Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 106 (2016) 258 – 278

Energy Procedia

1st Energy Economics Iberian Conference, EEIC | CIEE 2016, February 4-5, Lisbon, Portugal, APEEN (www.apeen.org) and AEEE (www.aeee.es)

An application of Soft Systems Methodology in the evaluation of policies and incentive actions to promote technological innovations in the electricity sector

Carlos Henggeler Antunes [a,c], Luis Dias [b, c], Guilherme Dantas [d], João Mathias [d], Lucca Zamboni [e]

[a] *Dept. of Electrical and Computer Engineering, University of Coimbra, Portugal; ch@deec.uc.pt*
[b] *Faculty of Economics, University of Coimbra, Portugal; lmcdias@fe.uc.pt*
[c] *INESC Coimbra, Coimbra, Portugal*
[d] *GESEL, Federal University of Rio de Janeiro, Brazil; guilhermecrvg@yahoo.com.br, mathias@ie.ufrj.br*
[e] *EDP Brasil, Brazil, lucca.zamboni@edpbr.com.br*

Abstract

The promotion of a reliable and sustainable power system has as key drivers the development of smart grids associated with demand-side management schemes, diffusion of electric mobility, integration of larger shares of distributed (micro)generation, and the introduction of storage systems. In addition, these technological developments represent new business opportunities for several players, which should be considered by regulatory guidelines accounting for technical efficiency, economic feasibility and tariff affordability. The technical and economic characteristics of the electricity sector do not induce that the process of technological innovation happens in an endogenous manner within the sector dynamics. Therefore, public policies have a role to play in this process. This work presents an approach using Problem Structuring Methods to frame the problem of analyzing and evaluating technological innovations and associate incentive policies in the electricity sector. The results of this structuring phase using Soft Systems Methodology under different perspectives suggest a large number of issues to be taken into account that were organized as a hierarchy of objectives. These objectives correspond to the criteria of a multicriteria decision analysis model to assess policies promoting technological innovations. This methodology provides decision support to decision makers to shape policies aimed at fostering more reliable and sustainable electricity systems.

Peer-review by the scientific conference committee of EEIC | CIEE 2016 under responsibility of Guest Editors.

Keywords: *Electricity sector; technological innovations; problem structuring; Soft Systems Methodology; multicriteria decision analysis; innovation policies.*

Peer-review by the scientific conference committee of EEIC | CIEE 2016 under responsibility of Guest Editors.
doi:10.1016/j.egypro.2016.12.121

1. Introduction

Investments associated with technological innovations to guarantee the reinforcement, expansion and modernization of electrical network infrastructures to satisfy a growing demand with security, quality and less environmental impacts should be analyzed taking into account distinct perspectives of evaluation. The offer of a sustainable and reliable electricity system has as an important driver the evolution towards smart grids associated with demand side management schemes, increase of distributed generation, in particular micro-generation, diffusion of electric mobility and introduction of storage systems. Additionally the technological development vectors represent new business opportunities, which should be considered by regulation guidelines to make viable the smart grids evolution process in the pursuit of technical efficiency, economic viability and tariff moderation.

The diffusion of smart grids is not just a technological innovation, but a technological transition is at stake. In this context, the analysis of the technological variables arising in this process is necessary, and the interests of the different stakeholders involved in the process should be considered. The techno-economic characteristics of the electricity sector (capital intensive, undifferentiated product, regulated tariffs, almost inelastic demand, need of an instantaneous balance between supply and demand, etc.) do not induce that the innovation process occurs endogenously to the sector dynamics. Therefore, public policies are required to foster this process.

The complexity of the study of innovation technologies and incentive policies associated stems mainly from the need to take into account aspects of distinct nature (technological, economic, financial, social, regulatory), several of them of intangible nature, in the evaluation models. Therefore, the structuring of the problem characteristics is an essential step to develop such models. Since decision making in the energy sector should take into account variables of heterogeneous nature and stakeholders of different spheres, traditional evaluation methods such as cost-benefit analysis do not enable the explicit consideration of all elements involved on a consensual and realistic basis. This limitation is essentially due to the difficulties of monetizing several aspects of the problem, as well as making transparent the trade-offs to be established between the multiple perspectives the evaluation should encompass.

In this context, multicriteria decision aid (MCDA) methodologies are particularly adequate to deal with a vast range of problems, in which potential alternatives (courses of action) should be judged according to different evaluation axes that are explicitly considered in the model. MCDA models enable to include evaluation criteria of different nature, which are generally conflicting and incommensurate, taking into account the points of view of different stakeholders, each one displaying in the decision process his/her own values, preferences and criteria.

This paper deals with the importance of problem structuring as an essential step of the analysis, enabling to unveil a deeper understanding of the problem, as well as the essential elements that should be included in the MCDA model through the interaction with the stakeholders, in order to provide decision support in the appraisal of policies and actions of incentive to technological innovations in the electricity sector.

2. Problem structuring methods - Soft Systems Methodology

As it is recognized by several authors [1-6], the problem structuring phase should constitute the first step, and one of the most important ones, in decision support processes. Real-world applications emphasize the critical nature of problem structuring in order to gather in a systematized manner all the relevant information, improve the understanding of the overall decision situation and clearly define the problem to be tackled.

In general, real-world problems arise in complex and ill-defined contexts. Therefore, it is necessary to identify the essential characteristics of the decision situation, establish the scope and the boundaries of the analysis, recognize the stakeholders involved, as well as their main motivations and objectives, and understand which actions can be carried out [1]. This analysis enables to offer all participants in the process of a common view and an operational basis from which the identification of the fundamental points of view, the operational criteria, and the potential actions to be evaluated will emerge.

Several Problem Structuring Methods (PSM) have been proposed for structuring complex decision situations [7]. According to Rosenhead [7], these situations for which PSM are particularly useful are characterized by multiple actors and multiple perspectives, non-consensual or even antagonistic interests, different measurement units of the impacts, evaluation aspects of intangible nature, and uncertainty over several elements of the decision situation. PSM present two essential characteristics: facilitation and structuring. Facilitation aims to offer an environment in which the debate between the participants is duly oriented according to the components of each specific PSM, enabling to clarify the understanding of the decision situation. Structuring refers more generally to the process of systematization of the elements unveiled during debate, in order to enable advancing on a common basis of knowledge about the problem, thus contributing to improve the quality of the decision making process.

Each PSM proposes a particular representation of the decision situation to: enable the analysis of different perspectives, be cognitively accessible even for actors less familiarized with the topic, work in an interactive manner reflecting the evolution of debate and learning of the actors, enable identifying and compromise of partial improvements rather than requiring a global solution. These requirements do not entail mathematical models or methods [8]. PSM foster a better understanding of the role of each actor, his/her degree of intervention and power to influence decisions, the relationships between the different actors and the identification of their values, objectives and concerns. PSM have been applied to decision situations in the energy sector, with emphasis on Soft Systems Methodology (SSM). SSM is a general system analysis method developed from systems engineering concepts [3, 9]. Neves et al. [10] used SSM to structure a problem of evaluation of initiatives for the promotion of energy efficiency. Ngai et al. [11] used SSM to identify opportunities in management support of rational use of energy in textile manufacturing processes. Coelho et al. [12] also used SSM to study problems in urban energy planning.

