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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.

Contents

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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 iterations or step iteration sequences are often required, and depending on the situation, some steps can be omitted. The procedure reflects the working steps and the decision-making process. The selection of steps can vary from situation to situation, depending on the problem–goal relation, the amount of time available, the resources and the stakeholder interests. For more details regarding this general scheme and its application to the integrated energy planning procedure for territories and cities, please see [13].

Fig. 1 summarizes the dynamics and the components of the planning process in cities and territories. The following three levels are considered during the planning process:

- *Participatory level*. The participants of the planning process are members of the following groups:
  - Steering committee: the members of this group have the greatest decision-making power (e.g., the local administrative body or the investors).
  - Interested parties (e.g., the affected groups e.g. end user, the media or NGOs).
  - Planner or other experts: in the liberalized energy market, everyone can be a planner (e.g., the local or the territorial energy agencies, the utility companies or other private companies).

  Each participant does not necessarily take part in all of the planning phases. For example, in the phases I and III, most of the participants are present, but only the planner and the experts are typically involved in phase II.
- *Process level*. This level consists of the planning steps, activities and tasks.
- *Methodical level*. This level involves the methods and the tools that are used to support several activities during the planning process, including the following:
  - Analytical tools, which allow the quantitative analysis and the impact assessment to be performed.
  - Procedural tools, which support the participatory, interactive planning process and the decision-making process.

The development of integrated long-term energy plans for cities or territories is complex because the plans account for different aspects (e.g., environmental, social, technological), different sectors (e.g., residential, transportation), different energy carriers (e.g., gas, oil, electricity), and diverse technologies required to extract, convert, transport, and distribute energy, where there are several dynamic links among component of the energy system [23]. To have an efficient planning process and develop successful plans, several methods and tools are needed, including those that are analytical and participatory in nature [24]. In the early 2000s, several studies [25–27] noted that the planning instruments that were available for cities and territories focus on their physical and economic infrastructures of cities; however, there also need to be planning instruments in place to support the participatory process [25]. These assertions are still relevant. In the next chapter, the different analytical and procedural methods and tools are reviewed based on survey research papers and case studies. The tools and the methods for each planning phase are reviewed and presented in the tables. The study conclusions are summarized and discussed in the final chapter.

2. Methods and tools used in cities and territories for integrated energy planning

The methods and the tools reviewed in this chapter are widely available and have been implemented in cities and territories for integrated multi-carrier and multi-sector energy planning. The tools and the methods are analyzed according to the planning process activities that are performed during the different phases of the generic process presented in Section 1.2.

2.1. Phase I: preparation and orientation

2.1.1. Planning process in phase I

In phase I (see also Fig. 1), the initial situation is roughly analyzed, the problems are formulated, the potential solutions are

