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Integrated energy planning in cities and territories: A review of methods and tools

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ABSTRACT

Although the integrated energy and environmental planning processes of cities and territories with more than 50,000 inhabitants differ, previous studies suggest that long-term, model-based energy planning processes have a common scheme that can also be used as a framework for reviewing the methods and the tools that are used in the integrated energy planning of these cities and territories. This paper first presents a generic integrated energy planning procedure in which the planning activities are divided into four main phases. Second, the methods and the tools that are used for these diverse planning tasks are mapped to the suggested generic planning procedure tasks. Finally, the combined use of these methods and tools in the scope of integrated energy planning are briefly discussed from a mapping point of view.

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1. Introduction

During the 1970s, the International Energy Agency (IEA), along with several states, proposed the concept of integrated energy planning (IEP) in response to the oil crisis to increase energy diversity and decrease dependence on foreign oil. Different IEP methodologies, including Integrated Resource Planning (IRP), Integrated Assessment of Supply and Demand-Side Options (IASDO) and Least-Cost Planning (LCP), have typically been practiced at the national level. However, the liberalization of energy markets in several countries, along with the growing emphasis on environmental protection and sustainable development worldwide, has increased the interest for IEP at the sub-national (territory or city) level [1]. The importance of using integrated approaches in the sustainable development of cities and territories has been recognized by the European Commission [2] and previous research [3–8]. The general trends in the evolution of city- and territory-level energy planning approaches are as follows:

- Within the cities and the territories, a growing community awareness of the environmental issues.
- Growing interest in the use of distributed generation technologies based on renewable resources and small cogeneration systems.
- An increasing number of decision makers with different interests and preferences participating in the planning process.
- Development of a cross-sectoral analysis among several sectors, such as industry, households and transportation.

Because of these trends, the dynamics and the complexity of energy planning tasks at the sub-national level increased and the planning activities and procedures have to evolve. This review is a first step for evaluating how these issues are handled.

1.1. Basic definitions and background

Previous studies have discussed several definitions of the term "sustainability", as well as the term's broad application in the field of energy planning. This paper uses the definition that was proposed in [9], stating that "*Sustainability is a continuous process of balancing the environmental, economic and social aspects related to the living environment and their systematic improvements*". Several sustainability indicators have been used for both energy planning and environmental planning. The United Nations (UN) has proposed several indicators for sustainable development [10]. In the guidelines of the International Atomic Energy Agency (IAEA) and the International Energy Agency (IEA) [11], energy indicators for sustainable development are listed and grouped into four fundamental dimensions: social, economic, environmental and institutional.

The literature provides several definitions of energy planning. In this study we focus on the integrated long-term, model-based energy planning. This study's definition of integrated energy planning for sustainable development in cities and territories is based on [12,13]: "*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*". Furthermore, integrated planning entails defining the goals and the problems to implement the appropriate solutions.

The basic features of integrated energy planning are similar to those of the current energy planning and environmental planning practices, including integrated assessment, life-cycle assessment and IRP. However, IEP is unique because it mainly focuses on issues relating to energy extraction, transportation, transmission, distribution and use. The planning can be multifaceted, including economic, environmental, social or institutional aspects.

"*Methodology is a structured set of guidelines or activities to assist people in undertaking interventions or research*" [14]. The planning methodology will often consist of various methods or techniques, not all of which must be used for every situation. The primary focus of a methodology is its stages; it provides a conceptual account of what needs to be accomplished during the planning process.

The method or the technique is defined in [14] as follows: "*A technique or method is a specific activity that has a clear and well-defined purpose within the context of a methodology*". Example methods include developing a discrete-event simulation model or undertaking a statistical analysis. The methods and the techniques provide the manner through which the potential solutions will be obtained.

> "*A tool is an artifact, often computer software, which can be used in performing a particular technique e.g., a linear optimizer, a systems dynamics package*" [14].

The need for a city- or a territory-level energy planning process that is supported by different analytical or procedural tools has been previously mentioned in the literature [15]. Previous studies suggested that "*The new strategic discourse needs to emphasize the process more than the content, the actors more than the structures separating of the planning and operational elements of the process*" [15]. More recently, a study [16] concluded that "*the tools can contribute to a broader scope, more comprehensive assessments, and better legitimacy of the energy planning*".

This paper reviews the methods and the tools for city- or territory-level integrated energy planning while considering the aforementioned background and issues. The remaining portion of this introductory section presents the general planning process that is used as guideline for this review.

1.2. Generic energy planning process and actors

Bagheri and Hjorth [17], Mirakyan et al. [13] or IEA [18–21] present several planning phases and sub-steps that have been used in practice. Bertoldi et al. [22] provides an overview of several existing methodologies for the development and the implementation of Sustainable Energy Action Plans. The strengths and the weaknesses of these methodologies, as well as their implementation in several European countries, are documented. The long-term, model-based energy planning processes that are described in these studies share a common general scheme that is described in [13]. From the methodological point of view, the planning processes can be divided into the following four phases:

- Phase I: Preparation and orientations.
- Phase II: Model design and detailed analysis.
- Phase III: Prioritization and decision.
- Phase IV: Implementation and monitoring.

Each phase consists of several interlinked sub-steps. Because the different phases and steps are interlinked, they are not necessarily performed in a predetermined sequence. Moreover, the step