The main reasons for the selection of SSM to carry out this study are rooted on our experience in problem structuring in the energy sector [10, 12], its flexibility in the description of the decision situation, including the definition of the role of each participant, his/her degree of involvement and intervention capacity, and the relationships between the participants. The SSM approach offers a systemic framework to carry out process analysis in which technological issues and the intervention of decision makers are interdependent. SSM was developed to use systems engineering concepts to complex and ill-defined problems in which the multiple inter-related issues are not clearly defined [3, 9], with multiple world views and then multiple conflicting objectives pertaining to the stakeholders.

The SSM approach enables the linkage between the structuring and alternative evaluation steps, contributing to shed light on the main issues of distinct nature that should be incorporated in MCDA models. The approach to problems using SSM is carried out, in general, using a search process consisting of seven stages as illustrated in Fig. 1. In this diagram a clear distinction is made between the real world and the (conceptual) systems world. The line separating stages 1, 2, 5, 6 and 7 from stages 3 and 4 indicates that the SSM analysis addresses two main concerns: one associated with the real world and another one focused on the systems world in a systemic perspective.

The SSM approach begins with the identification of a real world situation that is considered problematical by some stakeholder. The description of the situation aims at making a diagnosis of the existing situation, identifying the participants and the problem nature. The most common strategy is the graphical representation of the problem under study. This graphical representation, called “rich picture”, includes all stakeholders and their relationships in order to offer a broad view of the problem. In stages 3 and 4 the SSM approach builds the conceptual models. This implies having a clear definition of the system to be modeled, which is known as root definition, whose construction should be guided to contain the following components (CATWOE): Customers, Actors, Transformation process, Weltanschauung (world view), Owner, and Environmental constraints (Table 1).

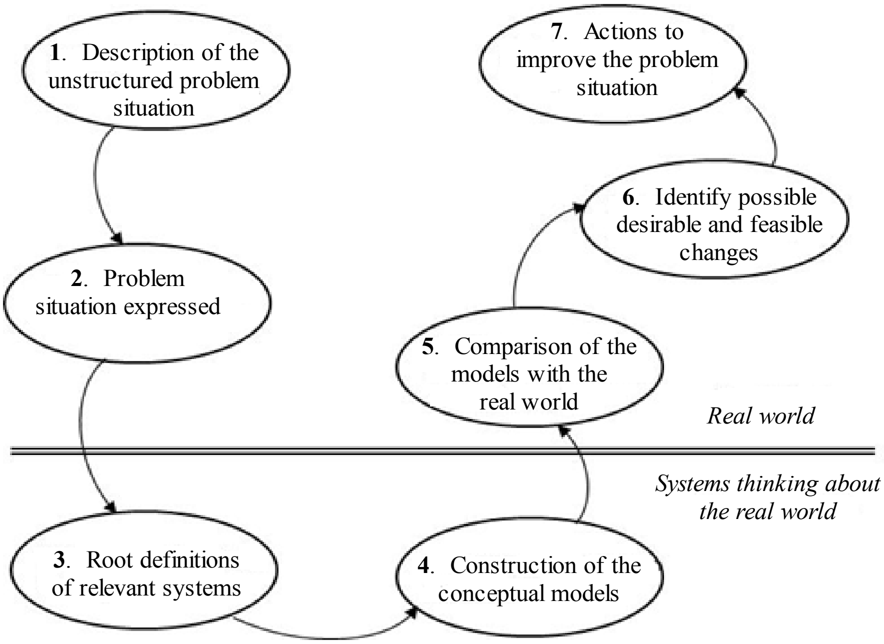

Fig. 1. The steps of SSM

From the root definition the conceptual model is developed as simple as possible to accomplish the transformation described in stage 3. This model is constituted by a set of activities conceived as a transformation process and connected by logical dependencies [13]. The conceptual models should then be validated by comparing them with a formal system. A formal system should possess the following elements: Purpose/mission; Performance measure; Decision making process; Sub-systems; Interaction with the environment; Physical and human resources; Continuity. This model should also include the monitoring and control activities to assess the system efficacy, efficiency and effectiveness [9].

Once the model is developed and returning to the real world problem situation, in stage 5 the SSM approach makes a comparison between the model and the real world. In this comparison stage, the participation of the stakeholders is of utmost importance in order to generate debate on possible changes that desirably may occur to improve the situation. Based on the comparisons, in stage 6 it is possible to identify change proposals that will be necessary to introduce in the real system processes and structures, which will be implemented in stage 7. The success of the implementation requires that change proposals are desirable and feasible.

Table 1. Root definition - CATWOE

C	*Client* – the immediate beneficiaries or victims of the system results.
A	*Actors* – the participants in the transformation, i.e. those who carry out activities within the system.
T	*Transformation* – the core of the human activity system, in which some inputs are converted into outputs and given to the clients. Actors play a role in this transformation process.
W	*Weltanschauung* (world view) – the perspective or point of view that makes sense of the root definition being developed.
O	*Owner* – the individual or group responsible for the proposed system. He/she has the power to modify or even stop the system, overlapping other system actors.
E	*Environmental constraints* – the human activity systems work under some constraints imposed by the external environment, as legal, physical or ethical constraints.

3. Multi-criteria decision aiding

Rather than trying to convert all aspects important for a decision into a single "currency", which is often difficult and subject to controversy, the paradigm of MCDA considers explicitly several evaluation criteria [14]. According to Bouyssou [15] there are three main advantages of adopting this paradigm: it allows a solid base for dialogue by acknowledging the concerns of all stakeholders, encouraging joint ownership of the evaluation models, it breaks down the problem thus facilitating the definition of assessment instruments and uncertainty modelling, and it invites decision makers to consider any choice as a compromise between conflicting objectives, since there is rarely an option better than all the rest on every evaluation criterion. The areas of energy and environment have been a fertile ground for the application of MCDA approaches, as can be witnessed in several books and reviews [4, 16-20].

There are three main stages of a decision process under an MCDA paradigm: problem structuring, construction of the evaluation model, and exploitation of the model.

The stage of structuring the problem is the basis for all analyses that ensue. Structuring entails defining what the problem is, what the alternatives and their consequences are, and what criteria should be used to evaluate alternatives. Keeney [5] sustains that decision makers should focus on objectives first and then alternatives, mainly because this can foster creativity in designing new alternatives and ensures the evaluation criteria are aligned with an individual's or an organization's objectives. The use of PSM such as SSMs can be quite helpful to the process of identifying relevant actors and objectives [21].

The stage of constructing the evaluation model entails, first, evaluating the performance of each alternative according to each one of the different evaluation criteria. These performances can be measured on quantitative or qualitative scales. Criteria such as costs or pollutant emissions can be measured quantitatively. If a direct indicator is not available for the assessment in question, it is possible to use an indirect indicator. For instance, acres of forest destroyed can be an indirect indicator for loss of biodiversity. On the other hand, criteria such as degree of opposition of the population, or aesthetic perception of the landscape, will usually be assessed on a qualitative scale using levels such as negligible, significant, etc., through a precise description (a descriptor table) for the meaning of each level, to avoid different interpretations of the same words [22].

