexpected costs (Hidden costs/ Costs vary regionally (Fragmented ability))
			b_{EC6}: Financial crisis/Economic stagnation
			b_{EC7}: Embryonic markets
	IN		b_{IN1}: Split Incentive
			b_{IN2}: Legislation issues (Lack of relevant legislation/Lack of regulatory provision /Change of legislation for local/regional administrative division/ Complex/inadequate regulatory procedures)
			b_{IN3}: Building stock characteristics/aging stock/ Historical preservation
			b_{IN4}: Poor compliance with efficiency standards or construction standards/ Technical problems/ Performance gap/mismatch
			b_{IN5}: Lack of data/information-diversion of management
			b_{IN6}: 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)
			b_{IN7}: Disruption/Hassie factor
			b_{IN8}: Security of fuel supply

Table 2. Set of behavioural barriers for the transport sector.

Goal	Group	Sub-group	Barrier
Limiting efforts for achieving the EE target	S-C-E	S	b_{s1}: Low satisfaction with public transport/lack of trust
			b_{s2}: Concerns of vehicle reliability/Hesitation to trust new technologies
			b_{s3}: Heterogeneity of consumers
			b_{s4}: Suburbanisation trends/Low density
			b_{s5}: Mobility problems (Vulnerability of pedestrians / Lack of adequate space for walking/ Cruising traffic/ Parking problems)
			b_{s6}: Inertia
		C	b_{c1}: Car as a symbol status and group influence
			b_{c2}: Habit and social norm of driving, car ownership and use
			b_{c3}: Cycling is marginalized
			b_{c4}: Attitude (Attitude-action gap /Bounded rationality/Buyer attitude)
		E	b_{E1}: Lack of knowledge/information (on green transport/ULEVs/EVs - fuel economy)
			b_{E2}: Low/Limited awareness (of impact of EE in transport /towards eco-driving/benefits-environmental impacts)
			b_{E3}: Confusion about car and fuel costs (conventional vs ULEVs/Evs) – *Negative perception*
			b_{E4}: Lack of certified instructors/examiners/technicians/professionals for eco-driving /integrated transport/mobility/ ULEVs/Evs
	EC		b_{EC1}: Lack of finance/Limited financial incentives for new vehicles/ULEVs/public transport/ - Inefficient or absent fiscal measures for supporting EE
			b_{EC2}: Limited infrastructure investment (road/train/cycling) – for public transport
			b_{EC3}: Low purchasing power of citizens/Financial crisis
			b_{EC4}: High cost/Low cost competitiveness of electric vehicles - High cost of batteries for electric vehicles
			b_{EC5}: Payback period of fuel efficient vehicles
			b_{EC6}: Negative role of Investment schemes/employee benefits encourage transport EE
	IN		b_{IN1}: Administrative fragmentation and lack of integrated governance
			b_{IN2}: Transport EE on the Government Agenda/priorities
			b_{IN3}: Barriers to behavior change due to problems with infrastructure/public transport services (Inefficient urban/public transport infrastructure and planning/ Undeveloped cycling/walking infrastructure/ Lack of support for rail transportation/Limited rail infrastructure/ Undeveloped infrastructure for recharging of EV)
			b_{IN4}: Lack or limited policies to support behavior change on specific transport issues (Lack of national strategy for bike and pedestrian mobility/ Limited policy on freight efficiency/city logistics
			b_{IN5}: Limited/complex funding in urban public transport
			b_{IN6}: Barriers to behavior change due to no policy support to technological issues/research needs (Immature status of developing technologies for EVs/ULEVs - Range of distance travelled between charges for EVs)
			b_{IN7}: Contradicting policy goals (particularly road/car-oriented planning)

Table 3. AHP matrix for pair-wise comparisons.

Group of barriers	S-C-E	EC	IN
S-C-E	1	A_{12}	A_{13}
EC	$A_{21} = 1/A_{12}$	1	A_{23}
IN	$A_{31} = 1/A_{13}$	$A_{32} = 1/A_{23}$	1

Table 4. Relative importance between comparisons of AHP method.

Intensity	**Definition**	**Explanation**
1	Equal importance	Two barriers contribute equally to the goal
3	Moderate importance	Experience and judgement slightly favours the one over the other
5	Essential or strong importance	Experience and judgement strongly favours the one over the other
7	Demonstrated importance	Dominance of the demonstrated in practice
9	Extreme importance	Evidence favouring the one over the other of highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed

Table 5. Calculations in AHP matrix for the respective Impact factors.

