Inserting end-users behaviour into forward looking energy efficiency modelling

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Structure

- Concept
- Methodology
- Conclusions

Concept

- Definition of “barrier”
  - Element that limits the individuals’ willingness to implement policies
- Need to quantify barriers’ impact
  - Numerical inputs for forward looking energy efficiency modelling
  - Understandable meaning of numbers for policy makers
  - Useful outcomes for designing effective EE policies and measures

Step 1

Selection of multi-criteria decision analysis method

- Analytical Hierarchical Process (AHP)
  - is justified mathematically
  - presents better the problem
  - offers guidelines in defining weight coefficients and has a consistency index for verifying their consistency
  - is suitable for incorporating preferences of relevant stakeholders regarding the importance of criteria/sub-criteria

Step 2

Categorization of barriers per groups/sub-groups

- Three groups based on literature research
  - Social-Cultural-Educational
  - Economic
  - Institutional

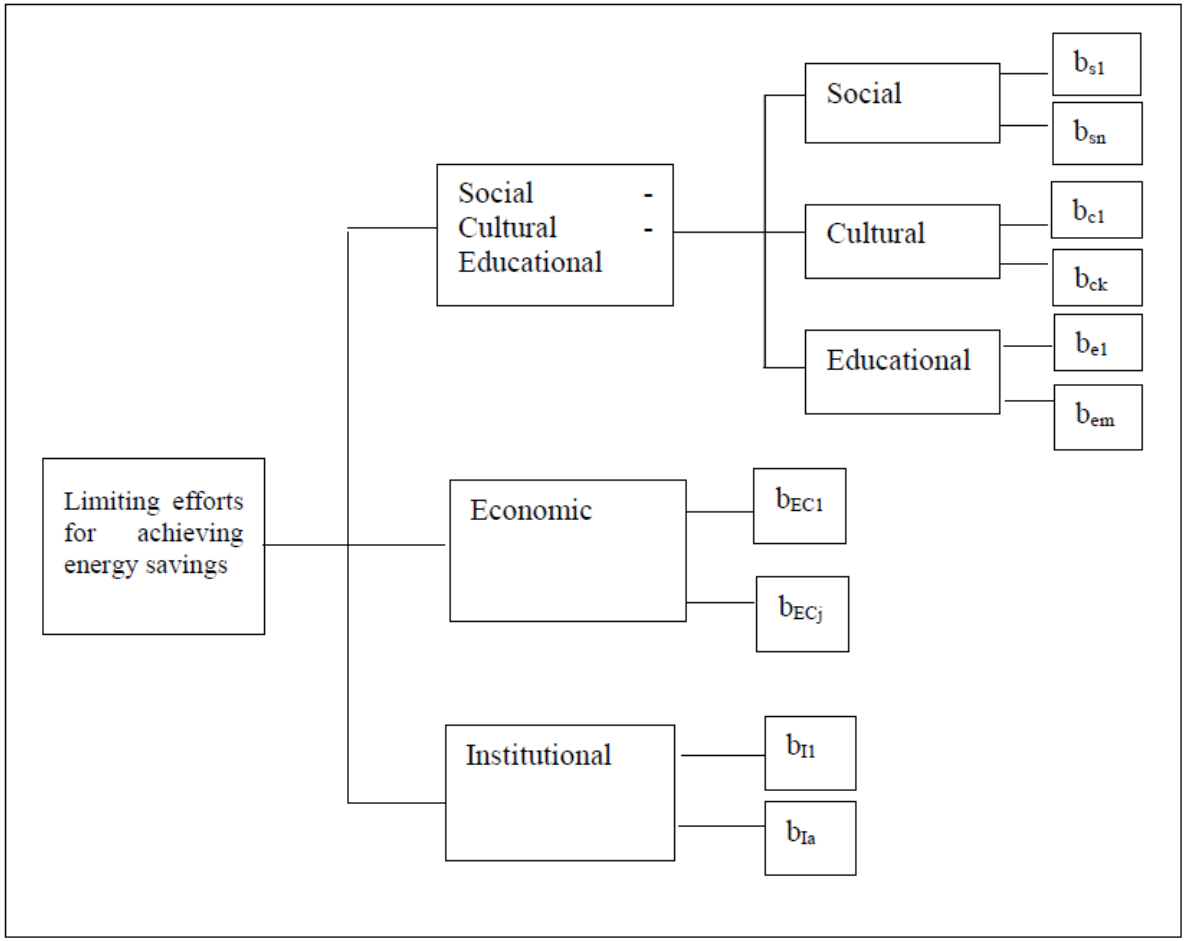
Step 3

Merging the same/similar barriers

- Rationality
  - Same content/ similar title
  - Same behavior or need to be handled by the same manner
  - Ensuring that the set of barriers
    - complete,
    - non-redundant,
    - minimalistic,
    - with non-overlapping barriers,
    - decomposable
  - Considering that the preferable maximum size for each AHP matrix, for examining its consistency, is 8x8

Step 4

Formation of the AHP tree and the AHP



Step 5

Conducting pair-wise comparisons

5.1 - First level pair-wise comparisons

- comparing the object of each row with the respective object of the column;