Once a performance table is built summarizing the assessment of each alternative on each criterion, the following step in an MCDA study consists in deriving a recommendation using an appropriate aggregation method. There are three main pathways to perform an aggregation of single-criterion performances [23]: obtaining an overall synthesis value (allowing to rank all the alternatives), obtaining a binary relation (not necessarily complete) comparing alternatives in a pairwise way, or obtaining answers to simple questions from the decision maker in the course of an interactive questioning protocol able to identify the most interesting alternatives at its end.

4. The process followed to structure objectives

Recognizing and structuring decision objectives is essential to reach adequate recommendations, but often decision makers fail in this crucial step [24]. Bana e Costa and Beinat [1] and Keeney [5] presented methodologies to elicit and structure objectives (or points of view) for an MCDA process. Such methodologies allow identifying the so-called fundamental objectives set. Each fundamental objective should be controllable, essential, concise, specific and understandable. Fundamental objectives often comprehend different sub-objectives, but it should be possible to assess alternatives on each fundamental objective, one at a time, independently of the other fundamental objectives. As a set the fundamental objectives should be complete but not redundant.

Fundamental objectives are not means to a higher-level concern. They represent an end in themselves. For instance, let us consider an objective of reducing the consumption of electrical energy. Asking the decision maker why is this objective important the answer might reveal the objective of reducing costs to consumers, or the objective of reducing greenhouse gas emissions, or both. This distinction between means-objectives and end-objectives is important. For instance, if the fundamental objective is to reduce greenhouse gas emissions then not only the consumption of electricity matters, but also the carbon intensity of the country's mix.

The construction of a hierarchy of objectives can be carried out using a top-down or a bottom-up approach [5, 25]. The top-down approach starts by identifying the fundamental objectives, which are then decomposed into lower level sub-objectives, down to the relevant attributes of the alternatives. Its main advantage is that it focuses on the main concerns behind the evaluation process, but it risks omitting a few relevant sub-objectives. A bottom-up approach starts by considering a set of many attributes of the alternatives that are considered to be relevant for the decision process, and then these attributes are successively coalesced into higher-level objectives. Its main advantage is to allow discussing objectives at a more concrete and understandable level, but it risks missing a broader perspective.

The strategy followed in the current work sought to combine the advantages of bottom-up and top-down approaches. First, a bottom-up approach was followed to inform the definition of a set of fundamental objectives. Then, a top-down approach ensured no relevant aspects were missing.

Fig. 2 presents the rich picture for the problem of evaluation of policies and incentive actions to foster technological innovations in the electricity sector with a focus on the development of smart grids. This diagram results from information gathered in the scientific literature, namely a thorough revision of the practices in eighteen countries, technical visits to several entities in Portugal, France, Italy and Germany, including distribution companies, regulators, energy service companies and research centers on end-user energy needs, as well as discussions held at the International Seminar on "Challenges of Regulation in the Electricity Sector" (Coimbra, 12-13 February 2015). This information has been then extensively discussed among experts at BNDES (Brazilian Development Bank), EDP Brazil, ONS (Transmission Network System Operator, Brazil) and ANEEL (Brazilian regulator of the electricity sector) in November 2015, to assess its relevance for developing a thorough model for the appraisal of policies to promote technological innovations in the electricity sector.

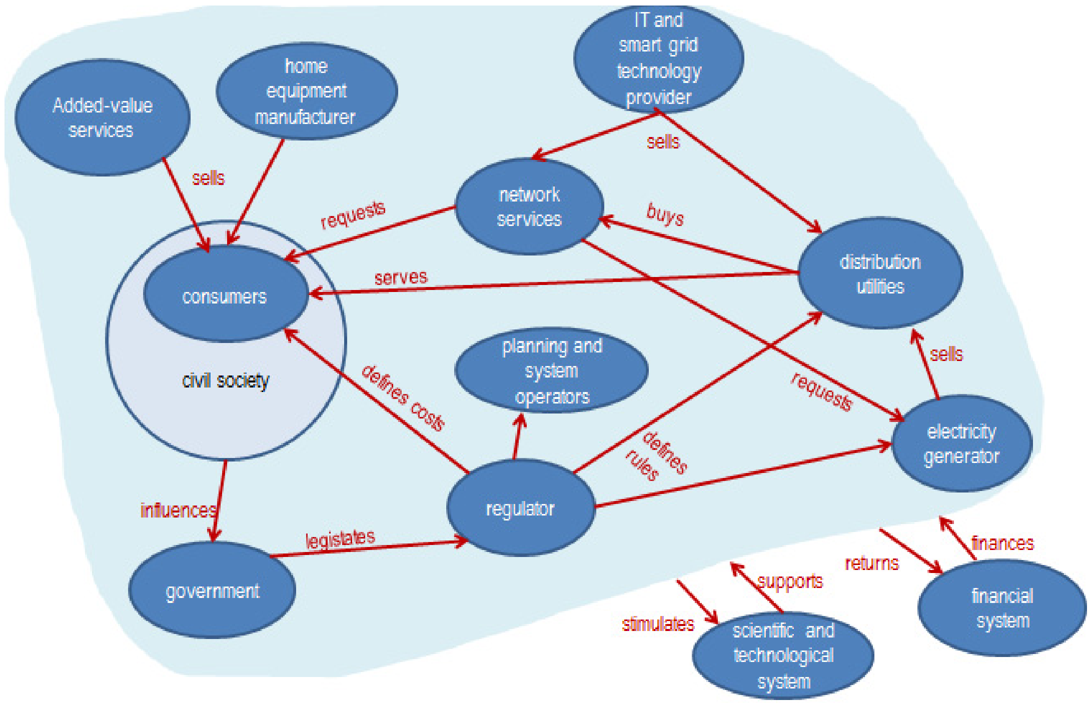

Fig. 2. Rich Picture

The following actors have been identified:

- *Consumers* are the final clients of the electricity distribution service; they may be individuals or companies.
- Consumers are a relevant part of the *Civil Society*, which also includes organizations representing them such as consumer associations, industry associations, or even the media, all influencing government policies.
- The *Government*, at different territorial levels, determines the energy policies at large.
- The *Regulator* has a mediation role between all the stakeholders in the electricity sector. This actor defines the rules that apply to generators, distributors and retailers of electric energy, also with the power to define the costs (or part of the costs) seen by the consumers in the tariffs.
- *Generators* of electric energy invest in generation capacity and sell energy in the market.
- *Distributor* / Retailers (in some countries these can be the same of different entities) supplies energy to consumers, charging the availability of service (power tariff wherever it exists) and the energy sold. It can buy network services to other entities to better achieve its aims, ensuring the best way to manage and satisfy demand.
- *Planning and operation entities* include those that have the mission of the long-term planning of the electricity system, the transmission network operator, to ensure the overall operation of the system according to quality of service standards.
- The *network service companies* may assume a more relevant role in the smart grid. These may include aggregators that use the demand flexibility of end-users for demand-side actions such as peak shaving and offering of ancillary services.
- Smart grids can foster new business for *equipment and technology suppliers*, who sell their services to the actors intervening in electricity distribution, as well as manufacturers of equipment and appliances

for end-users. New business opportunities also arise for *added-value service suppliers* (energy service companies) to consumers.

