TECHNOLOGICAL AND ECONOMIC DEVELOPMENT OF ECONOMY

2010
16(4): 641–653

USING SSM FOR STRUCTURING DECISION SUPPORT IN URBAN ENERGY PLANNING

Dulce Coelho[1], Carlos Henggeler Antunes[2], António Gomes Martins[3]

[1]Department of Electrical Engineering, ISEC, Polytechnic Institute of Coimbra, Rua Pedro Nunes – Quinta da Nora, 3030-199 Coimbra, Portugal
E-mail: dcoelho@isec.pt
[2, 3]Department of Electrical Engineering and Computers, University of Coimbra, Polo II, Pinhal de Marrocos, 3030-290 Coimbra, Portugal
[1, 2, 3]INESC Coimbra, Rua Antero de Quental, 3000-033 Coimbra, Portugal

Received 11 February 2010; accepted 20 October 2010

Abstract. This paper describes the use of Soft Systems Methodology (SSM) as a tool for problem structuring, which is the first phase encompassed in a methodological approach currently under development to provide decision support based on Multi-Criteria Decision Analysis (MCDA) in energy planning problems in an urban context. In order to apply the methodology to a real-world problem, a medium sized Portuguese city has been chosen as the decision setting. SSM is used for characterizing as precisely as possible the decision problem context, identifying the main stakeholders and their relations, and discerning the relevant criteria at stake for each one. Future work directions based on this phase are also envisaged.

Keywords: Soft Systems Methodology (SSM), Multi-Criteria Decision Analysis (MCDA), urban energy planning.

Reference to this paper should be made as follows: Coelho, D.; Antunes, C. H.; Martins, A. G. 2010. Using SSM for structuring decision support in urban energy planning, *Technological and Economic Development of Economy* 16(4): 641–653.

1. Introduction

Urban energy planning may be characterized as the decision making process of selecting the local energy infrastructures to invest in, the energy efficiency initiatives to promote, as well as all policies with impact on energy consumption patterns. Adequate energy planning is a crucial task to contribute to sustainable development, enabling to match future energy supply with future energy demand (Van Beeck 2003). The planning of an integrated urban energy

ISSN 2029-4913 print/ISSN 2029-4921 online doi: 10.3846/tede.2010.39
http://www.tede.vgtu.lt

system (comprising several energy carriers and energy distribution networks) is a complex process, with many stakeholders involved, influenced by many factors, among which the most important are the availability of energy resources and the competition between different energy carriers in satisfying energy demand (Catrinu 2006). This process inherently involves a broad range of issues, multiple and conflicting evaluation criteria (economic, technical, political, environmental and social), several stakeholders and their values.

The urban energy planning process may be viewed as a political process involving negotiations and trade-offs among key stakeholder groups with an interest in the planning process. Thus, decision problems arising in the realm of urban energy planning are well suited to be tackled using MCDA methodologies (Diakoulaki *et al.* 2006). The aim of MCDA is to improve the quality of decisions by providing a rational basis for the comparison of competing solutions, since a prominent alternative does not exist whenever multiple conflicting criteria are at stake. This is accomplished by: displaying trade-offs among criteria so that planners, regulators and the public can understand the advantages and disadvantages of alternatives; helping people to reflect upon, articulate and apply value judgements, resulting in a choice, ranking or sorting of alternatives. Moreover, MCDA also has some desirable features that make it an appropriate tool for analysing complex problems such as urban energy planning process. First, it can deal with mixed sets of data, quantitative and qualitative, including expert opinions. Second, it is conveniently structured to enable a collaborative planning and decision making environment. This participatory environment accommodates the involvement and participation of multiple experts and stakeholders.

We are currently developing a methodological framework for decision support based on MCDA that can be used to facilitate decision making in energy planning problems in an urban context. For this purpose a problem structuring phase has been carried out for organizing the problem situation using a systems thinking approach, which lays the foundation for the development of MCDA models and the application of MCDA methods.