Group of barriers	S-C-E	EC	IN	W
S-C-E	1	A_{12}	A_{13}	$W_{S\text{-}C\text{-}E} = (1/S1 + A_{12}/S2 + A_{13}/S3)/3$
EC	$A_{21} = 1/A_{12}$	1	A_{23}	$W_{EC} = (A_{21}/S1 + 1/S2 + A_{23}/S3)/3$
IN	$A_{31} = 1/A_{13}$	$A_{32} = 1/A_{23}$	1	$W_{IN} = (A_{31}/S1 + A_{32}/S2 + 1/S3)/3$
Sum	$S1 = 1 + A_{21} + A_{31}$	$S2 = A_{12} + 1 + A_{32}$	$S3 = A_{13} + A_{23} + 1$	

Step 3.2: Calculation of weight coefficients for the first level of the AHP tree

The necessary calculations of the AHP method are conducted for the determination of the weight coefficients (W) for each *group of barriers* (first level of AHP tree). The weight coefficients of this level express the contribution of the respective group to the goal. This means in the limitation of efforts for achieving the EE target. Due to this contribution, the calculated weight coefficients are defined as “Impact factors (I)” for the groups of barriers. The procedure is the same for all AHP matrices, differences are due to the different rank of the matrix (see Table 5):

a. Sum of each column (add three numbers in this specific case-level); denoted as Si where i refers to the number of the column;

b. Divide each number of the first row with the respective sum of the column it belongs to (A_{11}/sum of column 1 = A_{11}/S1, A_{12}/S2, A_{13}/S3 etc);

c. Sum up the "n" outcomes of step b (here the three outcomes of step b);

d. Divide them with n (since there were *n* outcomes) (*n* is the number of columns and rows of this AHP matrix) (here divide them with 3 (three outcomes for step c));

e. The outcome is weight coefficient for group 1 of barriers (located at row 1, column n+1 or a separate column) (sub-groups or barriers in the next levels);

f. Repeat for the second row the steps b, c, d, e;

g. Repeat for the next rows the steps b, c, d, e;

h. Check if each weight coefficient fulfills the condition 0 < W < 1;

i. Check if all together, the weight coefficients, sum up 1 (here the three calculated ones).

Step 3.3: Calculation of the consistency test

Values derived from step 3.2 are tested – before being used - for their consistency following the Saaty approach which requires the calculation of the random ratio of consistency (CR*) of the respective AHP matrix.

First, the consistency index (CI) is calculated as

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad (1)$$

where: λ_{max} is the maximum eigenvalue of the matrix and n is the rank value of the matrix.

Then, the random ratio of consistency (CR*) is calculated as

$$CR^* = CI/CR \qquad (2)$$

Where: CR is the corresponding mean random index of consistency. CR is 0 for a 2x2 matrix and CR* is not calculated. For the other nxn matrices, CR receives the values of Table 6 (Bongchul K. et al., 2017; Da A. et al., 2014; Ishizaka A., Labib A., 2011; Konidari P., Mavrakis D., 2007; Berritella M. et al., 2007).

A matrix is consistent (outcomes reliable) if CR* < 0.10, otherwise, the matrix is not consistent and its CR* value should be adjusted. This is done by re-assigning intensities and checking the importance of one object (here for the group of barriers) over the other.

The calculation procedure using the respective AHP matrix is (here Table 5 turns into Table 7):

a. Multiply the first cell of the first row with the first weight coefficient (final matrix of step 3.2), the second cell of the first row with the second one, the third cell of the first row with the third weight coefficient) etc;

b. Sum the products and divide by the first weight coefficient. This will be A1;

c. Multiply the first cell of the second row with the first weight coefficient etc;

d. Sum up the products and divide with the second weight coefficient. This will be A2.

e. Repeat the steps a, b for the third row and any other remaining ones respectively.

f. Add outcomes A1, A2, …… An and divide the sum with "n". Here, add outcomes A1, A2 and A3 and divide the sum with number three. This leads to λ.

g. Calculate CI = (λ – n)/(n-1) for the specific AHP matrix.

h. Calculate CR* = CI/CR (CR value from Table 6). Here CR* = CI/0.58 (matrix 3x3) (Table 7).

i. If CR* fulfils the condition 0<CR*<0.10, then the results are consistent.

When CR* = 0 the respective matrix is perfectly consistent. But due to the fact (argument) that decision-makers do not normally make "perfect" judgements, the value is not accepted (Alonso J.A., Lamata T., 2006).

Table 6. Values of mean random index of consistency.

Size of matrix	3x3	4x4	5x5	6x6	7x7	8x8	9x9	10x10
CR	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 7. Calculations for λ of Table 5.

Group of barriers	S-C-E	EC	IN	Outcomes using AHP matrix and its W.
S-C-E	**1** * $W_{S\text{-}C\text{-}E}$	**A_{12}** * W_{EC}	**A_{13}** * W_{IN}	$A1 = (1 * W_{S\text{-}C\text{-}E} + A_{12} * W_{EC} + A_{13} * W_{IN}) / W_{S\text{-}C\text{-}E}$
EC	**A_{21}** * $W_{S\text{-}C\text{-}E}$	**1** * W_{EC}	**A_{23}** * W_{IN}	$A2 = (A_{21} * W_{S\text{-}C\text{-}E} + 1 * W_{EC} + A_{23} * W_{IN}) / W_{EC}$
IN	**A_{31}** * $W_{S\text{-}C\text{-}E}$	**A_{32}** * W_{EC}	**1** * W_{IN}	$A3 = (A_{31} * W_{S\text{-}C\text{-}E} + A_{32} * W_{EC} + 1 * W_{IN}) / W_{IN}$
				$\lambda = (A1 + A2 + A3)/3$

Table 8. AHP matrix for the third level of barriers.