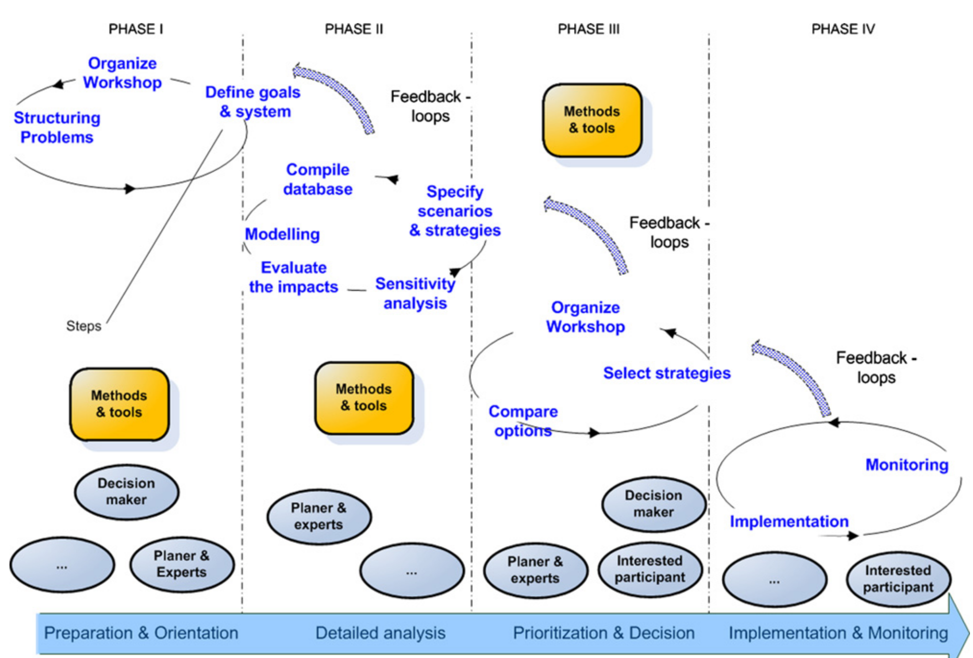

Fig. 1. General procedure for integrated energy planning in cities and territories (modified from [13]).

listed and the objectives and the targets are set [13,28,29]. The following is a list of some of the possible main planning activities of phase I.

(1) Organize workshops. (2) Perform an initial rough analysis of the historical and the present situations, relevant issues and trends. (3) Identify, describe and structure the problems of the energy and the environmental issues. (4) Propose a shared vision and goals for the future sustainable development in the city or the territory. (5) Identify the initial strategies, plans or programs and the potential solutions. (6) Describe the barriers that prevent the goals from being reached. (7) Develop first planning concept or conceptual model. (8) Inform the media and all affected groups.

2.1.2. Implemented methods for phase I

To better understand sustainability in cities and territories, some have argued that the objectives have to be determined more effectively during the energy planning procedure [9]. The European Parliament documents have underlined the need for setting clearer objectives and targets as the central component of transparent policy making [30]. However, only a small number of studies on energy planning in cities and territories have systematically performed this phase by using methods and tools to define the problems and the goals in systematic way, which could also be implemented in phase II for model design or phase III for multi-criteria decision aid (MCDA). This situation can thus be explained by a general lack of problem structuring, goal-setting methods and integration with the other approaches relating to MCDA [31].

One of the important tasks in this phase is the initial identification and generation of strategies or solutions. A potential approach to address this task is to use the experience and the best practices of others cities and territories. To share these experiences, several associative networks and Internet platforms have been established worldwide [32–43]. These initiatives are also additional motivation for cities and territories to perform sustainable development measurements. These types of cooperation can be initiated for either long-term collaboration or specific projects. However, the specific conditions of cities and territories can vary significantly, and the experiences of other studies are not always applicable. Thus, some studies implement methods for phase I while taking into account the specific context of cities. Strengths, weaknesses, opportunities and threats (SWOT) for diagnosing problems and sketching future action lines are implemented in the study [44]. Another study [45] uses soft systems methodology (SSM) to define the context of the decision problem and disclose the relevant objectives for each stakeholder. To analyze the initial situation, define the problems and set the goals while taking into account the existing or the potential solutions, another study implemented an OTSM–TRIZ[1] -based approach [13].

2.1.3. Software resources for phase I

To our knowledge, there is currently no reported software support for the phase I tasks, with the exception of [46]. An Internet portal for local sustainability provides a platform for local governments in Europe to support local sustainable development. A user-friendly online tool and online guidance provide help for activity (4) of this phase and for local governments that are undertaking the target-setting step of their sustainability cycle [46], (mentioned in Section 2.1.1).

[1] OTSM is a Russian acronym for General Theory of Powerful Thinking compatible with TRIZ.

2.2. Phase II: model design and detailed analysis

2.2.1. Planning process in phase II

Several activities and tasks can be performed in this planning phase. The analyses and the evaluations in this phase are rather quantitative. The following is a list of some of the possible main planning activities of this phase.