The report of the application of MCDA in energy planning is abundant in the scientific literature (for further details see Diakoulaki *et al.* 2006; Pohekar and Ramachandran 2004). Nevertheless, no previous attempts of using soft systems problem structuring tools in an urban energy planning context have apparently been done. In a survey of papers reporting practical applications of Problem Structuring Methods (PSMs), presented in Mingers and Rosenhead (2004), in a total of approximately 50 applications, only one refers to the application of Soft Systems Methodology (SSM) in the energy field, which is focused on rational use of energy. Neves *et al.* (2004) used SSM to rethink the analysis of energy efficiency initiatives in general. As referred by Van Beeck (2003), it seems that local energy planning is not well documented in the literature and not much information is available on how energy planning in an urban context evolves in practice.

In this paper we describe the use of SSM as a tool for problem structuring, which is the first phase encompassed in a methodological approach currently under development to provide decision support based on MCDA that can be used to facilitate decision making in Integrated Urban Energy Planning (IUEP) problems (also with impact on land use planning, waste and water management) involving multiple evaluation aspects and multiple stakeholders. In order to apply the whole decision support methodology under development to a real-world problem, a medium-sized Portuguese city was chosen as the actual decision context.

2. The Urban Energy System

Within the framework of sustainable development, the ongoing trend for market deregulation, the increasing importance of distributed generation technologies based on renewable energy sources and the legislation emanating from the Rio Earth Summit (Agenda 21) and the Kyoto Protocol (requiring the reduction of greenhouse gases), meeting the increasing demand of energy in urban areas is an issue of the highest importance. Since sustainable urban development is closely linked to patterns of energy use and urbanization, local governments all over the world are planning and implementing more sustainable approaches to energy production and use. Local governments have strong reasons to promote sustainable energy planning practices (California Energy Comission 2005). They can engage in sustainable energy planning in three primary ways: within their own operations (local governments are often large users of electricity in buildings and public facilities, in water systems and in other capital infrastructures such as streetlights); promoting efficient energy use and alternative resources in the private sector through their dominant role in shaping the built environment; helping to shape long-term development patterns in order to promote location efficiency and reduce the effects of urbanization on the energy system and the environment in general.

However, conventional energy strategies, which are sectoral in nature (focused mainly on energy efficiency, supply and demand side), and the essential linkages between energy and socio-economic development are not approached in an integrated fashion, and therefore do not tend to address the relationship of energy to other complex problems. Therefore, a holistic approach is required to handle the development of urban energy systems that can help solve many wider problems associated with energy (Fielden and Jacques 1998; McIntyre and Pradan 2003). This holistic approach entails the consideration of all and each one of the factors that may integrate the urban planning process. The main factors are: interconnected infrastructures for local renewable energy sources (with positive impact on local employment, national energy dependence and environment), storage, and distribution of several energy carriers that can supply consumers with different consumption patterns and diversified types of energy end-use services; transport policies (with a significant impact on the urban energy demand and urban environment); buildings (generally one of the main energy consumers in the urban context) and energy efficiency (with positive impact on energy consumption and the environment).

3. Problem Structuring Methods

Problem Structuring Methods (PSMs) are a class of decision support methods designed to assist management groups to agree on the nature and boundaries of the problem they must tackle, and to secure shared commitments to action (Rosenhead 1989, 1996; Rosenhead and Mingers 2001). Therefore, PSMs can provide groups of stakeholders gaining a better understanding of a problematic situation, characterized by high levels of complexity, uncertainty and conflict. Rosenhead (2006) argues that the problematic situations for which PSMs aim to provide analytic assistance are characterized by: multiple actors (see the CATWOE definitions in section 4.2.); multiple perspectives; incommensurable and/or conflicting interests;

important intangibles and key uncertainties. Two characteristic features that are central to the soft systems approach are facilitation and structuring. Facilitation aims to provide an environment where participants or stakeholders are properly guided and discussions or debates are adequately channelled. Structuring, on the other hand, pertains to the process with which the management problem is organized in a manner that stakeholders or participants can understand, and hence ultimately participate in the planning and decision making processes. These approaches can be characterized as being non-mathematical, using system-based concepts, process and techniques, and emphasising dialogue and participation with the clients.