Social Barriers (3rd level)	b_{s1}	b_{s2}	b_{s3}	……	b_{sn}	**W_{sn}**
b_{s1}	1	A_{12}	A_{13}	……	A_{1n}	**W_{s1}** = $(1/S1 + A_{12}/S2 + \dots A_{1n}/Sn)/n$
b_{s2}	$A_{21} = 1/A_{12}$	1	A_{23}	…..	A_{2n}	**W_{s2}** = $(A_{21}/S1 + 1/S2 + \dots A_{2n}/Sn)/n$
b_{s3}	$A_{31} = 1/A_{13}$	$A_{32} = 1/A_{23}$	1	…..	A_{3n}	**W_{s3}** = $(A_{21}/S1 + A_{32}/S2 + \dots A_{3n}/Sn)/n$
……….	……	…..	…….	1	….	**…..**
b_{sn}	$A_{n1} = 1/A_{1n}$	$A_{n2} = 1/A_{12}$	$A_{n3} = 1/A_{13}$	$A_{n\,n-1} = 1/A_{n-1\,n}$	1	**W_{sn}** = $(A_{n1}/S1 + 1/S2 + \dots 1/Sn)/n$
	$S1 = 1 + A_{21} + \dots A_{n1}$	$S2 = A_{12} + 1 + \dots A_{n2}$	….		$Sn = A_{1n} + A_{2n} + 1$	

Step 3.4: Calculation of weight coefficients for the second level of the AHP tree

Weight coefficients are defined again, but now for each one of the sub-groups of barriers (“W_S”, “W_C” and “W_E”) (second level) to which the wider group “S-C-E” is divided to. These weight coefficients express the relative importance that each sub-group has as part of the wider group “S-C-E”. The previous steps (3.1 – 3.3) are repeated. The conditions of step 3.1 are used for this level also.

Once the weight coefficients of each one of the sub-groups are calculated (ie W_S, W_C, W_E), then – following previous procedure - their equivalent Impact factor (I) in “limiting the efforts for achieving the EE target” is determined as:

$$I_S = W_{S\text{-}C\text{-}E} * W_S \qquad (3)$$

$$I_C = W_{S\text{-}C\text{-}E} * W_C \qquad (4)$$

$$I_E = W_{S\text{-}C\text{-}E} * W_E \qquad (5)$$

The Impact factor expresses the contribution of the sub-group to the goal of the AHP tree. “Economic” and “Institutional” barriers are not divided into sub-groups.

Step 3.5: Calculation of weight coefficients for the third level of the AHP tree

The previous steps (3.1 – 3.3) are repeated for this level of the AHP tree. Under each sub-group there is a number of identified barriers (Figure 1). Following the described procedure, the AHP matrix for the “Social barriers” and their weight coefficients is that of Table 8.

The AHP matrix is filled through the assignment of the intensities that result from the comparison of the identified barriers (b_{s1}, b_{s2}…b_{sn}) against each other by taking into consideration the following conditions (different from those in step 3.1):

- A barrier is more important than the other if the *number of different sources* that refer to it are more than those for the second one;
- A barrier is more important that the other if the *number of sub-sectors* that were linked with it are more than those with the second one;
- A barrier is more important compared to the second one if there are *more difficulties to confront it* (the easier to be confronted the less important it is or if difficulties are encountered in more than one level (local, regional, national) it is more important);
- A barrier is more important compared to the second one if it exists *longer than another* (longer recorded duration of the barrier compared to the other);
- A barrier is more important compared to the second one if the *number of different policy instruments that were linked with it is* higher than those of the other;
- A barrier is more important than the second one if it is identified *as a cross-cutting barrier* (common among two or more different sectors (ie buildings and transport));
- A barrier is more important than another if there are available *expressed preferences of stakeholders for it*.

Calculations are performed for this level following those of step 3.2. Again, the calculated weight coefficients are checked for their consistency (step 3.3). The procedure of this step (3.5) is repeated for the “Economic” and the “Institutional” barriers.

Step 4: Definition and calculation of the Impact factors of barriers

The calculated weight coefficients of the previous step express the importance of each barrier as part of the group or sub-group to which it belongs. The Impact factor of a barrier (I) is defined as the weight coefficient of the barrier that expresses its importance to the goal of the AHP tree.

The Impact factor is calculated as the product of the weight coefficients of each one of the identified

Table 9. Impact factor of barriers for the building and transport sectors.