- The whole system interacts with the *financial system*, which finances investments in smart grids.
- Also this system interacts with the *scientific and technological system*, which supplies knowledge and qualified human resources for the operation of all actors, for innovation and decision support.

In the CATWOE analysis four perspectives have been identified and explored. These perspectives under which it is relevant to promote smart grids and the associate technological developments are:

a) The smart grids as an instrument to optimize resources - smart grids will provide an intelligent manner to optimize resources, namely generation and distribution capacity but also the potential "hidden" resource which is the more efficient use of electricity by consumers.

b) The smart grids as opportunity of development and business - smart grids constitute an opportunity for economic development, fostering the creation of new businesses thus promoting technological innovation.

c) The smart grids to foster environmentally friendly technologies - smart grids constitute an opportunity to promote environmentally friendly technologies and energy efficiency, namely concerning the higher integration of renewable sources in the energy mix

d) The smart grids to empower consumers / micro-generators - smart grids constitute an opportunity to increase the power of consumers and micro-generators, promoting their intervention capacity.

For each one of these perspectives the CATWOE analysis enabled to identify a set of elements to be taken into account for the definition of evaluation criteria in MCDA, as suggested by Neves et al. [21]. The discussions with the experts originated the opportunities to examine issues that suggested the consideration of objectives deemed relevant for diverse actors. Just the simple initial question regarding why the present situation was considered problematical hinted objectives that cannot be satisfactorily met with the existing conditions (for instance, concerning weaknesses in the telecommunication networks). The discussion about current norms and social constraints enabled to understand that they exist to comply with the objectives of some stakeholder (for instance, making a more efficient utilization of installed capacity). Also, unveiling the values used to ascertain what a good performance is may be used to construct objectives associated with the stakeholder's role (for instance, regarding improving market efficiency). Tables 2a) to 2d) present the analysis carried out for each perspective.

The SSM approach described above, together with literature reviews, led to the identification of a "cloud" comprising about a hundred items, each one reflecting an attribute or a concern that could be evaluated when assessing policies to foster technological innovations in the electricity sector. The semantic analysis of this "cloud" of items ("social acceptance", "tax benefits", "costs of metering", "to modernize the grid", etc.) took into account the context in which each one emerged. This analysis allowed forming clusters of interrelated concerns pertaining to the same high-level objective. This formation of clusters is an important support to identify objectives, as demonstrated by research in psychology about memory [24]. By defining categories one enhances the ability to enrich the list of objectives by means of cue-dependent retrieval: categories act as stimuli to remember targets in memory associated with them.

The categories that were formed are associated with fundamental purposes for technological innovation in the electricity sector. They can be seen as the top of a functional value hierarchy [25], which are combinations of the functional hierarchies from systems engineering with value hierarchies of decision analysis. Following Parnell et al. [25], the top-level fundamental objectives are end-objectives (rather than means-objectives). They are stated using expressions that are familiar to the stakeholders (in this work, actors involved in the electricity system), and are expressions that combine a verb plus an object for a clearer reading.

Table 2a). CATWOE analysis for the perspective “The smart grids as an instrument to optimize resources”

Clients System operator, Distributor Society	**What are the benefits and the disadvantages and why are they important?** Lower costs, better quality of service, better information/monitoring, management flexibility, lower technical risks Cyber risks Lower costs and losses, better quality of service Lower privacy, lower equity
Actors System operator, Generator, Distributor Consumer	**What is a good/bad performance?** Lower costs, higher resiliency and reliability Collapse/network dysfunction, loss of sensitive information, loss of commitment Fraud/crime, loss of commitment, lack of collaboration
Weltanschauung Smart grids contribute to avoid/mitigate inefficiencies	**Objectives unveiled** Efficient utilization of installed capacity More efficient market
Owner Government, Regulator	**Why stop or change the activity?** Social acceptance, lack of funding, unverified economic benefits
Environmental constraints Financial resources Present technological basis Existing know-how Existing potential	**Objectives unveiled** Modernize the network Form qualified staff and engage in R&D Technological diffusion Security of supply

Table 2b). CATWOE analysis for the perspective “The smart grids as opportunity of development and business”

Clients Centralized producer, Microproducer Distributor Service companies, manufacturers, ICT sector	**What are the benefits and the disadvantages and why are they important?** Changes in demand patterns Management complexity New products and services
Actors Centralized producer, Microproducer Distributor Service companies, manufacturers, ICT sector	**What is a good/bad performance?** Profit Market share New products and services Qualified jobs
Weltanschauung Smart grids originate a new business paradigms	**Objectives unveiled** Foster economic activity, innovation, and competition
Owner Entrepreneurs, Financial system, Government, Regulator	**Why stop or change the activity?** Taxes, competition, debt, trade deficit
Environmental constraints Legislation Capital Technological maturity Human resource qualification	**Objectives unveiled** Avoid legislation barriers Attractive return on investment Promote technological maturity of the country Develop highly qualified human resources

Table 2c). CATWOE analysis for the perspective "The smart grids to foster environmentally friendly technologies"

Clients Society, Government, Producer using fossil fuels	**What are the benefits and the disadvantages and why are they important?** Impact on climate change, biodiversity, habitats, human health. Less use of fossil fuels
Actors Government, Regulator	**What is a good/bad performance?** Carbon intensity of the grid, penetration of renewable energy
Weltanschauung Smart grids are a means to increase the share of renewable energy and to foster electric mobility	**Objectives unveiled** Foster electric mobility. Increase the share of renewable energy in the mix
Owner Government Regulator Public opinion	**Why stop or change the activity?** Costs to the consumer Difficulty to meet demand Existence of cheaper alternatives
Environmental constraints International agreements, Existing potential	**Objectives unveiled** Meet agreed targets Use potential in an efficient way Expand the potential

Table 2d). CATWOE analysis for the perspective "The smart grids to empower consumers / micro-generators"

Clients Consumer Microproducer	**What are the benefits and the disadvantages and why are they important?** Savings (energy and tariff) More information Economic benefit, access to the markets
Actors Government, Regulator	**What is a good/bad performance?** Existence of grid access barriers Benefit to all agents Better quality of service
Weltanschauung Smart grids allow a more liberalized market, allowing to achieve efficiency gains	**Objectives unveiled** Market efficiency Increased competition
Owner Consumer Microproducer Government	**Why stop or change the activity?** Bureaucratic barriers Lack of return on investment Grid instabilities Lack of sustainability of traditional business model
Environmental constraints Consumer education level Technical and financial capability	**Objectives unveiled** Ability of the agents to perform as expected