Although taking distinctive forms, PSMs share certain features and each PSM offers support for problematic situations in a way of representing the situation (that is, a model or models) that will enable participants to clarify their predicament, converge on a potentially actionable mutual problem or issue within it, and agree commitments that will at least partially resolve it (Mingers and Rosenhead 2004). The most well-known PSMs include: Strategic Options Development and Analysis (SODA); Soft Systems Methodology (SSM); Strategic Choice Approach (SCA); Robustness Analysis; Drama Theory (Rosenhead and Mingers 2001).

The choice of Soft Systems Methodology

From the range of methods that could be used for the structuring phase, recognised by several authors as the starting point of a MCDA application (Pohekar and Ramachandran 2004; Belton *et al.* 1997), we have chosen SSM. The main reasons are that SSM showed more flexibility in describing the situation context, the stakeholders' roles and the interpretation and exploitation of the inter-related problems, being also more familiar to the authors' systems engineering background.

SSM was developed by (Checkland 1981) as a process of inquiry and action for improving unstructured problem situations where the issues of concern are vaguely perceived but not clearly defined. SSM is an organized way of tackling perceived problematic (social) situations. It is action-oriented. It organizes thinking about such situations so that action to bring about improvement can be taken. This methodology is suited for the resolution of conflicts arising from different world views, and hence conflicting objectives, of the various stakeholders (Daellenbach 1997). Having in mind the need to develop a methodology to assess distinct courses of action (alternatives) in the framework of IUEP problems, the capabilities of SSM to raise all the issues of distinct nature that must be incorporated into MCDA models have been recognized as a SSM advantage for bridging the structuring and the alternative evaluation phases. Neves *et al.* (2004) describe a combined SSM-MCDA approach to provide decision support in the evaluation of initiatives for promoting energy efficiency. SSM has been recognized as a useful tool in problematic situations arising in the energy sector (see Fielden and Jacques 1998) because it contributes to: unraveling complex unstructured problems; questioning the system and recognizing the fact that there are alternative system boundary definitions; enabling comparisons.

4. Applying SSM to urban energy planning

The application of SSM to IUEP followed the classic seven-stage process of analysis as described in Checkland (1981) and presented in a previous version of this work (Coelho *et al.* 2009). In this model there are five stages associated with the so called real-world thinking, two of them for understanding and finding out about a problem situation, and the other three for deriving change recommendations and taking actions to improve the problem situation. There are also two stages concerned with systems thinking, in which root definitions and conceptual models are developed.

Within the context of local policy decision making processes, this usually implies the prior identification of relevant stakeholders (see Fig. 1) and the inclusion of representatives of their interests in the process. Decision makers have three main objectives: (1) to produce knowledge concerning the context of a problematic situation; (2) to apply it in the service of problem definition; and ultimately; (3) to plan systemically for action. This tripartite configuration serves as a particularly useful framework for understanding the advantageous application of SSM main tools (Georgiou 2008).

During the "finding out" activities conducted in the real world the views of the stakeholders about immediate contextual concerns are investigated. For the identification of the relevant stakeholders in the process, interviews have been conducted with experts and representatives of a broad range of local stakeholders. These interviews had specific questions for different stakeholders, and evolved throughout the following issues: the stakeholders' role in the urban energy planning and their perception of important aspects, problems and opportunities concerning energy systems. The discussions organized around these issues aimed at getting a better insight in how the urban energy planning process evolves in practice.

Four ways of finding about a problematical situation become a normal part of using SSM: making rich pictures and carrying out three kinds of inquiry, known as Analysis One, Two and Three (Checkland and Poulter 2006). Analyses One, Two and Three provide, in addition to the rich picture, other frameworks which help grasping the problem situation in a way as rich as possible (Checkland 2000).

