# Uncovering the multiple objectives behind national energy efficiency planning

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## Abstract

This work seeks to identify the fundamental objectives behind the development of energy efficiency (EE) plans for countries. It also presents a method to quantify the degree of achievement of each objective, through the identification and operationalization of attributes. This was achieved by applying Keeney's value-focused thinking approach. For that purpose, three key decision makers in EE planning were interviewed along with a bibliographic review on the subject. From this process six fundamental objectives were identified formalizing the problem as a multi-objective one: i) to minimize the influence of energy use on climate change; ii) to minimize the financial risk from the investment; iii) to maximize the security of energy supply; iv) to minimize investment costs; v) to minimize the impacts of building new power plants and transmission infrastructures; vi) to maximize the local air quality. The respective attributes were: i) $CO_2$ emissions savings; ii) payback; iii) imported energy savings; iv) investment cost; v) electricity savings; and vi) total suspended particles savings. To show the usefulness of the work, the objectives and attributes identified were used to show the possible outcomes from five hypothetical EE plans for Portugal.

Keywords: energy efficiency, energy planning, multi-objective

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## 1. Introduction

It is nowadays widely accepted that Energy Efficiency shall play a key role in the transition to a more sustainable energy future [1][2]. Its potential contribution is not only at the level of improved energy conversion technologies, but also at the level of the organization and management of the infrastructures in a way to avoid intensive energy needs. The E.U. Green Paper on Energy Efficiency shows that a key way to improve energy efficiency is through policy instruments, as national energy efficiency plans [3]. In general, energy efficiency plans give guidelines to the process of achieving energy savings and reaching established quantified targets [4][5][6]. Often, besides the guidelines, the plans also include the identification of the concrete energy efficiency measures that enable achieving the plan goals.

In 2006 the European Union adopted the Directive 2006/32, also known as the energy end-use efficiency and energy services Directive [4]. This directive established that each EU country was obliged to develop a National Energy Efficiency Action Plan (NEEAP) to promote energy services and/or energy efficiency improvement measures in order to achieve formal final energy savings targets. The transposition of the Directive from the EU level to the Member State level required an effort to build NEEAPs, where Energy efficiency (EE) measures were selected and described with the expected singular and overall impacts on the final energy use of the respective Member State.

Energy efficiency measures can be seen as an activity or set of activities designed to decrease the overall energy use that a system needs to provide some service. Such decrease can be achieved through physical changes of systems and equipment (e.g., changing a motor at an industry for a more efficient one) or through changes on the management and operation of systems (e.g., turning the equipments off while they are not in use). The changes that occur in the physical world are here called physical or technical measures. In order to make EE measures operational, it is necessary to have promotion mechanisms and/or implementation processes. Such processes formalize how to encourage, or even force, the society to accept and implement the expected changes. Typical implementation mechanisms are the creation of new regulations to make mandatory minimum efficiency standards, fiscal incentives and information and education campaigns. Most measures can be implemented through many different mechanisms, which depend on contextual variables as well as volatile political issues and interests. This diversity of the implementation mechanisms that can be applied for each physical measure makes the problem of building energy efficiency plans even more complex than the already intricate problem of selecting the technical EE measures to be in a plan. Therefore, it may be advisable to break the problem into “the selection of physical measures” and then “the selection of implementation mechanisms” as separate stages. However, the fact of having two stages does not mean that after obtaining the results from the first stage this part is concluded as in a linear process. Instead, it is strongly recommended that an iterative process between stages one and two is performed until a final decision of a plan including the technical measures and the promotion mechanisms is achieved. This is the perspective adopted in this work.

In the challenging problem of selecting the most appropriate energy efficiency plan for a region or a country, considering here “plan” as a set of physical measures, the first issue to consider should be what does actually “most appropriate” mean? Beyond the obvious fact that energy efficiency aims to achieve energy savings, it must be understood that these savings affect the economy, the society and the environment in several different ways, helping to achieve other indirect but possibly more important objectives than actually the one explicitly stated of “saving energy”. For example, “saving energy” can have implicit the objectives of mitigating greenhouse gas emissions or increasing the security of energy supplies. Keeney refers to this issue as the differentiation between “means objectives” and “end-objectives” [7]. Therefore, the problem must not be seen as a single objective decision making problem which aims to reach an often pre-defined target of energy savings, restricted to some natural constraints (as budget), but it must instead be seen as a process of making decisions in the presence of multiple, and maybe conflicting objectives [8][9][10], such as reinforcing environmental compatibility while maintaining or decreasing the costs of energy.

This work proposes to use the value-focused thinking approach [7] to identify the real objectives behind the will to introduce EE plans or measures, to transpose such objectives into operational attributes, and to evaluate EE measures or plans testing the use of those hidden objectives in aiding decisions when selecting the most fitted EE measures to adopt in a plan for a country.

## 2. Identification of the Objectives

### *2.1. The value focused-thinking approach*

Generally, decision makers start their decision process thinking of possible alternatives or comparing alternatives that are already shaped as possible problem solutions, and only afterwards they address objectives and criteria to help to evaluate and/or choose such alternatives. This fact turns this process of thinking on the objectives in a reactive process in relation to the alternatives. Keeney refers to this standard problem-solving approach as alternative-focused thinking and defends that focusing on alternatives is a limited way to think through decision situations because it “solves” decision problems, but does not identify desirable decision opportunities that can be only reached if the decision maker starts by thinking on what he/she values [11]. According to Keeney, values are principles used for evaluation. Such principles can be articulated qualitatively by stating objectives, which are something that one wants to achieve in a specific decision process. Therefore they should be the driving force for the decision making process, while alternatives are only relevant because they are means to achieve values. Keeney names this process of thinking as “value-focused thinking” (VFT), and it is based on having significant effort to make values explicit by applying logical and systematic concepts to qualitatively identify and structure the values that best fit a decision situation.

Following the VFT approach, four procedures must be performed to guide the way of thinking in order to obtain the objectives. First, one must compile an initial list of objectives. Second, these objectives must be categorized as means or ends objectives and then be logically structured. Ends objectives concern the ends that decision makers value in a specific decision context, and means objectives are objectives that will lead the way to achieve the ends. Third, the objectives must be used to create alternatives. Fourth and last, the objectives should be examined to identify worthwhile decision opportunities [11].