(1) Determine a detailed conceptual model of the planning process. (2) Collect, describe and interpret the information. (3) Establish a formal model in a computer tool that is based on the conceptual model that was defined in phase I. (4) Perform a detailed analysis and impact assessment of the area's historical, current and future situations. (5) Perform an uncertainty and sensitivity analysis and establish the alternative scenarios.[2] (6) Examine the strategies or the initial plan that was suggested in phase I for the different scenarios by performing a comprehensive impact assessment. (7) Develop new innovative strategies that could be most compatible with the local conditions for the different scenarios (e.g., mitigation, energy efficiency improvement options, extensive use of renewable energies sources). (8) Review phase I. (9) Inform the media and all affected groups.

As mentioned earlier, the ordering of the planning activities in this phase may vary with the case study. An activity can be updated due to the task results.

2.2.2. Implemented methods in phase II

The underlying methods and tools for phase II are quantitative. There are several methods that are used to quantitatively analyze and assess the impacts of energy systems in cities and territories. The underlying methods and tools (see Table 1) are very different (e.g., simulation, linear optimization or physical accounting). Top-down and bottom-up modeling approaches to estimate the sectoral and the regional greenhouse gas emissions are compared in [47]. Methods that are based on paradigms such as agent-based simulation, system dynamics or evolutionary algorithms are proposed to perform the phase II tasks. To perform a holistic analysis of the entire life-cycle of an energy carrier or product in a city or territory, a life-cycle assessment (LCA) is also implemented.

2.2.3. Software resources for phase II

To manage the analysis and the assessment of this planning phase, numerous quantitative tools have been implemented. Several methods for classifying the tools have been proposed, particularly for energy system modeling (sometimes the term "energy models" [48] or "energy system models" [49,51] are used). For instance, reference [50] describes the energy models using nine criteria. Similar classification criteria have been used in the reviews [51,52]. Tools for the analysis and the assessment of the integration of renewable energies and the integration of the distributed generation systems into the energy system have been reviewed in [53,54]. Tools can also be classified into other categories, such as comprehensive and auxiliary tools [19]. Auxiliary tools are tools that generate additional information that is needed for the comprehensive tools to perform future analyses (e.g., based on the Delphi survey as an auxiliary method for forecasting). Comprehensive tools are tools that can evaluate the entire energy system from the primary energy analysis to the useful energy and services for all of the energy carriers; the tools assess the technical, economic or ecological aspects of the plans and perform a cross-sectoral analysis. In this paper, the comprehensive modeling tools are reviewed for phase II. These modeling tools have typically been used on the international or national level (e.g., the Model for Energy Supply

[2] A scenario is a plausible description of how the system and/or its driving forces may develop in the future.

Table 1
Modeling tools and their implementation in phase II.

Software name	Scope/focus of application	Method	License	Contact	Ref.
Energy plan	Integrated energy/environmental analysis	Sim.	Free for academic use	http://energy.plan.aau.dk/	[59–64]
etransport	Integrated energy/environmental analysis	Optimization	Free for academic use	www.sintef.no	[65–67]
ETEM or MARKAL-Lite	Integrated energy/environmental analysis	Optimization	Commercial	www.ordecsys.com/en	[68–71]
GEMIS	Life-cycle analysis	Sim., physical accounting	Free	www.gemis.de	[72–74]
LEAP	Integrated energy/environmental analysis	Sim., physical accounting, Optimization	Commercial and free	www.energycommunity.org	[75–80]
(MESAP) PlaNet	Integrated energy/environmental analysis	Physical accounting, Simulation,	Commercial	www.seven2one.de	[81,82]
MARKAL/TIMES	Integrated energy/environmental analysis	Linear optimization	Commercial	www.etsap.org	[4,83–89]
Anylogic	Generic	– Agent-based modeling – System dynamics – Discrete event simulation	Commercial	www.xjtek.com	[90]
iThink	Generic	System dynamics	Commercial	www.iseesystems.com/	[91]
Vensim	Generic	System dynamics	Commercial	www.vensim.com	[92]
simapro	Life-cycle analysis	Sim., physical accounting	Commercial and free	www.simapro.com/	[93]
Umberto	Life-cycle analysis	Sim., physical accounting	Commercial	www.umberto.de/	[94]