Analysis One takes aspects of the intervention itself as its subject matter. It clarifies who the "client" is, who commissioned the intervention, that is, who the "situation improving facilitator" is. During this analysis the facilitator also attempts to find out who all the "stakeholders" are, i.e., who have an interest in, or who are likely to be affected by, the situation. This information provides a starting point for sources of information about the situation. Analysis Two inquires into the social setting of the problematic situation in an attempt to identify the social roles and the norms of behaviour that are expected of these roles. Analysis Three attempts to uncover the power relationships in the situation, i.e., how power is manifested, spread, used, obtained, delegated, etc. This involves inquiring into the formal structures of power as well as the informal leadership that is accepted and given. This analysis alerts the facilitator to power issues that need to be taken into account during the later phases of the SSM process. At the most basic level, the three Analyses are taken together as an analytical tool: pick someone involved, identify the type and extent of their power, and describe their contextual immersion (Georgiou 2008).

4.1. Rich picture building

A rich picture is a cartoon-like representation that depicts all the stakeholders, their interrelationships and their concerns. It is intended to be a broad, high-grained view of the problem situation (Monk and Howard 1998). Drawing a rich picture requires that the analyst works closely with the stakeholders so that the representation captures the situation and related concerns from the stakeholders' points of view. As referred by Hobbs and Horn (1997), the early public involvement in energy decisions is necessary to: ensure that local public values are reflected in decisions; obtain information on impacts that might otherwise be overlooked; inform the local community; and enhance the fairness and transparency of the procedure. The achievement of these purposes helps building public support and confidence both for the decision process and its outcome. Based on the information gathered through the interviews, the following stakeholders, with different interests and preferences, appeared relevant: local authorities; national governmental authorities; international institutions; energy consumers; energy agency; technical officers; manufacturers of end-use appliances; local producers; energy companies; transportation companies; financial institutions and environmentalist groups. The resulting rich picture is presented in Fig. 1. This is a symbolic representation of the key stakeholders (and other elements) and the relationships between them. The picture attempts to capture the attitudes, norms, values, and power relationships in the situation under appraisal. The key stakeholders and their roles are as follows.

International institutions – influence the directions to be followed in energy policy; set legislative rules for eligibility of financing through sources or programs. National government – accepts or rejects applications for financing a special project; provide regulatory and policy framework within which the other stakeholders in local energy planning must operate: demand for energy supply security, energy savings and rational use of energy, and conservation of the environment; analyse the international competitiveness of the energy sector. Financial institutions – finance local producers to invest on renewable sources, consumers to invest in efficient technologies/appliances and the local government to support the planning process and develop new plans. Energy agency – demands the involvement in the planning process; provides information; promotes initiatives and oversees the implementation of measures. Environmentalist groups – analyse impacts from alternatives on environmental and social welfare; although they do not have a role in the legislation they exert an increasing pressure in this setting. Local government – demands for energy supply security, energy savings and rational use of energy, and conservation of the environment; can stop any project; demands more responsibility in the planning process; provides rules and specific legislation; ensures a market for new technologies; provides incentives to local energy producers; approves the construction plans of new houses and new infrastructures; its activity is in accordance with national energy policy; it is an active decision-maker. Consumers – are concerned with energy costs, the protection of the environment and reliability of supply; react to new infrastructures and technologies; have enough power to influence the decisions of all the stakeholders. Manufacturers – provide technical assistance; usually support the implementation of some consumption reduction measures; aim to maximize sales; can be forced to bring efficiency to the market through standards or mandatory labeling. Technical officers – act as sources of information and consultants of decision makers; are forced to observe national and local rules and norms. Energy companies – aim low costs, high revenues, reliability of supply and compatibility with existing energy infrastructures; aim the improvement of the energy infrastructures; have a great influence on the final decisions. Local producers – demand a role in the energy supply system; aim long life and an easy control of production systems.

In a second round of interviews we asked stakeholders for their comments about issues that could have been omitted, under or over valued or misunderstood. Their responses were useful to improve the rich picture and also contributed to our understanding of the social and cultural features of the situation, which is the subject of Analyses One, Two and Three (Checkland 1981; Checkland and Scholes 1990). Before moving on from the "finding out" activity, it is worth reiterating that "finding out" is never finished; it goes on throughout a study, and must never be thought of as a preliminary task which can be completed before modeling starts (Checkland 2000).