The most obvious way to identify objectives is to engage in a discussion with the decision makers about the decision situation [7]. The process requires creativity and hard thinking, and it can begin by asking the decision maker "What would you like to achieve in this situation?" The responses provide a list of potential objectives and a basis for further questioning. The next section presents the proposed interview structure that can be applied to decision makers to find the objectives for EE plans following this approach.

### *2.2. Interview structure*

Following the VFT approach, the process is initiated by introducing the problem and the reasons why understanding objectives is important. It is recalled that the problem is building/developing energy efficiency plans. Those are conceived in a natural multi-criteria environment, where the end-objectives are hidden behind the stated means objective of “reducing the total energy use”. To uncover such objectives, an interview process can develop along the following sequence:

1. Ask for a wish list of objectives for an energy efficient plan. Emphasize that this list has no ranking or priorities and should be done without any restriction, as if all the intents could be reached.
2. Explore the list to select only the objectives. Generally, decision makers do not have a clear definition of what is an objective and introduce other items of different nature in the list. For the non-objectives that may be included, as attributes, constraints, goals and guidelines, go through them to see if they are in fact “hiding” objectives.

   2.1. If items falling in the category of decision alternatives (i.e. possible problem solutions) are found, compare them with each other in order to find the best alternative or the best “facts” (future objectives) in each one. The reason why some alternatives are better than others can reflect an objective. Also try to push further, asking for a “perfect” and for a “terrible” alternative and redo the comparison.

   2.2. If items falling in the categories of constraints or goals are found, their aim may indicate an objective. If the decision maker also intends to go further than the goal or the constraint in a way of minimizing or maximizing, the constraint or goal can also be used as an objective.

   2.3. If items falling in the categories of guidelines are found in the list, one has to have in mind that they are less definitive than goals or constraints, but if the decision maker wants to go further than the guideline, or really enforce it, it can also be seen as an objective.

   2.4. If criteria or attributes are found, one should ask what the decision maker will gain from that and how he/she wants it to happen (minimize or maximize). If this attribute is natural, the answer will be just increasing or decreasing it; if not, he/she will tell what he/she seeks to achieve from that. At this point, the attributes can be assessed to reveal new objectives or not. This cycle shall be repeated until the attributes are totally related to objectives.

3. After having evolved to a version of the wish list which contains only objectives, it is time to separate ends objectives from specific means objectives, in order to find at least one fundamental objective. This should be done by asking: "Why is this objective important in the decision context?"

From this question, two types of answers are possible. One is that the objective is one of the main interests in the situation. Therefore, this objective is a fundamental objective. The other response is that the objective is important because of its implications for achieving some other objective, consequently, it is a means objective, and the answer given also identifies another objective. The "Why is it important?" test should now be given to this objective to ascertain whether it is a means objective or an ends/fundamental objective.

4. List the fundamental objectives and ask the decision maker if the objectives reflect the decision problem. If yes, the objectives involving EE plans were identified; if no, restart the process from beginning until the decision maker is satisfied with the result.

If the Decision process is being made on request of a single decision-maker for its own interests, then the process above suffices to identify the objectives. However, in the planning of energy efficiency at national level it is usually intended to address the interests of “the whole society”. Therefore, it is recommended for problems as complex as this one, to consult several decision makers to obtain a more comprehensive group of objectives, as described in the next section.

### 2.3. *Interviews with decision makers*

The procedures described in previous section were used in interviews with three key decision makers to identify the ends objectives for energy efficiency plans. The interviewees were selected according to their position as decision makers responsible for the promotion of energy efficiency at local and national levels. The selected interviewees were the president of the Porto Energy Agency in Portugal (AdEPorto), the Director of energy audits in industry area in the Portuguese Energy Agency (ADENE), which is the institution responsible for the National Energy Efficiency Action Plan for Portugal, under the context of the EU Energy end-use efficiency and energy Services Directive (ESD) [4], and a representative from the Department of Economy and Energy Studies at the Brazilian Enterprise for Research and Energy (EPE), who was also one of the responsible persons in the development of the Brazilian National Energy Efficiency Action Plan (PNEf).

During the process of listing the objectives, all the decision makers realized that increasing (maximizing) the final energy savings was not a fundamental objective, but a means objective to make the fundamental objectives possible or, as in the specific case of the ESD [4], a restriction that should be respected. From the interviews, and after applying the 4-stage interview sequence described in the previous section, it was possible to list six fundamental objectives to evaluate EE plans mentioned by at least one decision maker (Table 1): to minimize the influence of energy use on climate change, to minimize the financial risk from the investment, to maximize the security of energy supply, to minimize the risk of failure, to minimize the investment costs and to minimize time until the plan starts to produce effect.

**Table 1 – List of fundamental objectives from interviewed decision makers**

| Objectives | Decision Makers |
|---|---|
| Minimize the influence of energy use on climate change | 1,2 |
| Minimize the financial risk from the investment | 2,3 |

| | |
|---|---|
| Maximize the security of energy supply | 1,2,3 |
| Minimize the risk of failure | 3 |
| Minimize time until the effect of the plan | 1,3 |
| Minimize investment costs | 1,3 |

Key:1 AdEPorto; 2 ADENE; 3 EPE

Two of these objectives had little relevance to this research, which addresses only the stage of selecting the physical/technical measures, because they were strongly linked to the implementation mechanisms (e.g. regulation, finance incentives). They were: i) the minimization of the risk of failure, intended to give priority to measures that are less difficult or complicated to be implemented and also to measures which the expected results are more reliable; and ii) the objective related to minimize time until effect of the plan, that reflects the time that one must wait to observe the results from measures.

### **2.4.** ***Comparison with literature***

In a second stage towards the identification of the objectives behind the EE plans, in order to assess if the objectives from the interviews were complete, reflecting all of the important consequences from the energy efficiency plans in a decision process, the list that resulted from the interviews was compared with the objectives interpreted from the ESD [4]. In addition, the works from Neves [12] and Brown [13] were revised to collect more perspectives of objectives applied to evaluate EE policies and measures.