Barriers linked with end-users behaviour	Social-Cultural-Educational	Economic	Institutional
Social-Cultural-Educational	1	A_{12}	A_{13}
Economic	$A_{21} = 1/A_{12}$	1	A_{23}
Institutional	$A_{31} = 1/A_{13}$	$A_{32} = 1/A_{23}$	1

Step 5

Conducting pair-wise comparisons

5.1 - First level pair-wise comparisons

- assigning appropriate intensity (based on judgement)

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

Step 5

Conducting pair-wise comparisons

5.1 - First level pair-wise comparisons

- Conditions for assignment of intensity (judgement)
  - number of identified barriers
  - level of difficulty with which it can be confronted (the more difficult, the more important);
  - divided in more different sub-groups; and
  - available preferences of experts on EE issues clearly quote importance

Step 5

Conducting pair-wise comparisons

5.1 - First level pair-wise comparisons

- Intensity is assigned depending on overall importance of first object over second one
- Selected intensity is quoted in respective cell
- If second object is more important than the first one, then the quoted intensity is 1/intensity

Step 5

Conducting pair-wise comparisons

5.2 - Calculation of indexes for the first level of the AHP tree

- Perform algorithm of nine actions
  - Results to weight coefficients (or indexes) for each group
    - Weight coefficient expresses the contribution of the group in the limitation of efforts for energy efficiency

Step 5

Conducting pair-wise comparisons

5.3 - Calculation of the consistency test

- Perform algorithm of nine actions
  - Results to the random ratio of consistency CR* for the AHP matrix
    - If CR* fulfils the condition 0<CR*<0.10, then the results are consistent