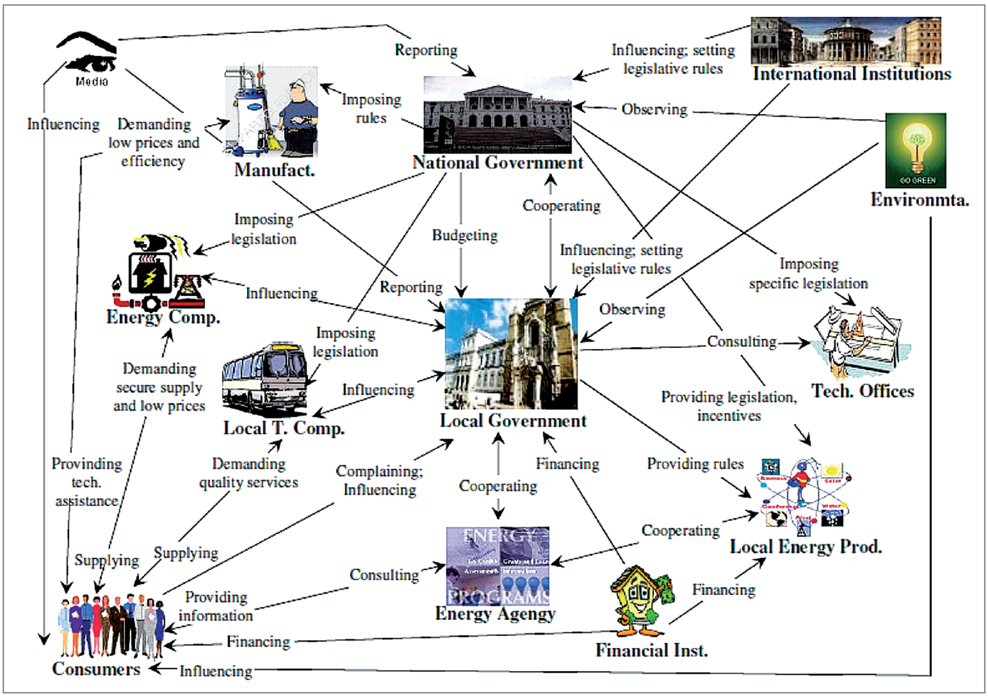

Fig. 1. The rich picture of urban energy planning

4.2. Formulating root definition

In this phase the practitioner enters the "systems thinking world" and generates root definitions of systems that are relevant to the problematic themes that have been identified. A root definition is essentially a sentence that describes, in an abstract way, the fundamental nature of a system when viewed from a particular view point.

As a guide to the construction of root definitions, Checkland (1981) provides the CATWOE elements by which he means that a complete root definition should identify the Customers (C), the Actors (A), the Transformation (T), *Weltanshauung* ("world view") (W), the Owners (O) and the Environment (E).

The CATWOE mnemonic results into the following definitions:

Customers – are the victims or beneficiaries of the system who are affected or benefit from the system's output. The beneficiaries: the consumers who benefit with low prices of energy, a reliable energy supply, and have freedom of choice; the manufacturers that can benefit with the increase of sales of renewable energy technologies/equipments; the society as it concerns to sustainable development and national energy dependence. The victims: the energy companies that reduce sales; the manufactures of replaced technologies/equipments.

Actors – are the ones who know best the technical skills and requirements. A local planning committee composed by municipal planners, developers and consultants and energy companies' managers.

Transformation – changes that happen within or because of the system. Existing sectoral urban plans related with energy → an integrated urban energy planning that defines goals, policies and procedures in order to match future demand and supply in a sustainable way on the medium term.

Weltanshauung – integrated urban energy planning that aims to improve the decision-making by supporting actors engaged in or affected by local energy planning in selecting an appropriate mix of energy technologies for the development of the infrastructures.