Sim. = simulation

Strategy Alternatives and their General Environmental Impact (MESSAGE) [55], Instrument for climate gas mitigation strategies (IKARUS) [56] or Energy and Power Evaluation Program (ENPEP) [57]). Another modeling tool is the Retscreen [58] 'Clean Energy Project Analysis Software', which was developed by Natural Resources Canada, is mainly used for project-level implementation and does not include a cross-sectoral demand analysis.

Table 1 provides a non-exhaustive summary of some of the representative tools for phase II. In addition to these tools, there are other tools that may also be suitable for this phase.

2.3. Phase III: prioritization and decision

2.3.1. Planning process in phase III

There are several tasks and activities that can be performed during the phase III analysis. During the interactive planning process where different participants' interests and preferences are taken into account, some possible planning activities for this phase are presented below.

(1) Review the results of phases I and II, the problem dynamics and the results of the different scenarios (e.g., in a workshop). (2) Fix and reformulate the goals that were defined in phase I and if necessary, establish a new objective hierarchy for the different scenarios. (3) Review the strategies and the solutions that were generated in phases I and II. (4) Implement the objective hierarchy in a MCDA approach for each scenario for proposed strategies. (5) Use the MCDA methods for the preference elicitation including also qualitative aspects, performing sensitivity analysis and impact assessment of the suggested strategies in the different scenarios. (6) Recommend an integrated or master plan with the different implementation strategies or solutions. (7) Inform the media and all affected groups.

2.3.2. Implemented methods in phase III

The past energy and environmental planning and decision-making approaches have used economic benefit as a single measurement criterion [95]. However, these planning issues are complex and multi-dimensional. The sub-optimal, single criterion solutions do not always support long-term sustainable development. Furthermore, the tools or the methods used in the planning process must support decision-making procedure, which involves different stakeholders with varying interests and preferences. From the group decision perspective, the conventional economic methods have limited use because the actions and policies must take several aspects and criteria into account [95]. "*MCDM (Multi-Criteria Decision Making) methods can be used in such a situations to identify a set of Pareto optimal (or non-dominated) solutions, such that no other feasible option exists which is just as good in every objective and strictly better in at least one*" [95].

As shown in a multi-criteria decision study, decision makers cannot clearly express all their expectations when they are setting the goals [96]. Therefore, in phase I, the objectives must be properly defined and then the MCDA methods have to be carefully selected because they can significantly influence the results [96].

In the context of integrated energy planning, the purpose of the MCDA method is not just to define the "right" plan, but to support the understanding of the multi-criteria complex situation that supports the interactive planning and learning, helps people systematically consider, articulate and apply value judgments and documents the values and the alternatives of each recommendation.

The literature provides several surveys of the MCDA methods. A review of the MCDA methods in the different stages of sustainable energy planning and decision making (i.e., criteria selection, criteria weighting, evaluation and final aggregation) has been conducted in [97]. The importance of the use of the MCDA methods in the integrated assessment (IA) framework is highlighted in [98]. In [98], more than 270 references were reviewed to classify the MCDA methods according to the problem types that may be analyzed using the appropriate methods. Classification categories have been established for the statistical analyses and testing suitability of the different methods for several application areas, including energy policy analysis (I), electric power planning (II), technology choice and project appraisal (III), energy utility operations and management (IV), energy-related environmental policy analysis (V), energy-related environmental control and management (VI), and a miscellaneous category (VII) [98]. The application areas I, III and V are closely related to the city- and territory-level integrated energy planning.