Type	**Barriers of sector**		**Function**
	Building	Transport	
S	b_{s1}	b_{s1}	$I_{s1} = W_{S-C-E} * W_S * W_{s1}$
S	b_{s2}	b_{s2}	$I_{s2} = W_{S-C-E} * W_S * W_{s2}$
S	b_{s3}	b_{s3}	$I_{s3} = W_{S-C-E} * W_S * W_{s3}$
S	b_{s4}	b_{s4}	$I_{s4} = W_{S-C-E} * W_S * W_{s4}$
S	b_{s5}	b_{s5}	$I_{s5} = W_{S-C-E} * W_S * W_{s5}$
S	b_{s6}	b_{s6}	$I_{s6} = W_{S-C-E} * W_S * W_{s6}$
C	b_{c1}	b_{c1}	$I_{c1} = W_{S-C-E} * W_c * W_{c1}$
C	b_{c2}	b_{c2}	$I_{c2} = W_{S-C-E} * W_c * W_{c2}$
C	b_{c3}	b_{c3}	$I_{c3} = W_{S-C-E} * W_c * W_{c3}$
C	b_{c4}	b_{c4}	$I_{c4} = W_{S-C-E} * W_c * W_{c4}$
E	b_{E1}	b_{E1}	$I_{E1} = W_{S-C-E} * W_E * W_{E1}$
E	b_{E2}	b_{E2}	$I_{E2} = W_{S-C-E} * W_E * W_{E2}$
E	-	b_{E3}	$I_{E3} = W_{S-C-E} * W_E * W_{E3}$
E	-	b_{E4}	$I_{E4} = W_{S-C-E} * W_E * W_{E4}$
EC	b_{EC1}	b_{EC1}	$I_{EC1} = W_{EC} * W_{EC1}$
EC	b_{EC2}	b_{EC2}	$I_{EC2} = W_{EC} * W_{EC2}$
EC	b_{EC3}	b_{EC3}	$I_{EC3} = W_{EC} * W_{EC3}$
EC	b_{EC4}	b_{EC4}	$I_{EC4} = W_{EC} * W_{EC4}$
EC	b_{EC5}	b_{EC5}	$I_{EC5} = W_{EC} * W_{EC5}$
EC	b_{EC6}	b_{EC6}	$I_{EC6} = W_{EC} * W_{EC6}$
EC	b_{EC7}	-	$I_{EC7} = W_{EC} * W_{EC7}$
IN	b_{IN1}	b_{IN1}	$I_{IN1} = W_{IN} * W_{IN1}$
IN	b_{IN2}	b_{IN2}	$I_{IN2} = W_{IN} * W_{IN2}$
IN	b_{IN3}	b_{IN3}	$I_{IN3} = W_{IN} * W_{IN3}$
IN	b_{IN4}	b_{IN4}	$I_{IN4} = W_{IN} * W_{IN4}$
IN	b_{IN5}	b_{IN5}	$I_{IN5} = W_{IN} * W_{IN5}$
IN	b_{IN6}	b_{IN6}	$I_{IN6} = W_{IN} * W_{IN6}$
IN	b_{IN7}	b_{IN7}	$I_{IN7} = W_{IN} * W_{IN7}$
IN	b_{IN8}	-	$I_{IN8} = W_{IN} * W_{IN8}$
	The sum of all these barriers fulfils the condition: $\sum_{i=1}^{27} I_i = 1$		

barriers (b), in the relevant groups and subgroups, based on the outcomes of the previous steps and the mathematical equation is as follows:

$$I = W_G * W_{S-G} * W_b \qquad (6)$$

where

I is the Impact factor of a barrier towards the goal of the AHP tree;

W_G is the weight coefficient of the *Group of barriers* to which the sub-group belongs;

W_{S-G} is the weight coefficient of the *Sub-Group of barriers* under the respective group of barriers;

W_b is the weight coefficient of the barrier under the sub-group to which it is classified and expresses the importance of the barrier compared to the other barriers of the same sub-group.

The same procedure and mathematical expression is applied for all barriers of the third level.

For the barriers, that are not classified in sub-groups, the Impact factor is calculated as

$$I = W_G * W_b \qquad (7)$$

All calculated Is do not have measurement units as they express the contribution of the barrier in not achieving the EE target ie the ratio scale in limiting efforts for achieving the EE target. The values of these Is range from 0 to 1, ie $I \in (0,1)$. Table 9 shows the sets of barriers for the building and transport sectors and their calculated impact factors. The numerical outcomes of the impact factors depend on the judgement of the user after applying the respective steps.

Step 5: Linkage of Impact factors of barriers with technologies and policies

EE technologies or practices are promoted - depending on national needs and priorities -through implemented policy instruments. Their penetration is affected by a set of linked barriers.