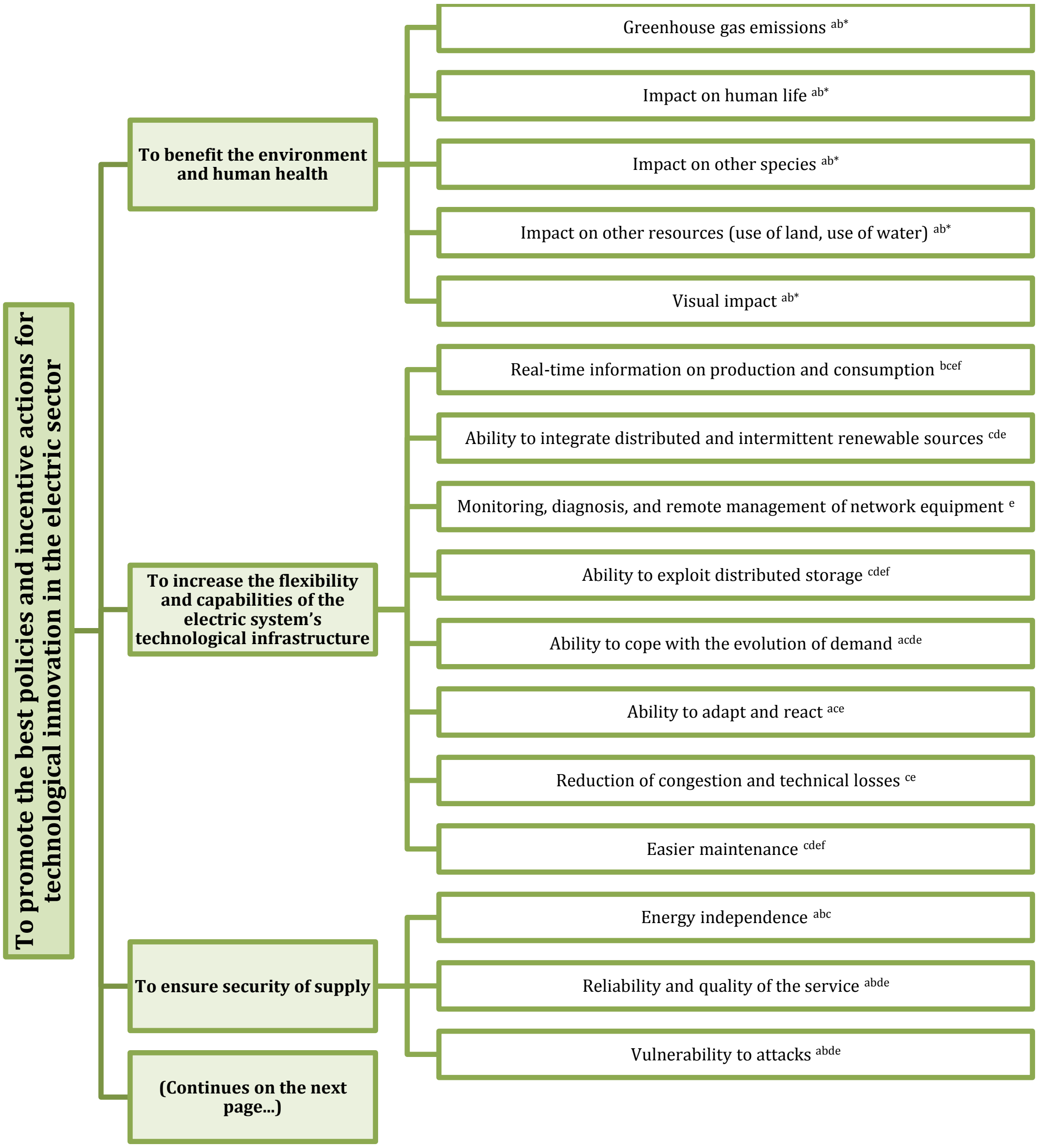

Figure 3. Objectives hierarchy identifying the interested stakeholder groups: a) Government and regulator, b) Consumers and civil society, c) Distributor / energy supplier, d) Power producer, e) system operator, f) Equipment and/or services suppliers, g) scientific and technological system, h) financial system, *) also relevant to other stakeholders.

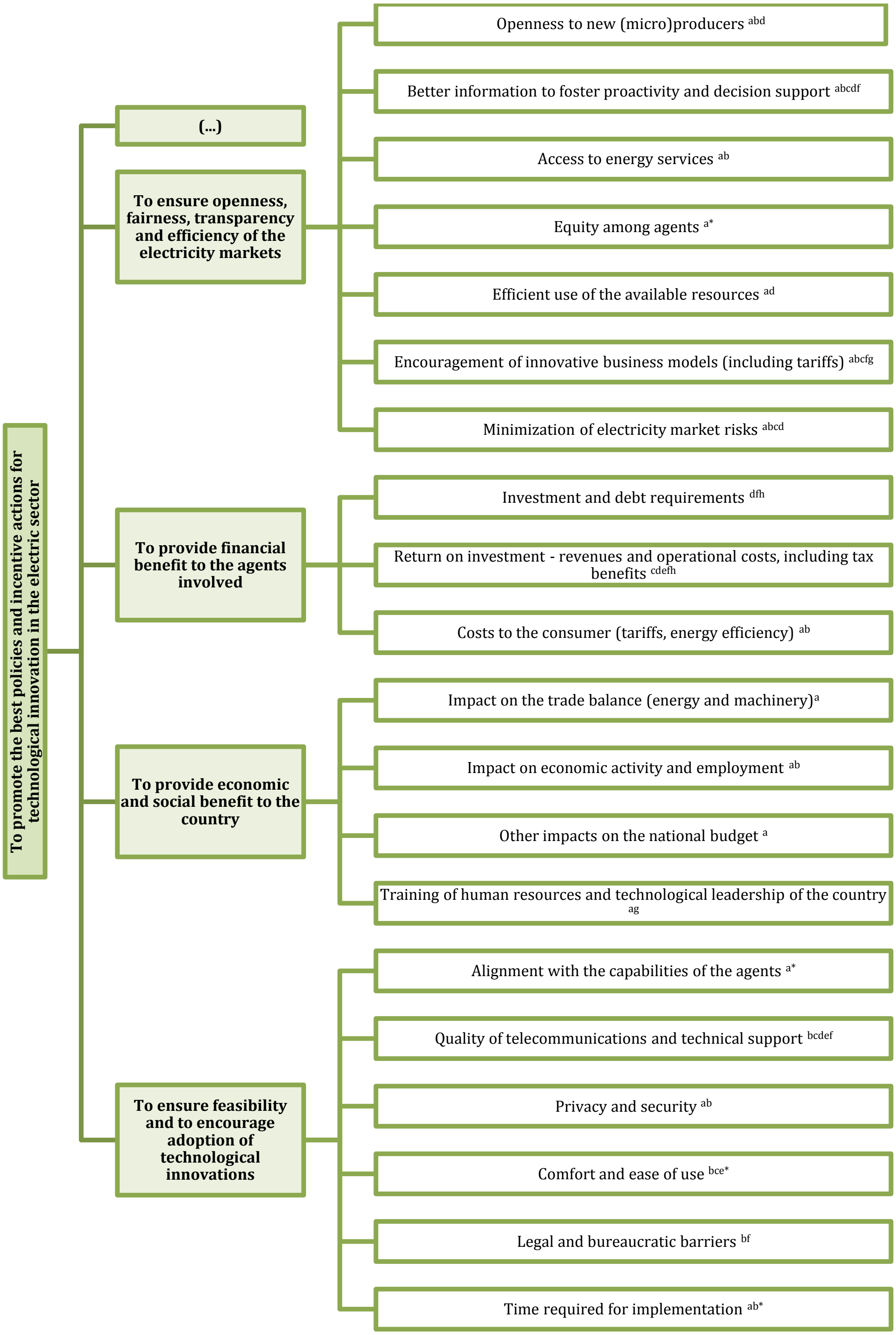
To promote the best policies and incentive actions for technological innovation in the electric sector
(...)
To ensure openness, fairness, transparency and efficiency of the electricity markets
Openness to new (micro)producers abd
Better information to foster proactivity and decision support abcdf
Access to energy services ab
Equity among agents a*
Efficient use of the available resources ad
Encouragement of innovative business models (including tariffs) abcfg
Minimization of electricity market risks abcd
To provide financial benefit to the agents involved
Investment and debt requirements dfh
Return on investment - revenues and operational costs, including tax benefits cdefh
Costs to the consumer (tariffs, energy efficiency) ab
To provide economic and social benefit to the country
Impact on the trade balance (energy and machinery)a
Impact on economic activity and employment ab
Other impacts on the national budget a
Training of human resources and technological leadership of the country ag
To ensure feasibility and to encourage adoption of technological innovations
Alignment with the capabilities of the agents a*
Quality of telecommunications and technical support bcdef
Privacy and security ab
Comfort and ease of use bce*
Legal and bureaucratic barriers bf
Time required for implementation ab*