Regarding the ESD, from the explicit or inferred objectives there found, it is considered that the objectives directly related to the technical measures seem to be covered by the list resulting from the interviews.

In the work from Brown et al. on energy efficiency and renewable energy policies at state level in the Unites States [13], seven objectives were identified: three for economic development, two related to energy security and two of environmental orientation. From the objectives suggested in their work, the three economic ones were essentially related to how the measures are implemented and not directly to the technical nature of the measures. Two others, the decrease of fuel (energy) imports and the greenhouse gas emissions reductions, were already in list resulting from the interviews (Table 1). The two other were considered actual new elements: local air quality impacts and fuel diversity. The local air quality impact was, therefore, added to the list as an objective due to its consistency with the problem (tackling local pollution). The fuel diversity was not adopted because during the discussions with the decision makers in the interviews described above it was clear that, as far the resources are endogenous and the sources reliable, the diversification was not relevant.

Regarding the work of Neves [12], developed in the stricter scope of energy efficiency in the use of electricity, it had identified thirteen objectives. From the objectives these, the ones that can be directly linked to measures of technical nature are the objectives of: i) minimizing the impacts from energy use; ii) minimizing the impacts from peak load; iii) minimizing the costs in general terms; and iv) the possibility to evaluate alternatives. Apart from the minimization of the peak load to avoid building new power plants, and taking into consideration that all physical-based EE alternatives can be evaluated, the other objectives are in line to those already mentioned in the interviews. The minimization from the peak load was adopted as a means objective and included in the form of a fundamental objective as minimizing the impacts of building new power plants and transmission infrastructures.

Having selected the relevant objectives from the interviews and added another two from the process of bibliographic review, the resulting group appears to be complete, non-redundant, concise, specific and understandable, pertaining collectively to the set of fundamental objectives, in line with the requirements specified by Keeney [7] and Eduard [14]. This indicates that a satisfactory group of objectives was obtained to evaluate the energy efficiency plans and measures, and, moreover, that those findings also changed the problem to a decision opportunity where efforts can be directed to find alternatives that will bring more outcomes than just specific final energy savings, as defined at the ESD. Table 2 lists the fundamental objectives that resulted from the interviews, combined with the bibliographic review.

**Table 2 – Fundamental objectives resulting from the interviews and bibliographic review**

| Fundamental objectives | Relevant sources |
|---|---|
| Minimize the influence of energy use on climate change | 1,2,4,5,6 |
| Minimize the financial risk from the investment | 2,3,4,5 |
| Maximize the security of energy supply | 1,2,3,4,5,6 |
| Minimize investment costs | 1,3,5 |
| Minimize the impacts of building new power plants and transmission | 5 |

| | |
|---|---|
| infrastructures | |
| Maximize the local air quality | 6 |

Key: 1 AdEPorto; 2 ADENE; 3 EPE; 4 ESD; 5 Neves; 6 Brown.

The nature of the objectives identified seems to be quite general and not particular of the Portuguese or Brazilian specific contexts, and therefore very likely applicable to other geographical contexts. Nevertheless, it is worth reminding that the good practices of VFT do recommend performing the whole process again with the respective decision makers in a case of applying this research to another country.

## 3. Identification of Attributes

Once the fundamental objectives were identified, it becomes necessary to measure them in order to use the objectives to evaluate alternatives. For that purpose, attributes were defined to indicate the degree to which an objective is measured. Following the process proposed by Keeney [7], all fundamental objectives were translated into attributes, and this translation ultimately received the agreement from the decision makers interviewed. The next subsections describe the attributes that are proposed related to all the fundamental objectives. It is important to highlight that often or even usually  the attributes are not the most accurate that could in theory be established, but instead obey to a trade-off between accuracy and computability within reasonable time and effort It is necessary to take into account the effort of creating specific models, the effort of acquiring data, the benefit in having more accurate attributes, and the capacity to be transparent and have an easy comprehension by any decision maker involved, independently of his/her background. These arguments were taken into consideration for the development of the following attributes.

### 3.1. *$CO_2$ emissions savings*

After identifying “minimizing the influence of energy use on climate change” as a fundamental objective, the decision makers were asked how they would be able to verify this achievement. All the decision makers asked were unanimous in expressing that their preferred way to measure the objective was through the $CO_2$ emissions saved or avoided. Due to the fact that $CO_2$ emission is widely identified as the most important agent of the climate change process [1], the $CO_2$ emission savings was chosen as the attribute to represent the minimization of the influence of energy use on climate change.

Considering the premise that the outcomes from EE plans or measures are savings on final energy, not necessarily compared to the present situation but compared with the expected evolution without an EE plan (business as usual (BAU) scenario), it was proposed to quantify the $CO_2$ emission savings as:

$$CO_{2savings} = \sum_{y=1}^{m}\sum_{i=1}^{n}\left(Q_{fiy} \times CO_{2EFiy} - Q_{fiplany} \times CO_{2EFiy}\right)\ [tCO_2] \qquad \text{eq.1}$$

Where:

$Q_{fiy}$: Original final energy use for energy carrier i at year y in the BAU scenario [MWh]

$Q_{fiplany}$: Yearly final energy for energy carrier i at year y, with the application of an EE plan or measure [MWh]

$CO_{2EFiy}$: $CO_2$ emission factor for energy carrier i at year y [$tCO_2/MWh$]

n: total (number of) energy carriers

m: total number of years analyzed for assessing the effect of the plan.

Following the methodology and data from the IPCC Guidelines for National Greenhouse Gas Inventories [15], it was possible to determine the $CO_2$ emission factors for the main energy carriers used in a country. The $CO_2$ emissions from use of bio-energy were not accounted as emissions in the energy sector, since they are considered stock losses in the land use sector following the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol [1].