5.4 - Calculation of indexes for the second level of the AHP tree

5.5 - Calculation of indexes for the third level of barriers

- Repeat 5.1 – 5.3

Step 6

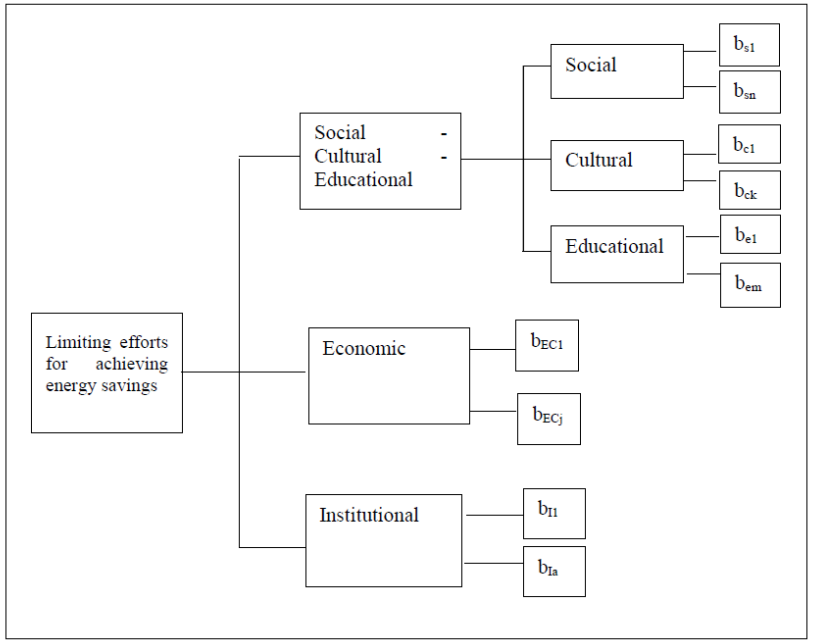
Calculation of Total Impact per barrier

b_{1s} impact = Index $_{\text{social-cultural-educational}}$ * index $_{\text{social}}$ * Index $_{\text{social 1}}$ = $W_{\text{S-C-E}} * W_s * w_{s1}$

b_{2s} impact = Index $_{\text{social-cultural-educational}}$ * index $_{\text{social}}$ * Index $_{\text{social 2}}$ = $W_{\text{S-C-E}} * W_s * w_{s2}$

b_{EC1} = Index $_{\text{Economic}}$ * W_{EC1}

b_{EC1} = Index $_{\text{Economic}}$ * W_{EC2}



Step 6

Building sector – First group

Type	Name of barrier	Function
Social	Social group interactions and status considerations	$TI_{s1} = W_{S\text{-}C\text{-}E} * W_s * W_{s1}$
Social	Socio-economic status of building users	$TI_{s1} = W_{S\text{-}C\text{-}E} * W_s * W_{s1}$
Social	Strong dependency on the neighbors in multi-family housing	$TI_{s1} = W_{S\text{-}C\text{-}E} * W_s * W_{s1}$
Social	Inertia	$TI_{s1} = W_{S\text{-}C\text{-}E} * W_s * W_{s1}$
Social	Commitment and motivation of public social support	$TI_{s1} = W_{S\text{-}C\text{-}E} * W_s * W_{s1}$
Social	Rebound effect	$TI_{s1} = W_{S\text{-}C\text{-}E} * W_s * W_{s1}$
Cultural	Lack of interest/low priority/Undervaluing energy efficiency	$TI_{c1} = W_{S\text{-}C\text{-}E} * W_c * W_{c1}$
Cultural	Customs, habits and relevant behavioural aspects	$TI_{c1} = W_{S\text{-}C\text{-}E} * W_c * W_{c2}$
Cultural	Bounded rationality/Visibility of energy efficiency	$TI_{c3} = W_{S\text{-}C\text{-}E} * W_c * W_{c3}$
Cultural	Missing credibility/mistrust of technologies and contractors	$TI_{c4} = W_{S\text{-}C\text{-}E} * W_c * W_{c4}$
Educational	Lack of trained and skilled professionals/ trusted information, knowledge and experience	$TI_{E1} = W_{S\text{-}C\text{-}E} * W_E * W_{E1}$
Educational	Lack of awareness/knowledge on savings potential/information gap on technologies	$TI_{E2} = W_{S\text{-}C\text{-}E} * W_E * W_{E2}$