Figure 3 (cont.). Objectives hierarchy identifying the interested stakeholder groups.

5. Results

The resulting hierarchy of objectives is not tailored to any specific stakeholder. When using such a hierarchy to evaluate alternatives, all stakeholders can recognize the relevance of the objectives without having to agree on which are the most relevant or important ones. The resulting list of fundamental objectives is described in the following paragraphs, using an arbitrary presentation order.

Objective 1 - To benefit the environment and human health. One of the most frequently cited issues when discussing technological innovation in the energy sector is to reduce dependence on fossil fuels and the progressive replacement of these fuels by renewable energy. This is, however, a means-objective, i.e. using less fossil fuels is not a value in itself. The replacement of fossil fuels with renewable primarily seeks a fundamental goal that is the mitigation of greenhouse gas emissions or, more broadly, it aims at not harming the environment. Since there was also mention of other impacts on wildlife and human health, it was decided to define this objective in a more comprehensive way.

This objective can be decomposed into five lower level objectives:

- *Greenhouse gas emissions* – it accounts for emissions of CO2 and other gases that impact global warming. This impact can be expressed in CO2eq units per unit of electrical energy delivered to the grid, based on a life cycle assessment. The replacement of gasoline and diesel vehicles by electric vehicles can also contribute to fewer emissions if the carbon intensity of the grid is low enough. Furthermore, the pursuit of energy efficiency is also reflected in this objective, as far as a decreased consumption of electricity entails fewer emissions. This reflects items mentioned by stakeholders, such as “meeting CO2 emission targets”, “climate change”, “more renewable energy”, “foster electric mobility”, or “grid carbon intensity”.
- *Impact on human life, Impact on other species and Impact on other resources (use of land, use of water)* – these three areas of concern account for emissions of gases and particles to the atmosphere, or contamination of soil and water, impacting human health, as well as the possibility of accidents. Such impacts and accidents may stem not only from electricity generation, but also from the construction and transformations involved in building power plants and transmission lines. This reflects items mentioned by stakeholders, such as “particulate matter emissions”, “health impact”, “biodiversity”, “threat to endangered species”, or “fatalities caused by accidents”.
- *Visual impact* – it is another concern associated with building power plants and transmission lines.

Objective 2 - To increase the flexibility and capabilities of the electricity system’s technological infrastructure. Technological innovation in the energy sector, in particular with the development of smart grids, is seen as an opportunity to modernize an electricity system in need of renovation, as well as to provide the electricity system with technical capacity to improve and to make its operation more flexible (in terms of grid and load management). One can debate whether this is a means-objective or an ends-objective. Having an electricity system with a more modern and more capable infrastructure contributes to multiple purposes (lower costs, better quality of service, better environment, etc.). But the development of this capital can also be seen as a political objective in itself, given the set of elements associated with it and the impossibility of reflecting directly the impact of this objective on the multiple purposes that it can promote for the different stakeholders.

This objective can be decomposed into eight lower level objectives:

- *Real-time information on production and consumption* – it is the ability to have information about energy consumption (in energy units and in cost units) about generation and consumption, in real-time.

The ability of monitoring costs in real-time can contribute to change consumer behavior promoting load shifting. This objective reflects items mentioned by stakeholders, such as "detection of losses", "more information", or "consumer profiling".

- *Ability to integrate distributed and intermittent renewable sources* – it is the (improved) ability to integrate in a harmonious way electricity generation from sources that are highly distributed and intermittent, such as wind and solar energy. This reflects items mentioned by stakeholders, such as "allow increasing share of renewables" or "better use of generation resources".
- *Monitoring, diagnosis, and remote management of network equipment* – it is the (improved) ability of exploiting information technology and automation to have information about the grid and to act upon it. This reflects items mentioned by stakeholders, such as "network monitoring", "management flexibility", or "execute remote maintenance".
- *Ability to exploit distributed storage* – it is the (improved) ability of exploiting information technology and automation to integrate distributed storage at the consumers (e.g., home batteries, vehicle-to-grid) or at the grid (larger scale battery systems). This objective reflects items mentioned by stakeholders, such as "peak shaving" and "incorporation of distributed storage".
- *Ability to cope with the evolution of demand* – it is the flexibility of the electrical system to be scaled, in the medium and long run, according to the evolution of demand for electricity. In particular, it is expected that the economic development of the country and carrier shifting from fossil fuels to electricity (namely electric vehicles) will result in an increasing demand trend. It reflects the stakeholders concern of "ability to cope with increasing demand".
- *Ability to adapt and react* – it reflects the stakeholders concern of "ability to cope with demand fluctuations" in short run variation due to atypical events (e.g., demand surges, failure), aiming at increased resilience.
- *Reduction of congestion and technical losses* – it is the pursuit of efficiency in the system's flow of electrical energy from producers to consumers avoiding congestion and losses caused by technological limitations. This objective reflects items mentioned by stakeholders, such as "congestion", "transmission losses" and "distribution losses".
- *Easier maintenance* – it is the concern that new technologies should not bring new maintenance problems and, by the contrary, they should provide simpler and less costly maintenance operations. This objective reflects items mentioned by stakeholders, such as "remote maintenance ability" and "ease of maintenance".

Objective 3 - To ensure security of supply. Another desideratum sought when modernizing the electrical system is to ensure that demand is satisfied with low risk of disruption, considering technical risks (reliability) and political risks (foreign dependency). Note that the objectives 2 and 3 could be joined together in a more comprehensive formulation. However, the different nature of the concern regarding the risk advises for making this aspect explicit, as is often done in multicriteria benefits-costs-risks assessment.