Considering the fact that electricity is generated from the conversion of several different energy sources, through several different conversion processes, the $CO_2$ emission factor associated to electricity was accounted as a yearly weighted sum of the $CO_2$ emission factors from all sources that contributed for the electricity generation, whose several contributions in the past can be seen at the national energy balance of countries [16]. Forecasts for the expected future electricity generation mix also exist for most countries. Equation 2 formalizes the calculations for the $CO_2$ emission factor of electricity for a given reference year.

$$CO_{2EFelectricity} = \sum_{i=1}^{n} \frac{CO_{2EFi} \times Yearly\ share_i}{\eta_i} \quad [tCO_2/MWh] \qquad \text{eq. 2}$$

Where:

$\text{Yearly share}_i$: Yearly contribution share of the electricity converted from carrier i [-]

$\eta_i$: Average efficiency of the conversion process from carrier i to electricity [-]

$CO_{2EFi}$: $CO_2$ emission factor for energy carrier i [$tCO_2$/MWh]

n: total (number of) energy carriers used for producing electricity

To illustrate the calculations to find the $CO_2$ emission factor for electricity, data from the energy balances for Portugal between 2006 and 2008 were used [17]. The average conversion efficiency for each conversion process to generate electricity was calculated following equation 3 and is presented in Table 5 (annex 1).

$$\eta_i = \frac{Yearly\ share_i \times Q_{felectricity}}{Q_{si}}\ [-] \qquad \text{eq.3}$$

Where:

$\text{Yearly share}_i$: Contribution share of the electricity converted from carrier i [-]

$Q_{felectricity}$: Total electricity generated by the electric system [MWh]

$Q_{si}$: Energy source used from process i [MWh]

Using the energy contributions for electricity generation in 2008 [17] and the projected energy contributions for electricity from 2009 to 2020 [18], applying the conversion efficiencies presented in

Table 5 (annex 1) and using equation 2, it was possible to determine the reference values for the $CO_2$ emission factor from the Portuguese power generation system and thus quantify the attribute, as seen in Table 6 (annex 1).

It is important to highlight that the actual and future (projected) carbon intensity of electricity generation will directly affect the possible outcomes from the decision process regarding the selection of EE plans or measures. Therefore, such projections should be performed with care, and, preferably, using more scenarios to increase the robustness of the decision process.

### 3.2. *Investment cost*

Considering the fundamental objective of minimizing investment costs, the attribute suggested by the interviewed decision makers was the natural attribute of costs, measured in currency. In order to make this attribute operational, it was proposed that all costs involving the purchase of equipment and the respective installation costs, would compose this attribute, and that it would be seen as the total investment cost in the perspective of the society. The calculation of the monetary value was generally a straightforward process, with the exception of alternatives that would involve infrastructure change or operational modifications, such as alternatives involving modal shift which may require changes in the public transport system in order to cope with the increased demand. For the measures that do not fall under this category the investment cost can be assumed as the increase of the maintenance and operational costs to keep the system functional. The investment in EE in the demand side can be seen as a traded off investment in the supply side. However, in the scope of this work, it is not reflected at this attribute, but it is indirectly considered by the attribute electricity savings (section 3.4). This attribute only considers the (minimum) need to invest in a plan, since a plan should be put in place anyway.

Equation 4 formalizes the calculation for the investment cost.

$$Investment\ cost = P_c + Int_c + Imp_c\ [€] \qquad \text{eq.4}$$

Where:

$P_c$: Purchase cost of any item representing an EE measure (e.g. motor or wall insulation) [€]

$Int_c$: Installation cost [€]

$Imp_c$: Management costs associated with the implementation of the measure [€]

### 3.3. *Payback*

To translate the objective of "minimizing the financial risk from the investment" into a measurable attribute, two options were suggested by the decision makers: one was to perform a cost-benefit analysis, and the other was to use the payback time. The payback was chosen because it provides an assessment of the duration of the period during which the investor's capital is at risk [19], it has a relatively easy acquisition of data. In this case the simple (undiscounted) payback was chosen by the interviewees. It would be possible to use a discounted payback but this can be considered less transparent, less fair to future generations, and the choice of the discount rate is subject to controversy and uncertainties. Another motive why the payback was preferred was the fact that the cost-benefit is a method to evaluate alternatives that depends on the value of some benefits that can be considered to be other fundamental objectives.

The payback is the number of years necessary to recover the financial investments [19]. The way of computing the payback time or period is presented in equation 5.

$$Payback = \frac{\sum_{m}^{n} Investment\ costs_{m}}{\sum_{i}^{p} Q_{fi} \times E_{Ci} - \sum_{j}^{p} Q_{fjplan} \times E_{Cj} + \sum_{i}^{p} OM_{ci} - \sum_{j}^{p} OM_{cj}} \qquad \text{eq.5}$$

Where:

Investment costs$_m$: The non-discounted investment costs (equation 4) for each applied measure [€]

$Q_{fi}$: Final energy use of energy carrier i at the first year in the BAU scenario [MWh]

$Q_{fjplan}$: Final energy of energy carrier j at the first year with the application of an EE plan or measure [MWh]

$E_{ci}$: Energy costs for energy carrier i at the first year [€/MWh]

$E_{cj}$: Energy costs for energy carrier j at the first year [€/MWh]

$OM_{cy}$: Operational and maintenance cost for carrier i at the first year [€]

$OM_{cj}$: Operational and maintenance cost for carrier j at the first year [€]

n: Total number of measures applied

p: Total number of energy carriers

It is relevant to highlight that although the traditional payback concept does not consider the variation of the energy cost along the time, such changes may influence the robustness of the decision process. It could be interesting to express such problem with the decision makers, and even alter the calculations, in order to increase confidence. In this work it was decided not to consider such variations due to the uncertainties involved in the future of energy costs.