The Total Impact factor (TI) of barriers is calculated as the sum of all the Impact factors of the barriers linked with the specific EE technology or practice ie:

$$TI = \sum_{i=1}^{n} I_{Si} + \sum_{j=1}^{k} I_{Cj} + \sum_{a=1}^{m} I_{Ea} + \sum_{b=1}^{q} I_{ECb} + \sum_{d=1}^{r} I_{INd} \qquad (8)$$

where

n, k, …, r refer to the maximum number of the relevant barriers linked to the technology/practice under consideration. Each one of these maximum numbers fulfils the condition of being less than the total number of the barriers categorized under the respective group or sub-group (steps 1 and 2).

Equation (8) concerns the TI of barriers for only *one* EE technology or practice. The same equation is applied for calculation of the TI of barriers linked with an implemented policy instrument for EE.

The TI_{ol} of barriers for a *set* of EE technologies/practices is calculated applying the same rationality. The Impact factors of all barriers for all technologies are summed up. The Impact factors for barriers that are encountered for two or more technologies/practices are inserted only one time in the calculations (for avoiding duplication of the same impact factor).

Step 6: Incorporation of the Total Impact factors in the forward-looking EE modeling

The Impact factors (I) and Total Impact factors (TI) define the negative impact on the set of input drivers (or the defined EE target) in the frame of the forward-looking EE analysis. Consequently, the difference between the initially set value and the new one that incorporates Impact factors (I) and Total Impact factors (TI) defines the deviation created by the end-user's behavior.

For reducing this deviation, there are various options derived from the optimum combination of modified inputs, leading to a number of improved scenarios.

Step 6.1: Defining the deviation of EE targets due to behavioral barriers

The EE target is usually expressed by a percentage (±p%) of/about a specifically defined amount and is to be achieved until a defined target year. The numerical value of p% depends on the scenario and whether it concerns a country, region, municipality or sector/sub-sector (if the target concerns the tertiary or the road sub-sector) or even a specific housing type (if the examined sector is the building sector).

This specifically defined amount may refer to the: i) primary/final energy consumption; ii) penetration rates of EE technologies and iii) energy intensity. The latter is expressed in: i) MWh/m^2 or kWh/m^2 for the whole building sector or per any housing type (existing single-family house - housing type 1, existing multi-family building – housing type 2 etc) (Sustainable Energy Authority of Ireland, 2016); ii) tonnes of oil equivalent (toe) per tonne-km for the freight sub-sector and in toe per passenger-km for the passenger sub-sector[17].

The user assumes that a set of barriers affects the defined amount through the use of one EE technology (or the implementation of a policy instrument for supporting this technology). The impact of barriers leads to a new percentage, p_b (in %), which is calculated as

$$p_b = \pm p * (1 - TI) \quad \text{or} \quad p_b = \pm p * (1 - TI_{ol}) \qquad (9)$$

where TI is the Total Impact factor of all barriers linked with this one EE technology/action that is used for achieving the expected EE target and TI_{ol} the Total Impact factor linked with a set of EE technologies/actions for the same purpose.

The value of TI or TI_{ol} depends on the scenario and whether it concerns the whole sector or a specific sub-sector (residential or tertiary of the building sector) since these two elements define the final number of barriers linked with the assumed EE technology/practice.

The difference between the calculated amounts of p_b and p defines the deviation between the set target (ideal) and the target due to the existence of barriers (realistic). A number of scenarios can be developed for reducing this deviation.

Three cases encountered in forward-looking EE modeling about EE targets are examined for demonstrating how equation (9) is applied for specifically defined amounts used in EE targets (quoted in National Energy Efficiency Action Plans[18] for the European Union or National Determined Commitments[19] for the United Nations Framework Convention on Climate Change).

Case 1: EE targets about Primary or Final Energy Consumption

For this case, the aforementioned defined amount refers to Primary or Final Energy Consumption or energy intensity. The same rationality is applied for all these terms of EE targets. The following equations will use the Final Energy Consumption.

The *Final Energy Consumption with the use of a specific EE technology*[20] *for the reference year (which is denoted as 0) is F_o*. A new target about energy efficiency usually refers to a target year and is a percentage of the final energy consumption of the reference year. The expected/needed reduction in final energy consumption or the expected/needed energy savings for the target year (ES_o) without considering the impact of barriers is expressed as

$$ES_o = F_o * p \qquad (10)$$

While the final energy consumption for the target year without considering barriers will be

$$F = F_o - Es_o = F_o - F_o * p \qquad (11)$$

where p (in %) is the assumed expected reduction. The expected/needed reduction in final energy consumption or the respective energy savings for the target year - ***when barriers (b) are considered*** – after using equation (9) are

$$ES_b = F_o * p_b = F_o * p * (1 - TI) \qquad (12)$$

So, the final energy consumption for the target year, but considering barriers will be

$$F_b = F_o - ES_b = F_o - F_o * p * (1 - TI) \qquad (13)$$

The development of the scenarios aims now to reduce the deviation between the calculated amounts of ES_o (or F) and ES_b (or F_b respectively).