Owner – the Municipality, with a broader view on the problem, is the single decision-maker considered. The Municipality is the authority of reference and has a prime concern for the system and the ultimate power to cause the system to cease to exist.

Environment – difficulty to access information and the ability to challenge existing planning; economic, environmental and technological constrains; international agreements and directives.

The following root definition lends to the CATWOE described above: "A system to provide decision support to the Municipality, in the framework of sustainable development, to be operated by a local planning committee, which includes scenarios for energy demand and the identification of a portfolio of options impacting on the local energy systems (in the context of an overall vision of energy use) to be appraised according to multiple axes of evaluation".

4.3. Conceptual model

After subscribing root definitions, the next stage focuses on modelling the activities within the system. The conceptual model happens in the "system thinking" world, and is an analytical part of understanding the problem situation. Modelling is based on the root definitions and the CATWOE elements; it is done by using verbs to describe activities and by assembling a handful of such activities structured in terms of logical dependence (Checkland 1981; Checkland and Tsouvalis 1997). While the root definition accounts of what the system is, a conceptual model is an account of what the system must do in order to be the system named in the definition (Checkland 1981).

The conceptual model shown in Fig. 2 was constructed from the root definition. The diagram illustrating the modelling process consists of seven main activities, and also includes activities for monitoring and controling the performance in the transformation process. Activities 1 and 2 deal with the identification and gathering of all necessary data such as: local availability of renewable energy sources; set of available energy carriers; set of energy conversion technologies; opportunities for improvements in energy efficiency; clean transport technologies; existing energy infrastructures; legislative rules. These activities may ask for energy demand models aimed at obtaining future amounts and forms of energy demanded, reflecting economic development and growth rates. Activity 3 is needed to clearly define all the constraints related to the urban energy systems: legislative, environmental, economic and technical constraints as well as constraints related with resources availability and capacity.

The constraints defined in activity 3 can make contingencies on the technology choice, whose impact on the energy supply and energy demand cannot be omitted. The evaluation of technology impacts, namely related with investment and maintenance costs, performance and reliability, confidence, acceptability and applicability is made in activity 4. The impact on energy systems and on the environment must also be evaluated.

Activity 5 needs the information obtained in activities 2, 3 and 4 for analysing supply options matching future energy demand in terms of amounts and forms of energy and map the