### 3.4. *Electricity savings*

The impacts related with reduction of the need to build new power plants and transmission infrastructures are very difficult to quantify, and it is even more difficult to calculate the implications of energy efficiency initiatives at this level. According to Neves [12], it is safe to assert that these impacts depend on the peak load avoided. Thus, the peak load prevented is an indirect measure, or a proxy, of these benefits, as well as of the improvements in system reliability and capacity avoided costs. However, it may be not possible to account the load reduction in power units (W), since the hourly time-profile or load curves for most of the possible EE measures are not modeled. Therefore, in a compromise to the applicability of the methodology in practice to problems of such a large dimension, it was considered that reductions in electricity use would very likely attenuate the peak load and, consequently, affect the impacts related with building new power plants and transmission infrastructures. Ideally, load profiles would be used to better identify the effect of the measures at the peak load, and consequently on the power and transmission infrastructures. However, the compromise between not having to acquire large amount of data and to model the load curves, and having a less precise, but more straightforward, approach was accepted by the decision makers involved. Equation 6 presents how to calculate this proxy attribute.

$$Electriciy\ savings = \sum_{y=1}^{m} Q_{felectricityy} - Q_{felectricityplany}\ [MWh] \qquad \text{eq.6}$$

Where:

$Q_{felectricityy}$: Original final electricity energy use at year y in BAU scenario [MWh]

$Q_{felectricityplany}$: Final electricity energy use at year y with the application of an EE plan or measure [MWh]

m: total number of years analyzed

### 3.5. *Imported energy savings*

The maximization of the security of energy supply was the only objective mentioned by all interviewees, and it was present in all bibliographic sources analyzed for this specific review. All the decision makers were concerned about the importance of the energy availability to sustain their countries and their respective economies, and with the fact that this represents dependence from foreign countries. Consequently, it was proposed to quantify the objective "security of energy supply" in terms of imported energy savings, following [20–22]. The proposed quantification of the imported energy savings is expressed in equation 7.

$$Imported\ energy\ savings = \sum_{y=1}^{m} \left( \sum_{i=1}^{n} Q_{fiy} \times \eta_{pif} \times \eta_{Iif} - \sum_{j=1}^{n} Q_{fjplany} \times \eta_{pjf} \times \eta_{Ijf} \right) [MWh] \quad \text{eq.7}$$

Where:

$Q_{fiy}$: Original final energy use of energy carrier i for year y in the BAU scenario [MWh]

$\eta_{pif}$: Final to primary energy factor for energy carrier i

$\eta_{Iif}$: Imported energy factor for primary energy associated with energy carrier i

$Q_{fjplany}$: Final energy for energy carrier j in year y with the application of an EE plan or measure [MWh]

$\eta_{pjf}$: Final to primary energy factor for energy carrier j

$\eta_{Ijf}$: Imported energy factor for primary energy associated with energy carrier j

n: total (number of) energy carriers used

m: total number of years analyzed

The final to primary energy factor accounts for how much primary energy is used for each unit of final energy. It is applicable only when the transformation process from the primary energy to final is performed inside the country. In all other cases it is assumed to be one. For example, when oil is imported to be refined to further be used in the country as gasoline or diesel, the primary energy factor should be applied. The primary energy factor is also considered to be one when local electricity is accounted, because the imported energy factor for electricity already accounts the primary energy conversion as is demonstrated in equation 8. The primary energy factor follows the methodology proposed by the IEA and the Eurostat [23].

The imported energy factor is the ratio that expresses how much of an energy carrier is imported. Table 7 (annex 1) illustrates the imported energy factors for Portugal, based on energy balances from 2006 to 2008 [17].

Like in the case of the attribute $CO_2$ emissions savings, the electricity is dealt with separately due to the contributions of several energy carriers to its conversion. The imported energy factor for electricity was accounted as a yearly weighted sum of the imported energy factors from all energy carriers that contributed for the electricity generation. Equation 8 formalizes the calculations.

$$Q_{Ielectricityf} = \sum_{i=1}^{n} \frac{\eta_{pif} \times \eta_{Iif} \times Yearly\ share_i}{\eta_i}\ [-] \qquad \text{eq.8}$$

Where:

$Yearly\ share_i$: Yearly contribution share of the electricity converted from carrier i [-]

$\eta_i$: Average efficiency of the conversion process from carrier i to electricity [-]

$\eta_{Iif}$: Imported energy factor for energy carrier i

$\eta_{pif}$: Final to primary energy factor for energy carrier i n: total (number of) energy carriers used

Applying the conversion efficiencies presented in Table 5 (annex 1) and using equation 8, it was possible to find the reference values for the imported energy factor for the Portuguese power generation system, so as to enable the calculation of the attribute (Table 8, annex 1).

It is important to highlight that the actual and future (projected) imported energy factor from the electricity generation will directly affect the possible outcomes from the decision process regarding the selection of EE plans or measures. Therefore, such projections should be performed with care, and, preferably, using multiple scenarios to increase the robustness of the decision process.

### 3.6. ***Total suspended particles emissions savings***

The possible improvements on the local air quality are a fundamental objective that was not mentioned by any decision maker during the interviews, but which was recovered from the bibliographic review [13]. In order cope with the need to quantify the improvements on local air quality, Brown [13] proposed in her work to use the suspended particles emitted by energy use as a proxy. The total suspended particles (TSP) are widely associated with respiratory health problems and local air pollution [1,24], and it is relatively easy to find data related to energy carriers for this type of emissions, making this choice operational and transparent. Other relevant impacts do also exist in relation to local pollution and air quality, such as the acidification of aquifers and the acid rain related damages, resulting from $SO_x$ and $NO_x$ emissions, which are also strongly dependent on the energy use (and source). However, it was decided to keep the number of attributes as low as possible so that they would reflect a real decision situation but still be reasonably manageable.

Considering the premise that the outcomes from energy efficiency plans are savings on final energy, it was proposed to quantify the TSP emission savings as:

$$TSP_{savings} = \sum_{y=1}^{m}\sum_{s=1}^{o}\sum_{i=1}^{n}\left(Q_{fiy} \times TSP_{EFis} - Q_{fisplany} \times TSP_{EFis}\right)\ [t] \qquad \text{eq.9}$$

Where:

$Q_{fisy}$: Original final energy use for energy carrier i, sector s and year y in the BAU scenario [MWh]

$Q_{fisplany}$: Yearly final energy for energy carrier i, sector s and year y with the application of an EE plan or measure [MWh]

$TSP_{EFis}$: TSP emission factor for energy carrier i and sector s [t/MWh]

n: total (number of) energy carriers used

m: total number of years analyzed

o: total (number of) end-use sectors analyzed

Following the methodology and data from the EMEP/EEA air pollutant emission inventory guidebook [25], it was possible to calculate the TSP emission factors for the main energy carriers used in a country by end-use sector. For TSP emissions the sector is of relatively high importance since some sectors such as industry and transports have to follow several environmental laws forcing their TSP emissions to a maximum allowed level, while others such as the domestic sector do not. The TSP emission factor for the imported electricity was considered to be 0, since the burning process is not made at the country and would not influence the local air quality.