This objective can be decomposed into three lower level objectives:

- *Energy independence* – it concerns the minimization of risks to energy supply stemming from outside the country, namely political and economic risks. It reflects the stakeholders concern of "energy self-sufficiency".
- *Reliability and quality of the service* – it concerns the minimization of energy supply risks that stem from generation, transport and distribution of electricity and how these are coordinated. This objective reflects items mentioned by stakeholders, such as "quality of service", "grid stability", or "technical risk".
- *Vulnerability to attack* - it concerns the minimization of energy supply risks that stem from purposeful activity from adversaries, aiming at obtaining privileged information or causing damage to the system. This objective reflects items mentioned by stakeholders, such as "cyber risk" or "grid collapse".

Objective 4 - To ensure openness, fairness, transparency and efficiency of the electricity markets. Technological innovation is also seen as an opportunity to transform the electricity markets, corresponding to the aims of the regulator, the most competitive companies and the consumers. This reflects the aim to achieve a more open, efficient and transparent market, which can benefit from healthy competition between energy and services suppliers, and at the same time ensuring equity between the different agents.

This objective can be decomposed into seven lower level objectives:

- *Openness to new (micro)producers* – smart grids should facilitate the entry of (micro)producers who do not wish to limit themselves to produce for self consumption, thus maximizing the return on their investments in capacity. This objective reflects items mentioned by stakeholders, such as “access to the market”, “entry barriers”, or “increase competition”.
- *Better information to foster proactivity and decision support* – smart grids should inform decision making of proactive agents, who need information for their local level decisions. This objective reflects items mentioned by stakeholders, such as “ability to implement dynamic tariffs”, “market efficiency”, “consumer proactivity”, or “better information”.
- *Access to energy services* – smart grids should not create obstacles to accessing energy services; on the contrary, access should be widened. This objective reflects items mentioned by stakeholders, such as “access to energy services” and “entry barriers”.
- *Equity among agents* - smart grids should mitigate, rather than worsen, inequity among different market agents. This objective reflects items mentioned by stakeholders “equity” and “inequality”.
- *Efficient use of the available resources* – smart grids should maximize the utilization of production and transmission resources and allow agents to access, in every moment, to the least cost options. This objective reflects items mentioned by stakeholders, such as “stimulate competition”, “efficient market”, or “efficient use of installed capacity”.
- *Encouragement of innovative business models (including tariffs)* – smart grids should allow the appearance and development of new added-value services for the consumer and for other agents operating in the electrical sector, including new remuneration models. This objective reflects items mentioned by stakeholders, such as “ability to implement dynamic tariffs”, “stimulate competition”, or “active participation of consumers and prosumers”.
- *Minimization of electricity market risks* – smart grids should contribute to decrease market risks faced by investors in the electrical energy sector, by allowing less volatility and offering new risk coverage mechanisms. This objective was also mentioned by stakeholders.

Objective 5 - To provide financial benefit to the agents involved. Financial benefit is a ubiquitous aspect to stimulate the involvement of economic agents. The purpose of providing financial benefit translates the need to make investment in technological innovation interesting for those involved, because without this interest they will hardly accept these innovations.

This objective can be decomposed into three lower level objectives:

- *Investment and debt requirements* – this concerns the minimization of investment and the debt burden often associated with it. Although smart grids require investing in new technology and equipment, they might avoid other costly investments in new generation and transport capacity. This objective reflects items mentioned by stakeholders, such as “investment costs”, “peak shaving”, “capacity costs”, “lack of financial resources”, or “level of debt”.
- *Return on investment* - this concerns the maximization of revenues (e.g., items “gains from reducing fraud”, “market share”, “payback”, “sales” or “attractive remuneration” mentioned by stakeholders) and the reduction of costs including taxes (e.g., items “operational costs”, “metering costs”, “tax benefits” mentioned by stakeholders).

- *Costs to the consumer (tariffs, energy efficiency)* – this concerns the political objective of protecting the consumer by pursuing low electricity bills. Bills can be lowered either by reducing the costs of energy, by reducing the cost of service availability, or by decreasing consumption (namely by energy efficiency). This objective reflects items mentioned by stakeholders, such as “moderate tariffs” or “end use efficiency”.

Objective 6 - To provide economic and social benefit to the country. This objective is of concern mainly to political decision makers, but it may indirectly benefit all the agents. It reflects the perspective that technological development can contribute to benefit the country that promotes it.

This objective can be decomposed into four lower level objectives:

- *Impact on the trade balance (energy and machinery)* – it concerns minimizing energy imports and at the same time avoid imports of foreign equipment (or promote exports of national energy and goods). This objective reflects items mentioned by stakeholders “trade deficit” or “energy imports”.
- *Impact on economic activity and employment* - it concerns the positive and negative impacts on economic activity in the country and the level of unemployment. Smart grids can potentially promote economic activity and create jobs by the appearance of new enterprises, but jobs may be lost in obsolescing functions and technologies. This objective reflects items mentioned by stakeholders “contribution to national economy”, “qualified jobs” or “new added value businesses”.
- *Other impacts on the national budget* – it concerns minimizing other impacts on the national budget, namely subsidies, which cannot be compensated by taxes collected.
- *Training of human resources and technological leadership of the country* – it concerns the political objective of making the country a champion of new technology, allowing to develop the technology and the associated business ventures in the country and also abroad. This objective reflects items mentioned by stakeholders, such as “technology diffusion”, “development of national know-how”, “qualification of human resources”, or “technological leadership”.

Objective 7 – To ensure feasibility and to encourage adoption of technological innovations. Even if technological innovation can potentially bring many benefits, they will be of no avail if innovation is not adopted by the target stakeholders. Natural, financial and technical barriers may exist that hinder or prevent the success of innovation projects. This objective includes all the social and operational factors that could constitute a barrier to innovation projects, which can be decomposed into six lower level objectives:

- *Alignment with the capabilities of the agents* – to ensure that the different agents are able to perform the tasks expected from them. For instance, if one requires more capabilities to the consumers or the service providers than the ones they effectively have, then the anticipated benefits may not be reached. This objective reflects items mentioned by stakeholders, such as “alignment with the capability of the agents”, “compatibility with the status quo”, “management complexity”, or “availability of qualified human resources”.
- *Quality of telecommunications and technical support* – to ensure that providers of essential support services, such as telecommunication or technical support providers, are available and have enough quality to not become a barrier. This objective reflects items mentioned by stakeholders, such as “telecommunications quality”, “availability of support services”, or “possibility of agreement breaches”.
- *Privacy and security* – to ensure that fears relatively to the privacy and security (especially from the consumers) are not an obstacle to the use of automation and information systems. This objective reflects items mentioned by stakeholders, such as “privacy concerns”, “social acceptance”, or “cyber risk”.
- *Comfort and ease of use* – to ensure that the new technologies are easy to be used by end-users and that they do not imply too much sacrifice of time or comfort. Indeed, for instance, home demand

response systems should require from the householders too much interaction, or too abrupt routine changes, or too much thermal discomfort. This objective reflects items mentioned by stakeholders, such as “comfort”, “well-being”, “ease of operation”, or “information overload”.