[17] http://www.un.org/esa/sustdev/natlinfo/indicators/methodology_sheets/consumption_production/energy_intensity_transport.pdf

[18] http://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive/national-energy-efficiency-action-plans

[19] http://www4.unfccc.int/ndcregistry/Pages/Home.aspx

[20] such as space heating technology

If a set of EE technologies are used then TI becomes TI_{ol} in equations (12) and (13).

Case 2: EE targets and penetration shares for EE technologies or fuels

The initial share (in %) of an EE technology is denoted for the reference year, 0, as S_o. The share of the technology (in %) for the target year is assumed to be

$$S = S_o + p \quad (14)$$

The expected share of the technology *due to the presence of barriers* (S_b) for the target year, based on equation (17), is calculated as

$$S_b = S_o + p_b = S_o + p*(1- TI) \quad (15)$$

Minimizing the difference between S and S_b defines the range of scenario outputs derived due to improved assumptions for confronting barriers.

Case 3: General EE targets

A general EE target is set usually when there is lack of reliable and detailed data about the share of energy sources, types of energy uses etc. The achievement of such a general target is assumed to be accomplished without specified penetration shares or breakdown shares for sectors/sub-sectors; just assuming that it will be achieved through the adoption of available EE technologies.

The scenario developer then proceeds by: i) assuming the use of all available EE technologies for achieving this general EE target (knowing that they are indeed used, but with no official data about their shares, energy consumption etc); ii) selecting a specific set of them based on official documents (such as National Energy Efficiency Action Plans).

The final energy consumption for the target year will be

$$F_b = F_o – ES_b = F_o - F_o*p*(1- TI_{ol}) \quad (16)$$

Where TI_{ol} refers to the Total Impact of barriers on assumed EE technologies (all or selected as aforementioned) for the developed scenario. Common barriers are inserted only once in the calculations. Similar function is used for primary energy consumption or any other type of EE target.

Conditions for all cases

The following conditions complement the previous discussion and are used as check points for the assumptions of the developed scenarios.

First condition: $0 < TI < 1$ and $0 < TI_{ol} \leq 1$.

Out of the 27 barriers for the building or the transport sector (Tables 1 and 2 – Step 1), not all of them are assumed to be linked with only one EE technology, so TI is not equal to 1. If TI was equal to 1, then

$$p_b = \pm p * (1 – TI) = \pm p * (1 – 1) = 0 \quad (17)$$

This means that the EE target is not achieved due to the presence of barriers. For the examined case, this limits completely the achievement of the EE target since it results to $ES_b = 0$ (no energy savings), $S_b = S_o$ (no penetration), $F_b = F_o$ (the final energy consumption remains as it is). This situation requires the re-examination of the assumption adopted in the developed scenario.

The mapped barriers of step 1 include barriers for all available EE technologies and policies. Since the two sets (Tables 1 and 2) are universal not all of these barriers are linked with only one specific EE technology or practice. There are barriers that do not concern the used EE technology of the developed scenario. Also, not all of these barriers are mapped for only one examined case (whether this is country, national sector etc). If the condition is not fulfilled then a check is performed so that TI<1.

Second condition: $TI_{ol,new} < TI_{ol, old} <1$.

If one of the barriers is considered of being overcame sharply, this means that due to a new policy package of measures, its respective Impact factor will be equal to 0 starting from the year of implementing the policy package. The $TI_{ol,new}$ of all the rest barriers is calculated, the index “new” refers to the new set of barriers. $TI_{ol,old}$ refers to the Total Impact of the barriers before the aforementioned change (old set of barriers). The new percentage for the defined amounts is calculated as:

$$p_{b,\,new} = p^* \,(1 - TI_{ol,\,new}) \qquad (18)$$

with $TI_{ol,new} < TI_{ol,\,old} < 1$ and $p_{b,new} > p_{b,old}$.

Step 6.2: Calculation and optimization of the set of input drivers

The development of scenarios for reducing deviations is based on selecting EE technologies and barriers whose impact factors will be reduced.

Selecting suitable combination of EE technologies

The scenario is developed by assuming the use of: i) specific technologies out of a set of available ones (random selection or based on national strategies) or ii) the best combination of them (selection based on impact factors). The selection of the appropriate technologies out of a set of available ones for achieving the expected/assumed EE target is very difficult – in some cases not possible - due to the large number of combinations $\binom{m}{k}$ referring to the exploitation of k out of a set of m technologies. The combination of technologies $\binom{7}{2}$ and $\binom{7}{3}$, results to 21 and 35 respectively. All these combinations cannot be examined since only a few will be more feasible and closer to accomplish the EE target compared to the others.

Combinations with the potential to overcome their barriers successfully and achieve the set/expected target are those that need to be preferred and explored. For concluding with these more efficient or suitable ones the following procedure is followed:

Step 6.2.1: Combinations of available EE technologies with the **maximum number of common barriers** are more preferable than the others, because the efforts for minimizing these barriers will affect the penetration of all involved technologies.