The TSP emission factor from electricity was accounted as a yearly weighted sum of the TSP emission factors from all energy carriers that contributed for the electricity generation. Equation 10 formalizes the calculations for the TSP emission factor from electricity.

$$TSP_{EFelectricity} = \sum_{i=1}^{n} \frac{TSP_{EFi} \times share_{iy}}{\eta_i} \; [t] \qquad \text{eq.10}$$

Where:

$share_{iy}$: Contribution share of the electricity generated from carrier i in year y[-]

$\eta_i$: Average efficiency of the conversion process from carrier i to electricity [-]

$TSP_{EFi}$: TSP emission factor for energy carrier i [t/MWh]

n: total (number of) energy carriers used

Using the energy contributions for electricity in 2008 [17] and the projected energy contributions for electricity from 2009 to 2020 [18], applying the conversion efficiencies presented in Table 5 (annex 1) and using equation 10, it was possible to find the reference values for the TSP emission factors from the Portuguese power generation system and to present the attribute with values (

Table 10, annex 1).

## 4. Example of operational use: the case of Portugal

This section seeks to provide an example of how the objectives identified and their respective attributes can be used to evaluate possible alternatives EE plans and to give guidance to further select an appropriate EE plan for a country. To this purpose, 5 EE plans yielding the same amount of energy savings were built using 64 different EE measures (see Annex 1).

The expected energy savings resulting from each of the five EE plans, needed to estimate the degree of achievement of each objective presented in the previous section, were estimated based on an energy demand model developed for Portugal for the years of 2006 to 2016 [26], Table 3 shows the outcomes of each of the 5 EE plans on each of the six identified objectives. It also includes the final energy savings expressed in 2016, as a percentage of the expected energy use in for that year in a business as usual evolution (i.e., without any specific EE plan).

**Table 3 – Results from 5 EE plans for Portugal**

| Plan | Final Energy savings (%) | CO2 emissions savings (Mt) | Investment costs (M€) | Imported energy savings (TWh) | Electricity savings (TWh) | TSP emissions savings (kt) | Payback (years) |
|---|---|---|---|---|---|---|---|
| 1 | 9% | 52 | 22,030 | 195 | -12 | 28 | 5.8 |
| 2 | 9% | 43 | 16,818 | 159 | -15 | 46 | 8.6 |
| 3 | 9% | 33 | 23,714 | 120 | -34 | 63 | 7.0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 4 | 9% | 41 | 29,525 | 167 | 24 | 42 | 11.6 |
| 5 | 9% | 26 | 46,871 | 116 | 13 | 72 | 17.0 |

From Table 3, it is observed that it is possible to build EE plans with the same total final energy savings, but with very different outcomes for the objectives. This confirms that final energy savings are a means to obtain the ends objectives, and the choice of an adequate plan can be oriented by the most important objectives according to the preference of the decision makers involved. For example, a decision maker worried about the total cost of a plan would prefer plan 2 instead of plan 1, but a decision maker oriented by the return of the investment, or the security of energy supply, would prefer the opposite (plan 1).

## 5. Conclusions

This work provides an identification of the typical ends-objectives behind the development of energy efficiency plans, and presents a method to allow the quantification of the fulfillment of each objective. It departs from the principle that plans can be better built and chosen if they are oriented to get the most for these objectives and not only to fulfill energy savings targets.

The process for identifying the objectives and attributes followed the VFT guidelines indicated by Keeney [7,11], which were crucial to filter and organize the decision makers' values/objectives. It resulted in the identification of a set of "typical" fundamental objectives in energy efficiency planning, which are: i) to minimize the influence of energy use on climate change; ii) to minimize the financial risk from the investment; iii) to maximize the security of energy supply; iv) to minimize investment costs; v) to minimize the impacts of building new power plants and transmission infrastructures; vi) to maximize local air quality.

In order to make the objectives operational (possible to be evaluated), attributes associated with each objective were also identified, and a calculation method for each one was developed. The attributes are: i) $CO_2$ emissions savings; ii) payback; iii) imported energy savings; iv) investment cost; v) electricity savings; and vi) TSP emissions savings. The application of the method to evaluate plans was exemplified with a hypothetical set of 5 different plans for Portugal.

The results of the brief example confirmed that it is possible to build EE plans with similar total final energy savings, but with very different outcomes for the objectives. The evaluation and possible choice of energy efficiency plans should therefore be focused on ends-objectives and not simply on total final (or primary) energy savings.

The multiple-objective approach resulting from this work may be used as a base for identifying the most adequate EE plans for a country. The objectives, and their respective attributes, can be used to guide the search for solutions in a multiple objective space. Furthermore, the attributes can be used with any multi-criteria decision aid approach to select, rank or sort plans when a reasonable number of EE plans have been previously identified.

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# Annex

**Table 4 – $CO_2$ emission factors for energy carriers**

| Energy Carriers | $CO_2$ emission factor (kg/MWh) |
|---|---|
| Bio-energy (biogas, biodiesel, biomass, ethanol, liquor, methanol) | 0 |
| Coal (Anthracite) | 354 |
| Diesel | 267 |
| Diesel for Heating | 267 |

| | |
|---|---|
| Fuel Oil | 279 |
| Gasoline | 249 |
| Hydro, Solar, Wind | 0 |
| Industrial Wastes | 515 |
| Jet | 252 |
| LPG | 227 |
| Municipal Wastes | 330 |
| Natural Gas | 202 |
| Oil for lighting | 264 |
| Other | 264 |