- *Legal and bureaucratic barriers* – to ensure that there are no bureaucratic or legislative barriers to hinder investment in, or adoption of, smart grid technologies. This objective reflects items mentioned by stakeholders “avoid legislation barriers” and “Bureaucratic barriers”.
- *Time required for implementation* – to insure that implemented measures do not take too long to produce effects, otherwise there is a risk that projects are abandoned prematurely.

One may note that some of the elements contribute to different objectives, although under different perspectives. For example, end-use energy efficiency contributes to avoid emissions (considered in Objective 1) and lower costs to the consumer (Objective 5). Another option could have been to consider this concern as a new high-level objective, in order to emphasize the importance of this objective for national policy. Such an option, however, would require particular attention in order to avoid double counting of benefits on objectives 1 and 5.

The objectives listed above were then further developed by listing the most relevant sub-objectives for the stakeholders in the electricity sector. Fig. 3 presents this decomposition, identifying the stakeholders most interested in each sub-objective. Finally, the initial “cloud” of items was revisited to ensure no important aspect had been missed.

6. Concluding remarks

In the context of the project "Policies and incentive actions for technological innovation in the electricity sector: analysis of international experience and proposals for Brazil", this work aimed to develop and structure a set of fundamental objectives to promote innovation. Literature reviews, technical visits, and the use of SSM generated a dispersed cloud of aspects initially listed as potential concerns and criteria for the evaluation, which was necessary to structure. The systematization of these issues allowed developing a list of seven key objectives in line with priorities for technological innovation in the energy sector. This bottom-up approach was followed by a top-down approach aimed at breaking down each objective into sub-objectives clarifying the issues at stake under each perspective.

This work is an essential basis for the construction stage of the evaluation model, which is currently being developed towards the implementation of performance indicators for each objective and the definition of aggregation mechanisms to derive synthetic recommendations. The characterization of the courses of action to be evaluated as well as the elicitation of the decision maker’s preferences to instantiate the MCDA model is currently underway by means of a Delphi technique within the main stakeholders identified. Then the results generated by a MCDA method devoted to the sorting problem, consisting of assigning the policies under evaluation to order categories of merit according to the multiple evaluation criteria, will be presented to the stakeholder to validate the model.

Acknowledgements

This work has been supported by EDP (Bandeirante Energia and Espírito Santo Centrais Elétricas) project "Evaluation of policies and incentive actions for technological innovations in the electricity sector: analysis of the international experience and proposals for Brazil" part of the R&D Program regulated by ANEEL, Brazil.

References

[1] Bana e Costa CA, Beinat E. Estruturação de Modelos de Análise Multicritério de Problemas de Decisão Pública. In: Costa S, Nijkamp P, Dentinho TP, editors, *Compêndio de Economia Regional. Vol. II: Métodos e Técnicas de Análise Regional*, Cap. 20, p. 611-45. (in Portuguese)

[2] Belton V, Ackerman F, Shepherd I. Integrated support from problem structuring through to Alternative Evaluation using COPE and V.I.S.A. *Journal of Multi-Criteria Decision Analysis* 1997; 6(3): 115–30.

[3] Checkland P, Scholes J. *Soft Systems Methodology in Action*. Wiley; 1990.

[4] Diakoulaki D, Antunes CH. Martins AG. MCDA and Energy Planning. In : Figueira J, Greco S, Ehrogott M, editors, *Multiple Criteria Decision Analysis: State of the Art Surveys*, Springer; 2005, p. 859–90.

[5] Keeney RL. *Value-focused thinking*, Cambridge, MA: Harvard University Press; 1992.

[6] Von Winterfeldt D, Fasolo B. Structuring decision problems: A case study and reflections for practitioners. *European Journal of Operational Research* 2009; 199: 857–86.

[7] Rosenhead J. What's the problem. An introduction to problem structuring methods. *Interfaces* 1996; 26(6): 117–31.

[8] Mingers J, Rosenhead J. Problem structuring methods in action. *European Journal of Operational Research* 2004; 152: 530–54.

[9] Checkland P, Poulter J. Learning for Action. *A Short Definitive Account of Soft Systems Methodology and its Use for Practitioners, Teachers and Students*. Wiley; 2006.

[10] Neves LP, Martins AG, Antunes CH, Dias L. Using SSM to rethink the analysis of energy efficiency initiatives. *Journal of the Operational Research Society* 2004; 55: 968–75.

[11] Ngai E, Chester K, Ching KV, Chan L, Lee M, Choi YS, Chai P. Development of the conceptual model of energy and utility management in textile processing: A soft systems approach. *Int. J. Production Economics* 2012; 135: 607–17.

[12] Coelho D. Antunes CH, Martins AG. Using SSM for structuring decision support in urban energy planning. *Technological and Economic Development of Economy* 2010; 16(4): 641–53.

[13] Checkland P, Tsouvalis C. Reflecting on SSM: the link between root definitions and conceptual models. *Systems Research and Behavioral Science* 1997; 17: 153–68.

[14] Dias LC, Silva S, Alçada-Almeida L. Multi-criteria environmental sustainability assessment with an additive model. In: Ruth M, editor, *Handbook on Methods and Applications in Environmental Studies*. Northampton: Edward Elgar; 2015, p. 450-72.

[15] Bouyssou D. Décision multicritère ou aide multicritère?. *Bulletin du Groupe de Travail Européen "Aide Multicritère à la Décision"* 1993, Séries 2, No. 2, p. 1-2. (in French)

[16] Antunes CH, Henriques CO. Multi-objective optimization and multi-criteria analysis models and methods for problems in the energy sector. In: Ehrgott M, Figueira JR, Greco S, editors, *Multiple Criteria Decision Analysis: State of the Art Surveys*. Springer; 2016, p. 1067-165.

[17] Ehrgott M, Stewart TJ, editors. *Multiple Criteria Decision Making for Sustainable Energy and Transportation Systems*. Springer; 2010.

[18] Huang IB, Keisler J, Linkov I. Multi-Criteria Decision Analysis in Environmental Sciences: Ten Years of Applications and Trends. *The Science of the Total Environment* 2011; 409(19): 3578–94.

[19] Linkov I, Moberg E. *Multi-Criteria Decision Analysis: Environmental Applications and Case Studies*. CRC Press; 2012.

[20] Wang JJ, Jing YY, Zhang CF, Zhao JH. Review on multi-criteria decision analysis Aid in sustainable energy. *Renewable and Sustainable Energy Reviews* 2009; 13: 2263–78.

[21] Neves LP, Dias LC, Antunes CH, Martins AG. Structuring an MCDA model using SSM: A case study in energy efficiency. *European Journal of Operational Research* 2009; 199(3): 834-45.

[22] Keeney RL, Sicherman A. Illustrative comparison of one utility's coal and nuclear choices. *Operations Research* 1983; 31(1): 50–83.

[23] Roy B. *Méthodologie multicritère d'aide à la décision*. Paris: Economica; 1985. (in French)

[24] Bond SD, Carlson KA, Keeney RL. Improving the generation of decision objectives. *Decision Analysis* 2010; 7(3): 238-55.

[25] Parnell GS, Bresnick TA, Tani SN, Johnson ER. Handbook of Decision Analysis, Hoboken, NJ: John Wiley & Sons; 2013.