2.3.3. Software resources for phase III

The MCDA methods have been implemented in the software in various ways. Some web-based platforms of the MCDA allow the analysis to be performed online. Other MCDA panels also support MCDA software for offline use. DECISIONARIUM global space for decision support [99] and the Decision-Deck Project [100] are two examples of this type of large initiative. Table 2 presents a review of some of the available MCDA software.

A long list of the MCDA software with comments are presented on the homepages of "EURO Working Group Multi-criteria Aid for Decision" [104] and "International Society on Multiple Criteria Decision Making" [105].

2.4. Phase IV: implementation and monitoring

2.4.1. Planning process in phase IV

After phase III, the master or the integrated plan is typically developed. In the implementation step, the master plan is 'fleshed out' with individual projects or programs. The results of the programs or the individual projects are compared with the proposed conditions from the previous phases. If the results are unsatisfactory, additional projects or actions can be examined and implemented. The key sustainable indicators are also continuously observed and monitored. Some of the possible activities of the implementation and monitoring phase (phase IV) are provided below.

(1) "Flesh out" the integrated plan with individual projects, programs and proposals according to phases II and III and implement this plan within integrated framework. (2) Consider issues regarding timing, risks, money and other aspects as suggested from the previous phases. (3) Operationalize the quality targets and the measurable indicators. (4) Compare the results of the implemented strategies with the previous planning objectives and targets. If they are unsatisfactory, perform the remedial actions. (5) Inform the stakeholders about the progress and engage them if possible. (6) Continue to observe, monitor and document the key energy- and environmental-related developments. (7) Inform the media and all affected groups.

2.4.2. Implemented methods in phase IV

The methods and tools that can be implemented for the individual projects or programs can vary widely depending on the project and the competence and the needs of the investors or the planner. The companies have to perform the mandatory procedures to ensure the appropriate quality standards (e.g., ISO 14001 [106] or EMAS [107]).

2.4.3. Software resources for phase IV

Common communicative or quality management tools can be implemented in phase IV. A previous report [108] presents several software packages for energy management, energy control or rational energy use. These software packages can be very useful for continuous observation, monitoring and operational optimization.

3. Combined use of methods and tools

As shown in Section 2, integrated energy planning involves several aspects (e.g., economy, social, and environmental), and the planning process involves several sub-activities and tasks. A single method or tool cannot deal with all of the planning aspects and problems; therefore, studies that combine several tools or methods for the various planning phases to perform all of the planning tasks are of interest. Mingers [14] outlines the possible method or methodology combinations in the different areas and considers why such a development might be desirable for more effective practice. There are several types of multi-methodologies.

- *Methodology isolationism*: Using only one methodology or methods/techniques from only one paradigm.
- *Methodology enhancement*: Enhancing a methodology with the techniques or the methods from another.
- *Methodology combination*: Combining whole methodologies in an intervention.
- *Multi-methodology*: Partitioning methodologies and combining parts.

In the energy-planning practice, almost all types of multi-methodologies exist. In [109,79], energy-system modeling tools are combined with the MCDA method. A methodology combining the SWOT analysis, the MCDA and the "Delphi" method is proposed in [110]. Some studies combines the problem structuring methods with the MCDA approaches in the energy planning [45,111]. The combined use of the scenario technique and the MCDA is demonstrated in [112]. The integrated use of the MCDA methods with expert judgment and fuzzy logic is presented in [113]. The combined use of the energy-system modeling tool with GIS are shown in [114–117]. A framework that incorporates the energy system models and GIS is developed and implemented by the Indian Institute of Science [118]. To capture the dynamics at the macroeconomic level, the system dynamics model is integrated with the input–output energy model in [119]. The use of the combined macroeconomic approaches and the systems engineering models is often used to provide a joint energy–economy analysis; however, this has only been performed on the national

Table 2
Some implementation of MCDA methods in software resources for phase III.