Step 6

Building sector – Second and third group

Economic	Lack of any type of financial support (lack of financial incentive (Public and Private sector)/ Lack of funds or access to finance)	$TI_{EC1} = W_{EC} * W_{EC1}$
Economic	High capital costs/Financial risk/ Uncertainty on investment/ High cost of innovative technologies for end-users	$TI_{EC2} = W_{EC} * W_{EC2}$
Economic	Payback expectations/investment horizons	$TI_{EC3} = W_{EC} * W_{EC3}$
Economic	Relatively cheap energy and fuel prices/ misleading Tariff system not reflecting correct prices for energy use/EE	$TI_{EC4} = W_{EC} * W_{EC3}$
Economic	Unexpected costs (Hidden costs/ Costs vary regionally (Fragmented ability))	$TI_{EC5} = W_{EC} * W_{EC5}$
Economic	Financial crisis/Economic stagnation	$TI_{EC6} = W_{EC} * W_{EC6}$
Economic	Embryonic markets	$TI_{EC7} = W_{EC} * W_{EC7}$
Institutional	Split Incentive	$TI_{I1} = W_{I} * w_{I1}$
Institutional	Legislation issues (Lack of relevant legislation/Lack of regulatory provision /Change of legislation for local/regional administrative division/ Complex/inadequate regulatory procedures)	$TI_{I2} = W_{I} * w_{I2}$
Institutional	Building stock characteristics/aging stock/ Historical preservation	$TI_{I3} = W_{I} * w_{I3}$
Institutional	Poor compliance with efficiency standards or construction standards/ Technical problems/ Performance gap/mismatch	$TI_{I4} = W_{I} * w_{I4}$
Institutional	Lack of data/information-diversion of management	$TI_{I5} = W_{I} * w_{I5}$
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)	$TI_{I6} = W_{I} * w_{I6}$
Institutional	Disruption/Hassie factor	$TI_{I7} = W_{I} * w_{I7}$
Institutional	Security of fuel supply	$TI_{I8} = W_{I} * w_{I8}$

Step 7

Repetition of procedure for another sector

(ie the transport sector)

- Repeat 2-6 steps

Step 7

Transport sector – First group

Type	Name of barrier	Function
Social	Low satisfaction with public transport/lack of trust	$TI_{s1} = W_{S\text{-}C\text{-}E} * W_s * W_{s1}$
Social	Concerns of vehicle reliability/Hesitation to trust new technologies	$TI_{s1} = W_{S\text{-}C\text{-}E} * W_s * W_{s1}$
Social	Heterogeneity of consumers	$TI_{s1} = W_{S\text{-}C\text{-}E} * W_s * W_{s1}$
Social	Suburbanisation trends/Low density	$TI_{s1} = W_{S\text{-}C\text{-}E} * W_s * W_{s1}$
Social	Mobility problems (Vulnerability of pedestrians / Lack of adequate space for walking/ Cruising traffic/ Parking problems)	$TI_{s1} = W_{S\text{-}C\text{-}E} * W_s * W_{s1}$
Social	Inertia	$TI_{s1} = W_{S\text{-}C\text{-}E} * W_s * W_{s1}$
Cultural	Car as a symbol status and group influence	$TI_{c1} = W_{S\text{-}C\text{-}E} * W_c * W_{c1}$
Cultural	Habit and social norm of driving, car ownership and use	$TI_{c1} = W_{S\text{-}C\text{-}E} * W_c * W_{c2}$
Cultural	Cycling is marginalized	$TI_{c3} = W_{S\text{-}C\text{-}E} * W_c * W_{c3}$
Cultural	Attitude (Attitude-action gap /Bounded rationality/Buyer attitude)	$TI_{c4} = W_{S\text{-}C\text{-}E} * W_c * W_{c4}$
Educational	Lack of knowledge/information (on green transport/ULEVs/EVs - fuel economy)	$TI_{E1} = W_{S\text{-}C\text{-}E} * W_E * W_{E1}$
Educational	Low/Limited awareness (of impact of EE in transport /towards eco-driving/benefits-environmental impacts)	$TI_{E2} = W_{S\text{-}C\text{-}E} * W_E * W_{E2}$
Educational	Confusion about car and fuel costs (conventional vs ULEVs/Evs) – Negative perception	$TI_{E2} = W_{S\text{-}C\text{-}E} * W_E * W_{E2}$
Educational	Lack of certified instructors/examiners/technicians/professionals for eco-driving /integrated transport/mobility/ ULEVs/Evs	$TI_{E2} = W_{S\text{-}C\text{-}E} * W_E * W_{E2}$