**Table 5 – Reference average efficiency of the conversion processes to electricity in Portugal**

| Conversion process | η |
|---|---|
| Biogas - Thermal process | 0.31 |
| Biomass - Thermal process | 0.25 |
| Coal - Thermal process | 0.39 |

| | |
|---|---|
| Cogeneration (all carriers) | 0.79 |
| Diesel - Thermal process | 0.30 |
| Fuel Oil - Thermal process | 0.39 |
| Hydro, Wind, Geothermal and Solar | 1.00 |
| Imports | 1.00 |
| Municipal Wastes - Thermal process | 0.25 |
| Natural Gas - Thermal process | 0.51 |

**Table 6 - $CO_2$ emission factors of electricity in Portugal by year (verified for 2008, and projected until 2020)**

| Year | $CO_2$ emission factor for electricity (kg/MWh) |
|---|---|
| 2008 | 336 |
| 2009 | 275 |
| 2010 | 169 |
| 2011 | 182 |
| 2012 | 173 |

| | |
|---|---|
| 2013 | 165 |
| 2014 | 157 |
| 2015 | 141 |
| 2016 | 135 |
| 2017 | 135 |
| 2018 | 124 |
| 2019 | 124 |
| 2020 | 122 |

**Table 7 – Imported energy factor for primary energy associated with energy carriers for Portugal (2006-2008)**

| Energy Carriers | Imported energy factor |
|---|---|
| Biogas, biodiesel, biomass | 0 |
| Coal (Anthracite) | 1 |
| Diesel | 1 |
| Diesel for Heating | 1 |
| Electricity (imported) | 1 |

| | |
|---|---|
| Ethanol | 1 |
| Fuel Oil | 1 |
| Gasoline | 1 |
| Hydro, solar, wind | 0 |
| Industrial Wastes | 0 |
| Jet | 1 |
| Liquors (biofuel) | 0 |
| LPG | 1 |
| Methanol | 1 |
| Municipal Wastes | 0 |
| Natural Gas | 1 |
| Oil for lighting | 1 |

**Table 8 – Imported energy factors for electricity in Portugal: Historical for 2008 and forecasted until 2020 (based on data from [17] for 2008 and from [18] for the electricity from 2009 to 2020)**

| Year | Imported energy factor for |
|---|---|

| | electricity |
|---|---|
| 2008 | 1.43 |
| 2009 | 1.24 |
| 2010 | 0.87 |
| 2011 | 1.05 |
| 2012 | 0.97 |
| 2013 | 0.90 |
| 2014 | 0.82 |
| 2015 | 0.70 |
| 2016 | 0.66 |
| 2017 | 0.68 |
| 2018 | 0.60 |
| 2019 | 0.61 |
| 2020 | 0.59 |

**Table 9 – TSP emission factors for energy carriers (assuming default tier 1 emission factors for industry, services and transports, and uncontrolled emissions for the domestic sector [25])**

| Energy Carriers | Sector | TSP emission factor (g/MWh) |
|---|---|---|
| Biogas | All | 18 |
| Biodiesel | Domestic | 9 |
| | Industry, Services, Transports | 5 |
| Biomass | Domestic | 576 |
| | Industry, Services, Transports | 183 |
| Coal (Anthracite) | Domestic | 1800 |
| | Industry, Services, Transports | 108 |
| Diesel | Domestic | 18 |
| Diesel for Heating | Industry, Services, Transports | 10 |
| Electricity (imported) | All | 0 |

| | | |
|---|---|---|
| Ethanol | Domestic | 11 |
| Methanol | Industry, Services, Transports | 7 |
| Fuel Oil | Domestic | 216 |
| | Industry, Services, Transports | 90 |
| Gasoline | Domestic | 18 |
| | Industry, Services, Transports | 10 |
| Hydro, Geothermal, Solar, Wind | All | 0 |
| Industrial Wastes | All | 360 |
| Jet | All | 0 |
| Liquors (biofuels) | All | 576 |
| LPG | Domestic | 18 |
| | Industry, Services, Transports | 10 |
| Municipal Wastes | All | 360 |

| | | |
|---|---|---|
| Natural Gas | All | 3 |
| Oil for lighting | Domestic | 216 |
| Other | Industry, Services, Transports | 90 |

**Table 10 - TSP emission factors for electricity by year: Historical for 2008 and forecasted until 2020**

| Year | TSP Emission factor for electricity (g/MWh) |
|---|---|
| 2008 | 320 |
| 2009 | 104 |
| 2010 | 79 |
| 2011 | 73 |
| 2012 | 72 |
| 2013 | 71 |
| 2014 | 72 |
| 2015 | 69 |

| | |
|---|---|
| 2016 | 67 |
| 2017 | 66 |
| 2018 | 73 |
| 2019 | 73 |
| 2020 | 72 |

**Table 11 – Measures inside the 5 EE plans for Portugal**

| Sector | Measure | Presence of the measure in plan | | | | |
|---|---|---|---|---|---|---|
| | | Plan 1 | Plan 2 | Plan 3 | Plan 4 | Plan 5 |
| Domestic | Improving wall Insulation to U = 0.38 | √ | √ | | √ | |
| Domestic | Replacement of ambient cooling systems for most efficient air conditioning | √ | | √ | | |
| Domestic | Replacement of ambient heating systems for most efficient centralized electric heat pump systems | | | √ | √ | √ |
| Domestic | Replacement of ambient heating systems for most efficient centralized natural gas heating | √ | | | | |
| Domestic | Replacement of computers for most efficient desktop PC and LCD monitor | | | | | √ |

| Sector | Measure | Presence of the measure in plan | | | | |
|---|---|---|---|---|---|---|
| | | Plan 1 | Plan 2 | Plan 3 | Plan 4 | Plan 5 |
| Domestic | Replacement of computers for most efficient laptops | √ | √ | | | |
| Domestic | Replacement of hobs for most efficient electric hobs | √ | | | | |
| Domestic | Replacement of hobs for most efficient natural gas hobs | | √ | | | √ |
| Domestic | Replacement of ovens for most efficient electric ovens | | | | | √ |
| Domestic | Replacement of printers for most efficient ones | | | | | √ |
| Domestic | Replacement of tumble dryers for most efficient electric ones (label A, A+) | √ | | √ | | |
| Domestic | Replacement of washing machines for most efficient ones (label A, A+) | | √ | | √ | |
| Domestic | Substitution of domestic hot water systems for most efficient electric heat pump water heaters | | | | | √ |
| Domestic | Substitution of domestic hot water systems for most efficient electric storage water heaters | | | | √ | |
| Domestic | Substitution of domestic hot water systems for most efficient natural gas tankless water heaters | | √ | | | |

