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A methodology in innovative support of the integrated energy planning preparation and orientation phase

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ABSTRACT

Integrated, model-based energy planning particularly in cities and territories involves different planning and modelling activities, which, from a methodological point of view, can be divided into four phases. The analysis and findings of this study focus on planning "phase I", which is devoted to preparation and orientation. Despite the importance of this planning phase, which is underlined in several papers, only a few studies have addressed planning phase I partially using a systematic methodology. A brief review of planning activities, problems and methods enables mapping the applicability of these methods to their purpose in planning context. The review reveals that no methodological support is provided to fulfil all of the requirements and tasks of this phase. Thus, a methodology for supporting "phase I" activities is presented and illustrated using Singapore as a case study. The methodology combines methods that are either already used in energy planning or borrowed from the area of inventive problem solving, and a specially developed method. The methodology can explicitly reveal problems, key and hidden contradictions, which allows a better understanding of the situation and requirements for the next planning phase especially when looking for solutions beyond common optimality (innovative solutions).

1. Introduction

1.1. Basic problematic and definitions

Long-range integrated energy planning in cities and territories is usually model-based and is implemented to support local or regional sustainable development. Implemented working definition for integrated energy planning in cities and territories (IEPCT) is based on the following [1]: "*Regional (sub-national) integrated energy planning is an approach to find environmentally friendly, institutionally sound, social acceptable and cost-effective solutions of the best mix of energy supply and demand options for a defined area to support long-term regional sustainable development. It is a transparent and participatory planning process, an opportunity for planners to present complex, uncertain issues in structured, holistic and transparent way, for interested parties to review, understand and support the planning decisions*". Planning activities may include the analysis of different energy carriers, e.g., gas and electricity, different sectors, e.g., transportation and household, and the assessment of different technical, environmental, economic, social or institutional aspects. These planning activities are complex tasks, and all of the problems concerning long-range integrated energy planning are not known or well defined a priori. Thus, the problems of finding and formulating solutions are useful to be treated explicitly and systematically. IEPCT is an interactive process involving participants with different and sometimes opposite interests. In Ref. [1], it is suggested that the generic planning process can be divided into four main phases: Phase I: Preparation and orientations, Phase II: Model design and detailed analysis, Phase III: Prioritization and decision, Phase IV: Implementation and monitoring. The focus of this study is the development of a methodology for the implementation of phase I, assuming as in Ref. [2] that a "Methodology is a structured set of guidelines or activities to assist people in undertaking interventions or research". The planning methodology often consists of various methods or techniques, not all of which must be used for every situation. A method or a technique is defined in Ref. [2] as follows: *"A technique or method is a specific activity that has a clear and well-defined purpose within the context of a methodology."*

In most case studies, planning phase I is not performed by defining objectives, formulating problems or developing a

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conceptual model explicitly. Planning and modelling are typically performed quantitatively by an analyst or planner. "*In traditional modelling, one person or a group of experts builds the models and just explains the results to policy makers; however, to be within the process of learning, it is required that both policy makers and all stakeholders as well as experts be involved in the process of model building*" [3]. Additionally, for interactive, integrated energy planning, a clear statement of objectives, targets and problems and the explicit development of a conceptual model can help to avoid error types I and III discussed in Ref. [4]: "*Type I error is committed when the model results are rejected when in fact they are sufficiently credible*". Rejections can be made by stakeholders or decision makers. This error type is also called model builder's risk. Therefore, it is important to involve all interested parties, decision makers or stakeholders from a given study area at the very beginning of the planning and modelling process, integrating their problems and views in planning and supporting the learning process. "Type III error is committed when the formulated problem does not completely contain the actual problem" [4]. Several other problems concerning planning phase I have been mentioned in the literature:

- A confusion of ends/objectives with means/options [5];
- Ambiguity regarding the relevance of traditional solutions (known a priori or defined) under growing environmental restrictions [6];
- Cooperation difficulties among organizations having different formulating and problem solving traditions [6];
- Conflicting issues among organizations or planning participants having different objectives and/or options for solutions [6–10];
- Expertise in specific issues that can introduce distracting technical bias and also create a barrier to developing innovative solutions [9];
- Complexity of planning the entire energy systems of cities or territories, which have different partially independent subsystems, require a long time frame and large investment, interact with different strategic planning fields such as transportation or urban development and have multidisciplinary characteristics [7,10,11];
- Using existing planning traditions with single performance "economy efficiency" [7];
- Strong technically and administratively centralized energy system in some cities and territories [12,13].