Software, name	Origin	Comments	License	Link
WINPRE, PRIME …	Systems Analysis Laboratory/Aalto University School of Science and Technology Finland	DECISIONARIUM is a site for interactive multi-criteria decision support with tools for individual decision making as well as for group collaboration and negotiation	Commercial and free	[99]
Decision-Deck	Decision Deck Consortium/EU	The Decision-Deck project developed an open-source generic multiple criteria decision analysis (MCDA) software platform composed of modular components	Free	[100]
Criterium® DecisionPlus® 3.0, Coming Q4 2008: Priority Mapper …	InfoHarvest Services USA	Several software to manage the entire decision process	Commercial and free	[101]
Web AIM	School of Management, SUNY-Buffalo	An aspiration-level interactive model for multiple criteria decision making. Management science and systems	Commercial and free	[102]
DAM	International Atomic Energy Agency	The Decision Analysis Module (DAM) is the software developed to aid a decision analyst in solving multiple criteria decision analysis problems	Free	[103]

Table 3
The use and the type of different combined methods and tools in the different planning phases.

Planning phases	Multi-methodology type (M.=methodology)	Combined use of the methods and the tools	Literature
Phases II and III	M. combination	Energy system modeling tool+MCDA	[79,109]
	M. combination	Scenario technique+MCDA	[112]
	M. combination	MCDA+expert judgment+Fuzzy logic	[113]
Phases I and III; (phase II is performed roughly in the studies)	M. combination	SWOT analysis+"Delphi" method+MCDA	[110]
	M. combination	Problem structuring methods+MCDA	[45,111]
Phase II (the decision in phase III have been performed on the base of economic benefit as a single criterion in the studies)	M. enhancement	Energy system modeling tool+GIS	[13, 114, 115–117]
	M. combination	Agent-based+combinatorial optimization technique	[123]
	M. combination	System dynamics model+input–output energy model	[119]
	M. combination	Macroeconomic+energy system modeling tool	[120–122]
Phases I, II and III	Multi-methodology	OTSM–TRIZ+energy system modeling tool+MCDA	[13]

level to our knowledge (e.g., in [120–122]). A conceptual framework for the modeling of urban energy systems is developed in [123]. It combines an integrated data management and the simulation executive with the four interacting modeling tools in a hierarchical framework using a network optimization algorithm based on mixed integer programming, agent-based simulation and GIS. A method that combines a multi-criteria evolutionary optimizer for structural optimization with a code for the operational optimization and the simulation of energy supply systems is introduced in [124]. Table 3 presents the use and type of some of the combined methods and tools for the different energy planning phases.

4. Concluding remarks

Integrated energy planning, while mostly performed at the national level, has become increasingly important and popular in cities and territories. Many studies show that the integrated energy planning in cities and territories is contextual and process oriented. The review of the existing planning processes and activities for cities and territories shows that the long-term energy planning process in cities and territories has a common theme. In this paper, the planning tasks and activities have been presented and organized in a systematic and holistic way. The planning procedure can be divided into four phases with several interlinked sub-activities and tasks. From these phases, key planning aspects and issues were identified that can be performed using methods or tools. According to these planning phases, the methods and the tools are reviewed. The primary emphasis of this review was to examine the tools and the methods that are used for each planning phase and assess whether there are tools and methods that are used to cover all of the planning tasks.

For phase I, there are very few methods and tools that have been implemented in territories and cites. However, many studies recognize that this planning phase is very significant within the planning process. We shall address this issue in a further work. In contrast, phase II, which concerns the model design and the detailed analysis, applies numerous quantitative tools, and several reviews of these tools exist. A significant amount of progress has been made in the development and the improvement of several methods and tools for phase III. Different implementations of the MCDA methods and tools have been tested in cities and territories. The combined use of the MCDA approaches using inputs from other tools and methods from phases I and II are published in certain papers. However, the survey has shown that the methods and the tools have not yet been combined to manage all of the integrated energy planning processes and tasks.

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