| Sector | Measure | Presence of the measure in plan | | | | |
|---|---|---|---|---|---|---|
| | | Plan 1 | Plan 2 | Plan 3 | Plan 4 | Plan 5 |
| Domestic | Substitution of domestic hot water systems for most efficient solar water heaters + electric storage water heater | | | √ | √ | |
| Domestic | Substitution of freezers for most efficient freezers in market (A++) | √ | √ | √ | | |
| Domestic | Substitution of lamps for most efficient compact fluorescent lamps | √ | √ | | | |
| Domestic | Substitution of lamps for most efficient LEDs | | | | √ | |
| Domestic | Substitution of refrigerators for most efficient refrigerators in market (A++) | | | | | √ |
| Industry | Replacement of motors with output range between 0 and 0.75 kW for most efficient ones (EFF3) | | | √ | √ | |
| Industry | Replacement of motors with output range between 0.75 and 4 kW for most efficient ones (EFF3) | √ | | | | √ |
| Industry | Replacement of motors with output range between 10 and 30 kW for most efficient ones (EFF3) | √ | √ | | | |
| Industry | Replacement of motors with output range between 130 and 500 kW for most efficient ones (EFF3) | √ | | √ | | |

| Sector | Measure | Presence of the measure in plan | | | | |
|---|---|---|---|---|---|---|
| | | Plan 1 | Plan 2 | Plan 3 | Plan 4 | Plan 5 |
| Industry | Replacement of motors with output range between 30 and 70 kW for most efficient ones (EFF3) | | √ | | | |
| Industry | Replacement of motors with output range between 4 and 10 kW for most efficient ones (EFF3) | √ | √ | √ | | |
| Industry | Replacement of motors with output range between 70 and 130 kW for most efficient ones (EFF3) | | √ | √ | √ | |
| Industry | Replacement of motors with output range higher than 500 kW for most efficient ones (EFF3) | √ | | | | √ |
| Industry | Substitution of boilers for most efficient coal boilers | | | | √ | √ |
| Industry | Substitution of boilers for most efficient coal CHP | | | √ | √ | |
| Industry | Substitution of boilers for most efficient electric boilers | √ | | | | |
| Industry | Substitution of boilers for most efficient natural gas boilers | | √ | | | |
| Industry | Substitution of boilers for most efficient natural gas CHP | √ | | | √ | √ |
| Industry | Substitution of boilers for most efficient oil boilers | | | | | √ |
| Industry | Substitution of boilers for most efficient oil CHP | | | | √ | √ |

| Sector | Measure | Presence of the measure in plan | | | | |
|---|---|---|---|---|---|---|
| | | Plan 1 | Plan 2 | Plan 3 | Plan 4 | Plan 5 |
| Industry | Substitution of lamps for most efficient high intensity discharge lamps | √ | √ | | | |
| Industry | Substitution of lamps for most efficient LEDs | | | | √ | |
| Services | Replacement of ambient heating systems for most efficient centralized electric heat pump systems | √ | √ | √ | | |
| Services | Replacement of ambient heating systems for most efficient fuel oil furnaces | | | | √ | √ |
| Services | Replacement of ambient heating systems for most efficient individual electric space heaters | | | | √ | |
| Services | Replacement of ambient heating systems for most efficient natural gas furnaces | | | | √ | |
| Services | Replacement of commercial ovens for most efficient electric ovens | | | | √ | |
| Services | Replacement of computers for most efficient laptops | √ | | √ | | |
| Services | Replacement of motors with output range between 0 and 0.75 kW for most efficient ones (EFF3) | √ | | | | |
| Services | Replacement of motors with output range between 10 and 30 kW for most efficient ones (EFF3) | √ | | | | √ |

| Sector | Measure | Presence of the measure in plan | | | | |
|---|---|---|---|---|---|---|
| | | Plan 1 | Plan 2 | Plan 3 | Plan 4 | Plan 5 |
| Services | Replacement of motors with output range between 30 and 70 kW for most efficient ones (EFF3) | | | | | √ |
| Services | Replacement of motors with output range between 4 and 10 kW for most efficient ones (EFF3) | √ | √ | | √ | |
| Services | Replacement of motors with output range between 70 and 130 kW for most efficient ones (EFF3) | | | | | √ |
| Services | Replacement of ranges for most efficient electric ranges | √ | √ | | √ | √ |
| Services | Replacement of reach-in refrigerators for most efficient ones | √ | | | | √ |
| Services | Substitution of hot water systems for most efficient electric tankless water heaters | | √ | | | √ |
| Services | Substitution of hot water systems for most efficient solar water heaters + electric heat pump water heater | √ | √ | | | √ |
| Services | Substitution of hot water systems for most efficient solar water heaters + electric storage water heater | | | √ | √ | √ |
| Services | Substitution of hot water systems for most efficient solar water heaters + natural gas storage water heater | | | | √ | |

| Sector | Measure | Presence of the measure in plan | | | | |
|---|---|---|---|---|---|---|
| | | Plan 1 | Plan 2 | Plan 3 | Plan 4 | Plan 5 |
| Services | Substitution of lamps for most efficient high intensity discharge lamps | √ | √ | √ | √ | |
| Transports | Modal shift from bus to trains | √ | | | | √ |
| Transports | Modal shift from trucks to trains | | | √ | √ | |
| Transports | Substitution of buses for most efficient diesel buses | | | √ | | |
| Transports | Substitution of individual transports for most efficient diesel cars | | | | | √ |
| Transports | Substitution of individual transports for most efficient hybrid diesel cars | | | | | √ |
| Transports | Substitution of individual transports for most efficient hydrogen cars | | | | √ | |
| Transports | Substitution of individual transports for most efficient PHEV | √ | | | | |
| Transports | Substitution of trucks for most efficient diesel trucks | | | | √ | |
| Transports | Substitution of trucks for most efficient electric trucks | √ | √ | | | √ |