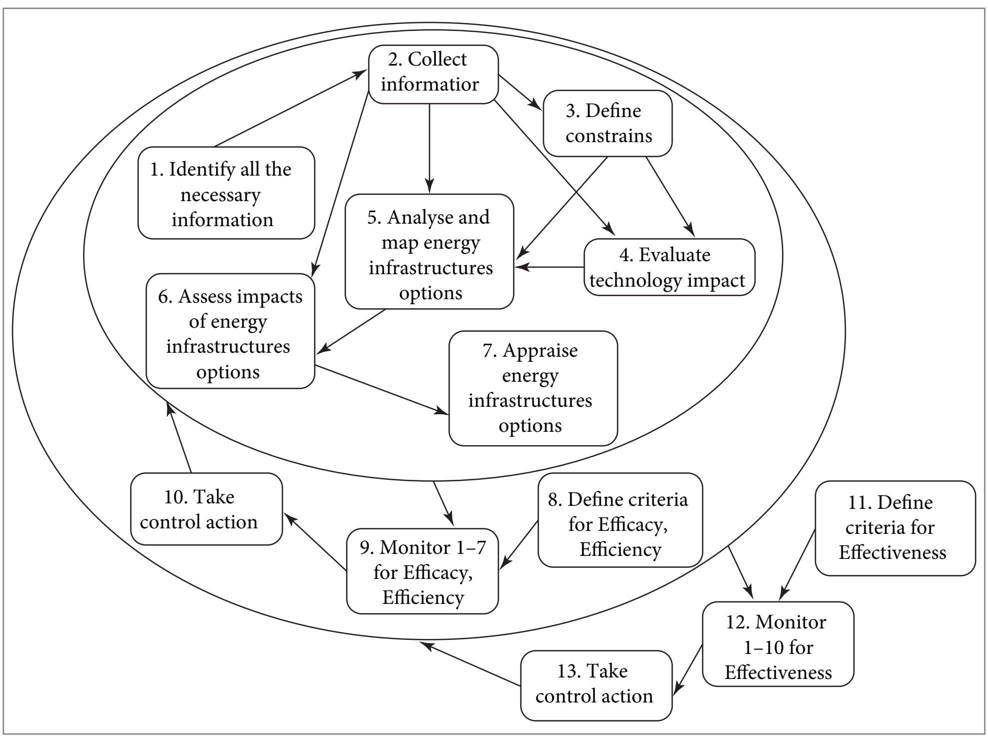

Fig. 2. The conceptual model of the system

energy infrastructure options. It requires the analysis of the existing energy infrastructure and the assessment of future energy supply options, using available resources and technologies.

The assessment of the impacts of the energy infrastructures options is made in activity 6 and requires that the interests and preferences of the relevant stakeholders, extracted from the interviews and risen out from the structuring phase and root definitions are translated into criteria. The assessment must contain all relevant aspects, including aspects expressed in different units and even measured in qualitative terms.

The appraisal of options made in activity 7 is the goal of this system and it emphasizes the need for a multi-criteria method that opens the possibility of incorporating the preferences of the Decision Maker into the decision support process. The ELECTRE TRI method (Yu 1992; Mousseau *et al.* 1999) seems to be an adequate algorithmic option because of its capability of incorporating indifference, preference and veto thresholds as well as the use of different scales (quantitative or qualitative) for distinct criteria.

Monitoring and control consist of three activities (Checkland and Scholes 1990): the definition of Efficacy, Efficiency, and Effectiveness (three Es) criteria; the monitoring of activities in accordance with the metrics defined for three Es; and taking control action using these metrics. In the urban context, the use of indicators makes it possible to monitor the return on investments, the assessment of efficiency (will it work with minimum resources – expressible in money and time) and the control of the systems efficacy (will it work at all – expressible in terms of options offered, purchased and provided at appropriate quality), but the system still needs to be effective. The effectiveness in municipal administration can be guaranteed through the development of long-term sustainable strategies.

4.4. Comparison

In the comparison stage, systems thinking provides a structure for a debate about change aimed at improving the system performance as a result of the insight captured in root definitions (Checkland 1981). Structure to the discussion is provided by using models as a source of questions about the situation (Checkland and Poulter 2006).

Four ways of doing the comparison are described by Checkland: informal discussion; formal questioning; scenario writing based on operating the models; and trying to model the real world in the same structure as the conceptual models. Of these, formal questioning has emerged as by far the most common (Checkland and Scholes 1990).

In the present study the comparison was made in an informal way also supported with a formal questioning. Some of the interviews already held contributed for comparisons between models and the real world. During the comparison stage, further interviews were conducted using a formal questioning.

Some issues raised from the comparison stage that should be taken into account are: improve energy supply/demand analysis and forecasts; perform and maintain municipal databases of information on local renewable sources and new technologies; provide and maintain databases that hold statistical information of the energy sector as well as related to environmental impacts; facilitate communication among participants and improve people's role component to identify opportunities to change; perform a preliminary screening of the constraints in the main topics; maintain an observation process to evaluate constraints; choose measures and units for all the indicators and determine scores on the indicators; perform impact assessment through quantitative modelling or qualitative analysis; use a decision support system based on a multi-criteria method devoted to classify alternatives in predefined ordered categories.

From the results obtained through the debate conducted in this stage, changes have been identified which could improve the problem situation. The assessment of changes is being carried out through discussion with the main stakeholders.

5. Conclusions and further work

This paper presents an SSM-based approach for structuring a framework for decision support in energy planning problems in an urban context as a first step for the development of MCDA tools to evaluate distinct courses of action. The SSM study has been used for characterizing as accurately as possible the decision problem context, identifying the main stakeholders and their relations, and discerning the relevant criteria at stake for each of them.