To address these issues, several methods have already been proposed in the literature. They are analysed in Section 3.2. First, however, let us clarify another issue that has not been explicitly addressed in the IEPCT literature and that is linked to an implicit hypothesis about the optimality of IEPCT solutions.

1.2. Optimality and notion of contradiction

The Oxford English Dictionary defines "optimize" as "to use something in the best possible way". In this case, the conditions that must be met to find optimal solutions are pre-defined and the solutions are known and directly implementable. The results of almost all energy planning schemes in cities and territories are based on optimality. The optimal solutions are defined either mathematically, e.g., by determining which solutions minimize costs using an optimization approach or in terms of multi-criteria optimality, optimal solutions are defined based on balancing the values of stakeholders using a multi-criteria decision aid approach. Studies using mathematical optimisation use different approaches. Bjorn et al. [14] used a mixed integer linear programming model for an operational analysis of the system and dynamic programming algorithm for the definition of investment strategies.

A bottom-up linear optimisation approach, MARKet ALlocation (MARKAL), was implemented in Ref. [15] to design optimal strategies for long-term energy security, climate change mitigation, and environmental sustainability for rapidly growing urban areas. The MARKAL model was also implemented in Ref. [16] to analyse the behaviour of the optimal mix of fuels and technologies in the presence of carbon dioxide emissions to outline the most effective actions for contributing to the national Kyoto Protocol targets.

The MARKAL linear programming model is implemented in Ref. [17] to analyse the Basilicata energy system and to investigate the possibility of reducing atmospheric pollutant emissions as well. In a detailed energy system analysis, Lund [18] proposed a simulation model to identify the optimal mixtures of different energy generation technologies using renewable energy resources. Jennings et al. [19] implemented a Mixed Integer Linear Program (MILP) incorporating both demand-side technologies, and explicit spatial and temporal resolution for strategic planning of retrofitting residential energy systems. Lin and Huang [20] developed an interval-parameter two-stage stochastic municipal energy system planning model for supporting decisions of energy systems planning and Green House Gases (GHG) emission management at a municipal level. Similarly, Zhu et al. [21] proposed an inexact mixed-integer fractional energy system planning model for supporting sustainable energy system management under uncertain conditions and optimising the system efficiency, represented as output/input ratios.

The second group of studies defines the optimal mix of solutions based on multi-criteria analysis methods incorporating the preferences of the decision maker. For example, the energy system simulation approach combined with Multi- Attribute Value Theory (MAVT) was implemented in Ref. [22] to support a range of policy interventions to help decision makers systematically develop alternatives to achieve multiple objectives. Another combined approach, is proposed in Ref. [23] using SWOT analysis, Multi-criteria decision analysis techniques, and the expert opinion "Delphi" method. The approach was applied in Jaen Province to design a renewable energy plan for the region. Kaya [24] implemented a classical multi attribute decision making technique and an Analytic Hierarchy Process with a Fuzzy logic approach to incorporate the fuzzy preferences of the decision maker and support the selection of the best energy policy, taking into account multiple criteria.

An extensive review of the different decision analysis approaches, such as multiple attribute utility theory or single objective decision making, implemented in energy and environmental modelling is provided by Zhou [25].

In both cases the solution or set of solutions is defined by changes in the values of the attributes of a given energy system model that occur under a given system structure and design constraints. These solutions represent what will be referred to as the first level of optimality. However, as mentioned in the previous section, the optimality of standard solutions does not always provide satisfactory results with respect to technology evaluation and environmental changes [6]. An example of such a situation is reported in Ref. [26] regarding the PACA region of France, where the so-called "optimal" solution obtained by balancing the values of evaluation parameters results in an unsatisfactory compromise due to contradictory requirements. Therefore, for situations in which the first level of optimality is not acceptable, there is a need to solve the problems another way: by changing the model of the system or redefining the problem so that a satisfactory solution can be developed. To construct these solutions, it is proposed here explicitly incorporating conflicting requirements into the IEPCT design problem, which in a conceptual model, can already be