Step 6.2.2: Additionally, to step 1, if there are combinations with the same number of common barriers, the more preferable are those with **the lowest Total Impact**, since: i) overcoming the set of these barriers as a group requires less efforts compared to other combinations ii) the barriers of this set will be more manageable in being confronted and will more likely allow to reach easier the set/expected EE target compared to others.

The TI_{ol} of the suitable combination of the EE technologies is calculated and used as described in step 5. If the combinations are more than those intended to be examined, then an upper limit for the Total Impact of the combinations is to be set ($TI_{ol}<a$, with $a\in(0,1)$ theoretically). By this way, only combinations with TI_{ol} lower that the upper limit are selected.

Minimizing the impact factors of barriers

The scenario developer has two options: i) to assume which barriers of the suitable combination exhibit a reduced impact factor or ii) to assume directly – not through a suitable combination of technologies - which barriers are those whose impact factor will be reduced.

For both options the Impact factor of a barrier is reduced by: i) the introduction in the calculations of the respective impact factor of the policy instrument that is assumed to confront it or ii) a mathematical equation that reflects its reduction over time as the result of the socio-economic and policy framework.

The selection of the barriers whose Impact factors are assumed to be reduced leads to modified input drivers and improved scenario outcomes.

Option 1 for minimizing: Using the Impact factor of policy instruments

The Impact factor of a barrier is assumed to be overcame or restricted due to the respective Impact factor of a Policy Instrument (I_p) with $I_p\in(0,1)$. This assumption is based on the approach adopted by scholars in modelling that the introduction of policies overcomes barriers (Rehmatulla N. et al., 2017). This I_p is defined similarly to the Impact factor of a barrier, but expresses the positive impact that the policy instrument has in achieving the defined EE target by supporting the use of an EE technology or practice.

Similar research efforts need to be exerted for calculating these I_p and then for linking each one with the EE technology or technologies that it supports. Calculation needs to be based on research and collection of data and information, different from the one that led to the calculation of the impact factors of barriers.

Equations (17) are formed as

$$p_{b,p} = \pm p * (1 - TI + TI_p) \quad \text{or}$$

$$p_{b,p} = \pm p * (1 - TI_{ol} + TI_{p,ol}) \quad (19)$$

where $p_{b,p}$ is the resulting percentage for the specifically defined amount after considering barriers and policy instruments linked with one or more EE technologies. TI_p is the Total impact factor of the policy instruments that support the EE technology and confront the barriers linked with it. The TI_p is the sum of the impact factors of all the policy instruments supporting the defined EE target through one EE technology, ie

$$TI_p = I_{p1} + I_{p2} + \ldots + I_{pn} \quad (20)$$

where n is the number of these policy instruments

Similarly, the $TI_{p,\,ol}$ (in equation (19)) is the Total impact factor of all the policy instruments that support the set of EE technologies used for achieving the EE target.

The reduction in the final energy consumption or the respective energy savings due to barriers and policy instruments are calculated as

$$ES_{b,\,p} = F_o * p * (1 - TI + TI_p) \quad (21)$$

Then

$$F_{b,p} = F_o - ES_{b,\,p} = F_o - F_o * p * (1 - TI + TI_p) \quad (22)$$

Option 2 for minimizing: Using linear function for reducing impact factor of a barrier

The function that describes the reduction rate of the Impact factor of a barrier follows that of the change rate (increase or reduction) over time of the primary/final energy consumption, energy intensity, energy savings or of penetration rates. Assuming that this change rate over time is a linear function then the reduction of the Impact factor is calculated as:

$$I_{t,i} = I_{o,i} (1 - (c/15)*t) \quad (23)$$

where

$I_{o,i}$ is the Impact factor of barrier i in year t=0,

$I_{t,i}$ is the Impact factor of barrier i in year t after the implementation of a policy instrument (or instruments) that addresses it. For any other year than t=0, the $I_{t,i}$ satisfies the mathematical condition $I_{t,i} < I_{o,i}$.

The initial conditions that define this final form, starting from the general one, $I_{t,i} = a*t + b$, are:

- For year t=0, the $I_{o,i}$ is already calculated following steps 1-4 of the methodology, and $I_{t,i} = I_{o,i}$.
- For year t = 15 (in 2030), the assumption is that $I_{o,i}$ is to be reduced by c (20% < c < 80%). This reduction means that barrier i, has a lower contribution in preventing the achievement of the EE target. The 20% reduction was selected as an indicative value because: i) the mapping of the barriers (Step 1, Tables 1 and 2) showed that the majority of them remains important for several years despite the implementation of policy instruments; ii) there are estimations of 20% higher achievement of the EE target after the implementation of behavioral measures (UNEP, 2016). Additionally, depending on the measure or driver the abatement of a barrier may range from 5 to almost 80% (Trianni A. et al., 2016). Whether the assumed upper and lower limits capture sufficiently the reduction of the I or not, this requires further research (HERON, 2016).
- The year 2030 was selected due to its importance for: i) the Paris Agreement and the ii) European Union. The efforts under the Paris Agreement intend to lead to a projected level of 55 gigatonnes in 2030, while the EU aims to achieve at least 27% improvement in energy efficiency for year 2030 compared to

projections[21]. This corresponds to a time interval of 15 years (starting from 2015).