Step 7

Transport sector – Second and third group

Economic	Lack of finance/Limited financial incentives for new vehicles/ULEVs/public transport/ - Inefficient or absent fiscal measures for supporting EE	$TI_{EC1} = W_{EC} * W_{EC1}$
Economic	Limited infrastructure investment (road/train/cycling) – for public transport	$TI_{EC2} = W_{EC} * W_{EC2}$
Economic	Low purchasing power of citizens/Financial crisis	$TI_{EC3} = W_{EC} * W_{EC3}$
Economic	High cost/Low cost competitiveness of electric vehicles - High cost of batteries for electric vehicles	$TI_{EC4} = W_{EC} * W_{EC3}$
Economic	Payback period of fuel efficient vehicles	$TI_{EC5} = W_{EC} * W_{EC5}$
Economic	Negative role of Investment schemes/employee benefits encourage transport EE	$TI_{EC6} = W_{EC} * W_{EC6}$
Institutional	Administrative fragmentation and lack of integrated governance	$TI_{I1} = W_{I} * w_{I1}$
Institutional	Transport EE on the Government Agenda/priorities	$TI_{I2} = W_{I} * w_{I2}$
Institutional	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)	$TI_{I3} = W_{I} * w_{I3}$
Institutional	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	$TI_{I4} = W_{I} * w_{I4}$
Institutional	Limited/complex funding in urban public transport	$TI_{I5} = W_{I} * w_{I5}$
Institutional	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)	$TI_{I6} = W_{I} * w_{I6}$
Institutional	Contradicting policy goals (particularly road/car-oriented planning)	$TI_{I7} = W_{I} * w_{I7}$

Step 8

Linkage of Barriers Impact and technologies

$TI_{technology}$ = sum of Total Impacts of barriers linked with the EE technology

$= TI_{s1,\ linked\ with\ technology} + \ldots\ldots + TI_{Ia,\ linked\ with\ technology}$

Step 9

Incorporation of barriers impact in forward looking EE modelling

- Energy intensity per housing type (existing single family housing type 1, etc.) in kWh/m^2

$$F_t\,(k,a,c,d,e,h,TI_{\text{barriers linked with target}}) = F_o(k,a,c,d,e,h) - ES_{\,t,\,\text{barriers}}$$

$$= F_o(k,a,c,d,e,h) - Fo(k,a,c,d,e,h)*p\%*(1- TI_{\text{barriers linked with target}})$$

- Penetration shares for EE technologies or fuels (such as heating oil, natural gas, electric, heat pumps, biomass, LPG, etc.) per housing type (percentages)

$$S_{\,t,\,\text{barriers}} = S_o(k,a,c,d,e,h) + A\%*(1- TI_{\,\text{barriers related with the penetration of the technology}})$$

Step 9

Incorporation of barriers impact in forward looking EE modelling

- Mathematical expressions
  - First approach

$$BaselineValue - Interp(reference\ year;\ 0;\ target\ year;\ F_o(k,a,c,d,e,h)*(p\%)*(1- TI_{barriers\ linked\ with\ target})$$

$$BaselineValue - Interp(reference\ year;\ S_o(k,a,c,d,e,h)\ or\ 0;target\ year;\ S_o(k,a,c,d,e,h) + A\%*(1- TI_{barriers\ related\ with\ the\ penetration\ of\ the\ technology}))$$

  - Second approach
    - Calculations in developed software, insert outcomes in forward looking energy efficiency modelling

Step 9

- Minimization of barriers impact
  - First approach
    - Considering the impact of policy instruments
  - Second approach
    - Use of exponential function $Q = Q_0 e^{-t}$

Conclusions

The methodology allows the calculation of the negative impact that barriers created by the end-users behavior have on inputs (concerning technologies and practices) of forward looking energy efficiency scenarios and thus leading to deviation from the expected targets

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Thank you