The structuring phase rises out a set of interests, preferences and concerns of the relevant stakeholders and their relations of power. This information is then used to frame the decision support phase namely regarding the development of criteria trees appropriate for evaluating interventions in integrated urban energy planning. The use of the Value Focused Thinking approach (Keeney 1992) will follow to identify a comprehensive set of values, structure this list of values into a set of fundamental objectives and mean objectives (Coelho *et al.* 2009); define performance measures for the fundamental objectives; clarify the stakeholders' views on relevant value trade-offs among the fundamental objectives.

The appraisal of possible courses of action for urban energy planning will be made in the framework of a sorting problem, that is, they will be classified into pre-defined ordered categories according to their absolute performances. For this purpose the ELECTRE TRI method has been selected, which allows for the use of different (qualitative or quantitative) scales for different criteria. This enables to evaluate the potential courses of action on an "as they come" basis and accounts for the uncertainty associated with their performances in some criteria.

Acknowledgments

The authors would like to thank for the constructive comments of the reviewers on a first version of this paper. This research has been partially financed by the Portuguese Foundation for Science and Technology under project grant PTDC/ENR/64971/2006.

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OPERACINĖS SISTEMOS METODOLOGIJOS TAIKYMAS PLANUOJANT MIESTO ENERGETIKĄ

D. Coelho, C. Henggeler Antunes, A. Gomes Martins

Santrauka. Straipsnyje aprašoma operacinės sistemos metodologija (OSM), kuri bus taikoma kaip daugiakriterinės analizės metodais pagrįsta sprendimų paramos sistema miesto energetikos planavimo problemoms spręsti. Siekiant metodologiją pritaikyti realiame gyvenime, eksperimentui buvo parinktas vidutinio dydžio Portugalijos miestas. Operacinės sistemos metodologija taikyta kuo tiksliau nustatant pagrindines problemas, identifikuojant pagrindines suinteresuotas šalis ir jų santykius, nustatant vienas kitam įtaką darančius rodiklius. Numatytos būsimos darbo kryptys.

Reikšminiai žodžiai: operacinė sistemos metodologija, daugiakriterinė sprendimų analizė, miesto energetikos planavimas.

Dulce COELHO. M.Sc., Adjunct Professor. Department of Electrical Engineering, ISEC, Polytechnic Institute of Coimbra, Portugal. First degree in electrical engineering, University of Coimbra (1980). Master of Science (1994). Ph.D student in Electrical Engineering – Energy Systems. Researcher of the R&D unit Institute for Systems Engineering and Computers, Coimbra. Author of about twenty scientific articles in journals and conference proceedings. Research interests: energy planning, energy efficiency, sustainable development.

Carlos HENGGELER ANTUNES. Ph.D., Full Professor. Department of Electrical Engineering and Computers. University of Coimbra, Portugal. First degree in electrical engineering, University of Coimbra (1983). Ph.D. in Electrical Engineering – Optimization and Systems Theory (1992). Director of the R&D unit Institute for Systems Engineering and Computers, Coimbra. Coordinator and researcher in several national and international projects on decision sciences, energy planning, multi-criteria decision analysis and multi-objective optimization. Member of the organizing and programme committees of several national and international conferences. Author of about one hundred scientific papers in journals, books, and conference proceedings. Research interests: multi-criteria decision analysis, multi-objective optimization, energy planning, energy efficiency, sustainable development.

António GOMES MARTINS. Ph.D., Full Professor. Department of Electrical Engineering and Computers. University of Coimbra, Portugal. First degree in electrical engineering, University of Coimbra. Ph.D. in Electrical Engineering – Energy Systems (1985). Researcher of the R&D unit Institute for Systems Engineering and Computers, Coimbra. Coordinator and researcher in several national and international projects on energy planning and energy efficiency. Member of the organizing and programme committees of several national and international conferences. Author of about one hundred scientific papers in journals, books, and conference proceedings. Research interests: energy planning, energy efficiency, load modelling, demand-side management, sustainable development.