— Based on these initial conditions, the calculations resulted to a = - c/15 and b = $I_{o,i}$. This linear function is used for each barrier whose impact factor is assumed to be reduced.

TI and TI_{ol} are calculated using the previous equations and the calculated $I_{t,i}$ wherever it is needed according to the assumptions of the developed scenario.

For reduction by 20% in year 2030, equation (23) becomes

$$I_{t,i} = I_{o,i} (1 – (0,2/15)*t) \qquad (24)$$

In the case of the most suitable combination of technologies the minimization of the impact factor of a common barrier is divided equally among the involved technologies. The outcomes are inserted in the forward-looking EE model as described previously.

3. Outcome of methodology

The methodology allows the development of various EE scenarios that incorporate the end-users' behavior. Through the selection of the most suitable combination of EE technologies and the minimization option, different deviations from the set/expected EE target are achieved. The scenario with the lowest deviation is not necessarily the most promising one for the examined case. These scenarios need to be assessed using the multi-criteria evaluation method AMS, that will rank them based on their overall performance against three main criteria (environmental performance, political acceptability, feasibility of implementation). The evaluation outcome shows the scenario that: i) considers end-users' behavior; ii) exploits the most suitable combination of EE technologies and iii) has the most promising policy package in achieving the set EE target.

4. Conclusions

The developed methodology through its six steps leads to: i) the quantification of the barrier impact based on qualitative information; ii) the incorporation of end-users' behaviour in forward looking EE modelling; iii) the development of EE scenarios that reflect better the future development of the set/assumed targets. It allows the understanding of: i) which barriers are more important compared to others; ii) the deviation from the set/expected EE targets (primary or final energy consumption, energy intensity or penetration share of an EE technology) due to barriers linked with end-users' behavior; iii) how the minimized impact factor of barriers lowers the deviation from the set/expected EE target.

Steps 1-4 are followed for any sector that is to be examined in forward-looking EE modelling. The sets of barriers were presented in the paper for two important sectors for EE, buildings and transport. An analysis of the final end use of energy in the EU-28 in 2015 shows three dominant sectors: transport (33.1 %), households (25.4 %) and industry (25.3 %)[22]. The user of the methodology may conclude to a different number of barriers as a total or for each group/sub-group, but the AHP tree has the same structure as in Figure 1.

The groups and the sub-groups of barriers are the same among the sectors, but the barriers themselves differ in their titles and numbers per group or sub-group.

With the aim to simplify the AHP procedure, the preferable maximum number for each AHP matrix is 8x8. It will be thus easier and less time consuming for users to have 8 or less barriers to compare each time under an AHP matrix instead of 9 or 10. Additionally, the consistency test will be fulfilled

[21] Similar to the objective of saving 20 % of the Union's primary energy consumption by 2020 compared to projections. (Energy Efficiency Directive – 2012/27/EU, available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0027&from=EN

[22] http://ec.europa.eu/eurostat/statistics-explained/index.php/Consumption_of_energy

easier as well. All identified barriers are either grouped or merged so as to form the respective groups and sub-groups with up to 8 barriers the most for each. If this is not achievable then inevitably the user can have the 9x9 or the 10x10 matrix.

The reliability of the outcomes of the methodology depends on the inputs. The Saaty consistency index is used for securing the acceptable consistency of the judgements across all pairwise comparisons and the validity of the outcomes (Abbas M. S., Kocaoglu D.F., 2016).

A second consistency index – such as that of Pelaez-Lamata (2003) - may be used additionally, leading to higher level of consistency and reliability of the results. Its inclusion as part of the methodology depends on the user requirements. The following disadvantage needs to be considered. If the AHP matrices are larger than 6x6 then the consistency index of Pelaez-Lamata becomes sensitive and more time consuming in being achieved in case that the condition is not fulfilled with the initial inputs of the AHP matrices. These inputs need to be re-examined and re-assigned for fulfilling the condition of the consistency test of Pelaez-Lamata. This procedure lasts much more compared to that of the Saaty approach particularly for rank values of the AHP matrices higher than 6. This was the main reason for not including it in the developed methodology since the size of the AHP matrices can be higher than 6x6 and the majority of the potential users will be having difficulties to proceed and complete the methodology.

The deviation from the set/expected EE target reflects the impact of the barriers in achieving it. The calculated Impact factor along with the proposed combination of EE technologies or practices allows the modeler to select the barriers that need to be confronted and assume how the appropriate means (policy instruments) minimize or eliminate their impact factor. The assumptions for reducing the deviation through the minimization of the selected barriers define the synthesis of the policy mixture that may be adopted.

This methodology under which scenarios for energy efficiency are developed allows also their comparative evaluation so as to understand which one fits better the national needs and may reach the best possible results given the national social, economic and administrative framework.

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